SAIIE33

THE INDUSTRIALS

MARVELLOUS WORLD OF IE

Proceedings

3 – 5 October 2022

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OF THE 33RD ANNUAL SOUTHERN AFRICAN INSTITUTE FO INDUSTRIAL ENGINEERING CONFERENCE

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"LIFE DOESN'T GIVE US PURPOSE. WE GIVE LIFE PURPOSE."
(THE FLASH)

Preface

The theme for this year's SAIIE conference reflects the potential for industrial engineers to make a difference in society. Our papers truly do highlight the Marvellous world of IE and challenge each of us to become our friendly neighbourood Super Hero as we tackle the many challenges surrounding us. Each year, I am intrigued by the themes that emerge from the submitted papers. Mimicking the inevitable change and needs around us, the topics and scope of submissions evolve and adapt. This year, there is a strong emergence of work related to sustainability, water and energy management and food security. The traditional focus areas remain, foregrounding the breadth of the profession from hospitals to mines.

The proceedings of the 33rd SAIIE conference of the Southern African Institute for Industrial Engineering (SAIIE) showcase industrial engineering research and practice with relevance that extends far beyond our physical borders. The conference continues to retain a focus on developing authors, reviewers, practitioners and researchers to create and sustain an active and reflective industrial engineering community of practice.

The submission and review process

For this conference, prospective speakers could submit full papers or abstracts only. Successful submissions from both categories were invited to submit video presentations and participate in interactive discussions through our poster or presentation sessions at the in-person conference event. Submissions were themed in tracks to explore emergent ideas and facilitate future collaboration to extend the scope and impact of our collective work.

Abstracts for the full-paper track were screened based on suitability, and successful authors were invited to submit a full-length paper. These submissions were screened using Turnitin plagiarism software to uphold academic integrity. Submissions that passed this screening process were then reviewed using a double-blind, peer-review process. The review process was managed through an online conference system that allows reviewers to provide online feedback and records all reviewer feedback and editorial decisions taken during the process. Papers were allocated at least two reviewers, often teaming up academics and industry experts to facilitate a true peer-review process. This year, a workshop developed new reviewers and challenged more experienced reviewers to provide constructive and detailed reviewer feedback to authors, supporting the purpose of the conference and its proceedings. Only papers that passed the peer-review process are published in the conference proceedings. As has become the tradition of this conference, the best papers were selected to appear in a special edition of the South African Journal of Industrial Engineering (SAJIE). The selection process of these papers considered the reviewer feedback, reviewer ratings and suitability checks by the journal's editor. The conference proceedings contain submissions from 9 of the 11 academic institutions with industrial engineering departments in South Africa. No institution contributes more than 30% towards the papers published in the proceedings.

A total of 98 full paper submissions were accepted after the peer-review process, possibly the highest number of conference papers ever accepted for a SAIIE conference. Nineteen of these papers were selected for the special edition of the journal that will be published separately. As a consequence, these papers were withdrawn from the proceedings. A full list of these papers is included on the next page. The conference programme also includes three abstract-only submissions, three invited keynote presentations, six workshops and one panel discussion. Twenty-one papers

This conference, therefore, has three outputs:

- The *Conference Event* This includes a series of pre-recorded videos and the abstract of each paper shared with conference delegates using the online conference app and

programme and abstract book. The conference event also includes interactive discussions in parallel sessions, themed by paper topic at the in-person conference.
- The ***Conference Proceedings*** (this document) is an electronic document distributed to all delegates and contains full papers submitted, reviewed and approved for the full paper track. The purpose of the proceedings is to give full open access to the output from the conference. The proceedings are available online via the SAIIE website.
- The **Special Edition of the South African Journal of Industrial Engineering (SAJIE)** will be published in November 2022, honouring the best work submitted to this conference. The Special Edition also contains submissions from other related conferences.

Acknowledgements

Thank you to our authors, for being our Super Heroes! For doing amazing things and for sharing this with us through our conference.

Thank you to our reviewers whose time and wisdom makes a positive contribution to every paper and author.

Thank you to the section editors who administered the review process: Chanel Bisset, Chantelle du Plessis, Hanneke Meijer and Philani Zincume.

Thank you to Chantelle du Plessis for putting together the final conference proceedings and Lynette Pieterse for your tireless administrative support.

Thank you to the entire conference organising committee, whose enthusiasm, crazy ideas and unwavering standards make the conference what it is.

And lastly, thank you to Prof Corne Schutte for your continued support and encouragement.

I trust that you will find the work presented as part of this conference truly outstanding – welcome to the Marvellous world of IE.

Prof Teresa Hattingh
Editor
September 2022

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IMPLEMENTATION OF A ROBOTIC ARM FOR PALLET LOADING AND UNLOADING IN THE BEVERAGE INDUSTRY

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ABSTRACT

This research is based on the design of a robotic arm to remove pallets from the palletizer station to a queuing conveyor. It is a case study for ABC Beverages, a manufacturer, bottler and distributer of carbonated soft drinks (CSD), and bottled water. The root cause analysis techniques of the fishbone diagram and 5 whys analysis showed that pallet accumulation at the palletizer was the major cause of line stoppages, accounting for 36% of the overall causes of line stoppages. Time studies showed that an average of 30 minutes was lost at every line stop and start interval. The study focuses on eliminating the main problem, which is pallet accumulation. The robot has a payload of 300 kg. The results from the study show that pallet accumulation was eliminated and 120 minutes of production time was saved.

Keywords: Robotic arm, pallet, beverage industry.

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1 INTRODUCTION

The beverage industry is making great strides in as far as robotics is concerned. The robotics market in the food and beverage industry is expected to grow at a compound annual growth rate (CAGR) of 11.6% to reach USD 2.02 billion by 2028 [1]. Utilizing new technology plays a pivotal role in improving product quality [2]. It also smoothens product flow, and increases the rate of production. This results in high productivity and reduced lead time to market [3]. It is a well known fact that the design, installation and operation of robots is a very complex and capital intensive process. However, over time, the benefits outweigh the capital injection. Manual operations are associated with difficulties in moving and storing products [4]. Labour-intensive processes limit agility, more so in an industry where the risk of losing the market to competitors is very high in the event of delays to reach the market. It is therefore against this background that this research is based on the implementation of a robotic arm to move pallets from the palletizer station to a queuing conveyor. It is a case study based research for ABC Beverages, a manufacturer, bottler and distributer of carbonated soft drinks (CSD), and bottled water. The purpose of the research is to eliminate line stoppages by improving the flow of pallets and preventing accumulation at the palletizer machine.

ABC Beverages has two twelve hour shifts per day and operates 2 CSD lines, 1 canned soft drinks line and 1 bottled water line. Each line has 15 operators. The production targets are given in Table 1.

Table 1: ABC Beverages production targets

Line	Product	Pallets/hour	Cases/pallet	Bottles/case	Bottles/hour
1	CSD	17	60	24	24 480
2	CSD	25	60	24	36 000
3	Cans	6	100	24	14 400
4	Bottled water	15	60	24	21 600

The company previously operated two CSD lines and 1 bottled water line. A third line was installed to cater for the demand for canned soft drinks. The company did not increase the number of mechanical handling equipment (MHE) like forklifts. This resulted in pallets accumulating at the palletizer. Line stoppages became frequent. Pallet accumulation is shown in Figure 1.

Figure 1: Pallet accumulation at the palletizer

The root cause analysis showed that pallet accumulation at the palletizer was the major cause of line stoppages, accounting for 36% of the overall causes of line stoppages. The line is synchronous. If the palletizer stops, so do all the machines in the line. Time studies showed that an average of 30 minutes was lost at every line stop and start interval. Regular breakdowns increased due to the random and frequent restarts. Visual inspection showed that the forklifts were driven in haste to allow production after line stops due to accumulation. That led to the damage of pallets and products. This created the need for the implementation of a robotic arm to move pallets from the palletizer to a queuing conveyor. The main objective of the research is to implement the robotic arm on the production line in order to move pallets from the palletizer station to a queuing conveyor. The rest of the paper is organized as follows. Section 2 systematically reviews literature on the subject under study. Afterwards, section 3 outlines the research methodology techniques used to identify, select and process the problem, and analysing the findings. Section 4 describes the design of the robot. The results are discussed under section 5. Section 6 concludes the research.

2 LITERATURE REVIEW

The Robot Institute of America defines a robot as a re-programmable, multifunctional manipulator designed to move material, parts, tools or specialized devices through variable programmed motion for a variety of tasks [5]. Robotics is a form of automation. Automation is the technology that utilizes mechanical, electronic and computer based systems to monitor and control the production and delivery of products without human assistance [6]. A robot performs tasks and interacts with its environment without human assistance.

2.1 The main parts of a robot

Figure 2 shows the overall structure of a robot and a block diagram showing how it functions. The main parts are the mechanical system or manipulator, end effector, sensors, controller and actuators.

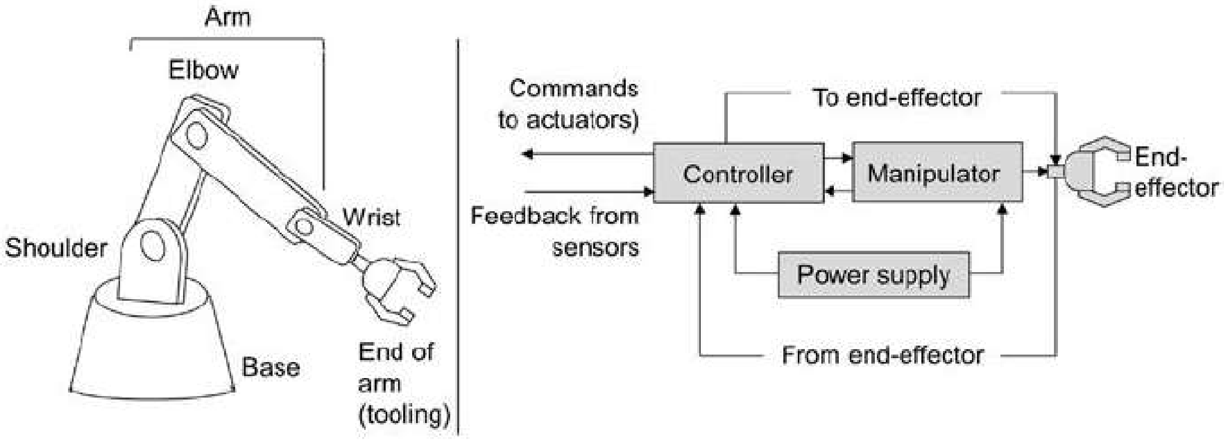


Figure 2: Main parts of a robot and functional block diagram [7]

2.1.1 Mechanical system or manipulator

This is the “skeleton” of the robot. It consists of the rigid members referred to as links which are connected by articulations referred to as joints [8]. The main parts of the manipulator are the arm, wrist and the end effector.

- Arm: enables mobility.
- Wrist: provides rotational motion to the end effector. This allows the end effector to orient and align the loads.
- End effector: this is either the gripper for handling objects or the end-of-arm-tooling for performing operations.

2.1.2 End effector

These are the "hands" of the robot. The end effector is mounted at the end of the manipulator for performing tasks similar to those done by the palm and fingers of a human hand. The tasks include picking up pallets without dropping or crushing them, packaging, gripping/handling, and picking and placing objects [9].

2.1.3 Sensors

These are the "senses" of the robot. Robots are equipped with sensors which allow them to detect any changes around their environment. They detect any physical changes – which is the input signal, and convert it to an electrical signal – the output signal [10-11]. The output signal is sent to the controller, which sends the signals to the actuator to move the robot's links and joints [12]. Different types of robotic sensors are used. They include the light, sound, temperature, pressure and contact sensors. They perform tasks such as:

- Monitoring parameters such as force, speed, and temperature.
- Sensing the position of nearby objects and obstacle avoidance (proximity sensors) [13].

2.1.4 Controller

These are the "brains" of the robot. The controller controls the motion of the manipulator. Sensory feedback is processed and signals are sent to the robot's links and joints to move the robot [12]. Robotic control is based on kinematics and dynamic modelling. Kinematic modelling refers to actuation of the links and joints without regarding the contact forces acting on the robot members and causing the robot to move [14]. Dynamic modelling is about the relationship between the actuation and the contact forces acting on the robot members and causing the robot to move [15].

2.1.5 Actuator

These are the "muscles" of the robot. Actuators are the opposite of sensors. Sensors convert physical signals to electrical signals. Actuators convert those electrical signals to physical signals that set the robot in motion. Industrial robots are powered by electric motors, hydraulic, or pneumatic actuators [16]. Actuators provide force/torque needed to move the robot links to perform various tasks [17]. Electric motors are the common types because they are more precise, clean, quieter and highly efficient. They include the servo motors, stepper motors and direct-drive electric motors. Even though the hydraulic actuators offer high power-to-weight ratio, they are limited to robots that must work in an open environment because they are noisy and are subject to oil leakage [18]. The pneumatic actuators are commonly applied for material handling on end effectors such as grippers [19].

2.2 Robot specifications

- **Degrees of freedom (DOF)**

Degrees of freedom (DOF) are the modes in which a mechanical device or system can move. The number of degrees of freedom is equal to the total number of independent displacements of aspects of motion that a mobile robot or the end effector of a robotic manipulator can make [20]. A robot has three major axes. This gives it three degrees of freedom. The robotic manipulator moves within the arm sweep (base rotation), shoulder swivel (reach forward and backward), and elbow extension (up and down). Additionally, the wrist provides up to three additional degrees of freedom. These are the roll (rotating the wrist about the arm axis), pitch (up-down rotation), and yaw (left-right rotation) [21]. This is shown in Figure 3.

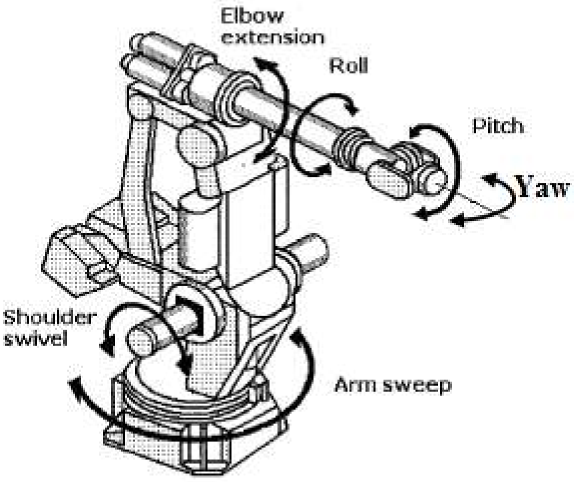


Figure 3: Robot axes [21]

Robots with fewer degrees of freedom are also common.

- **Payload**

This is the maximum load that a robot can lift. It consists of the weight of the load plus the weight of the end effector.

- **Reach**

This is the maximum distance a robot can reach within its work envelope. It measures how the robot can reach when it is fully stretched. It defines the robot's workspace.

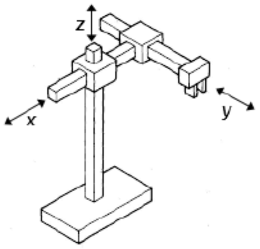
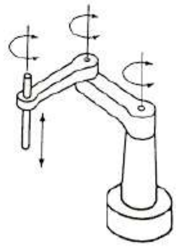
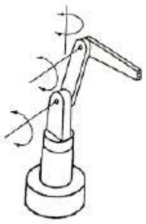
- **Repeatability**

This is the precision with which a robot can attain pre-taught points or values if the motion is repeated several times.

2.3 Palletizing robots in the beverage industry

Table 2 shows the some of the palletizing robots used in the beverage industry.

Table 2: Palletizing robots used in the beverage industry [22], [23], [24]

Type of robot	DOF	Functionality	Applications	Image
Cartesian/ Rectangular/ Rectilinear/ Gantry	3	It only moves along the x, y and z axis. It has no rotational axis.	Material handling, palletizing, pick and place objects.	
Selective Compliance Assembly Robot Arm (SCARA)	4	3 rotations and 1 translation.	Packing.	
Articulated	6	3 rotations and 3 translations.	Material handling, palletizing, pick and place objects.	

In this study, a 6 degree of freedom robot is developed. This type of robot has many advantages over other robots in as far as palletizing is concerned. The major advantage is better flexibility and more wrist actions. This allows the robot to be able to pick up the pallet from the palletizer station, make 180 degrees turn, move towards the queue conveyor, and place the pallet on the queue conveyor.

3 RESEARCH METHODOLOGY

The research methods carried out in this study are based on the case study that was done at ABC Beverages. The root cause analysis was carried out to determine the main causes of the line stoppages. An investigation on the amount of time which was lost during the stop and start intervals was also conducted.

3.1 Root cause analysis

Root cause analysis (RCA) is a systematic process for identifying "root causes" of problems or events and an approach for responding to them [25]. The root cause analysis techniques used are the fishbone or Ishikawa diagram and the 5 Whys analysis. The Ishikawa cause and effect was used to identify all the possible causes of the line stoppages emanating from the 4 Ms of manufacturing – Machine, Materials, Man and Method. The 5 whys analysis was used to get to the root cause of the problem.

3.1.1 The fishbone or Ishikawa cause and effect diagram

Also referred to as the cause and effect diagram, the fishbone diagram provides a way to look for the effects, the frequent unplanned line stoppages, and the causes that contribute to those effects. As demonstrated in Figure 4, the fishbone diagram illustrates all the elements that influence the unplanned line stoppages.

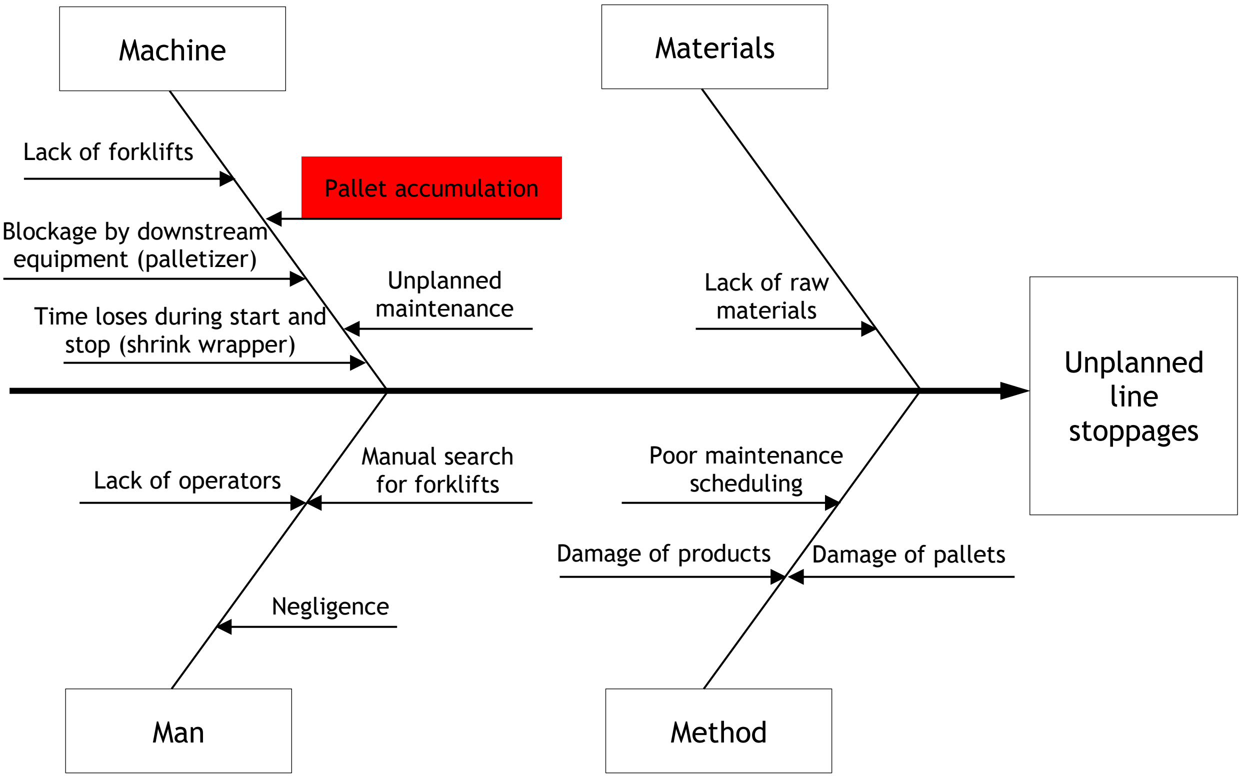


Figure 4: Fishbone diagram for unplanned line stoppages

3.1.2 The 5 Whys analysis

The 5 whys sheet for ABC Beverages was constructed as and diagrammatically illustrated in Figure 5.

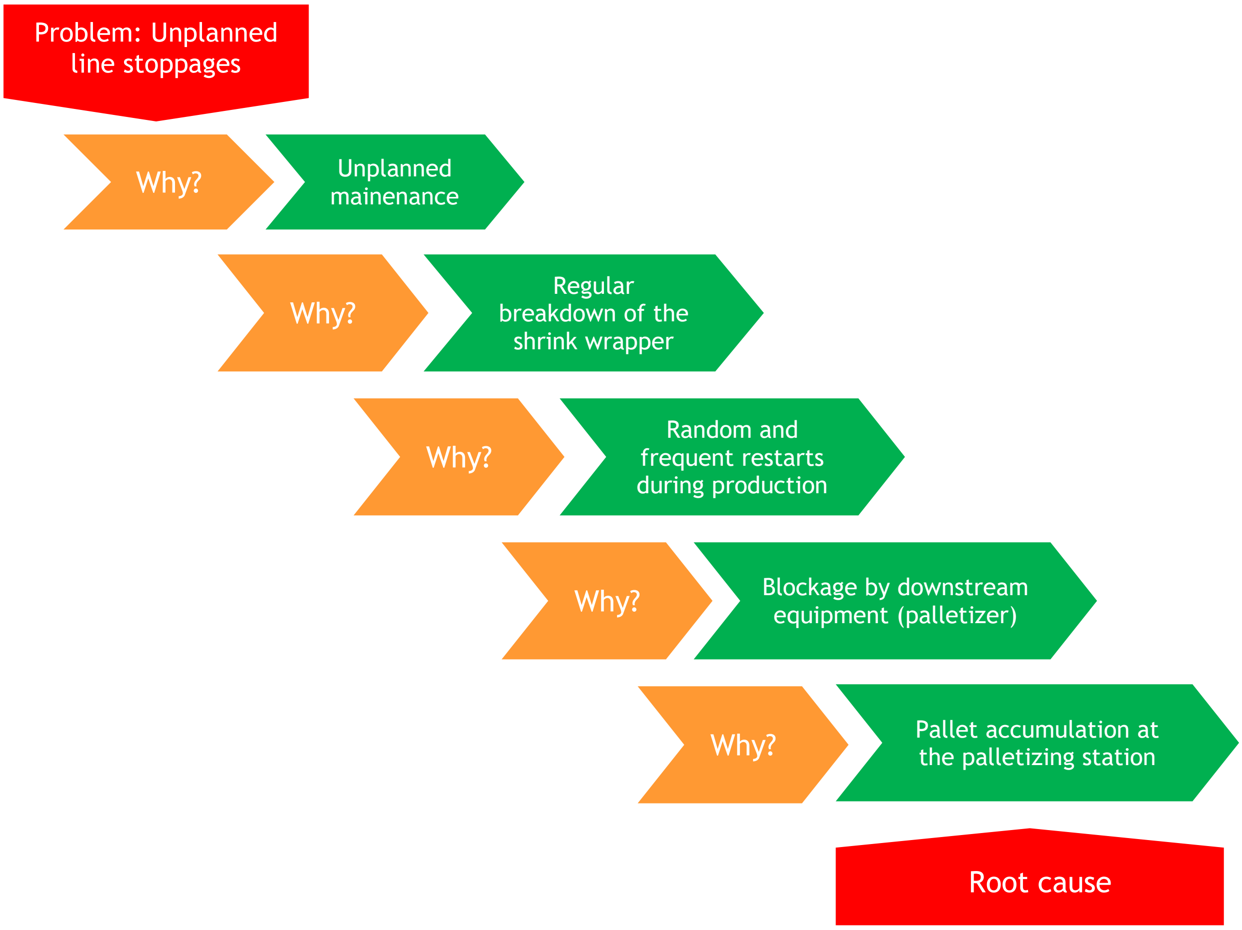


Figure 5: The 5 why analysis for ABC Beverages

The root cause analysis shows that pallet accumulation at the palletizer is the root cause of the unplanned line stoppages. It accounts for 36% of the overall causes of line stoppages. This contributes to 25% of the production time lost per shift. It is the major cause of line stoppages at ABC Company. Figure 6 shows the major causes of line stoppages at ABC Beverages.

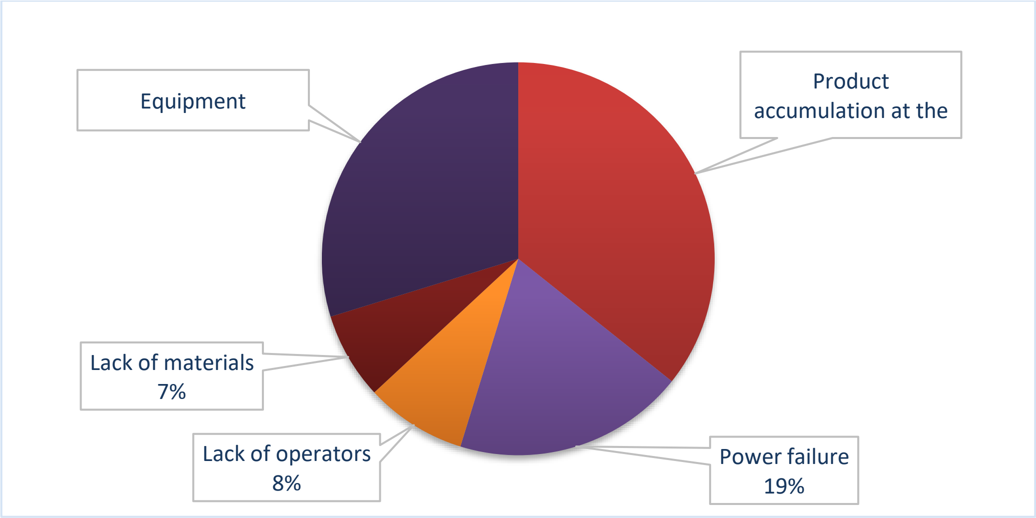


Figure 6: Major causes of line stoppages at ABC Beverages

3.2 Time losses

An investigation on the amount of time which was lost during the stop and start intervals was conducted. The time was largely affected by downtime. The results also showed that an average of 30 minutes was lost at every line stop and start interval. As many as four stop and start intervals were observed. This gives a total of 120 minutes which was lost per shift. Figure 7 shows the big six production time losses at ABC.

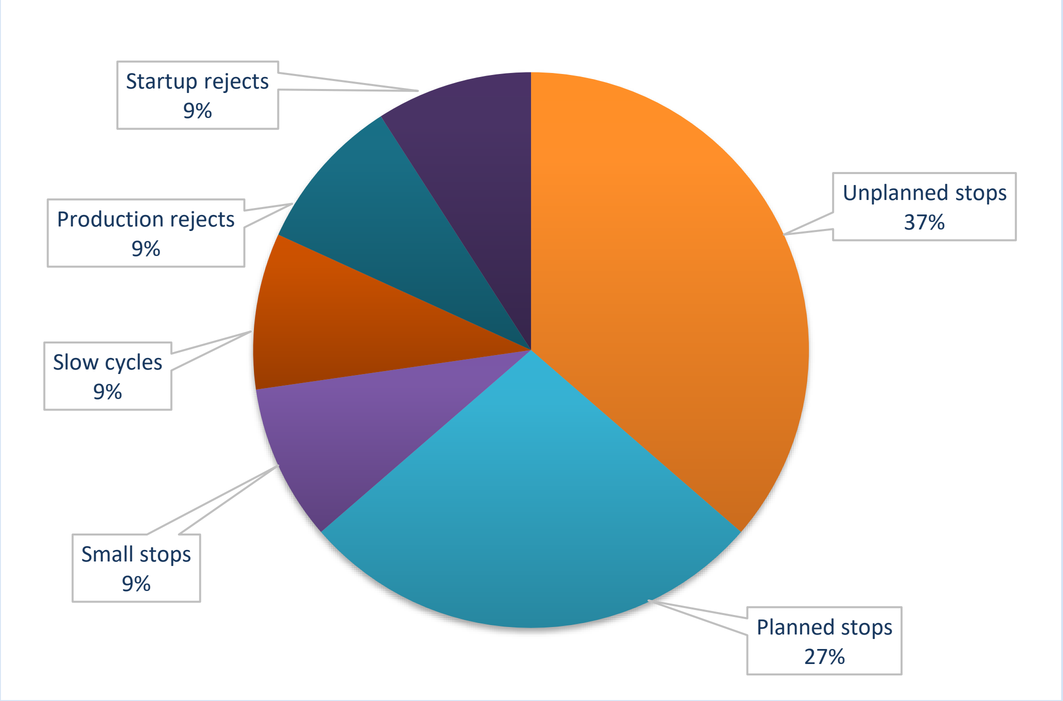


Figure 7: Big six production time losses at ABC

4 ROBOTIC SYSTEM

4.1 End effector configuration

The system is integrated into the production line. It is of great importance to maintain other working components of the production line including the type of pallets used. This affects the design in that the end effector must resemble a forklift. This is the constraint under which the end effector design is based. The storage warehouse is designed and optimised for pallets and forklifts. A change in the pallet design would be costly.

4.2 Robotic arm configuration

The robotic arm was designed under the following constraints:

- It must be integrated with the current system.
- It must have a stationary base that only rotates or moves within a confined predetermined space of 9 m^2.
- It must be capable of carrying heavy loads continuously throughout the two twelve hour shifts per day. Each pallet has a mass of 250 kg.
- It must operate without supervision or guidance.
- It must be easy and cheap to maintain.

4.3 Mechanical system

The main components of the robot arm include:

- *Leadscrew and nut with table:* These drive the motion of the robotic arm in the horizontal and vertical orientation.
- *Motor:* It is used to run the lead screw.
- *Gear system:* Transmission system.
- *Arms, supports and frame:* The material used is stainless steel. This is a common material amongst robot designs.
- *Base platform:* The robot only rotates or moves within a confined predetermined area.
- *Servo motor:* This is a rotary actuator used to turn the robot.

4.4 Control system

The system design constitutes of controlling the robot using microcontrollers and sensors. The control system moves the robotic arm to accurately pick and drop the pallets from the loading area to the conveyor for movement into the warehouse. It follows these set of rules:

If the proximity sensor senses a pallet a given set point away

and

If the weight reading from the weight sensor on the conveyor is pallet weight of 250 kg

then

Robot arm moves towards the conveyor at the palletizer machine, picks up pallet and offloads it on the queue conveyor

The flow chart in Figure 8 shows the control system for the robot.

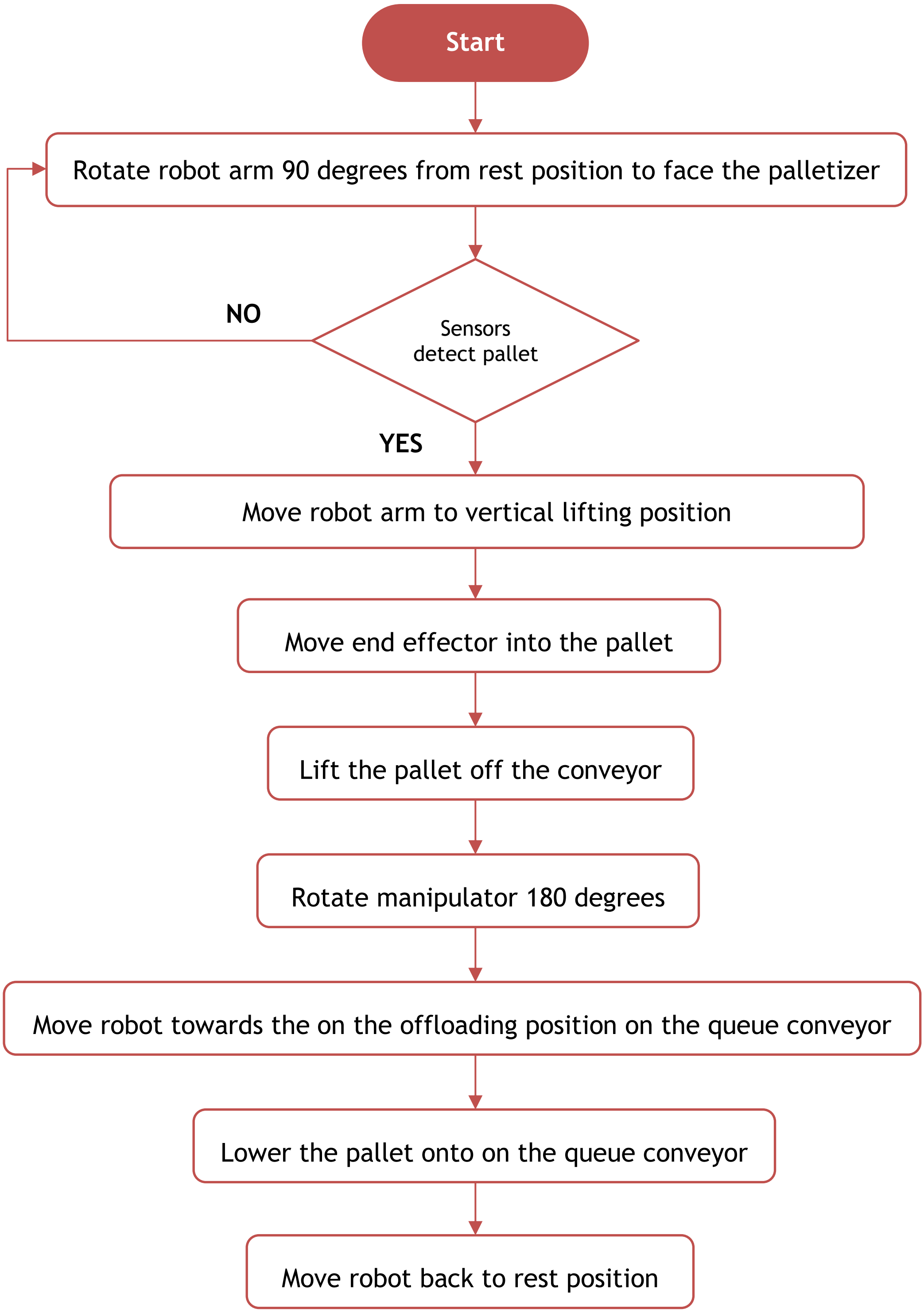


Figure 8: Robotic arm control system flow chart

4.5 Robotic arm principle of operation

Figure 9 shows the design for the robotic arm.

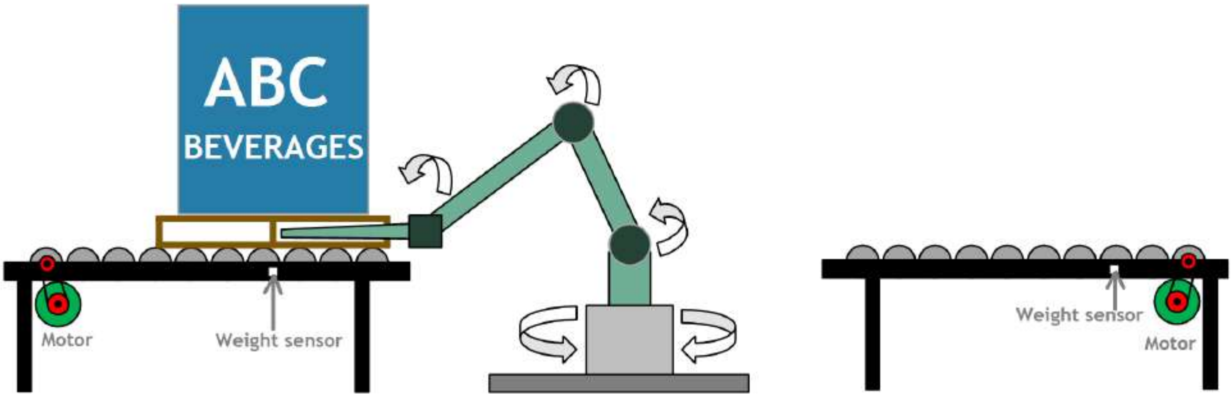


Figure 9: Robotic arm design

The sensors sense that there is a pallet ready for loading. The signal is sent to the controller to actuate the robot's links and joints to move towards the pallet. The end effector lowers to the pallet picking position. It rotates to face the pallet. The base of the arm moves from rest position in the direction of the conveyor. The end effector then enters the pallet rails, and lifts the pallet off the conveyor. The arm then moves up, rotates and moves to the queue conveyor while maintaining stability and being parallel to the ground. It then offloads the pallets to the conveyor. This is shown in Figure 10. The next pallet is ready to be moved from the palletizing station to the queue conveyor. The robot then returns to the rest position. The conveyor moves one step. Proximity sensors then count the number of cases in a pallet.

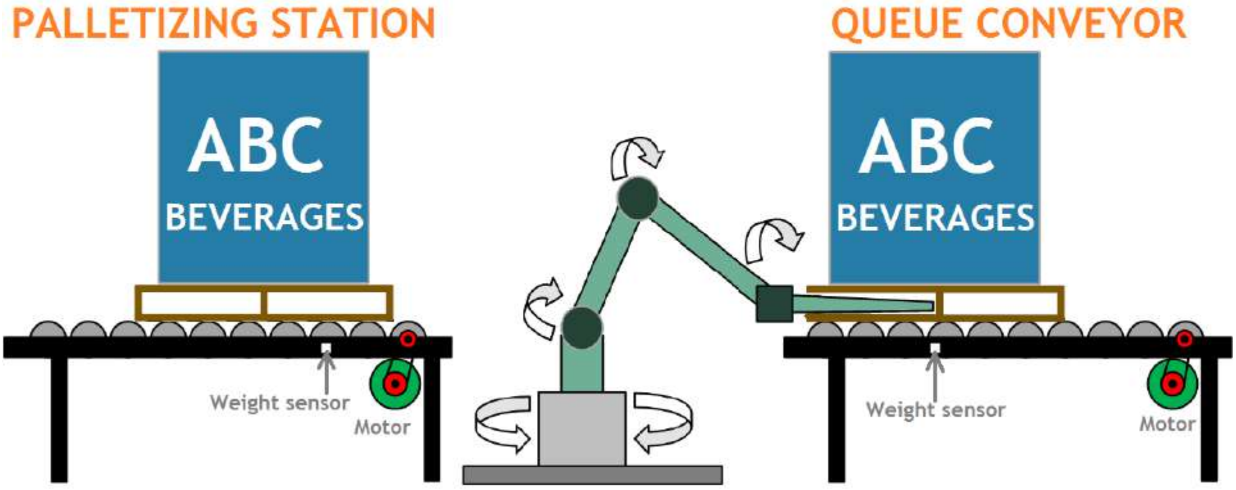


Figure 10: Robot offloading pallet to the queue conveyor

5 RESULTS

The robot design results are tabulated in Table 3. The robot which was developed is an articulated robot which has 6 degrees of freedom and operates at an ambient temperature range of between 0 and 45 degrees Celsius. Of great interest is the payload and the palletizing capacity. The robot is able to carry a maximum of 300 kg. This is over and above the mass of the pallet, which is 250 kg. the robot is able to conduct 800 cycles per hour and this effectively eliminates pallet accumulation at the palletizer station.

Table 3: Robot design

Parameter	**Results**
Type of robot	Articulated
Degrees of freedom	6
Material	Stainless steel
Maximum payload	300 kg
Mass of pallet to be carried	250 kg
Palletizing capacity	800 cycles / hour
Position repeatability	±0.9 mm
Reach	2000 mm
Mounting	Floor
Installation temperature	Ambient temperature (0 - 45 ℃)

6 CONCLUSION

The study presented an approach which was used to solve the unplanned line stoppages at ABC Beverages. The root cause analysis techniques of the fishbone diagram and 5 whys analysis identified pallet accumulation as the major cause of line stoppages, accounting for 36% of the total line stoppages. Through time studies, it was determined that up to 120 minutes of production time was lost due to the unplanned line stoppages. To solve the problem, the research presented a robotic arm which was designed to remove pallets from the palletizer station to a queuing conveyor. This was done to eliminate pallet accumulation. The designed robot has a payload of 300 kg. The results from the study show that pallet accumulation was eliminated and 120 minutes of production time was saved.

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THE INFLUENCE OF ORGANISATIONAL CULTURE ON TACIT KNOWLEDGE SHARING BEHAVIOUR: THE CASE OF ANGLO AMERICAN COAL

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ABSTRACT

This paper explores the influence of organisational culture on tacit knowledge sharing behaviour in Anglo American Coal South Africa (AACSA) projects. The paper establishes the inherent organisational culture in these projects and how this culture enables the sharing of tacit knowledge. This study, utilising the Competing Value Framework (CVF) and thematic analysis, collected data from 15 interviews with project department members. The findings suggest that the market and hierarchy organisational cultures are inherent in AACSA projects. However further improvements in tacit knowledge sharing call for continuing professional development, compulsory social events, as well as accredited education, training, and development sessions. One mining company was studied, this limits the generalisability of the findings. This paper will contribute to further research in the discipline of tacit knowledge, provide understanding and guide mining organisations in their tacit knowledge sharing efforts, and how the organisational culture can be utilised for tacit knowledge sharing.

Keywords: knowledge, tacit knowledge, tacit knowledge sharing, organisational culture, mining.

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1 INTRODUCTION

Knowledge is regarded as personal information which includes ideas, data, expertise, and authority. These facets of knowledge are important for the success of people, teams and organisations [1]. According to Chumg, *et al.* [2], there are two forms of knowledge: overt, also known as explicit knowledge, and tacit knowledge. Explicit knowledge refers to clear information that can be stored in records or files and written down. In contrast, tacit knowledge, also referred to as implicit knowledge, or head knowledge. This type of knowledge is considered more important because it includes individuals, places, ideas and interactions with contexts. Intensive personal communication and commitment is required to effectively communicate it [3]. Sharing tacit knowledge requires members of an organisation to voluntarily add their knowledge to corporate memory. Employees work together to identify issues, express their thoughts and perspectives, and exchange knowledge to find a solution as a team [4].

Information management is a major obstacle for many companies around the world [5].This is because institutions continually lose the knowledge of retiring employees and/or those that resign from the organisation. Heisig, *et al.* [5] add that many firms are experiencing a generational challenge in their workforce due to the growing number of skilled people who are retiring. The problem is exacerbated by the lack of qualified, younger workers, who can replace the skilled workers who need to retire. As workers leave the company, they take with them operational knowledge including their mistakes and achievements, as well as tools and internal processes of previous research and development initiatives [6]. Obeidat, *et al.* [7] claim that before a worker departs, many organisations struggle to understand the value of the tacit information held by that worker. The lack of qualified workers impacts organisational administration/human resources as well as operating processes which ensure the firm has capacity to participate efficiently and without complications [8]. Therefore, efforts to ensure tacit knowledge sharing should be prioritised for organisational sustainability. The effectiveness thereof also depends on how much the organisation exploits their workers' intellectual capital and how they distribute it inside and across their boundaries [6-8]. Consequently, organisational culture is an important resource for inspiring people to share knowledge [9]. According to Alshamsi, *et al.* [10], knowledge sharing is only possible when a corporate culture permits and promotes change, exchange of thoughts, engagement, collaboration and debate. These authors point out that culture can either promote or deter creative approaches in information management and knowledge sharing systems.

Organisational culture is a collection of human behaviour and organisational activity that explain what a business entity is and what it consists of [11]. Organisational culture is often shaped by the principles, goals, traditions, working language, processes, and signs of the organisation; including beliefs and behaviours [12]. Organisational culture can be explained by the perceptions of various individuals or groups in the organisation and how they go about completing tasks. This culture also incorporates the way individuals and organisations communicate with each other, with customers, and with partners in the course of fulfilling organisational objectives [12].

1.1 Background

Mining companies around the world have been severely affected by a lack of skilled resources and knowledgable expertise to fulfil their development needs [13]. Moreover, the global mining industry, is facing challenges due to a lack of young incumbents. Zhang, *et al.* [13] states that the mining industry in South Africa faces a skills shortage in many of the scientific disciplines such as geology, mining, metallurgical, chemical, electrical and mechanical engineering, analytical chemistry, mine surveying, as well as project management [14]. In addition, Mulongo and Kholopane [15] acknowledge that the new, young mining employees do not possess the requisite skill sets and experience to replace retired employees. The lack of knowledge transfer before employees leave the mining industry is a significant challenge. The departing employees frequently leave with unique and hard-to-imitate expertise as well as vital information of what they know [16].

This study was conducted within Anglo American Coal South Africa (AACSA) projects. Anglo American is the world's largest platinum producer, with 40% of global production. It is also a significant producer of metallurgical and thermal coal, diamonds, copper, nickel and iron ore. AACSA is however also suffering from a knowledge deficit [17]. Anglo American's 2018 sustainability report [17] indicates that the organisation has different research partners which enable it to share its production knowledge and help the organisation explore opportunities to improve overall productivity. The same report states that the organisation is struggling with knowledge retention, particularly in coal projects, as the organisation continuously shifts towards cleaner sources of energy such as solar and other forms of green energy or clean power [17]. So, the coal production division is not spared from this knowledge deficit since its production is being channelled towards sustainable energy use.

More recently, the knowledge systems in the contemporary mining industry have been compromised by the COVID-19 pandemic, which implies the need for heavy investment in knowledge management systems within the sector. There is an on-going challenge that knowledge systems in coal projects are compromised and slowly deteriorating as organisations embark on cleaner energy sources [13, 18]. As a potential solution, senior management identified organisational culture as one of the aspects which can support the advancement of tacit knowledge sharing in and across the organisation. Organisational culture can be used as a resource tool to instill the correct values and norms in both old and new employees to enable them to solve any problems they may encounter.

The objective of this paper is to evaluate the influence of organisational culture on tacit knowledge sharing behaviour within AACSA projects. Organisational culture types has been shown to influence tacit knowledge sharing behaviour and such influences may be positive or negative depending on the culture type [19]. The research questions of this paper are as follows:

Q1: What is the inherent organisational culture in AACSA projects?

Q2: What is the influence of organisational culture on tacit knowledge sharing behaviour among the AACSA employees?

Q3: What recommendations can be given on how AACSA organisational culture can better facilitate tacit knowledge sharing behaviour in its projects?

By answering these questions, this research aims to investigate the inherent organisational culture in a South African mining company and how this culture can be utilised to better facilitate tacit knowledge sharing behaviour in its projects. This research contributes to furthering the discipline of tacit knowledge through a case study investigation to guide mining organisations in their tacit knowledge sharing efforts by utilising organisational culture.

This paper begins with a brief overview of organisational culture and tacit knowledge sharing behaviour.This is followed by the description of research method and case study. The prevailing organisational cultures inherent in AACSA projects are described as well as their influence on tacit knowledge sharing. Then further improvements in tacit knowledge sharing is discussed. The paper concludes with discussion for further research and contribution of this paper.

2 LITERATURE REVIEW

2.1 Knowledge

Obeidat, *et al.* [7] states that knowledge remains a 'secret power' until a person uses it to do something, understand something, make a choice or to fix a problem. The importance of knowledge to a business has risen exponentially as a result of globalisation and the change from an information age to a knowledge era [10]. Campbell, *et al*. [16] suggest that the primary driver of a business's profitability is knowledge. This stance is supported by the fact that newer organisations consider the development of specific and original knowledge to be a vital determinant for strategic dominance [20].

2.2 Knowledge sharing concepts and aspects

Since the 1990s scholars have been exploring knowledge management issues [21]. The terms knowledge transfer and knowledge sharing are often used interchangeably which creates confusion. Knowledge transfer is a broader term, since it includes both knowledge exchange by the knowledge source and knowledge development and implementation by the user [22]. The term knowledge transfer is frequently used to define the movement of knowledge between organisational levels (through various areas, units or businesses), but not at the level of individuals.

Knowledge sharing is among the knowledge-based operations that need staff to bring forth new information and share the information to gain a competitive advantage [23]. Knowledge sharing is a significant predictor of business performance in both manufacturing and service organisations [24] and therefore also in mining organisations. Sharing practices may include knowledge collecting, coordinating, exchanging and application.

There are different techniques for organisational knowledge sharing. These techniques include educational exercises, human resource management (HRM) policy, reward schemes, corporate cultures and processes such as web 2.0 software, social networking sites, intranet etc [25]. Organisations perform in-house and external training to improve employee ways of doing work, while HRM techniques are implemented to promote knowledge sharing through interaction [26]. This develops commitment as workers are inspired to communicate, codify, construct information and encouraged in knowledge sharing practices [25]. Reward strategies which include accolades, awards, competitive wages, advancement, incentives, and appreciation have been found to improve employee knowledge sharing behaviours [27]. Furthermore, when organisations provide competitive salaries and promotions it has a significant effect on improving knowledge sharing [23].

Wipawayangkool and Teng [28] stress that online information exchange platforms are one of the essential outlets for promoting the sharing of knowledge. Global developments such as COVID-19 have emphasised the importance of the Internet as a great tool for knowledge sharing [24]. Importantly, organisations need to have their own culture to focus on its operational activities which include information sharing among employees [29].

2.3 Knowledge sharing behaviours

Nonaka and Takeuchi [30] seminal study gives advice on how to distill explicit knowledge from tacit knowledge and vice versa through various knowledge sharing behaviours which are influenced by the organisation's culture. Organisational culture types has been shown to influence tacit knowledge sharing behaviour and that such influences may be positive or negative depending on the culture type [19]. Research has proposed four tacit knowledge sharing behaviours, which include; organisational communication, personal interaction; mentoring and/or tutoring; and willingness to share knowledge freely.

2.3.1 Organisational communication

Organisational communication refers to the modes and networks that organisations use to communicate and maintain knowledge [31]. It facilitates knowledge sharing behaviour to the extent that relationships are formed, maintained, changed, or terminated by increases or decreases in meaning through space and time [19]. This type of communication requires good interactions within the organisation as well as direct communication to the employees.

2.3.2 Personal interaction

Personal interaction or professional engagement in the organisation involves a formal way of exchanging views and thoughts with people working in the same (or related) field on subjects of professional interest, with the expectation that the individuals participating in the discussion have learned something from it [32]. While this may not be a form of tacit knowledge sharing behaviour, Bouncken and Reuschl [32] note that employees may learn indirectly from one another without even using formal procedures. Positive personal interactions boost positive emotions, productivity, and job satisfaction [19].

2.3.3 Mentoring/tutoring

Mentoring is perceived as a knowledge sharing tool in organisations. Mentoring is characterized as a fluid approach that is fuelled by both parties [33]. Suppiah and Sandhu [19] noted that the existence of mentors can directly or indirectly necessitate the sharing of tacit knowledge among their subordinates. This corroborates Wang, *et al.* [34] who determined that transmitting tacit knowledge resides in informal networks where relationships are created almost by chance when a protégé spontaneously seeks assistance. Innformal mentoring differentiates itself from structured mentoring in that the informal mentor protégés indicated that their mentors experienced more professional growth and psychosocial roles than those of structured mentors.

2.4 Organisational culture

Organisational culture can be defined as the shared, basic assumptions that an organisation adopts while coping with the environment [35]. Organisational culture provides the ultimate way of addressing organisational problems and it is an essential aspect of organisational competitiveness [36].

2.4.1 Concepts of culture

Kathiravelu, *et al.* [37] indicate that the most significant aspect in determining success or loss in businesses is culture. They identify three major core aspects of culture, which are values, culture network and rites and rituals. Values include the belief systems that live in the hearts of the business, as well as in the 'culture heroes' who are the people who hold the values whilst rites and rituals encompass all the interaction routines that have representative qualities [37]. The culture network includes hierarchies of power that are unspoken in the organisation, as well as in its information communication system. In terms of organisational culture elements, values are the most important factor in a business that promotes a strong bond between people [9, 38].

Al Saifi [39] claims that if there is no consensus, or if there is a disagreement or problems that are not obvious, a community won't have a culture. The culture of an organisation's owner also plays an important role in shaping the organisational culture, promoting the adoption of knowledge sharing activities by employees, and accessing key information in the company [40]. An essential aspect of organisational culture is the organisational structure since it impacts the competence of a company and its management style [41].

Moreover, incentive programmes, gestures and procedures are also important and can be viewed as elements of organisational culture Kucharska and Bedford [41] indicate. Other aspects of organisational culture include inspiration, law and processes, incentive structures, tales, and language [1]. Abdelrahman and Papamichail [12] add that organisational culture requires principles and objects that provide the employees of an organisation with input about how to address the challenges they encounter.

2.4.2 Role of organisational culture

Organisational culture plays a major role in any organisation. In recent years, researchers have found that most organisations are knowledge based and their knowledge sharing success is dependent on the type of culture the organisation is administered under [19]. The culture of an organisation has to fulfil two functions; the first function is the socialising, feeling identities of members and setting boundaries of the organisation. Secondly, the culture has to coordinate competition, making the organisational environment stable and acceptable to members [19]. The role and importance of culture is to create a cognitive framework for employees and shape the manner in which they perceive their organisation’s competitive landscape [42].

2.4.3 Organisational culture and knowledge

The literature shows that the terms organisational culture and knowledge are interrelated. Davenport and Prusak [43] were the first to use the term knowledge-friendly culture; Janz and Prasarnphanich [44], refer to knowledge-centred culture and Oliver and Kandadi [45] use the term knowledge culture. Brunet-Thornton, *et al*. [11] note that culture is vital for shaping the staff and helping them understand what knowledge is significant to the organisation. It enables individuals to understand the different types of relationships between knowledge levels, that is, what knowledge should belong to individuals and what should belong to the firm, it also enables the establishment of social context.

Studies such as those by Al-Alawi, *et al*. [35] and Zin [46] demonstrate that various aspects of organisational culture may have a substantial effect on the knowledge sharing process in an organisation. Campbell, *et al*. [16] uses the phrase ‘culture-aligned to knowledge’ and conceives it as part of organisational processes, as one of the most significant requirements for knowledge creation and sharing.

Every company's organisational structure affects its knowledge sharing processes because the organisational framework ties business divisions to their objectives; it also discusses and standardises policy procedures and tracks policies and laws. In a hierarchically structured company, for example, the knowledge sharing processes will focus more on sharing and transferring knowledge between teams and organisational units, than on the role of individuals in knowledge sharing. Leveraging knowledge resources rather than innovation is the primary reason for sharing [24].

3 CONCEPTUAL MODEL

The study adopted the Competing Value Framework (CVF) as the underpinning conceptual framework, see Figure 1. The CVF was initially developed from studies carried out by faculty members at the University of Michigan on the main dimensions of successful organisational efficiency [47]. The CVF looks at an individual’s leadership behaviour, and how that behaviour produces a specific type of organisational culture and competency, as well as how that competency produces various and specific types of values, and synchronizes them [47]. CVF provides for clan, market, adhocracy, and hierarchy organisational culture.

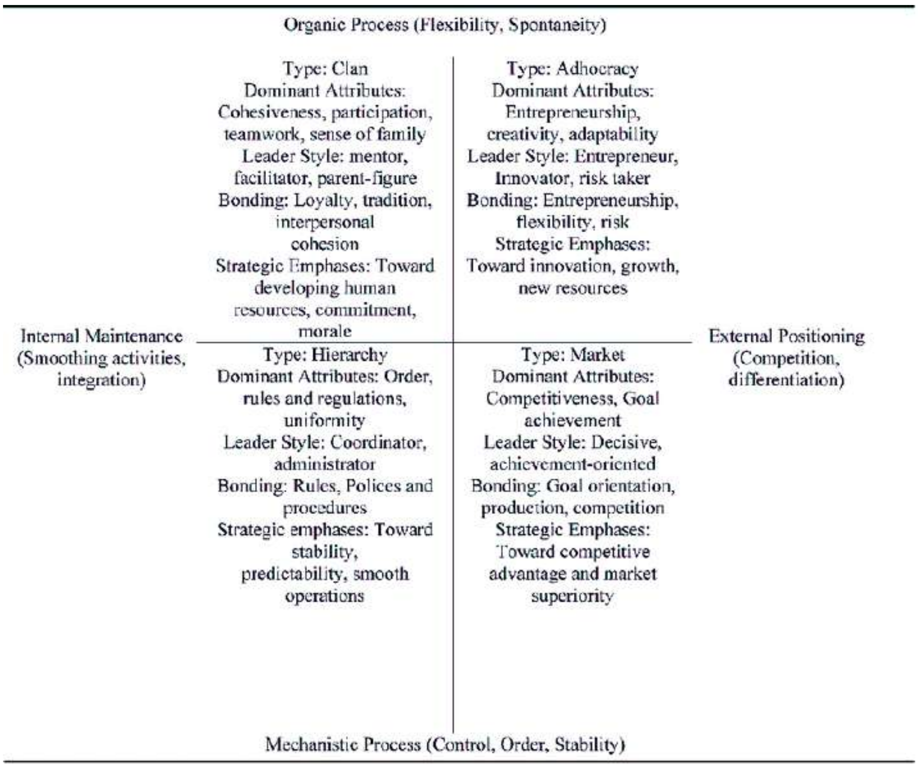

Figure 1: CVF model of organisational culture types (Source: [48, 49])

Market culture emphasizes competitiveness and goal achievement [48]. It looks into the transactions that function with (mainly) external role players of the market such as suppliers, customers, contractors, licenses, unions, and regulators to create competitive advantage [50]. Clan culture is a sociable culture like ‘one big family’, people with common interests and it is characterized by teamwork, co-workers and high corporate commitment to employees [50]. Adhocracy culture emphasizes the values of entrepreneurship, creativity, and adaptability. The essential beliefs in adhocracy are flexibility, tolerance and being effective. Hierarchy culture stresses order, rules and regulations. Transactions in the hierarchy culture are under surveillance, evaluation and direction. Organisational effectiveness in the hierarchy is defined as consistency and achieving the clearly stated goals [51]. CVF has been used in thousands of organisations and has been found to predict organisational performance [52]. The CVF model of organisational culture assists organisations to identify their predominant leadership type as either clan (collaborative), adhocracy (creative), market (competitive) or hierarchy (controlling) [53].

4 RESEARCH METHOD

An exploratory research design was used to investigate the research problem as it was not well understood [54]. Qualitative analysis was used to explore this contextual study. Qualitative analysis offers a unique method for analysing what is behind or underpins a judgment, mindset, actions or other factors, thanks to its capacity to objectively analyse subjects [55]. In this study, an in-depth inquiry was conducted in order to understand:

- the types of organisational cultures that are inherent at AACSA projects and
- the influence of the organisational cultures on tacit knowledge sharing behaviours.

The population used in this study comprised of AACSA project team members and project managers who have been working in the project department for at least a year or more. A population of 50 individuals was provided by the AACSA human resources department. A purposive sample of the 15 most experienced participants were selected from list provided. It is assumed that these participants possess the most in-depth knowledge of the organisation's culture and its influence on tacit knowledge sharing behaviour.

Purposive sampling was used to select the study participants as they were limited in number and it is a cost and time effective sampling method. The authors used an interview guide to gather the respondents' information. Grix [56] noted that the benefit of interview guides is that they provide a certain degree of versatility and provide unintended enquiry lines to be scanned during the interview session. Interviews allow respondents to answer questions in their own language [57]. Interviews allow large amounts of data to be gathered in a short period of time. The interview guide was first piloted with five participants who assisted to refining it further. A total of 15 participants were interviewed, consisting of 10 project team members and 5 project managers. Data saturation was reached after conducting 12 interviews. According to Guest, *et al*. [58], if the aim of the study is to understand common perceptions and experiences among a group of relatively homogeneous individuals, 12 interviews should suffice. The interviews were transcribed and then inductive thematic content analysis was done. This method includes data selection, data coding in pattern search and data categorization into themes and sub-themes [59].

5 RESULTS & DISCUSSION

A number of themes emerged from the data and these themes were further categorised under broader themes emanating from the research questions.

5.1 Inherent organisational culture type in AACSA projects

5.1.1 Market culture

In order to understand what the participants of this study regarded as the inherent organisational culture type in AACSA projects, primary research was conducted where open-ended questions were asked. Initially, the participants provided different perspectives on organisational culture types. After further discussions, several participants indicated that market culture is the inherent organisational culture type in AACSA projects. Market culture, according to Palahudin and Mukmin [60], is a culture in which the aim is to get down to business, get things done, and get results. Even among co-workers, this is frequently a competitive environment. Working at a company with this sort of culture is all about making as much money and acquiring as much market share as possible [61]. A market culture is also a form of corporate culture that emphasises rivalry not just between the firm and its market rivals, but also among workers [61]. Critics of the market culture say that its emphasis on individual success might foster dishonesty and an unpleasant – and hence unproductive – work environment [60]. The quotes below support this finding:

> *"Our projects have an aggressive and capitalistic culture to them. Management encourages employees to set high standard goals that they should strive to achieve." (Project Manager 2)*
>
> *"AACSA projects operate on the basis of employee performance and this performance is closely monitored and often directly rewarded or punished. The success of the project is based on the emphasis that is placed on individual performance which leads to greater achievements and rewards for the individual employee and, as a result, for the greater success of the projects". (Project Team Member 2)*
>
> *" Our projects are always one step ahead in all the processes because management and employees are always working with competitors in mind and through having this market culture the organisation is always dedicated to market research and staying on the ball with daily trends and goings-on within the industry". (Project Team Member 5)*

5.1.2 *Hierarchy culture*

The majority of the participants (9) indicated that market culture was the most common, however it was also noted that hierarchy culture was inherent in AACSA projects.

> *"There is no doubt that at AACSA Projects, there is also hierarchy culture because the work environment is very formal, with strict institutional procedures in place for guidance." (Project Manager 1)*
>
> *"Personally, I believe that we have a hierarchy organisational culture because I feel more secure; get paid on time; and I also feel safe to stay in my position for a long time for the success of the project. Our organisation is well structured, you basically know where everything is, and where to find certain information" (Project Team Member 8)*

According to Irfan and Marzuki [62], organisations with hierarchy cultures adhere to the conventional corporate structure. These are organisations that prioritise internal structures through a clear hierarchy and numerous management layers that divide employees from leadership [62]. Hierarchy cultures have predetermined methods of doing things, which makes them stable and risk-averse. With that, hierarchical cultures have clear direction, allowing for easy information transfer among personnel [62].

5.2 Influence of the organisational culture on tacit knowledge sharing behaviour among the employees

5.2.1 *Encourage team bonding*

More than half of the participants stated that the market and hierarchy culture fosters team bonding, which also supports tacit knowledge sharing behaviour. Even though the literature alludes to the contrary, the study found that the market and hierarchy culture which exists in AACSA projects promotes team work and cohesiveness, the project team have a willingness to work together and share knowledge in order to reach a common goal, which unites the team and brings about a huge sense of achievement.

> *"Team bonding is pivotal to social learning. Without a sense of community, the motivation to actually share is reduced as it feels awkward when there is no bond between employees. However, I believe that our culture allows employees to work together effectively through sharing of ideas in order to achieve organisational goals." (Project Manager 3)*
>
> *"Our organisational culture promotes team building activities, which also improves our coal projects through teamwork. As a result of this, employees better understand each other's strengths, weaknesses, and interests through effective communication as well as information sharing. This understanding helps them work even better together."(Project Team Member 2)*

5.2.2 *Efficient productivity*

The study participants believe that one of the influences of organisational culture on tacit knowledge sharing behaviour is efficient production within the projects. Particularly the project manager participants believe that the market culture, which is founded on competition and obtaining real outcomes, emphasizes the importance of good communication with employees to ensure project success.

> *"Efficiency is as a result of a market culture, it increases profitability. By having our teams share ideas and knowledge, efficiency and profitability definitely increases." (Project Team Member 3)*

The study's findings support the literature. Market culture leads to efficient production, which is supported by information sharing among team members [33]. Efficient production may be measured in monetary and/or non-monetary terms. Bakotić [63] claims that non-financial organisational success measurements can also be shown in the form of enhanced efficiency and improved levels of motivation. Thus, organisational culture and tacit knowledge sharing behaviour are believed to be factors that increase productivity in all parts of an organisation.

5.2.3 Increasing profitability

Participants indicated that AACSA's inherent organisational cultures increase profitability of the organisation through tacit knowledge sharing behaviour among employees.

> *"Our projects have been profitable for many years because there is a good platform that allow teams them to share success stories, lessons learned, and how to do better in the next project." (Project Team Member 3).*

The study findings provided above are validated by the literature. According to Kathiravelu, *et al*. [37], the organisation would be able to monitor all of the profitability connected with various divisions if it adopted a profit-focused organisational culture that also fosters knowledge sharing among its workforce. This is significant because it makes it easier to work toward a single shared objective. As a consequence, an organisation may take advantage of very profitable operations while also adjusting others that result in little profit.

5.2.4 Enhancing employee morale

The majority of the participants provided various reasons as to why they believe that employee morale is enhanced in AACSA projects as a result of the inherent organisational cultures, which in turn promotes tacit knowledge sharing behaviour among employees.

> *"The organisational culture of AACSA projects allows employees to interact and share ideas at all times. Through the process of sharing ideas, there is enhancement of employee morale which goes a long way in producing good results, however a lot needs to be done to encourage interaction of employees outside the office." (Project Manager 3)*
>
> *"I think one of the benefits of our organisation culture is its ability to encourage workers to help each other through knowledge sharing about projects, especially when there are new employees. They need to be provided with adequate information so that they can work towards one goal. They are given the freedom to ask without any judgement, and learn from fellow team members. When I first joined Anglo, I felt very supported. All this increases employee morale." (Project Team Member 1).*

Based on the number of participants who had sentiments to those above, it was found that organisational culture has an influence on tacit knowledge sharing behaviour, which in turn enhances employee morale Suppiah and Sandhu [19] note that market culture promotes knowledge sharing in the organisation, which in turn increases employee efficiency, morale and fieldwork, and organisational effectiveness.

5.2.5 Saving resources

From the interviews the study found that saving company resources is one of the influences of organisational culture on tacit knowledge sharing among employees.

> *"Our organisational culture has created a working environment that promotes good communication and through that process employees do not often require external training. This saves the organisation external training costs." (Project Manager 1)*

> *"There are policies and processes that encourage employees to work and share information that leads towards the realisation of the company's mission. It is also through information sharing that everyone works effectively without wasting the resources of the company." (Project Manager 5)*

The literature offers conflicting data on the effects of organisational culture on tacit knowledge sharing behaviour when it comes to saving resources. Market culture leads to resource savings, which is often evaluated in terms of costs [12].

On the other hand, Kumar and Sharma [42] remark that if divisions are conflicting, organisational culture would suffer, which will negatively affect knowledge sharing among employees. The main problem is that different resources, particularly monetary, must be employed to guarantee good collaboration across departments.

5.3 Improvements in tacit knowledge sharing behaviour

5.3.1 Continuing Professional Development Sessions (CPDS)

One of the important findings of this study is that the majority of the participants indicated that there is need for continuing professional development sessions in order to promote tacit knowledge sharing behaviour. Participants indicated various CPDs such as formal courses, informal learning, conferences and meetings. CPDs ensure that employees retain and improve their knowledge and skills required to provide a professional service to all stakeholders. Furthermore, employees are then more aware of the organisation's changing trends and directions.

> *"We need to have CPD session in order to improve knowledge sharing behaviour among employees. This is important as it helps to ensure that further learning is progressed in a structured, practical and relevant way to guarantee that there are applied efficiencies in sharing of information." (Project Team Member 5)*
>
> *"For me, CPD sessions are always the best when promoting knowledge sharing among employees. It should not be informal all the time, even though informal can be great too." (Project Team Member 3)*

According to Kumar and Sharma [42], CPDs are important because they ensure competency within organisations and this competency provides employees with the ability to share knowledge with others in order to achieve the organisation's goals and mission. Suppiah and Sandhu [19] state that CPDs help employees continue to make a meaningful contribution in their team and become more effective in the workplace. As a result, this assists employees to advance in their careers and move into new positions where they can lead, manage, influence, coach and mentor others.

5.3.2 Compulsory social events

In addition to the CPD sessions identified above, compulsory social events were also identified as one of the recommendations that can be used to promote tacit knowledge sharing behaviour among employees.

> *" Because of the nature of the work and the culture, the team is always busy and chasing targets so there is little time for employees to interact so we need events that are compulsory so that everyone has the opportunity to share ideas not just ideas coming from the management." (Project Team Member 4)*
>
> *"Everyone is chasing because of the nature of the projects and there is little knowledge sharing between employees except what is coming from the management. I think if we can have compulsory social function employees will have the ability to share knowledge on various operations" (Project Manager 1)*

Campbell, *et al.* [16] states that employees can effectively share skills and knowledge when they are given enough time to interact with one another and this can be achieved through hosting professional social events in the organisation. It is interesting to note that through hosting of social events, it leads to friendships and positive relationships within the workplace that promotes skills and knowledge sharing behaviour [41]. Additionally, Kucharska and Bedford [41] note that social events allow employees to relax, which provides them with a chance to share ideas that they cannot share under normal working hours.

5.3.3 Accredited education, training and development sessions

The majority of the participants believe that it is useful for all employees to undertake related courses and training that promote tacit knowledge sharing behaviour. Participants gave reasons such as the opportunity to interact with each other, increased capacity to adopt new technologies and methods, increased job satisfaction and morale among employees.

> *"Teams should receive training because one of the advantages of training workshops is that there is interaction among employees and there will be more knowledge and skills sharing as well as increased job satisfaction and morale among employees." (Project Team Member 8)*

Education, training, and development conducted by private companies yield many benefits such as worker confidence and retention, productivity, employee satisfaction, and learning new ideas and skills [19], yet it can be costly and time consuming.

6 CONCLUSIONS AND RECOMMENDATIONS

The study found that market culture was the inherent organisational culture of AACSA projects. Market culture is a form of corporate culture that stresses competitiveness not just among the business and its market competition, but also among workers. Moreover, hierarchy culture also appears to be inherent in AACSA projects. Participants' responses clearly demonstrated that the hierarchy culture is due to the organisational structure type and control. The workplace was found to be formal, with strong institutional processes in place to provide direction. Leadership is built on systematic coordination and monitoring, with a culture that values efficiency and predictability. In terms of the influence of organisational culture on tacit knowledge sharing behaviour, the participants reported that there is improved team bonding, increased profitability, efficient production, enhance employee morale and resource savings as a result of these inherent cultures. It is possible that these factors may have been impacted by the participants' perception of the study and its context. The participants recommended that CPD sessions be instituted to promote informal and formal tacit knowledge sharing behaviour among employees. Furthermore, there is a need for education, training, and development and compulsory social events to encourage tacit knowledge sharing.

This study has established the inherent organisational culture in AACSA projects and its influence on tacit knowledge sharing behaviour. The study revealed that several measures can be instituted so that a market/hierarchy organisational culture facilitates tacit knowledge sharing behaviour. The study limitations suggest potential fruitful opportunities for future research. The authors acknowledge that the generalisability of results may be limited because the data was collected from a mining organisation in the one country: South Africa. In this case, it might be useful to see if the findings replicate in other national settings. Second, it is suggested that the organisational culture factors that impact the success of knowledge sharing behaviour be investigated as this paper only studied organisational culture as a construct. To this end factors such as interpersonal trust, communication between staff, information systems, rewards and organisational structure could be considered for further study.

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AN EXPLORATION OF TOTAL QAULITY MANAGEMENT ON TRANSPORTATION SERVICES

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ABSTRACT

The purpose of this study is to explore the impact of Total Quality Management (TQM) on safety performance within an Air Navigation Service Provider (ANSP). The objectives of the study are how TQM can enhance aviation safety and explore top management commitment to safety improvement. The study followed a quantitative method, using the questionnaire survey to gather data. A descriptive analysis method was carried out using the Statistical Package for Social Sciences (SPSS) software. The study has concluded that total quality management has a positive impact on aviation safety as it encourages commitment to safety behavior, focuses on customers, adopts a strategic and systematic approach, a process-driven approach and adopts a factual approach to decision-making. The study concluded with the implication of the research and the limitation of this study.

Keyword: Total Quality Management, Safety, Safety Management, Aviation

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1 INTRODUCTION

The increased focus on quality has made it a legal necessity for businesses to implement a streamlined, structured, and standardized quality management system with the goal of managing all quality-related processes while minimising operational risks. Because good Quality Management System (QMS) is required for successful TQM in an organization, the TQM approach cannot be applied without it. However, not every approach to quality management is appropriate for attaining company goals and total quality management [1]. The Total Quality Management (TQM) approach began during the 1980s in the United States, many organisations, the early adopters rushed and got on board, however it was long that small and medium organizations felt that the required changes were unaffordable as it required high investment of time some thought that this approach would not affect their organizations. The existence of the quality revolution was proven in 1994 when the world competitiveness report was released, a couple of significant countries had already adopted within the United States were at the top of the list, Japan third [2]. TQM has gained popularity over the years, and in recent years, it has gained much attention worldwide. Some organisations view TQM to achieving competitiveness, while others believe it is a mere management gimmick, as many organisations have already failed to successfully implement it [2].

Flight operations worldwide involve interactions amongst different key role players, namely the Air Traffic Control (ATCs), Pilots, flight attendants, aircraft technical maintenance personnel, dispatchers, airport ground crew and ground equipment technical maintenance personnel, also known as Air Traffic Safety Electronic Personnel (ATSEP). All these stakeholders from various organizations collaborate closely and well-coordinated to ensure that high levels of quality and safety in air travel are attained and maintained [3]. On the larger scale of air traffic control, The ANSP generally houses the ATCs and the ATSEPs. According to the Federal Aviation Administration (FAA), cited in [4], state that Air Traffic Controllers are trained personnel stationed at different air traffic control centres to guide aircraft movements from taxiways, take-off, throughout the air and safely land on the ground and back to packing bay. ATSEPs Are technically skilled professionals that provide technological, equipment, and software related support to Air Traffic Controllers, allowing them to operate successfully [5].

Academic studies on aviation safety have revealed that the sector desperately needs comprehensive aviation safety management [6]. In aviation, quality of services is viewed mainly by passengers as safely departing from one point to the other without aircraft accident or incident (surviving the aircraft trip), reliability of the aircraft services, efficiency, convenience, and timelines. The aviation industry is highly safety sensitive, and high-quality levels of services and reliability of hardware and personnel skills are required [7]. The aviation industry is divided into four key role players, namely. The objectives of this paper are to determine how TQM can improve safety performance, the role of top management to strive for continuous improvement in safety management and to examine the benefits of integrating TQM with the ANSP safety management system.

Quality of service or goods has become a demand by customers to fulfil their needs. Achieving quality requires commitment and hard work to find dynamic means to meet customers' needs [8]. The sentiment above is echoed by [9], who stated that the demand by customers for high quality services at rates reasonable in today's global market had forced businesses to deliver high quality services at reasonable rates in the market today in a bid to gain a competitive advantage against their competitors. In trying to gain a competitive advantage, airlines try to outshine their competitors by providing quality services that meet or exceed the expectation of customers. Thus, customer satisfaction in the airline industry is never ending as they face numerous challenges and competition daily. This makes Quality management critical to the airlines as they strive to continuously improve their services to meet customers' expectations. Service quality is necessary for the airline industry as it is a significant determinant of competitiveness. Airlines paying strict attention to service quality will be differentiated from others and will gain competitive advantage.

Quality Management System, as per the International Aerospace Quality Group (IAQG) AS9100, is a standard set of requirements for implementing the process of a QMS. It is based on best practices that are recognized worldwide and tailored to the aerospace industry. It was developed by the International Aerospace Quality Group (IAQG); AS9100 comprises a set of requirements that reflect time-proven, universally accepted good business practices, the majority of which are mandatory. AS9100C includes all the ISO 9001requirements in their entirety, plus additional Aerospace Industry specific requirements [12]. The ICAO Framework of Safety Management System (SMS) has the following four components and twelve elements and is accepted by ICAO member states [11]. They are as follows; Safety policy and objectives: management commitment and responsibility, safety accountabilities, the appointment of key safety personnel, coordination of emergency response planning and SMS documentation. Safety risk management: hazard identification, safety risk assessment and mitigation. Safety assurance: safety performance monitoring and measurement, the management of change and continuous improvement of the SMS. Safety promotion: training and education and safety communication.

The identification of hazards is a prerequisite to the safety risk management process, and Hazards may require categorizations according to the severity/likelihood of their projected consequences. Hazard identification shall be based on a combination of reactive, proactive, and predictive methods of safety data collection [11]. The safety risk is the projected likelihood and severity of the consequence or outcome from an existing hazard or situation. Safety risk probability is the likelihood or frequency that a safety consequence or outcome might occur [11]. Risk management is another component of a safety management system that encompasses the assessment and mitigation of safety risks. The objective of safety risk management is to assess the risks associated with identified hazards and develop and implement effective and appropriate mitigations. Safety risks are conceptually assessed as tolerable and intolerable [11]. Safety Culture refers to the extent to which every individual and every group of the organization is aware of the risks and unknown hazards induced by its activities; is continuously behaving to preserve and enhance safety; is willing and able to adapt itself when facing safety issues; is willing to communicate safety issues, and consistently evaluates safety-related behaviour.

The essence of safety culture resides in the people beliefs about the importance of safety, including what they think their co-workers, supervisors and leaders really believe about safety‘s priority. It is demonstrated through attitudes, accepted norms and behaviours. It‘s about how things work and the way things are done. Safety culture, as defined by [13], rests on five components, namely: Informed culture -The organization generates significant data on incidents and accidents, which is complemented by safety audits and surveys on the safety environment; Reporting culture – Employees are encouraged to report their errors or near misses, and take part in surveys on safety culture; Just culture – The establishment of a trust relationship between employees and employer where reporting mistakes and incidents are encouraged and employees know they will be treated fairly if they make any unintentional mistake; Flexible culture -The organization shows that it is able to adapt its practices when warranted; Learning culture - The organisation learns from incident reports, safety audits and internally-reported issues, resulting in improved safety. As Stated by [14], Developing Safety Culture in an organization on a continuous basis is essential in Aviation and Aerospace Safety, it states the point that safety culture is something an organization either has or not.

An organization ―fostering strong safety culture would encourage employees to cultivate a questioning attitude and a rigorous and prudent approach to all aspects of their jobs and to set up necessary open communication between line workers and middle and upper management [14]. As indicated by [15], an effective SMS can produce the following benefits: a reduction of incidents and accidents, reducing direct and indirect costs, reducing insurance premiums, an improvement in staff productivity, safety recognition by the travelling public, Proof of diligence in the event of legal or regulatory safety investigations [15].

2 RESEARCH METHODOLOGY

The study adopted a quantitative research design through a questionnaire survey. The survey was conducted among aviation professionals, limited to the Gauteng province, South Africa. The premise for conducting the study in this province is that Gauteng hosts the busiest airport in South Africa, namely O.R. Tambo International airport, as well as considering the size of the airport and the number of flights departing and arriving the airport, would require several people working on rotation.

The research instrument for the study was a structured questionnaire adopted due to its ability to reach a wide range of respondents within a short period [18] and ensure quantifiability and objectiveness in research [19]. Furthermore, it has been observed that the questionnaire is a widely used instrument for harnessing information in social science research [20], hence its adoption in this current study. The questionnaire used was designed in sections, with the first section gathering background information of the respondents to ascertain their suitability for the study. The following sections of the questionnaire focused on the following: ascertaining if aviation safety can be enhanced through total quality management, determining if top management involvement is essential in the implementation of quality safety management and lastly, exploring the benefits of the implementation of TQM as part of the safety management system. These questions were evaluated on a 5-point Likert scale.

The designed questionnaire was conveniently distributed using the Google form—an online mode of distribution. This mode of administering questionnaire was adopted due to its ease in reaching many people across a considerable distance [21]. The link developed for the designed questionnaire was distributed via email to the aviation body identified. The designed questionnaire had a cover page describing the nature of the research, the information on respondents' voluntary participation and assurance of anonymity in the study. At the end of the survey, which spanned from July to September 2021, a valid response of 78 was retrieved and deemed fit for data analysis. Firstly, the Cronbach alpha (a) test was used to ascertain the research instrument's reliability. A value of 0.925, 0.897 and 0.927 was derived the ascertain if aviation safety can be enhanced through total quality management, to determine if top management involvement is essential in the implementation of quality safety management and to explore the benefits of the implementation of TQM as part of the safety management system. These figures showed that the instrument used was reliable as the a-value was closer to one. The next step was descriptive analysis using percentages to analyse the background information and mean score (X) to rank the factors measuring the objectives.

3 FINDINGS AND DISCUSSION

From Table 1, the respondents strongly agreed that TQM encourages commitment to safety behaviour, with a mean of 4.21 and a deviation of 0.827. In support of the findings,[22] stated that preparing and instruction have a hugely beneficial outcome on work contribution, work fulfilment, and hierarchical responsibility. Strengthening and cooperation fundamentally upgrade work contribution, work fulfilment, profession fulfilment, and hierarchical responsibility. As far as TQM assisting the ANSP to be customer focused, the respondents agreed with the mean of 3.99 and deviation of 0.712. [23], cited in [24], argued that one of the common guiding principles of TQM is focusing on the satisfaction of the customer. Asked if they believed TQM would assist the ANSP Adopt a strategic and systematic approach to improvement of safety, the respondents agreed with a mean of 3.99 and a deviation of 0.798. According to According to [25], TQM is a proven systematic way to improve an organization's complete business process, including product and service quality. The respondents also agreed that TQM assists the ANSP in being inclusive and involving its employees in matters relating to safety improvements, with a mean of 4.15 and a deviation of 0.839. Some of the well-known TQM practices are training and development and employee involvement [26]. The respondents agreed that to improve safety further, the ANSP should consider Adopting a process-driven approach in dealing with safety improvements with a mean of 4.00 and a deviation of 0.79. [27] argues that to achieve TQM, the ideal method is to take a process-oriented approach. The process approach is both a quality management principle (defined by ISO 9001:2015 as a set of seven principles) and a method for attaining continuous improvement.

On whether the TQM can enhance the quality of service, the respondents strongly agreed with a mean of 4.29 and a deviation of 0.824. Users' expectations and requests for increased service quality are increasing as society matures in terms of education, culture, and living circumstances. This is one of the factors prompting service firms to investigate total quality management (TQM) to include quality improvement in all their operations [28]. The respondents also agreed that TQM assists the ANSP in Adopting an objective approach to decision-making with a mean of 3.99 and a deviation of 0.764. According to [29],TQM embraces a scientific method and the use of data for a decision-making approach to truth and rationality; this value is commonly referred to as 'management by fact'; it is a central value of TQM, and it is critical because all systems based on cause and effect exhibit relationships that are too complex to be evident without such data collection and analysis; it is a central value of TQM and it is essential because all systems based on cause and effect exhibit relationships that are too complex to be evident without such. Asked if the TQM promote continuous process improvements, the respondents agreed with a mean of 4.17 and a deviation of 0.813. [29], in their research, established that TQM is about continuous and continuous improvement of quality through a process of cultural and organizational transformation, rather than measuring quality performance as an aim.

The respondents also agreed that TQM assists in Integrating organization systems with a mean of 3.94 and a deviation of 0.931. The findings of this study are aligned with [30], who stated that TQM is a management concept that aims to integrate all organizational activities (marketing, finance, design, engineering, and production, among others) to focus on meeting customer demands and achieving organizational goals. On whether TQM improves safety through Quality-of-service improvements, the respondents agreed with a mean of 4.06 and a deviation of 0.762. according to [31], the Continuous Improvement method is a systematic process that incorporates everyone in the business to provide higher productivity, better service quality, fewer breakdowns, motivating working conditions, and improved safety. Furthermore, [31] underlined the importance of improving service quality in organizations throughout the TQM implementation. The respondents also strongly agreed that TQM Increases focus on Service Quality and thereby improves safety with a mean of 4.21 and a deviation of 0.762. According to [31], Restructuring operations, culture, and systems to be customer centred to offer quality and achieve client satisfaction is one strategy a firm may employ to become more competitive. As a result, the ability to provide exceptional customer service is critical to surviving and remaining globally competitive. Significantly, providing outstanding quality improves the organization's performance and raises customer happiness. One-way firms aim to provide excellent services to consumers is through the implementation of quality initiatives such as Total Quality Management (TQM). On whether TQM assists in advocating for doing the right thing the first time, the respondents agreed with a mean of 3.96 and a deviation of 0.797.

According to [30], A company is viewed as a collection of processes in TQM. It asserts that businesses must attempt to enhance these processes on a constant basis by incorporating workers' expertise and experiences. "Do the right thing the first time, every time" is the straightforward goal of TQM. The respondents also agreed that TQM assists in Meeting customers' expectations through safety improvements with a mean of 4.06 and a deviation of 0.843. [32], in support of the study findings, stated that in terms of quality philosophy, total quality management (TQM) is a game-changer. All members of the organization participate in the TQM process, which includes meeting the needs of internal and external customers and pursuing continuous quality improvement. The respondents agreed that TQM improves safety through Commitment to continual improvement with a mean of 4.10 and a deviation of 0.815. [33] argue that TQM is a procedure that, if applied correctly, can consistently improve the aviation industry's quality through a management philosophy that prioritizes consumers' or clients' happiness. Proper management and principles enhance the quality of the aviation sector while lowering the total cost of ownership.

Table 1: Enhancing aviation safety through TQM

	Mean	**Std Deviation**
Encourages commitment to safety behaviour	4.21	0.827
Focus on customers	3.99	0.712
Adopt a strategic and systematic approach	3.99	0.798
Involve Employees	4.15	0.839
Adopt a process-driven approach	4.00	0.790
Enhance Quality of Service	4.29	0.824
Adopt a factual approach to decision-making	3.99	0.764
Promote Process Continuous improvements	4.17	0.813
Integrate organization systems	3.94	0.931
Quality of service improvements	4.06	0.762
Increased focus on Service Quality	4.21	0.762
Advocate for doing the right thing the first time	3.96	0.797
Meeting customer's expectations	4.06	0.843
Commit to continual improvement	4.10	0.815

From Table 2, the respondents agreed that TQM strengthens its competitive position with a mean of 3.86 and a deviation of 0.879. According to Powell (1995), TQM is viewed as an intangible resource and capability that helps businesses gain a competitive advantage. The respondents agreed that TQM assists with the Cultural Transformation Drive with a mean of 3.59 and a deviation of 0.797. TQM is a management method in which internal customer relationships, teamwork, and supplier partnerships are used as tools for cultural transformation, and it necessitates a significant cultural shift in the organization [34]. When asked about productivity levels, the respondents agreed that TQM pushes productivity levels high with a mean of 3.85 and a deviation of 0.927. The employee's motivation to identify quality issues is an essential aspect of the TQM philosophy. Employee motivation leads to superior quality, increased productivity, and increased market competitiveness [35]. The respondents also agreed that TQM enhances ANSP's market image with a mean of 3.96 and a deviation of 0.932. According to [36], Supportive market benefits for TQM go a long way toward helping you achieve your goals.

The market benefits that businesses obtain because of promoting their products have a direct impact on business outcomes. These advantages include a positive market image, marketing, more significant product usage, and a positive brand image. The respondents agreed that TQM eliminates time wastage with a mean of 3.85 and a deviation of 0.898. In support of the findings above, [37] established that Lower production costs, increased customer satisfaction, enhanced product and service quality, shorter delivery times, improved employee morale, and reduced waste are just a few of the advantages of TQM. On whether TQM assists with cost reduction and cost management, the respondents agreed with a mean of 3.86 and a deviation of 0.922. in line with the findings, [38] states that Total quality management is a management strategy that emphasizes quality in an organization's areas, processes, and activities with the goal of reducing waste, lowering costs, and increasing production efficiency. The respondents also agreed that TQM led to higher profitability with a mean of 3.55 and a deviation of 1.015. According to [38] Evidence suggests that organizations use TQM to increase profitability and shareholder value. The respondents agreed that TQM provides an environment that Improves customer focus and satisfaction with a mean of 4.06 and a deviation of 0.811. research suggests that TQM has no direct impact on employee satisfaction because its primary goal is to promote customer satisfaction [39].

Respondents also agreed that TQM Increases customer loyalty and retention with a mean of 3.83 and a deviation of 0.986. [40] suggest that the provision of quality service to consumers is one of TQM's critical success criteria and quality of service, which increases customer happiness and leads to customer retention. The respondents were unsure if TQM really increased Job Security, with a mean of 3.32 and a deviation of 1.063. this split finding is not surprising as [41] discovered that some Employees perceive that managerial innovations such as Total Quality Management have a negative impact on their career prospects and job security (TQM).

On whether TQM improves employee morale, the respondents agreed with a mean of 3.68 and a deviation of 1.013. According to [42], The data analysis supported the hypothesis that TQM had a favourable impact on all aspects of organizational performance, including employee relations (improved employee morale and participation). The respondents agreed that TQM enhances shareholder and stakeholder value with a mean of 3.73 and a deviation of 0.817. TQM increases operational performance, and all stakeholders profit from it, according to the findings by [43]. The respondents also agreed that TQM is an Improved and innovative process with a mean of 3.81 and a deviation of 0.854.

Table 2: Top Management's involvement in quality and aviation safety

	Mean	Std Deviation
Strengthened competitive position	3.86	0.879
Cultural Transformation Drive	3.59	0.797
Higher productivity	3.85	0.927
Enhanced market image	3.96	0.932
Elimination of defects and waste	3.85	0.898

Reduced costs and better cost management	3.86	0.922
Higher profitability	3.55	1.015
Improved customer focus and satisfaction	4.06	0.811
Increased customer loyalty and retention	3.83	0.986
Increased job security	3.32	1.063
Improved employee morale	3.68	1.013
Enhanced shareholder and stakeholder value	3.73	0.817
Improved and innovative processes	3.81	0.854

From Table 3, the respondents responded to the statement that they strongly agreed that management had created a strong quality culture with a mean of 4.29 and a deviation of 0.740. Nasim (2018) indicates that TQM stresses and acknowledges quality culture to monitor organizational culture and generate better and enhanced TQM processes in order to maintain high organizational and quality-related outcomes. When asked if management promoted a safety culture, the respondents strongly agreed with a mean of 4.31 and a deviation of 0.726. in line with the studies' findings, Kobayashi (2019) advocates for Managers and supervisors to enforce the promotion of safe workplace culture; however, with the participation of all employees, a solid and robust safety culture requires participation from all members of an organization. Safety pioneers like Lederer and DuPont have demonstrated their knowledge of this, and the Federal Aviation Administration has recognized the promotion of a safety culture as the aviation industry has evolved. This was a negative connotative question. The respondents agreed that management uses a proactive approach to address safety concerns with a mean of 3.32 and a deviation of 1.201. More aggressive methods of safety management are required to produce behavioural safety among the operatives in order to turn the tide on the high rates of accidents and fatalities (Ajayi et al., 2021). They agreed that management presents a positive corporate image in the eyes of customers with a mean of 4.03 and a deviation of 0.805. According to Esmaeilpour and Barjoei (2016) [46], prior studies found that Customer happiness is influenced by a positively corporate image. The respondents also strongly agreed that management believes that Continuous quality improvement is a necessary expense, with a mean of 4.23 and a deviation of 0.805. TQM is a complicated system that takes several years to implement fully. Organizations that focus on the correct quality practices during the implementation phase are more likely to improve their performance and become successful cases [47]. The respondents strongly agreed that management Emphasizes continuous improvement of processes through the identification of threats and the management of risk, with a mean of 4.23 and a deviation of 0.737. By linking risk management and continuous improvement by connecting the two domains, one can move from a reactive method of limiting variations to a proactive approach of removing probable failure sources. Continual improvement focuses on improving customer satisfaction through continuous and incremental changes to processes, including the removal of needless tasks and variations, in terms of organizational quality, risk, and performance. Risk management is an essential component of a continuous improvement strategy. The mapping of critical risks for the Group and its subsidiaries reinforces the continuing identification and treatment of hazards [48]. When asked if they believed management values its employees with their knowledge, the respondents agreed with a mean of 4.00 and a deviation of 0.897. Employee empowerment promotes learning and achievement through encouraging innovation, creativity, and drive, as well as instilling shared ideals [49].

Table 3: Top management commitment to safety and continuous improvement

	Mean	Std Deviation
Create a strong quality culture	4.29	0.74
Promote safety culture	4.31	0.73
A reactive approach to addressing safety concerns	4.06	0.63
Present a positive corporate image in the eyes of customers	4.03	0.81
Continuous quality improvement is a necessary expense	4.23	0.80
Emphasizes continuous improvement of processes through the identification of threats and the management of risk	4.23	0.74
Values employees with their knowledge	4.00	0.90

4 CONCLUSION

QM and SMS have a favourable and significant link, according to the results of this study. Companies in TQM environments are more likely to implement Safety Management Systems; according to[56]), TQM raises an underlying concern about the ramifications of occupational hazards. As a result, it has been demonstrated that a holistic approach to TQM includes attitudes, beliefs, and principles that might encourage the use of Safety Management Systems. TQM's capacity outweighs what essential risk assessment techniques, assumption of duties, and training could give on their own. As a result, it is claimed that TQM provides firms with continuous improvement criteria that can be used in the implementation of an SMS even if essential practices are not implemented. Considering TQM's objective to reduce variability, the effects of unsafe working conditions are not overlooked. Furthermore, interactions have revealed that when a company runs in a quality management environment, the likelihood of implementing SMS is significantly higher. Quality management excellence requires the organization to stay vigilant and interested in identifying, removing, decreasing, and controlling factors that disrupt and threaten intended performance. SMS relies heavily on training and the acceptance of responsibilities. Risk assessment techniques, on the other hand, are more closely aligned with TQM to encourage SMS adoption. SMS relies heavily on training and the acceptance of responsibilities. Risk assessment techniques, on the other hand, are more closely aligned with TQM to encourage SMS adoption.

The existence of (ANSP) in the country is the most significant constraint of this study. Given the importance of TQM and SMS in scientific literature, it is with confidence that this study will encourage new editions of similar studies. Only operations were surveyed on the influence of TQM on aviation safety due to the ANSP's design, as they are the people who use both TQM and SMS tools and approaches. At the same time, this obvious constraint represents a new study direction. Because of TQM's multifaceted nature, it's essential to keep an eye on how its practices are impacting aviation safety. The ANSP could be more effective and efficient in addressing safety concerns if it could test the individual synergistic effects of TQM practices on aviation safety.

The ANSP seem to have un-informally adopted TQM but without knowing that the approach adopted is indeed the principle of TQM. Throughout the study, it was noted that both SMS and TQM adopt similar principles; however, they can supplement one another if implemented correctly with the support of top management. There is always room for improvement, and safety can be improved beyond where it is now, and the ANSP should consider officially implementing TQM, given the fact that it is already embedding most of TQM principles.

In conclusion, the study has accomplished its objectives and has made interesting findings in relation to the impact of TQM. From the findings of the study, it is concluded that total quality management has a positive impact on aviation safety as it encourages commitment to safety behaviour, focuses on customers, adopts a strategic and systematic approach, process-driven approach and adopts a factual approach to decision-making. Findings indicated that the ANSP has elements of TQM within its operations and that management is generally committed to a safety culture, allocating resources to safety. It was also found that the organization is dedicated to the organization's attainment of its safety objectives. The study also reveals that the ANSP encourages high-quality service delivery, that management readily distributes work to other employees, and that the ANSP has well-established quality standards.

As a result, it becomes clear that the ANSP's top management is actively involved in matters relating to service quality, which translates to safe air travel. The study concludes that the ANSP emphasizes continual process improvement through the identification of hazards and risk management. The ANSP archives its competitive advantage against any possible competitor through the quality of services, reliable services, and quality service assurance. Through the elements above, the ANSP can sustain itself in the market. Furthermore, the study concludes that the ANSP Values its employees' contributions and their knowledge.

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DESIGN OF EXPERIMENTS PROCEDURE FOR EVALUATING THE FORMABILITY OF SHEET METALS COMPONENTS IN FORMING PROCESSES

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ABSTRACT

Sheet metal forming operations are often preceded by numerical simulations and experiments. Some of the important experiments include material characterisation tests and finite element simulations. These experiments help to determe critical variables that affect the formability of the metals used in the forming process. When these variables have been established, optimisation techniques are employed to find the variable levels that produce the best formability. This paper applies general design of experiment procedures in design of experiments to evaluate the formability of sheet metal for forming processes like the deep drawing process. The procedure starts with identifying the variables that affect the deep drawing process like Temperature, Blank Holding Force, Drawing Force, Friction, Tool Geometry, Blank thickness, Tool Velocity and Drawing Stages among others. These variables require at least 19683 experiments to be conducted by testing them at three levels. Applying Taguchi Design of Experiments methods reduces the experiments to 27 experiments only.

Keywords: Design of Experiments, Taguchi Orthogonal Arrays, Deep Drawing Process

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1 INTRODUCTION

Material characterisation and optimisation experiments are essential in evaluating sheet metal formability [1]. These experiments help to determine the key variables that affect the formability of sheet metals in forming processes. The material charactersiation experiments are used to determine physical properties of materials. These properties can be used for numerical simulation of the forming processes [2]. After the physical experiments have established the physical properties of the materials, numerical simulations are then used to optimise process parameters to ensure good product quality. Numerical simulations can be done using Finite Element Modelling (FEM) software programs. It is paramount to apply Design of Experiments (DoE) principles in order to produce valid and unbiased results during the experiments. The DoE are also essential in minimising the cost and number of experiments thereby speeding up the process and making the experiments economic [3]. This paper reviews the DoE principles and the DoE methods with the view of having an appropriate experimental design to evaluate the formability of sheet metal components in forming processes such as the deep drawing process.

2 LITERATURE REVIEW

An experiment is a research strategy used to establish causal relationships between variables or factors that influence in a process. According to Cosgrove and O'Reilly [4], experiments are essential in order to generate valid theories. Experiments tend to be quantitative in nature and hence should be designed to eliminate bias from the researcher. The design of experiments becomes critical for experiments to produce valid knowledge [5]. Though experiments find their roots in natural sciences and laboratory work, they can also be effectively used in social sciences [6]. It is, therefore, necessary to review the fundamental principles of design of experiments and the design of experiments methods before the problem setting for the formability of sheet metals in deep drawing.

2.1 Principles of Design of Experiments

In an experiment, purposeful alterations are made to input parameters while observing changes in the output parameters [7]. Experiments are done to generate knowledge from data that has been collected, and adhering to principles of experimental design when designing and conducting experiments ensures the validity and objectivity of experiments [8]. The principles of designing valid and objective experiments are randomisation, replication, and blocking which are discussed in this paper.

2.1.1 Randomisation

Randomisation is the foundation of experimental design that removes bias when running experiments. In randomised, both the distribution of the material used in the experiments and the order in which the experiments are run are performed randomly [7]. Randomisation is done to satisfy one of the requirements of statistical methods: the observations and errors from an experiment must be independently distributed random variables. This is done to remove the effect of uncontrollable factors from an experiment. In formability experiments, samples of sheet metal alloys are tested to determine the parameters that affect its formability. Efforts should be made to ensure that the samples have the same specifications. It may be difficult to guarantee consistency hence the need to randomise the distribution of the samples when running the experiment. Randomisation is a crucial concept of experimentation [8].

2.1.2 Replication

Another principle of experimental design is replication [8]. When running experiments, it is essential to collect data from a number of samples so as to apply statistical methods to find the mean and standard deviations to be able to establish the cause-and-effect relationships between factors by eliminating experimental errors. The basis of replication of experiments is that repeated experiments may not be under the same conditions as it may be difficult to hold factor levels constant but each repeat run should have the same factor combination [7]. The formability experiments need to be replicated in order to maintain consistency of results. Where possible the experiments may be repeated to check the repeatability of measurements.

2.1.3 Blocking

One source of error that needs to be countered when running experiments is the effect of inhomogeneous materials and conditions. These conditions are known as nuisance factors that can cause variability in measurements and it is necessary to try by all means to block these factors from influencing the results of the experiments. This is done by running experiments in blocks under the same conditions. Only experiments that are run under the same block can be fairly compared against each other [7]. Blocking is an important key principle in the DoE [8]. Blocking should be considered by utilising the same material under the same conditions in the formability experiments.

2.2 Design of Experiments Methods

Having laid the principles of experimental design as the foundation for conducting valid experiments that produce reliable data to generate knowledge, the next step is understanding the DoE methods available for selection when conducting experiments. The DoE methods work together with the principles to produce valid data from which conclusions are drawn after statistical analysis. According to Montgomery [7], DoE is a methodology for executing experiments and analysing data. The main focus of DoE is to establish the key parameters that influence the outcome of a process, since all parameters cannot have the same effect on a process. DoE methods also help in establishing the number of experiments that can be made in order to obtain reliable data. In the evaluation of the formability of sheet metal for forming operations, the focus should be to carrying out formability tests in order to determine the critical process parameters that can be used for the forming process. Some of the generic DoE methods include; the Best-guess approach, One factor at a time, Full factorial, Fractional factorial and the Taguchi method [7]. In addition there are several variations of the generic DoE methods like the Plackett–Burman, Central Composite, Simplex Lattice, Design-Optimal, and Irregular Resolution [8]. Another variation of the DoE method is the Response Surface Methodology [9]. A review of the generic DoE follows in order to understand the strengths and weaknesses of each method.

2.2.1 Best Guess Approach

The best-guess strategy of experimentation is frequently used in practice by engineers and scientists. The strategy works well using the researchers' theoretical and practical experience [7]. This method is also popularly known as the trial-and-error method. Since the method relies on the researcher's experience, the approach is not systematic, which means that if the initial guess does not produce desired results, the experimenter has to keep on guessing for a long time without a guarantee of success. Sometimes the guess may produce desired results, and the experiments are discontinued without knowledge of the optimum solution. Due to these shortcomings the method is not recommended, but expert knowledge will not be discounted as it may help get experiments closer to the real values, thereby saving resources and time.

2.2.2 One Factor at a Time (OFAT)

The One Factor at a Time (OFAT) method is also known as the One Variable at a Time (OVAT) method. It involves varying one factor across all its levels while holding other factors constant and taking measurements of the response parameter [7]. This approach may probably be the most common experimental method amongst many researchers because it is easier and straightforward to execute. The method seems to be preferred in biological experiments as applied by Saha and Mazumdar [10], Abou-Taleb and Galal [11] and Meena et al. [12]. This approach neglects the effect of interactions of factors at different levels, which may often lead to unsatisfactory and misleading results since each factor is not tested at the different levels of other factors.

2.2.3 Full Factorial

To counter the adverse effects of the OFAT method, researchers can use the full factorial method to investigate all possible factors and factor levels combinations of an experiment [13]. This implies that there will be many experiments, depending on the number of factors and levels, For example, with two factors that have two levels, a total of four experiments will be required, while an experiment with two factors varied across three levels would require eight experiments. The full factorial method is also known as the complete factorial method [14]. Sometimes the experiment may present itself as a mixed-level factorial experiment in which the factors can be varied across different factor levels and under such an experiment the total number of experiments will be equal to the product of the factor levels and would be given by;

$$Number\ of\ runs\ =\ l_1 \times l_2 \times l_3 \dots \dots l_k \qquad \textbf{(1)}$$

where l represents the number of levels and k the number of factors.

When all factors are to be varied across the same number of levels, the number of experiments can be simply given by;

$$Number\ of\ runs = l^k \qquad \textbf{(2)}$$

where l represents the number of levels and k the number of factors.

As the number of factors and factor levels increase, the number of experiments also increase drastically to uneconomic levels. The full factorial method is not recommended for more than five factors [7]. Reducing the number of experiments to manageable levels by applying the fractional method is required. In the deep drawing process, there are more than seven key process parameters [19]. This means that if each parameter is to be varied across a minimum of two levels, the number of experiments required will be a minimum of 128 runs which may not be easy to manage hence the need to explore the fractional factorial method.

2.2.4 Fractional Factorial

The fractional factorial method is a variation of the full factorial method, but only a fraction of the total required experiments is performed. The fractional factorial method is also known as the reduced factorial method [14]. Suppose an experiment has seven factors varied across two levels, for example, it requires 2^7 translating to 128 runs using the complete factorial method. If half of the experiments are to be done only $2^{(7-1)}$, which gives 64 experiments. This implies that one-half fractional factorial for a two-level experiment requires $2^{(k-1)}$ runs, and similarly one-third fractional factorial experiment with three-levels will result in $3^{(k-1)}$ runs. The number of runs will be reduced significantly, but the approach guarantees that all the factors will be tested at different levels, and the effects of interactions can be observed [7]. Fractional factorial experiments can also be used together with screening experiments in which experiments that are deemed unnecessary are removed, and researchers get more time to concentrate on critical experimental runs.

2.2.5 Taguchi Orthogonal Arrays

In a quest to further reduce the number of experimental runs, Taguchi proposed a highly fractionated factorial experimental design method [7]. The Taguchi method makes use of orthogonal arrays. The orthogonal arrays only test for pairs of combinations [15]. Orthogonal arrays are unique tables of numbers that help researchers to design experiments [16]. The Taguchi design is a powerful method that provides a robust process that also minimises the Signal to Noise ratio (S/N). Signals are controllable factors that influence the process, while Noise refers to uncontrollable factors in an experiment [7]. Modi and Kumar [9] used the Taguchi method together with the Response Surface Methodology in the DoE to optimise process parameters in hydroforming. The Response Surface Methodology is mainly to model continuous variables, and optimised parameters can be selected from the surface plots developed from simultaneously varying variables [17]. Table 1 shows the standard orthogonal arrays for different factors and factor levels [15].

Table 1: Standard Orthogonal Arrays [15].

Orthogonal Array	Number of Experiments	Maximum Number of Factors	Maximum Number of Columns at These Levels			
			2	3	4	5
L_4	4	3	3	-	-	-
L_8	8	7	7	-	-	-
L_9	9	4	-	4	-	-
L_{12}	12	11	11	-	-	-
L_{16}	16	15	15	-	-	-
L'_{16}	16	5	-	-	5	-
L_{18}	18	8	1	7	-	-
L_{25}	25	6	-	-	-	6
L_{27}	27	13	1	13	-	-
L_{32}	32	31	31	-	-	-
L'_{32}	32	10	1	-	9	-
L_{36}	36	23	11	12	-	-
L'_{36}	36	16	3	13	-	-
L_{50}	50	12	1	-	-	11
L_{54}	54	26	1	25	-	-
L_{64}	64	63	63	-	-	-
L'_{64}	64	21	-	-	21	-
L_{81}	81	40	-	40	-	-

2.3 Statistical Data Analyses

Statistical methods are predominantly used in the analyses of results in order to draw objective conclusions rather than subjective judgements by the researcher [7]. The main objective of statistical analysis is to formulate the cause-and-effect relationships between process inputs and outputs. Different analysis techniques may be employed for the experimental runs [16]. Statistical principles such as the Analysis of Variance (ANOVA) and the Signal to Noise (S/N) ratio were used by Vahdani et al. [18] to determine the significant parameters in forming depth. Software packages like Mathematica, Minitab, and Statistica, among others can be used for data analyses. Even simple graphical representations can be handy in data analysis [7]. The threshold recommended for statistical significance of correlations is set to 0.05 (5 %). A statistical significance value is referred to as a p-value also. It signifies the probability or risk of concluding that a process parameter influences a measured value when in fact it does not. This risk should be therefore kept as low as possible; hence a 5 % allowance indicates that it is nearly impossible to 100 % predict outcomes from experimental data. After data analyses, follow-up and confirmation experiments are recommended as a validation method for the conclusion made by Ranjit [16] and Montgomery [7].

3 METHODOLOGY

To develop experiments for evaluating the formability of sheet metals for forming operations such as deep drawing, the critical process variables have to be determined first, together with their factor levels. It is essential to specify at least three factor levels to cater for non-linear relationships between the variables. This process helps to determine the quantity of physical and numerical experiments that are required in the investigation. Design of experiment procedures are then employed to reduce the number of experiments to manageable levels without compromising the quality of the data.

3.1 Overview of experiments required in sheet metal forming operations

The evaluation of formability in deep drawing operations requires several experiments. The experiments can be conducted physically or numerically [2]. To improve the validity of the data from numerical simulation, material characterisation experiments are conducted to determine the physical properties of the materials. The physical properties are then used as input data into numerical simulation software to perform screening and optimisation simulations, as shown in Figure 1.

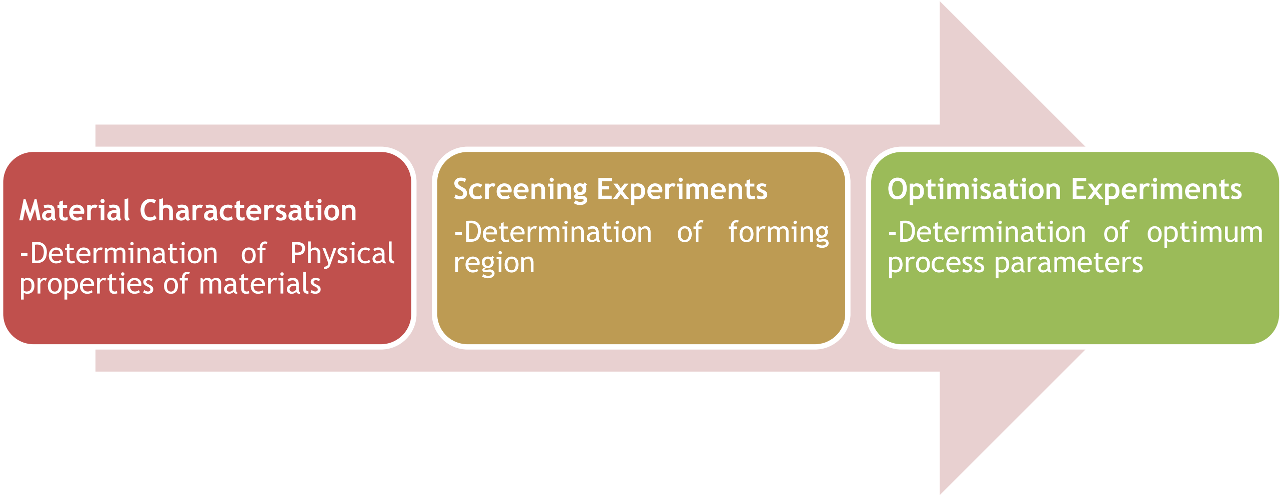

Figure 1: Experimental Design for formability of sheet metal components in deep drawing

3.2 Material Characterisation Experiments

The tensile tests and the forming limit curve determination are the most critical experiments in the formability evaluation for the deep drawing process. Figure 2 shows a typical tensile testing machine for the determination of the stress-strain curve of the material under different conditions.

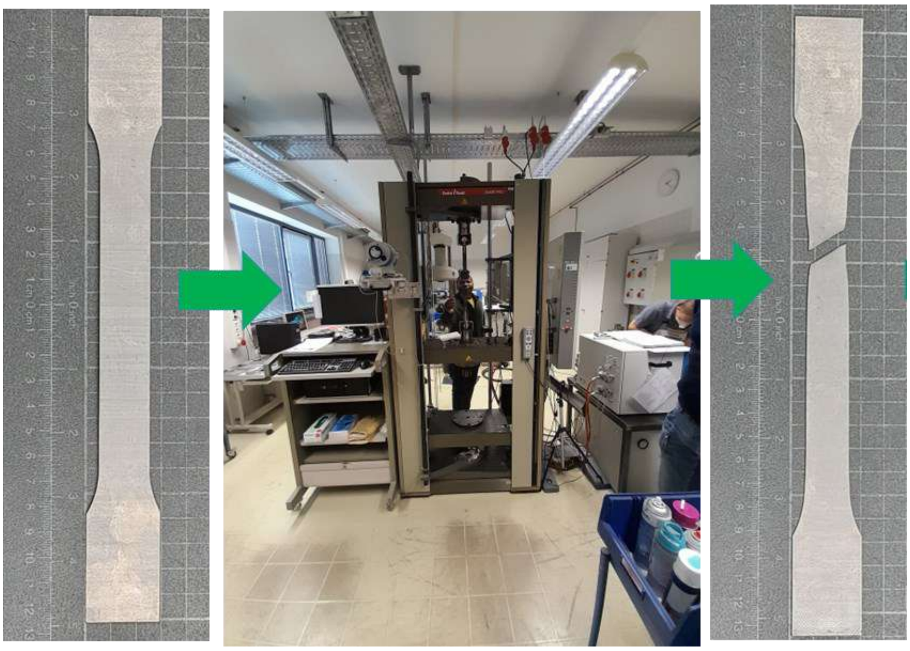

Figure 2: Tensile testing machine and samples

The tests may also be done in different temperature ranges to evaluate the possibility of cold forming, warm forming and hot forming. Data from these tests is then used in numerical simulation software to evaluate the formability of sheet metal components using the deep drawing process.

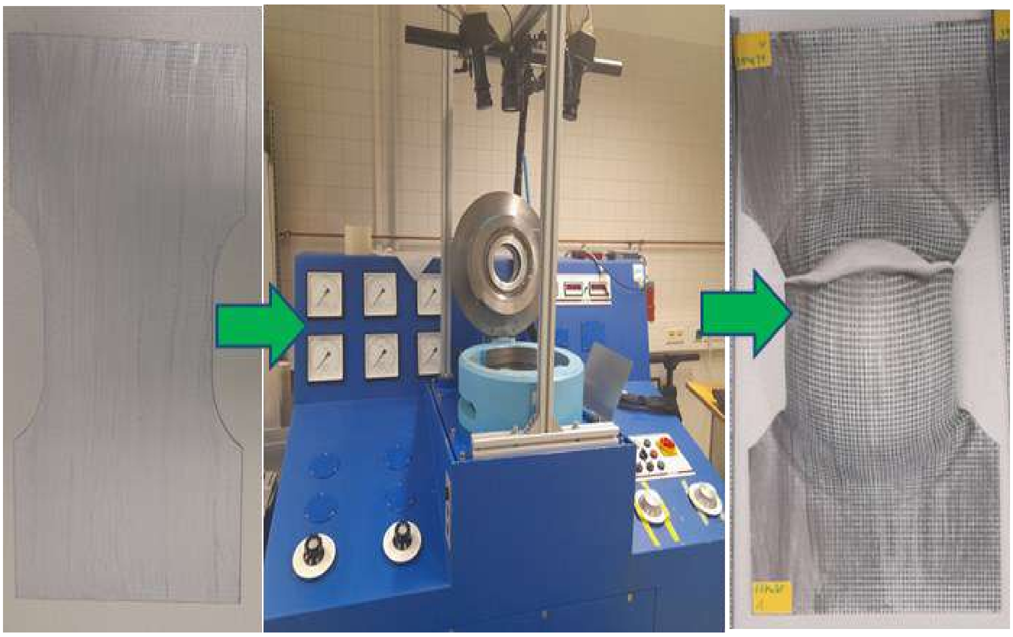

Figure 3: Forming Limit Curve machine and samples

Figure 3 shows a cupping test machine used to determine the forming limit diagram of sheet metal samples. The forming limit curve is also an input to the numerical simulation programs to evaluate the formability of sheet metal components using the deep drawing process.

3.3 Screening Experiments

When the material properties have been established, the next step is to perform screening experiments to determine the formability region of the product under study. The screen experiments assist in establishing the boundary conditions for the deep drawing process. In deep drawing processes researchers need to determine the forming temperatures and the drawing stages, hence it is, therefore, necessary to set up screening experiments for these parameters. Table 2 shows typical screening experiments for the process temperature and the drawing stages. The experiments consist of two factors that are temperature and drawing stages. Each factor can be tested at three levels to investigate non-linear combination interferences. The total number of screening experiments is given by 3^2 which is nine experiments. These experiments are few and can be conducted using the full factorial method.

Table 2: Screening factors and factor levels

	Drawing stages		
Temperature	Single Stage	Two Stage	Three Stage
Cold working (Room Temperature)	Run 1	Run 2	Run 3
Warm Working (Below Recrystallisation Temperature)	Run 4	Run 5	Run 6
Hot Working (Above Recrystallisation Temperature)	Run 7	Run 8	Run 9

The experiments can be done through numerical simulations first and validated with real experimental work. The screening phase will also determine the process parameters that affect the deep drawing process the most.

3.4 Optimisation Experiments

The optimisation experiments can first be done through numerical simulations, followed by physical experiments. When investigating the formability of sheet metal for the deep drawing process, the main process parameters include temperature, blankholder forces, friction, punch and die radius, the blank size, tool velocity and drawing stages [19]. Figure 4 shows the general factors and expected responses when doing formability assessments.

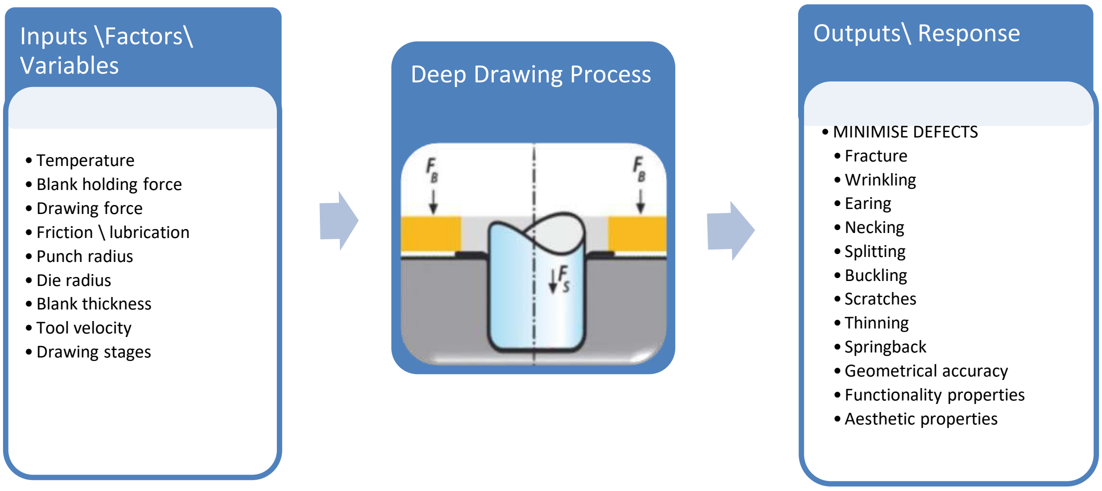

Figure 4: Inputs and outputs of the deep drawing optimisation process

A total of nine factors have been identified to be critical in deep drawing, as shown in Table 3 and varying these across three levels during the optimisation phase will result in the required runs being equal to 19 683 as given by 3^9. With additional experiments required for replication, these experiments are challenging to run hence the need to reduce the number of experimental runs to manageable levels using the Taguchi method.

Table 3 Optimisation factors and factor levels

Factors	**Factor levels**		
Temperature	T_1	T_2	T_3
Blank holding force	BF_1	BF_2	BF_3
Drawing force	DF_1	DF_2	DF_2
Friction and lubrication	FR_1	FR_2	FR_3
Punch radius	PR_1	PR_2	PR_3
Die radius	DR_1	DR_2	DR_3
Blank thickness	BT_1	BT_2	BT_3
Tool velocity	TV_1	TV_2	TV_3
Drawing stages	DS_1	DS_2	DS_3

4 RESULTS

The orthogonal arrays for experiments are constructed using standard guidelines. Table 1 shows the standard orthogonal arrays that can be chosen for different experiments. The nine factors at level three in this study require at least an L27 orthogonal array in order to test all the factors. An L27 array has a total of 27 experiments for 13 factors at three different levels. However, the array has to be modified for nine factors as some of the columns will not be used. Using the L27 orthogonal array yields Table 4. The table shows that 27 experiments are required at the levels shown to determine the influence of the factors on the deep drawing process.

Table 4: Taguchi Array for evaluation of formability in deep drawing processes

Run	T	BF	DF	FR	PR	DR	BT	TV	DS
1	T_1	BF_1	DF_1	FR_1	PR_1	DR_1	BT_1	TV_1	DS_1
2	T_1	BF_1	DF_1	FR_1	PR_2	DR_2	BT_2	TV_2	DS_2
3	T_1	BF_1	DF_1	FR_1	PR_3	DR_3	BT_3	TV_3	DS_3
4	T_1	BF_2	DF_2	FR_2	PR_1	DR_1	BT_1	TV_2	DS_2
5	T_1	BF_2	DF_2	FR_2	PR_2	DR_2	BT_2	TV_3	DS_3
6	T_1	BF_2	DF_2	FR_2	PR_3	DR_3	BT_3	TV_1	DS_1
7	T_1	BF_3	DF_3	FR_3	PR_1	DR_1	BT_1	TV_3	DS_3
8	T_1	BF_3	DF_3	FR_3	PR_2	DR_2	BT_2	TV_1	DS_1
9	T_1	BF_3	DF_3	FR_3	PR_3	DR_3	BT_3	TV_2	DS_2
10	T_2	BF_1	DF_2	FR_3	PR_1	DR_2	BT_3	TV_1	DS_2
11	T_2	BF_1	DF_2	FR_3	PR_2	DR_3	BT_1	TV_2	DS_3
12	T_2	BF_1	DF_2	FR_3	PR_3	DR_1	BT_2	TV_3	DS_1
13	T_2	BF_2	DF_3	FR_1	PR_1	DR_2	BT_3	TV_2	DS_3
14	T_2	BF_2	DF_3	FR_1	PR_2	DR_3	BT_1	TV_3	DS_1
15	T_2	BF_2	DF_3	FR_1	PR_3	DR_1	BT_2	TV_1	DS_2
16	T_2	BF_3	DF_1	FR_2	PR_1	DR_2	BT_3	TV_3	DS_1
17	T_2	BF_3	DF_1	FR_2	PR_2	DR_3	BT_1	TV_1	DS_2
18	T_2	BF_3	DF_1	FR_2	PR_3	DR_1	BT_2	TV_2	DS_3
19	T_3	BF_1	DF_3	FR_2	PR_1	DR_3	BT_2	TV_1	DS_3
20	T_3	BF_1	DF_3	FR_2	PR_2	DR_1	BT_3	TV_2	DS_1
21	T_3	BF_1	DF_3	FR_2	PR_3	DR_2	BT_1	TV_3	DS_2
22	T_3	BF_2	DF_1	FR_3	PR_1	DR_3	BT_2	TV_2	DS_1
23	T_3	BF_2	DF_1	FR_3	PR_2	DR_1	BT_3	TV_3	DS_2
24	T_3	BF_2	DF_1	FR_3	PR_3	DR_2	BT_1	TV_1	DS_3
25	T_3	BF_3	DF_2	FR_1	PR_1	DR_3	BT_2	TV_3	DS_2
26	T_3	BF_3	DF_2	FR_1	PR_2	DR_1	BT_3	TV_1	DS_3
27	T_3	BF_3	DF_2	FR_1	PR_3	DR_2	BT_1	TV_2	DS_1

The set of experiments required for evaluating the formability of sheet metal components in the deep drawing is shown in Figure 5. Empirical testing can be done after the numerical optimisation stage in order to minimise the cost of the experiments. These experiments may be less than the Taguchi orthogonal arrays as they can focus on confirmed optimum values from numerical simulation runs.

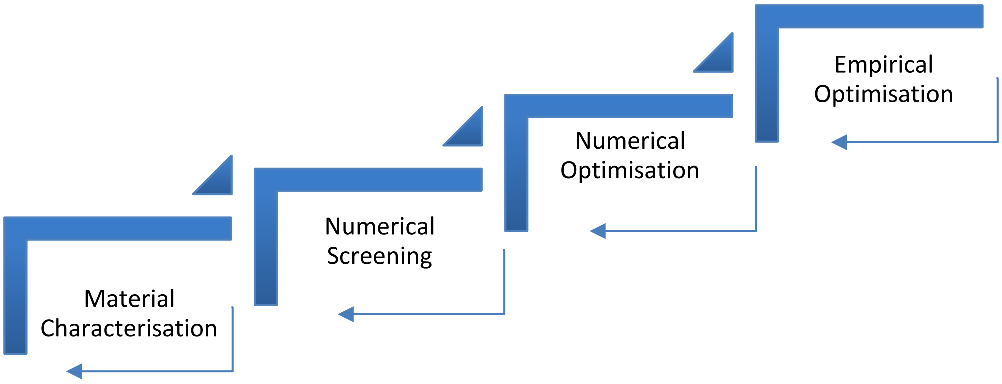

Figure 5: Summary of the experimental procedure

5 CONCLUSION

In conclusion, experiments should be designed following the DoE guidelines. In the evaluating the formability of sheet metal components, the experiments start with material characterisation to determine the material's physical properties. The data is then used to update numerical simulation software to prepare for further tests to be carried out through simulation. The second step is to conduct screening experiments in the numerical simulation software. These experiments are aimed at determining the boundary conditions for the forming process. Thereafter optimisation experiments are performed. Usually, these are the bulk of the experiments and can be minimised using approaches such as the Taguchi design of experiments. The experiments are also performed using numerical simulations followed by empirical runs to develop an optimisation model for the critical process parameters in deep drawing. Statistical techniques are also required to analyse data and deduce the cause-and-effect relationship for the determined deep drawing factors. Mathematical models are developed from statistical analysis and can be used to predict the forming process so parameters can be intelligently controlled. When optimising the process parameters triangulation approaches can be used to ensure the validity of the results. Response Surface Method can be used as a verification tool in triangulation.

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THE APPLICATION OF LEAN SIX SIGMA WITHIN THE DEVOPS CYCLE

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ABSTRACT

Numerous methodologies exist for improving the performance of a process within industry. In the software development industry, the processes are constantly evolving, with the DevOps cycle evolving from the Lean and Agile principles used. The DevOps cycle is still seen as an emergent process and there, therefore, exist various opportunities for improving the performance of its implementation within industry. This study investigated the application of Lean Six Sigma (LSS) within the DevOps cycle to improve its performance and increase the effectiveness with which software products can be delivered. As a case study, the LSS methodology was applied to a software development company's DevOps cycles, and the before and after application results were analysed. The results successfully illustrate the applicability of using LSS within the DevOps cycle due to the improved performance of the software development company's DevOps cycles.

Keywords: DevOps, Lean Six Sigma, Performance, Case Study

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1 INTRODUCTION

1.1 Background

Software development is a complex process that requires the coordination of various skillsets to function effectively [1]. In addition, the processes that are used in software development are constantly changing at a rapid pace [2], [3], with one of the more emergent processes being the DevOps cycle [4]-[7]. The DevOps cycle aims to increase automation across all aspects of software development and bridge the gap between the development and operations teams [4]-[7].

Implementing the DevOps cycle has seen numerous challenges across industry, resulting in a decrease in the performance of software delivery [8]-[10]. This poses the question of whether a Process Improvement Methodology (PIM) can be applied within the DevOps cycle, more specifically Lean Six Sigma (LSS).

This application can improve the challenges with its implementation and lead to an increase in performance. As a case study, LSS is implemented within a software development company's DevOps cycles. The results are analysed before and after implementation to examine the effects on its performance.

1.2 The DevOps Cycle

The increasing expectations of clients required that more frequent and reliable deployments of software products are made [8], [11]. This was achieved by increasing automation in all stages of software development [8], [11]. The DevOps cycle is a process that aims to bridge the communication gap between the Development (Dev) and Operations (Ops) teams [4], [8], [10], [12]. The cycle is composed of the Continuous Integration, Delivery and Deployment (CI/CD) pipelines to automate all aspects of the development cycle and improve the effectiveness of software delivery [9], [10].

Continuous Integration ensures that when changes are committed to a Source Control Repository (SCR)[†], the changes are automatically built and validated by running a series of tests [6], [8], [13]. Continuous Deployment is the automated step and Continuous Delivery is the manual step of releasing and deploying the validated code to the production environment[‡] [6], [8], [13]. The stages of the DevOps cycle and the incorporation of the SCRs and CI/CD pipelines are illustrated in Figure 1 [6], [8], [13].

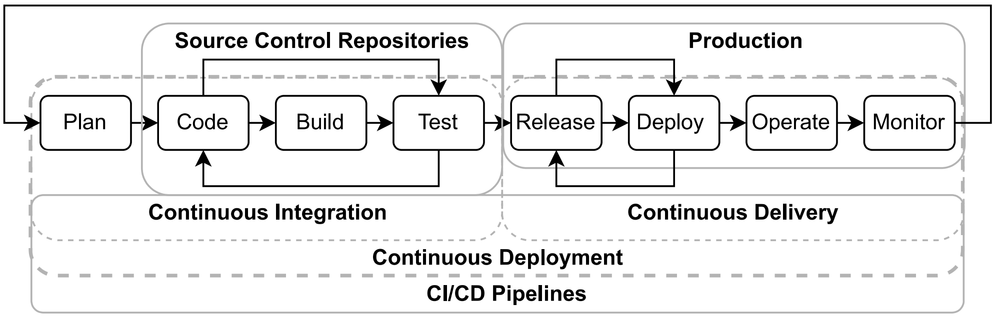

Figure 1: The DevOps Cycle, Source Control Repositories and the CI/CD Pipelines.

The implementation of the DevOps cycle has, though, seen numerous challenges, resulting in a decrease in performance in the delivery of the software applications [8], [14]-[16]. This led

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[†] A SCR is where the code for a software application is mainted by software developers [6], [8].

[‡] A production environment is where the latest version of a software product is made available for immediate use by the intended user [41].

to the DevOps Research and Assessment (DORA) team identifying four key metrics to measure the performance of the DevOps cycle defined in Table 1 [17].

Table 1: The DORA Metrics.

Metric	Definition
Deployment Frequency	The frequency at which an organisation deploys changes to production.
Lead Time	The time from the first commit until it is running in production.
Change Failure Rate	The percentage of changes that cause problems in production.
Time to Restore	The time it takes to recover from a failure in production.

For this study, the performance of the DevOps cycle refers to the performance of the activities within the cycle to increase the rate and quality of delivered software applications. Improving the performance of the DevOps cycle has a positive effect on the time-to-market of software products, team efficiency and customer satisfaction within organisations [10]. This study aims to use the DORA metrics to measure the performance of case study DevOps cycle implementations within industry. Focus is placed on obtaining data from the DevOps cycle according to the SCRs and the CI/CD pipelines to quantify the DORA metrics.

1.3 Process Improvement Within DevOps

An abundance of methodologies exists for improving the performance of a process such as Kaizen, Total Quality Management (TQM), Deming (PDCA) cycle and LSS, to name a few [2], [18], [19]. When considering the software development industry, it is forever changing and the processes used evolve at a rapid pace [2], [3]. Naturally, this increases the complexity of choosing the correct methodology to improve the performance of a process [2], [3].

PIMs have successfully been applied in several industries to increase the performance of their implemented processes [20], [21]. With this success seen, there have been several applications of these methodologies within the software development industry [2], [21]–[23]. PIMs have been applied within software development to improve the process of gathering software project requirements [24], the quality of software [25], the process of risk management [26], and several other applications.

The DevOps cycle is still seen as an emergent process within the software development industry with various challenges in its implementation [4]–[7]. This poses the question of whether there is a PIM that can be applied to improve the performance of the DevOps cycle.

The applicability of Lean principles within the software development industry is discussed in [28]. The study highlighted that there were cases of Lean being adopted in software development, but proposed that further work is done to gather empirical data on the application of Lean within software development.

In [27], the current literature was summarised on the use of Lean, Six Sigma (SS) and LSS in software development. Lean and SS form the foundation of LSS by combining the advantages of both efficiency and quality [27]. The literature was used to highlight future research patterns and software development improvement trends. The study found a gap in the use of these methodologies and the outcomes of the application of LSS in software development.

This study considers LSS, which aims to improve the efficiency of a process and provide the highest quality product possible by removing waste and variation [2], [21]. It is a top-down, continuous approach aimed at improving the inefficiencies within a process to improve its performance [20].

PIMs such as Kaizen, TQM and the PDCA cycle were also considered for application within the DevOps cycle, but the points brought forward for LSS are what justify its proposed application to increase its performance. This is not to say it is the only methodology that can be applied, but it is what is considered for the scope of this study.

The Define, Measure, Analyse, Improve and Control (DMAIC) methodology of LSS is about continuous improvement and is often used on a continuous cycle [2]. The focus on continuity makes applying LSS within the DevOps cycle a good candidate. The DMAIC methodology of LSS can be used within the software industry to create a systematic and structured flow [2], [3], [21], [29]. This can lead to the delivery of a more efficient and higher quality product, with an increase in the performance of the DevOps cycle [2].

1.4 Problem Statement and Aim

Challenges are seen to occur with the implementation of the DevOps cycle and opportunities exist for improving its performance. Improving the performance of the DevOps cycle can have a positive influence on the time-to-market, team efficiency and customer satisfaction within software development [10].

PIMs have been used in software development, but a PIM has not yet been considered for application within the DevOps cycle. This study aims to use LSS and apply it to a case study software development company to improve the performance of their DevOps cycles. The performance impact is quantified through the use of the DORA metrics.

1.5 Research Questions

The following Research Questions (RQ) are defined, to guide the study. The fulfilment of these questions will address the problem statement and aim of this study.

- **RQ1:** Can LSS be integrated and applied within the DevOps cycle?
- **RQ2:** Can the application of LSS improve the performance of the DevOps cycle?

2 LITERATURE

2.1 Evaluation Criteria

This study aims to highlight the state of the art for the application of LSS within the DevOps cycle to improve its performance. Table 2 defines the criteria used to analyse the state of the art from literature. These criteria were chosen to evaluate the literature based on the focus points and highlight the novelty of this study.

Table 2: State of the Art Evaluation Criteria.

Criteria	Definition
Lean Six Sigma	The use of Lean, Six Sigma or Lean Six Sigma within the context of the software development industry.
DevOps	Whether the study focused on the DevOps cycle involving SCRs and CI/CD pipelines.
Improvement	The improvement in the performance of the DevOps cycle by implementing a method to improve on the current challenges that exist with its implementation.
Application	A case study application of Lean, Six Sigma or Lean Six Sigma within the context of the software development industry, with a specific focus on the DevOps cycle.

2.2 State of the Art: Application of Lean Six Sigma Within the DevOps Cycle

Obtaining quality software requirements from customers is still challenging in software development. The study in [2] showed how a system can potentially be developed through the use of Lean-Agile that meets a customer's needs. LSS was shown to be a structured and systematic approach that can remove variations in software development.

The constantly changing requirements in software development can impact the quality of the final product. In [30], LSS was proposed as a new quality model to identify the exact requirements of a software development project. It was shown how LSS could eliminate non-value-added processes whilst improving software quality. This study successfully illustrated how LSS can be used to improve the software development process.

Delivering quality software is often sacrificed to meet deadlines, costs, and scope, thus, in [25], the SS DMAIC methodology was proposed. It was shown how companies can improve the quality of their software products by using a systematic approach to follow a structured sequence of steps. However, the study identified that the success rate for applying LSS in software development is still low, and future work is proposed.

It was noted that several studies showed the applicability of Lean, SS and LSS within software development [2], [21], [24], [25], [28], [30]–[32]. These studies showed how the performance of the software development process was improved and non-value-added tasks were eliminated by using a systematic approach. This can all lead to an increase in the performance of a process.

The literature highlighted the gap involving practical applications resulting in empirical results. Furthermore, literature also identified the gap in applying these methodologies within the DevOps cycle to improve its performance. This study aims to address this gap by being the first of its kind to apply LSS within the DevOps cycle to improve its performance.

2.3 Applying LSS Within the DevOps Cycle

Lean reduces the waste when transitioning between stages, and SS ensures the quality is maintained at each stage [21], [33]. This is accomplished by applying the DMAIC methodology that this study will utilise. Figure 2 illustrates how LSS can be integrated into the DevOps cycle [21], [33].

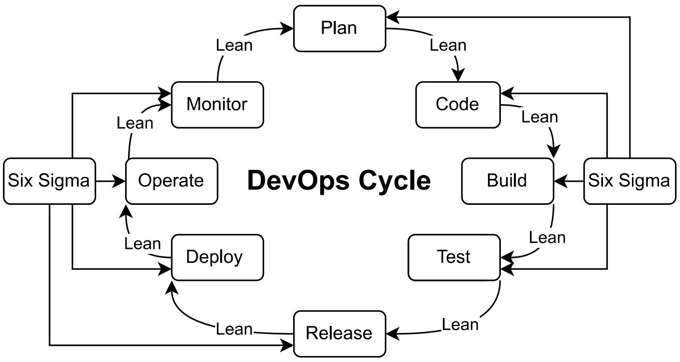

Figure 2: Lean Six Sigma Integrated Within the DevOps Cycle.

LSS uses the DMAIC methodology to systematically analyse a process to improve it [2], [3], [21], [29]. The application of the DMAIC methodology within the DevOps cycle is discussed in Table 3.

Table 3: The Application of the DMAIC Methodology Within the DevOps Cycle.

Stage	Definition
Define	The beginning and the end of the DevOps cycle to be analysed for improvement are defined. What is in scope is addressed to ensure the proper criteria are laid out.
Measure	Data on the current DevOps cycle implementations is gathered to measure their performance against the DORA metrics.
Analyse	The applicable stages of the DevOps cycle are analysed through different data analysis methods, such as Pareto Charts and Value Stream Mapping [34], [35].
Improve	After the root causes have been identified in the analyse step, a solution matrix is used to define the best course of action to improve on the identified problems.
Control	A control plan is used to ensure that the improvements can be maintained.

The application of LSS aims to improve the performance of the DevOps cycle. The initial performance is measured using the DORA metrics, and then LSS is applied. The post-application DORA metrics are then analysed to identify changes in performance.

Implementing the DMAIC methodology, as outlined in Table 3, verifies that LSS is correctly implemented within the DevOps cycle. It also illustrates how the DevOps cycle is a process that can potentially be improved through the systematic approach of LSS. This, therefore, illustrates how, through the correct implementation of this methodology, **RQ1** is answered.

3 METHODOLOGY

3.1 Population and Sample

This study gathered data from a case study software development company's DevOps cycle implementations. The cycles were chosen due to the performance problems they illustrated and the diversity of applications being developed. The software development company is a multidisciplinary engineering company, consisting of three teams, specifically a maintenance, research and development, and DevOps team, totalling approximately 16-20 members at the time of this study.

The method was implemented over 13 months (January 2021 – February 2022) involving five DevOps cycle implementations. A DevOps cycle is defined for each of the web applications that the company develops for their clients. However, to avoid skewing the results, December 2021 was excluded from the data, due to the company not fully operating during this period. The first nine months (January 2021 – September 2021) involved gathering the data. The remaining four months (October 2021 – February 2022) involved the gradual application of LSS; whereafter data was collected at the end of the application period. The following sections cover how the LSS DMAIC methodology is implemented within the software development company's DevOps cycles.

3.2 Define

This stage entails defining the project and is done using the project charter seen in Table 4 [34]. A project charter is used so that all the specifics involved in the study/project could be adequately outlined and defined [34].

Table 4: The Project Charter.

Category	Definition
Purpose	The case study software development company faces challenges with their DevOps cycle implementations causing longer than expected delivery times for their software applications. This study will use the LSS methodology to improve the performance of their DevOps cycle implementations.
Scope	The parts of the DevOps cycle where data can be gathered and analysed according to the DORA metrics. The aim is to encapsulate the quantifiable data from the DevOps cycle to effectively analyse its performance.
Objective	The objective is to apply the DMAIC methodology of LSS to improve the DevOps cycle implementations and the DORA metrics to measure the effect on performance.
Resources	Access was granted to the company's SCRs and CI/CD pipeline implementations.
Assumptions	All quantifiable data within the DevOps cycle on the DORA metrics can be obtained from the SCRs and the CI/CD pipelines.

3.3 Measure

This study analyses the performance of the DevOps cycle implementations by obtaining data according to the DORA metrics. The DORA metrics are the primary measure for analysing the performance difference before and after the application of LSS within the DevOps cycles. Table 5 highlights the data collection methods to obtain the values for each of the DORA metrics. The value for each metric was obtained through the use of an Application Program Interface[§] (API) [36]–[38].

Table 5: DORA Metrics Data Collection Methods.

Metric	Method
Deployment Frequency (/day)	The API for the CI/CD pipelines is used to query the number of deployments made per day for each DevOps cycle.
Lead Time (days)	The API for the SCRs is used to query and calculate the lead times for pull requests[**] on the repositories.
Change Failure Rate (%)	The API for the SCRs is used to retrieve the average number of issues created per day. This value is divided by the daily deployment frequency to obtain the percentage.
Time to Restore (days)	The API for the SCRs is used to query the time it takes to resolve reported issues.

Table 6 highlights the pre-application measures (January 2021 – September 2021) for the DORA metrics across the five DevOps (D) cycles.

Table 6: Initial DORA Metrics Across the DevOps Cycles.

Metric	DevOps Cycles				
	D1	D2	D3	D4	D5
Deployment Frequency (/day)	0.94	0.34	1.40	0.37	6.28
Lead Time (days)	9.97	5.22	8.25	14.58	9.18
Change Failure Rate (%)	663.83	441.18	252.14	451.35	230.36
Time to Restore (days)	31.75	35.91	23.57	24.88	62.73

3.4 Analyse

Data is gathered from the SCRs and CI/CD pipelines (January 2021 – September 2021) to analyse the values obtained in Table 6. The data from the SCRs correlates to the lead times and time to restore values. The data from the CI/CD pipelines correlates to the deployment frequency, and this data combined shows the change failure rate percentage. The five DevOps cycles are split at random into a testing set (D2, D3 and D5) for the application of LSS and a validation set (D1 and D4) with no application. This ensures that any improvements seen in the testing set are from the application of LSS and not external factors within the software development company.

3.4.1 Source Control Repositories

To analyse the lead times in Table 6, a Value Stream Map (VSM) for the processes in the SCRs is derived in Figure 3 to determine where most of the time is spent [35].

[§] An API is an interface that allows developers to access and obtain data on the operation of their systems [36]–[38].

[**] A pull request is an event that occurs when a software developer is ready to begin the process of merging new code into the main source control repository [42].

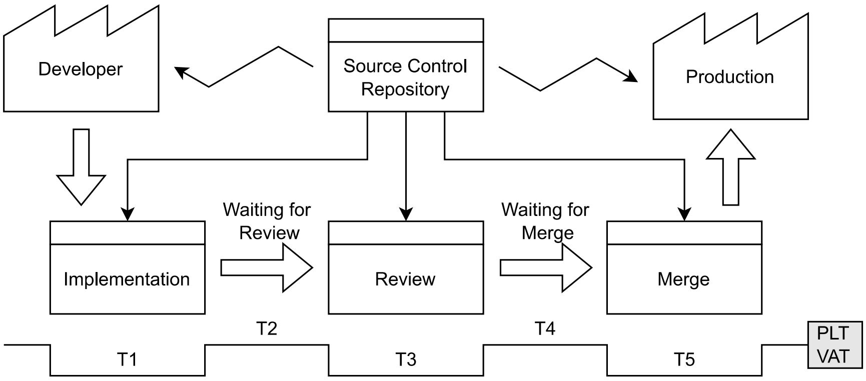

Figure 3: Value Stream Map of the Processes Within Source Control Repositories.

In Figure 3, T1-T5 represents the average duration (days) of each stage, PLT is the Process Lead Time, and VAT is the Value Added Time. The average durations seen in Figure 3 are quantified in Figure 4 for each DevOps cycle.

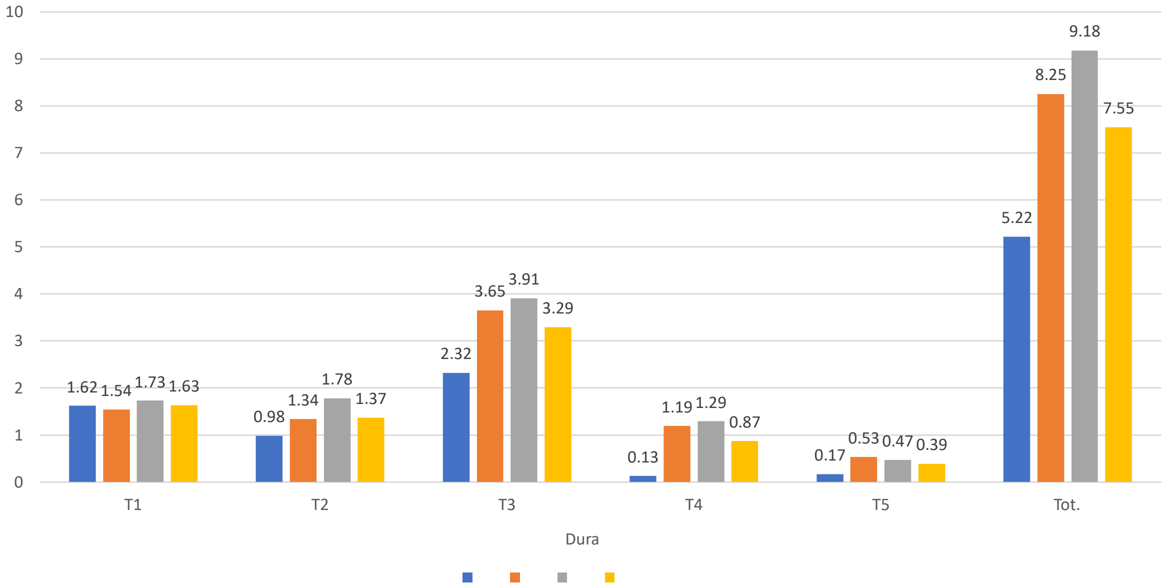

Figure 4: Value Stream Map Breakdown for the Durations Across Each DevOps Cycle.

In Figure 3, T2 and T4 are non-value-added tasks and summed in Figure 4, indicating that approximately 30% of the total time is spent waiting. This is where a significant improvement can be realised. T3 is also on average greater than T1, meaning that the review duration is longer than the implementation duration. These values all affect the deployment frequency and lead times within the DevOps cycles. To further understand the change failure rate, the quantities associated with the issues created on each SCR are analysed in Figure 5 for each DevOps cycle.

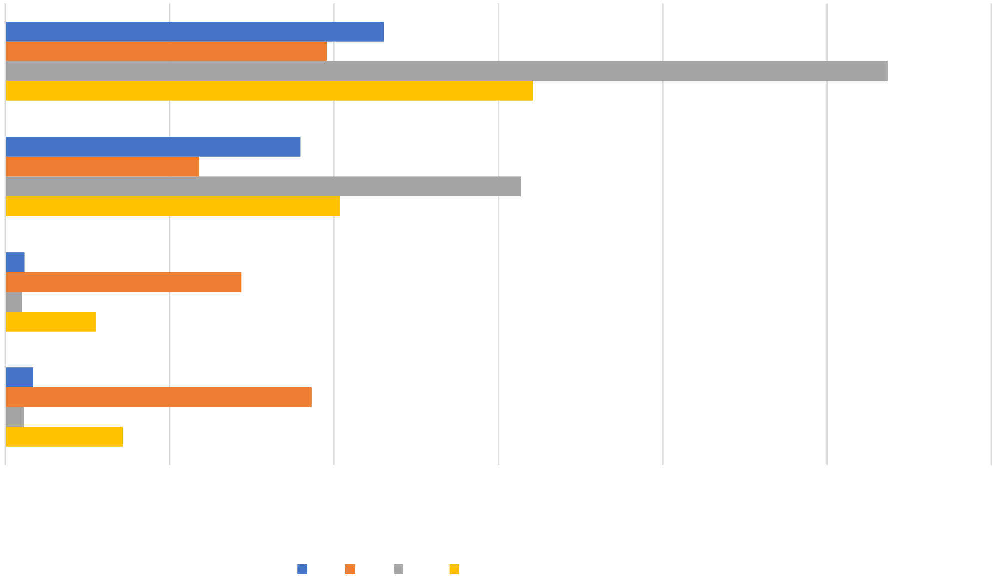

Figure 5: Issue Metrics Across Each DevOps Cycle.

From Figure 5, the average days to close an issue is just over a month. In addition, the average age of issues is also high, which means that there are unresolved or forgotten issues. Figure 5 also highlights how more issues are opened than closed per month across the cycles on average. Again, this data highlights the scope for improvement within the change failure rates and the time to restore metrics.

3.4.2 CI/CD Pipelines

The CI/CD pipelines consist of several tasks, for example, building, testing and deploying software [13]. Therefore, each task duration across the CI/CD pipelines within the DevOps cycles is analysed. This data is illustrated using a Pareto chart to identify where the task durations within a pipeline are concentrated.

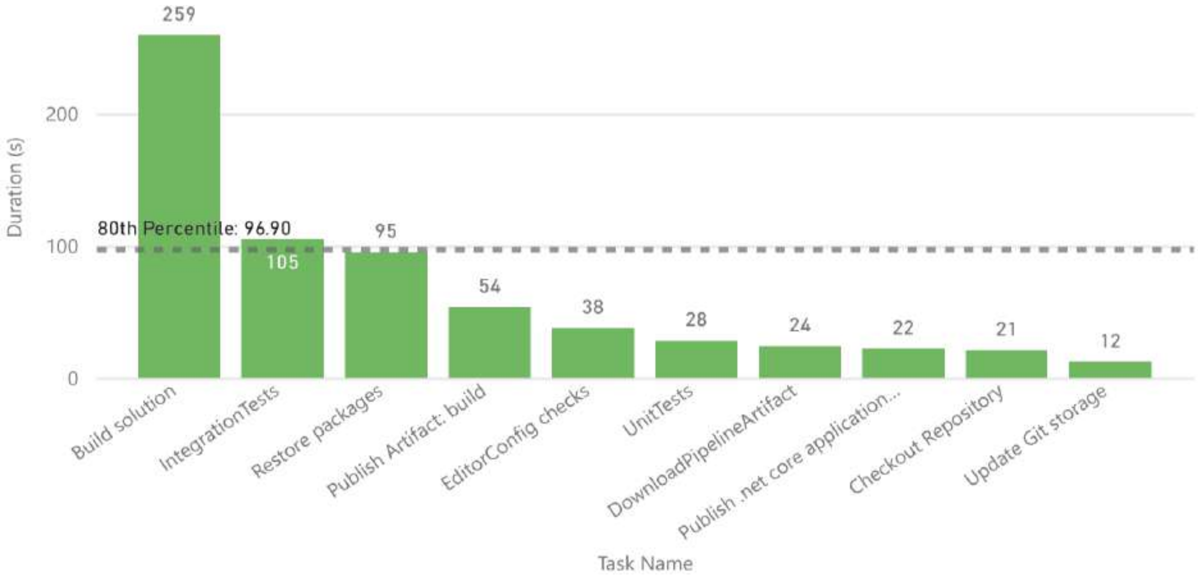

Figure 6: Pareto Chart Illustrating the Task Durations in the CI/CD Pipeline of D2.

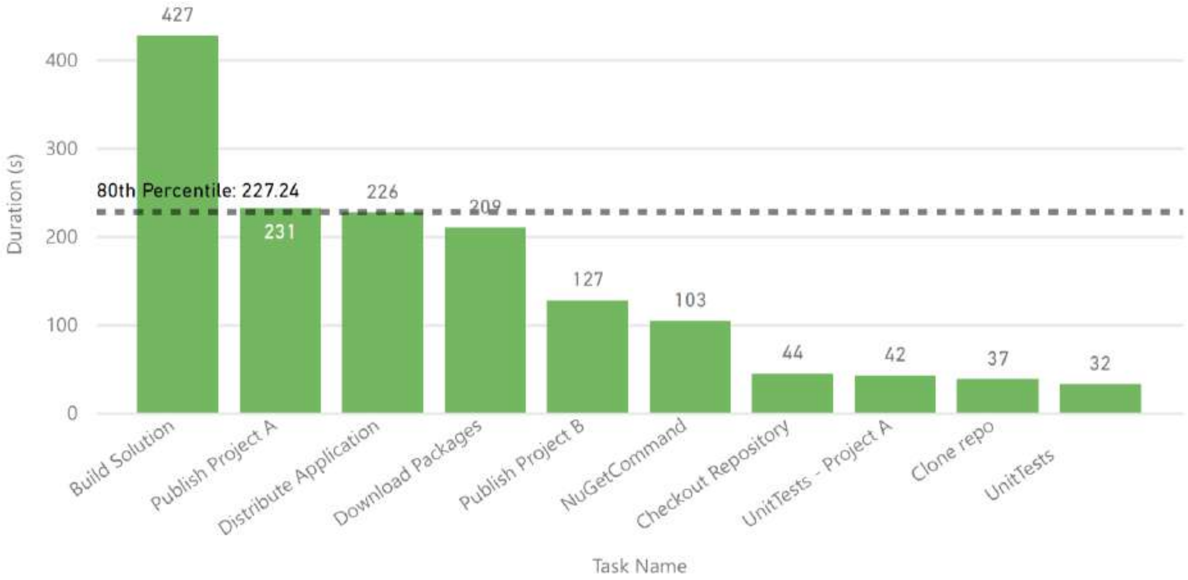

Figure 7: Pareto Chart Illustrating the Task Durations in the CI/CD Pipeline of D3.

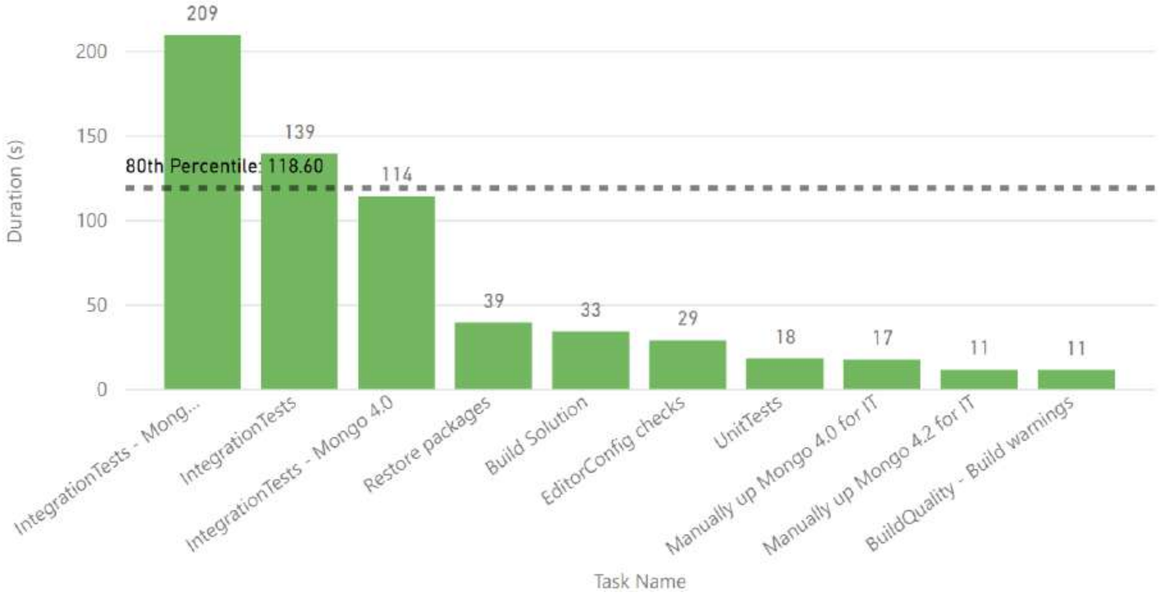

Figure 8: Pareto Chart Illustrating the Task Durations in the CI/CD Pipeline of D5.

The Pareto Principle states that 80% of the problem can be solved with 20% of the effort [39]. Therefore, in Figure 6, Figure 7 and Figure 8, the focus is placed on improving the tasks on or above the 80th percentile. In Figure 6 and Figure 7, the Build Solution and Restore/Download Packages tasks, and in Figure 6 and Figure 8, the testing tasks, have a high duration. The Distribute Application and Publish Project A tasks also have a high duration in Figure 7. All these quantities contribute to affecting the deployment frequency in the DevOps cycle.

3.4.3 Summary

To summarise and verify the data obtained, the problems identified, their root causes and Verification Methods (VM) are shown in Table 7. These problems are referred to in the remainder of this study.

Table 7: Problems Identified and Their Root Causes.

Problem		Possible Root Causes	VM	VM Reason
Source Control Repositories	**P1:** The wait times contribute to 30% of the total time.	Developers are not aware when they are assigned to pull requests for reviews or merging.	VSM of Durations in SCRs (Figure 3 and Figure 4).	The durations in the process can be properly visualised.
	P2: Review times are greater than implementation times.	Reviewers are not assigned immediately and are unaware of their assignments.		
	P3: Time to close and the average age of issues is high.	Issues are not handled on creation, go unassigned, duplicate issues are created, and there is no defined method for issue handling.	Tabulated data from issues (Figure 5**Error! Reference source not found.**).	A simplified method to compare the results.
CI/CD Pipelines	**P4:** High Build Solution, Publish and Distribute Durations.	The solution is not modular, it is too large and has unused or already referenced projects.	Pareto Charts (Figure 6, Figure 7 and Figure 8).	A simplified method to verify the highest contributing durations.
	P5: High Testing Durations.	Tests are not running individually and there are duplicate/irrelevant tests.		
	P6: High Package Restore Durations.	Packages are downloaded every execution, no package caching is used and there are unused or duplicate packages.		

3.5 Improve

The improvement phase is used to determine the most feasible solutions for the problems identified in Table 7 [2], [31]. The solution matrix in Table 8 identifies the solutions that were implemented across the DevOps cycles (D2, D3 and D5).

Table 8: Solution Matrix.

P	Solution	Reason
P1	Setup scheduled reminders for review requests.	Setting up reminders allows assignees of pull requests to remain up-to-date with their progress. In addition, this will ensure that they are reminded regularly when their attention is required.
P2	Setup scheduled reminders for review requests.	Remove as much user interaction as possible by automating reviewer assignments and setting up reminders for when attention on a pull request is required.
	Automate reviewer and author assignment.	
P3	Implement sprint planning for issue handling.	Sprint planning allows developers to assign a certain number of issues for resolution during a period. This will enable developers to remain focused and address issues in controlled batches [40].
P4	Separate projects into individual builds and CI/CD pipelines.	This will reduce the build duration of the solution and is especially effective when changes only occur on a single project. Removing unused projects and unused references will reduce the duration of building the solution.
	Remove unused or already referenced projects.	
P5	Reduce the cyclomatic complexity of tests.	Reducing the cyclomatic complexity and removing unnecessary tests will ensure a lower testing duration.
	Remove duplicate and irrelevant tests.	
P6	Use caching in pipelines.	If a package is not changed it can be restored from the cache between pipeline runs. Removing any unused packages also reduces the package download size.
	Analyse and remove all unused packages.	

3.6 Control

A control plan is defined to ensure that the solutions applied in the improvement phase are maintainable [31]. Table 9 defines the control plan for each of the identified problems in Table 7.

Table 9: Control Plan.

P	Source	Tool	Measurement Technique	Indicator	Freq.
P1	Source Control Repository	API	Collect data for the review and merge durations.	Abnormal increase in waiting time.	Monthly
P2					
P3			Collect data on the average time it takes to close issues and the age of active issues.	Abnormal increase in issue durations.	
P4	CI/CD pipeline		Collect data to view the average task durations.	Abnormal increase in task durations	
P5					
P6					

4 RESULTS AND DISCUSSION

4.1 Performance Analysis

LSS was gradually applied (October 2021 - February 2022) on D2, D3, D5, and data was gathered at the end of February 2022. This was used to deduce whether there were improvements after the application of LSS. The results obtained are illustrated in Table 10 and Table 11. D1 and D4, are where LSS was not implemented, and D2, D3 and D5, are where LSS was implemented. The DORA metrics were measured and indicate the results from the application of LSS.

Table 10: Post DORA Metrics on D1 and D4.

Metric		DevOps Cycles		Avg	Percentage Change
		D1	D4		
Deployment Frequency (/day)	**Before**	0.94	0.37	0.66	17% increase
	After	1.18	0.36	0.77	
Lead Time (days)	**Before**	9.97	14.58	12.28	2% decrease
	After	10.24	13.78	12.01	
Change Failure Rate (%)	**Before**	663.83	451.35	557.59	22% decrease
	After	244.92	627.06	435.99	
Time to Restore (days)	**Before**	31.75	24.88	28.32	39% increase
	After	56.33	22.30	39.32	

Table 11: Post LSS DORA Metrics on D2, D3 and D5.

Metric		DevOps Cycles			Avg	Percentage Change
		D2	D3	D5		
Deployment Frequency (/day)	**Before**	0.34	1.40	6.28	2.67	87% increase
	After	1.50	1.82	11.64	4.99	
Lead Time (days)	**Before**	5.22	8.25	9.18	7.55	18% decrease
	After	2.66	7.04	8.78	6.16	
Change Failure Rate (%)	**Before**	441.18	252.14	230.36	307.89	58% decrease
	After	162.00	133.52	91.76	129.09	
Time to Restore (days)	**Before**	35.91	23.57	62.73	40.74	52% decrease
	After	19.67	19.67	19.67	19.67	

From Table 11, the deployment frequency increased approximately 87% across D2, D3 and D5. This resulted from the reduced steps and durations of each task within the pipelines. A shorter pipeline duration allows for faster deployments, meaning more can be made per day. From

Table 10, D1 and D4 remained relatively consistent across the post-implementation evaluation period, with an average increase of approximately 17%.

From Table 11, the lead times were also slightly improved on average across D2, D3 and D5 by approximately 18%. This was due to the changes in how the reviews and merges are done. This ensured that a pull request is handled on time when it is made or approved. However, the lead times were not drastically improved as this value contains the most human involvement. The lack of automation is still present in these values, which require further investigation.

Due to the increase in the deployment frequency and the change in the way issues are handled, a decrease was seen in the change failure rates. The change in the way issues are handled, and the improvement in the CI/CD pipelines significantly assisted in reducing the percentage values. The change failure rates for D1 and D4 decreased by approximately 22%, whilst D2, D3 and D5 decreased further by approximately 58%.

The after time to restore values for D2, D3 and D5 are the same in Table 11. This is because the company decided to utilise a sprint methodology, grouping all issues into a singular sprint cycle. Therefore, it was decided to take the average across the sprint cycles and thus they have the same values. This saw an average decrease in the time to restore of approximately 52% for D2, D3 and D5, whilst from Table 10, D1 and D4 saw an increase of approximately 39%.

The increase in performance of their DevOps cycles should positively influence the time-to-market of their software products. Furthermore, the results obtained further merit the application of LSS within the DevOps cycle. The methodology followed should be applied to the remaining and any future DevOps cycles within the company.

This study saw successful improvement in the performance of the DevOps cycles for the case study. This might not be the case for all DevOps cycles, as implementations differ vastly across industries and only one software development company was considered for this study. Applications within other DevOps cycles may see varying improvements based on the maturity level and the method of implementation of their DevOps cycles.

This study contributes to the field of research by illustrating how, through the application of a structured and systematic approach within the DevOps cycle, it is clear that performance can be improved. Furthermore, this research contributes by illustrating the positive effects of applying a PIM within the software development context and addresses **RQ2**.

4.2 Limitations

The main limitation is that data was only gathered from one software development company, affecting the generalisability of the results. Data privacy is a big concern within software development companies, and gaining approval to access this data is challenging. To mitigate this concern, this study chose a company that had varying DevOps cycle implementations. A testing and validation set was also used to reduce the impact of the bias in the obtained results allowing them to be more generalisable.

There are different levels of maturity and methods of implementation seen with DevOps cycles not considered for this study. The maturity level and the implementation method affect the degree to which a DevOps cycle can be improved. Therefore, there is a limitation on when the application of LSS would become less or more effective.

The effective adoption and implementation of LSS is another limitation that needs to be considered. It is not always simple to propose a new methodology within a company, as the upfront implementation effort can pose resistance. This was not considered for this study but can affect the degree to which LSS can effectively be implemented.

4.3 Conclusion

The implementation of the DevOps cycle has seen numerous challenges in the software development industry. These challenges have affected the cycle's performance, resulting in a decreased time-to-market and quality of the delivered software. This study illustrated the applicability of using a PIM within the software development context, specifically the application of LSS within the DevOps cycle. LSS was applied as it is a top-down, continuous approach aimed at improving the inefficiencies within a process to improve its performance.

It was found that through the application of LSS the performance of the DevOps cycle can be increased according to the measured DORA metrics. This addresses the need and the problem statement set out by the study. This research is significant as it illustrates the scope for improvement that exists in improving the performance of the DevOps cycle. It was learnt that the DevOps cycle is a complex process, but that its performance can be improved through a structured and systematic approach.

The results obtained benefit software developers by defining an approach, according to the application of LSS, to improve the performance of their DevOps cycle implementations. Further, contributions are made to literature by being the first study to apply LSS within the DevOps cycle, thereby contributing to the gap that was identified.

5 RECOMMENDATIONS FOR FUTURE WORK

It is recommended that future work is done analysing data from implementations across different software development companies. This will further justify the reason for implementing LSS within the DevOps cycle. Further work is also suggested that compares the different maturity levels and the implementation methods of a DevOps cycle. The extent to which LSS can affect the performance of those DevOps cycles can then be determined.

The improvement in the performance of the DevOps cycle aims to have a positive influence on the time-to-market, team efficiency and customer satisfaction. Therefore, it is recommended that further work is done that collects data relating to these metrics. This would further justify why the performance improvement of the DevOps cycle is necessary.

LSS comes with its implementation challenges, and the implementation effort required for LSS within software development teams was not considered for this study. This study focused on the results that can be achieved with its implementation. Consequently, it is suggested that further work is done that analyses the effort required to implement LSS within software development teams and how viable it remains.

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DUST AND ASH PLANT HEALTH MONITORING DATA THAT IS NOT EFFECTIVELY UTILISED TO INCREASE PLANT UPTIME

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ABSTRACT

Southern Africa has recently been inundated with the energy supply crisis. The focus of this exploratory research was to identify levers that can be enhanced in order to minimise the energy supply crisis by enhancing plant uptime through ingenious tools management. Through the critical literature review of the power plants and general academic literature – plant health monitoring results were identified not to be integrated into one system, and these results were also not loaded on the computerised maintenance management system. This was found to have had a negative effect on the plant downtime as valuable production time was lost. Numerous tools have been identified with the objective of bringing this to the attention of the maintenance practitioners and the maintenance/operating software developers to develop a solution that captures their results in the management system so that plant recovery times can be reduced and exceed the energy consumers' expectations.

Keywords: Communication, Operating data, Maintenance data, Condition Monitoring data, Plant downtime, Maintenance system, Recovery times.

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1 INTRODUCTION

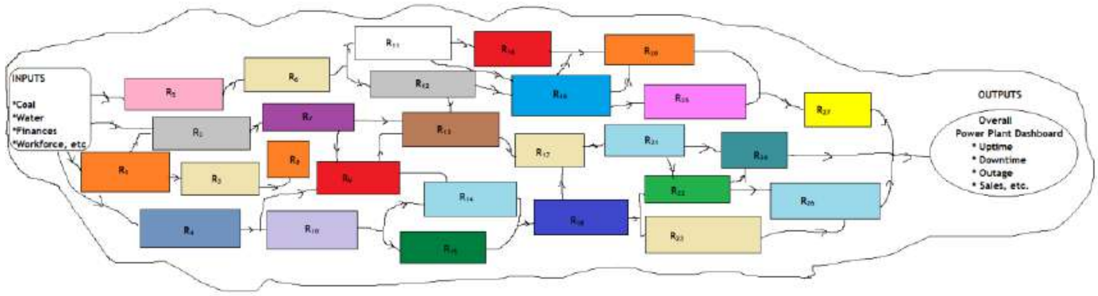
Southern Africa has recently been inundated with the energy supply crisis [1]. The focus of this research was to develop to identify levers that can be used to minimise the energy supply crisis by enhancing plant uptime through effective tools management. Dust and ash plant among 27 plant systems in a coal-fired power station plays a crucial role in the management of the safe removal and dumping of boiler residues [2]. Its uptime is vital for safe continued generation of power and compliance with the National Environmental Management: Air Quality Act, 2004 (Act No. 39 of 2004) [3] and emission laws that are becoming stricter every day [4]. Quality data in maintenance management is crucial in helping to reduce downtime [5]. In order to duly manage the plant items degradation of this system on a daily basis, engineers and technicians make use of various *online* and *offline tools* to assess the health of these items throughout the life of the plant and these results are not properly managed in order to maximise plant uptime and minimise downtime. A computerised maintenance management system (CMMS) was commonly used in the industry to load and manage the maintenance work using plant functional codes [6], while a plant operating management system (POMS) was used in the industry to log the operational performance history using functional codes also, these two systems were operating silos in the power plant, and this was also observed in the Finnish manufacturing companies [7]. The results of the various hand-held measuring instruments used on a daily basis to monitor plant health were neither stored in the CMMS nor POMS. This has a negative effect on plant failure management efforts, and this practice was also denying future plant maintenance decision-makers an opportunity to make plant items replacement policy on data that has integrity and has a comprehensive health history.

2 OBJECTIVES

The purpose of the proposed study was to do the following:

- To identify dust and ash plant condition monitoring *offline measuring instruments data* that were in silos and not being optimally managed to increase plant uptime.
- To accentuate the importance of the *offline (hand-held) measuring instruments data as a back-up to the online condition monitoring instruments* in order to enhance communication amongst various plant custodians and increase plant uptime.
- To call attention to the *Computerised Maintenance Management System (CMMS)* and *Plant Operating Management System (POMS)* software developers to develop a dynamic tool that will combine the hand-held condition monitoring, operating and maintenance data of the dust and ash plant for seamless communication and optimised plant uptime.
- To develop the plant items *condition-time graph/communication* (maintenance and operating teams) framework and identify *factors affecting production and plant recovery times*. This framework will be used in the future case study and applied in a system dynamics modelling of the dust and ash plant maintenance model.

Below in Figure 1 is a hypothetical 27 power plant systems series-parallel network model indicating R_{24} and R_{22} as dust and ash plant systems uptime in relation to the other 26 power plant systems.



R_i = Denotes the uptime of system i

R_{24} = Represent the dust plant uptime and it has a number of systems providing inputs

R_{22} = Represent the ash plant uptime and it has a number of systems providing inputs

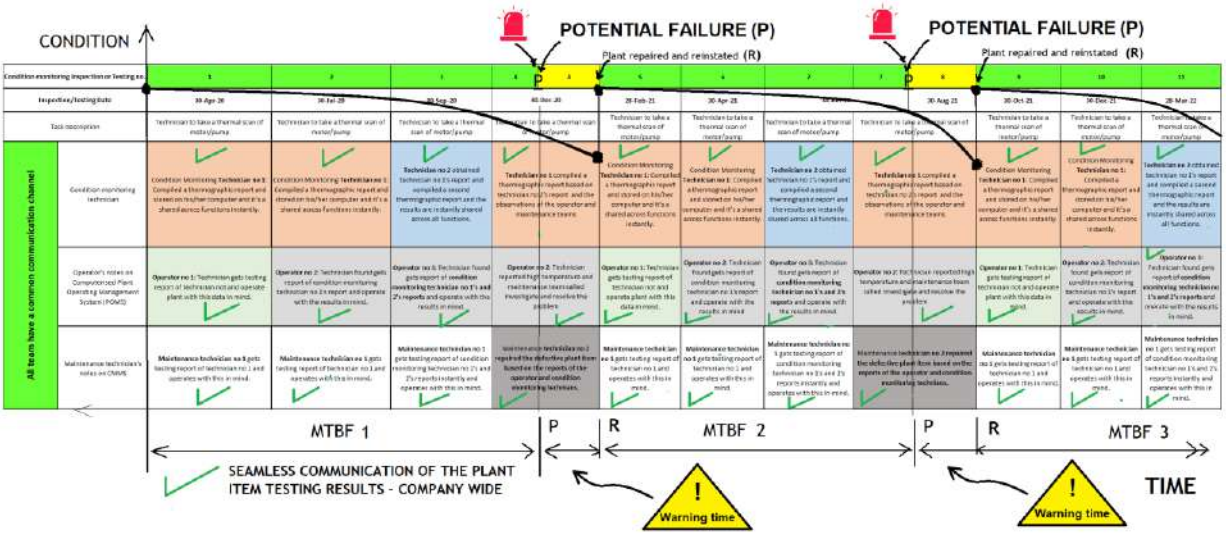
Figure 1: Hypothetical 27 power plant systems series-parallel network model indicating R_{24} and R_{22} as dust and ash plant systems, respectively.

3 RESEARCH METHODOLOGY

Leedy and Ormrod [8] argue that research is a systematic procedure of gathering, analysing, and interpreting information and data in order to increase understanding of a phenomenon that prohibits dust and ash plants from achieving high plant uptime.

This investigation followed an exploratory methodology by conducting literature reviews and making use of secondary data in order to understand the dynamics involved in a dust and ash system. According to Stebbins [9], in this exploratory work, the inquirer travels on unknown routes in order to discover the hurdles that are hampering dust and ash plants from attaining the desired plant uptime. The researcher adopted the pragmatism position and made use of an inductive approach in order to make sense of the phenomenal elements that were observed along the way.

A research framework (See Figure 2) has been developed based on the literature reviews and secondary data. In this framework, four groups are involved on a daily basis to manage the health of the dust and ash plant: (i) Condition monitoring team (ii) Operating team (iii) Maintenance team (iv) Online measurement instruments (not shown).



MBTF – Mean Time Between Failure

Figure 2: Research framework of a perfect communication system of condition monitoring data, plant maintenance data and operating data

Communication of the plant health status is seamlessly relayed to all functions in order to prevent incipient failures from developing towards the position of the functional failure. In this model, plant recovery times have been optimised so that MBTF can be maximised. Below in Table 1 is the categories of these measuring instruments to be explored.

Table 1: Dust and ash plant data collected through condition monitoring technicians, operators, maintenance technicians and online measuring instruments.

Type	Description	Redundant measuring instruments
Pen & Paper (Offline)	This involves walking the plant and jotting down the plant deviations with the aid of five (5) human senses. The observer records plant alpha-numeric to aid the maintenance team later.	The focus of the research
Smartphone or Tablet & stylus. Video/photo recording (Offline)	This involves walking the plant and jotting down the plant deviations observed. The observer records plant alpha-numeric to aid the maintenance team later. Video/photo used by the maintenance and engineering to conduct the diagnosis and root cause analysis.	
Portable Measuring instruments (Offline)	This involves walking the plant and measuring plant parameters to assess if it is normal; if not, the plant defect is captured on pen and paper. The observer records plant alpha-numeric to aid the maintenance team later.	
Online measuring instruments	This forms part of the permanent plant infrastructure. For example, four mass meters installed in parallel to measure ash mass in four different locations along the conveyor belts.	N/A

Bastos *et al*. [10] method of selecting a research instrument will be applied in the future in order to ensure that the instrument to be used in validating the model is *valid* and *reliable*. According to Yasar and Cogenli [11], *reliability* means that scores from an instrument are steady and constant, while *validity* means that the individual's scores from an instrument make sense and will assist the researcher in drawing good conclusions from the dust and ash plant samples under consideration.

4 LITERATURE REVIEW

A coal-fired power plant is composed of numerous plant items that are mostly in continuous operation to meet the energy consumers' needs. These items are unfortunately bound by the second law of thermodynamics, which states entropy (disorder) is greater or equal to zero [12]. This means that plant items' health does not remain constant and some of the negatively affected items include: valves, pumps, weld joints, pipelines, cables, motors, switches, online measuring instruments, etc. The premise of plant performance management is hinged on the effects of this law on plant items. The production manager does not want production plans to be disrupted by the negative changes in the plant items' health [13].

In order for the maintenance manager to satisfy this stringent demand while complying with the safety regulations and cost constraints, plant items' health has to be *measured* [14].

According to Finkelstein [15], measurement is "*defined as an empirical operational procedure which assigns numbers to members of a class of entities, in such a way as to describe them; by which is meant that relations between these numbers correspond to empirical relations between the entities to which they are assigned*". Jones [16] debates that measurement has been taking place for millions of years, and this has helped our ancestors to *survive*, whereas Scott, et al. [17] posits that measurement is the cornerstone of empirical science and that this necessitates the use of research tools that are valid and reliable.

The measurement system in a power plant is designed to keep the operating plants within safe and cost-effective margins [18]. Plant safety relates to keeping a specific parameter within maximum and minimum limits with the objective to comply with regulations, protect assets, and protect the environment and workers. Depnath and Basu [18] further defined parameters as the fundamental physical and chemical features or properties that can be used to characterize the state or condition of a matter or mass. These parameters are required for *measurement, control, data acquisition for analysis, storage and historical archives, and alarm annunciation systems*, amongst others. Below in Table 2 is a condensed list of essential parameters in the power plant.

Table 2: Essential parameters that are used to characterize the condition of the matters in the power plants. Sources: [18] and [19]

Steam	**Generator**	**Working fluid**	**Turbine**
Pressure	Voltage	Dissolved oxygen	Speed
Flow	Current	pH	Vibration
Level	Power (MW/M VAR)	Conductivity	Eccentricity
Humidity	Frequency	Hydrazine	Expansion
Viscosity	N/A	Turbidity	Valve position
Density	N/A	Sodium	N/A
Water	**Pollution**	***Coal [19]***	***Ash [19]***
Dissolved silica	Smoke/particulate emissions	*Calorific value*	*Calcium, CaO*
Dissolved hydrogen	SO_X	*%Ash content*	*Magnesium, MgO*
Conductivity	NO_X	*%Moisture content*	*Silica, SiO_2*
N/A	Carbon dioxide	*Volatile matter*	*Aluminium, Al_2O_3*
N/A	Carbon monoxide	*Abrasive index*	*Ferric, Fe_2O_3*
N/A	Oxygen percentage	*%Sulphur*	*Sulphur, SO_3*
N/A	N/A	*Mass*	*Mass*
N/A	N/A	*N/A*	*Electrical resistivity [10]*

Dust and ash plant has a high number of plant items that are measured online and offline. These include parameters in the arena of electrical, electronic, mechanical, hydraulic and those that are listed in Table 1 above. Fly ash in a power plant constitutes 80% of the dust and ash that is conveyed to the ash dump/dam [18] and [20]. In the process of conveying boiler residues to the dumping side, plant condition monitoring instrumentation is negatively affected by the unstable quality [21] and quantity of the boiler residues.

Nowlan and Heap [22] identified that failure of plant items did not just occur without providing signals that an item is about to fail. These signals were the foundation of what they defined as potential and functional failures. In order to illustrate their findings, they developed a P-F graph (see Figure 3 below).

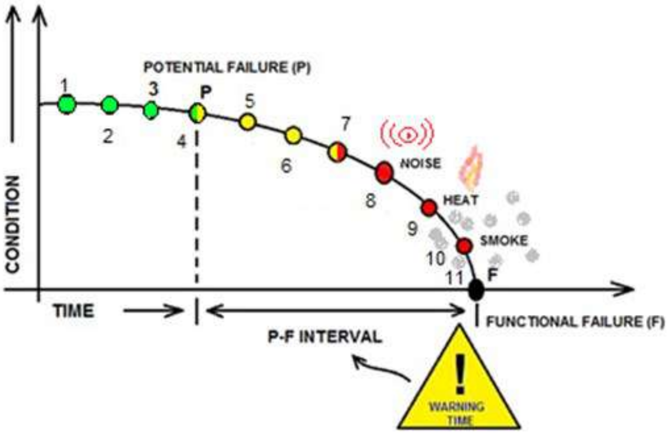


Figure 3: Potential and Functional failure definitions. Source: Adapted from [22]

The period between these failures played a critical in the development of the maintenance strategy (E.g., Online or Offline Condition Monitoring - Tribology analysis, Vibration analysis, Thermography, etc.), and this is the time when power plant operators subject their plant items to health check-ups with intensity to prevent functional failures. This is based on the notion that there is a ***warning time*** **(P-F interval)** between the **Potential failure** (P) and the **Functional failure** (F) in order for the maintenance, operating, engineering and production managers to react and prevent the **Functional failure.** Modern failure management or condition monitoring is laid on this bedrock, and it has been confirmed by ([23], [24] and [25]). Below in Table 3 is a list of some of the common failures found in the power plants.

Table 3: Common plant monitoring instrumentation and mechanical failures in a coal-fired power plant. Source: ([26]; [27];[28]; [29] and [30])

Instrument	Defect	Type
Gauge glass	Covered in dust and ash, the operator cannot see the reading	Instrumentation
Temperature probe	Covered in dust and ash, the temperature probe (E.g., Motor/Pump, etc.) is not able to measure true temperature.	Instrumentation and Electrical
Cable	Covered with hot ash, cut in the process of cleaning ash.	Instrumentation
Gauge	Covered in dust and ash, dust ingress into the hydraulic fluid lead to clearances being damaged or mating mechanical components tolerance being damaged.	Instrumentation and Mechanical
Gauge	Sprayed with highly pressurised water, damaged due to impact force.	Instrumentation
Gauge	Sandblasting, gauge glass damaged by the abrasive particles in the ash.	Instrumentation
Gauge	The environment is covered in dust, and visibility is poor	Instrumentation
Chain	Overloading of the submerged scrapper conveyor as a result of upstream conveyor stoppages.	Mechanical
Moving mechanical components	Submerged scrapper conveyor – flight bars, chain and sprocket eroded by abrasive dust and ash particles.	Mechanical

In order to maximize the plant uptime for the power plant, it is imperative that both online and offline plant data collection systems are kept in excellent condition, and data integrity is at its best [31]. The operations manager is intermittently disrupted by this failure phenomenon and forced to shut down production plant, and these disruptions destroy the brand of the energy suppliers. To reduce the impact of the unforeseen plant items failures, maintain zero harm to workers/environment and reduce operational costs, the maintenance manager has to develop an effective maintenance strategy that is based on the information derived from the effective data collection system or condition monitoring system.

This strategy is informed by the plant walks data, breakdown maintenance data, predictive maintenance data, condition-based maintenance data and operational experience data from the original equipment manufacturer (OEM), amongst others. Below in Table 4 is the list of some of the data sources used in the power plant.

Table 4: Power plant maintenance strategy data sources [18] and [32]

Source (s) of data	Description
Plant walks	Planned maintenance intervention or after sensing a deviation from the norm by Hearing, Smelling, Feeling, Touching and any diagnostic tool used plant inspector. Type of Data Collection: Offline Measuring instrument (s)
Breakdown maintenance	Sudden loss changes of key parameters (i.e. pressure, temperature, voltage, current, etc.). A signal is sent through a measuring instrument to the control room. Generally, this type of maintenance is applied on systems that have redundancy or where functional failure will not disrupt production processes. Type of Data Collection: Online or offline Measuring instrument (s)
Condition monitoring	This type of maintenance falls under a group of preventive maintenance (pre-installed). This is normally assigned to safety-critical or production-critical plants. A pre-set operating parameter has to operate within a control band. Outlier triggers an alarm to the control room operator for an action to remedy the deviation. This is composed of an online and offline monitoring instrument. Generally, this type of maintenance is triggered by a potential failure, and the maintenance manager has adequate time to intervene. Type of Data Collection: Online or offline Measuring instrument (s). See Table 5 and Figure 4 below for typical examples of condition monitoring applications.
Predictive maintenance	This type of maintenance falls under a group of preventive maintenance (pre-planned). This is normally assigned to safety-critical or production-critical plants. This is composed of an online or offline sensor sending the deviation results to a computer unit (artificial intelligence) to execute an analysis and establish the outcome; thereafter, a maintenance task is planned in the future depending on the calculation done by the computer unit. The CMMS will be prompt to issue a maintenance order for the plant item in the future. Generally, this type of maintenance is triggered by a deviation from a normal operating curve, and the maintenance manager has adequate time to intervene. Type of Data Collection: Online or offline Measuring instrument (s)
Condition-based maintenance	This type of maintenance falls under a group of preventive maintenance (pre-planned). This is normally assigned to safety-critical or production-critical plants. A known operating parameter has to operate until a pre-known number of times or cycles before the plant can be shut down for an intervention. This parameter can be hours or cycles measured by an hour-meter or cycle counter. This is composed of an online counting instrument. Generally, this type of maintenance is triggered when X hours have been reached or Y cycles have been reached; the CMMS will issue a maintenance order for the plant item that is due for intervention. Type of Data Collection: Online or offline Measuring instrument (s). Table 5 and Figure 4 below the typical examples of condition monitoring applications.
OEM tests and operational experience	This type of source is based on the engineering product tests conducted by the manufacturer and also based on the operational experience gained in the industry where this type of product/s has been implemented. In this scenario, OEM will gather practical data that tells one that plant item life is X hours versus the design life Y that was envisaged during the conceptual phases.

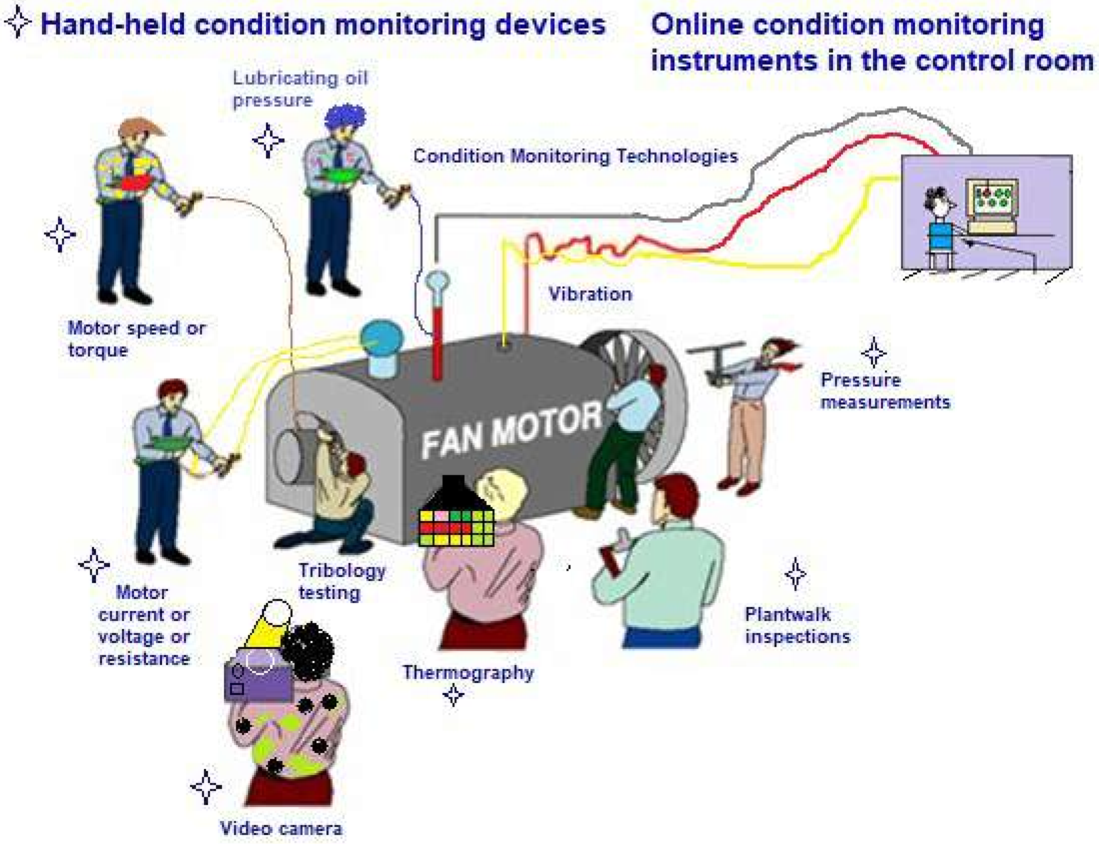


Figure 4. Condition monitoring testing techniques (*not exhaustive*) that are neither linked to CMMS nor POMS. Source: Adapted from [33]

Table 5: List of power plant hand-held measuring instruments (*not exhaustive*) that have been identified not linked to CMMS and POMS.

Failure detection instrument	**Description**	**Feedback after application of the instrument**
Observations through notebook	This is a method of inspecting a plant by making use of human senses. That is seeing, hearing, smelling and feeling.	Records of the plant walk findings are fed manually.
Photo/Video camera (24 hr CCTV)	This is a normal digital photo/video camera that is used to capture still footage of the plant.	This is used to map the sequence of the events in case of plant incidents. This can be used for security reasons. Digital photo/video of the plant walk findings is fed manually.
Thermographic camera (coal stockpile, electric motor, etc.) [34]	Thermal measurement technology measures absolute or relative temperatures of key equipment parts or areas being monitored. Abnormal temperatures indicate developing problems. Temperature and thermal behaviour of plant components are the most critical factors in the maintenance of plant equipment and have also been found to be the case by [35].	A digital thermal scan of the plant item findings is fed manually upon review.
Vibration measuring instruments (hand-held or installed) [36]	The instruments which are used to measure the displacement, velocity or acceleration of a vibrating body are called vibration measuring instruments. Studying vibration measurements allows teams to discover imbalance, looseness, misalignment, or bearing wear in equipment prior to failure.	A digital scan of the plant item vibration graph is fed manually upon review.
Electrical multimeters (voltage, current and resistance) (hand-held or installed condition monitoring)	A multimeter or also known as a VOM (volt-ohm-mill ammeter), is an electronic measuring instrument that combines several measurement functions in one unit.	Digital records of the plant test results are fed manually.
Online analysers or lab analysis (E.g., Oxygen content, Fly ash carbon analysis, etc.) (hand-held or installed condition monitoring) [32]	Chemical analysis is used to identify the contents, composition and quality of the materials used in the production process. An analyst might be interested in the oxygen. This can be done online or with a sample taken to the laboratory for analysis.	Laboratory analysis results are done manually.
Tribology testing [36]	Tribology testing generates critical information regarding the failure mechanisms of mechanical components, resulting in solutions that improve performance and/or lower operating costs.	Laboratory analysis results are manually
Thickness testing	Pipe wall thickness is a critical measurement for determining piping integrity. Corrosion and erosion in pipe/chain walls can increase safety risks and decrease productivity if left untreated, as internal build-up can prevent the product from moving through the piping.	Records of the plant test results are fed manually
Ultrasonic Testing [34]	In ultrasonic testing (UT), a transducer introduces ultrasonic waves into a material, which travel in a straight line and at a constant speed until they encounter a defect. This causes some of the wave energy to be reflected while the rest is transmitted. Analysing the amount of reflected energy vs transmitted energy provides information on the size and location of the discontinuity encountered	Records of the plant test results are fed manually

Failure detection instrument	Description	Feedback after application of the instrument
Acoustic Emission [34]	Acoustic emission (AE) testing is a non-destructive testing (NDT) technique that detects and monitors the release of ultrasonic stress waves from localised sources when a material deforms under stress.	Records of the plant test results are fed manually
Hardness testing [34]	A hardness test is typically performed by pressing a specifically dimensioned and loaded object (indenter) into the surface of the material you are testing. The hardness is determined by measuring the depth of indenter penetration or by measuring the size of the impression left by an indenter	Records of the plant test results are fed manually
Radiographic Testing (RT) [34]	Radiography is a common technique to inspect newly-constructed pipelines to ensure weld quality. Radiographic inspections can be performed using either X-Ray or Gamma ray radiation. The choice of radiation sources and their strength depends on a variety of factors, including the size of the component and the material thickness.	Records of the plant test results are fed manually
Flowmeter [32]	This instrument is used to measure the internal flow of fluid in the system.	Records of the plant test results are fed manually for the offline.
Vibration gauge [34]	Vibration meters are used in many installations and machines as well as in the development of products, such as tools or components, to measure vibrations and oscillations.	Records of the plant test results are fed manually
Running hours of plant item based on experience (kilometre or hours or any parameter)	Plant items running hours are the cumulative hours starting from when the plant was switched on to the time when it is switched off. The “hour-meter” only gets to operate when the plant is operating.	Records of the plant test results are fed manually
Carbonation test of reinforced concrete cover [37]	The objective of this test is to establish the depth of carbonation. Carbon dioxide from the atmosphere diffuses through the porous concrete cover by reducing the pH from 13.5-12.5 to 8-9, at which the passivating/oxide film is no longer stable, thus resulting in a lack of protective layer for the reinforcement bars.	Records of the concrete sample test results are fed manually
Schmidt hammer test [38]	Schmidt Hammer is a one-of-a-kind non-destructive test (NDT) device for determining the hardness of concrete’s surface.	Records of the concrete sample test results are fed manually
3D concrete structures survey [39]	This is a non-destructive tool used to detect defects (cracks) and mapping of the geometric shape (deflections) of the reinforced concrete structures.	Records of the sample test results are fed manually
Dynamic Cone Penetration (DCP) test [40]	DCP test is used to determine the underlying ash dump or any materials’ strength by measuring the penetration of the cone into the material after each hammer blow.	Records of the sample strength test results are fed manually

Data collection is the process of gathering and assessing information on parameters of interest in a systematic manner that allows researchers to answer specific research questions [41]. In the case of the power plant - an operator is provided with a pre-designed check sheet that has titles, parameters of interest, frequency, units of measure, and space for comments on data or readings to be manually gathered. The goal of plant data collection is to capture quality evidence that can be used for regular business decision-making on time so that plant uptime can be kept high at all times. Irrespective of the preference for defining data (i.e. quantitative or qualitative), accurate data gathering is vital to maintaining the integrity of plant operation [31]. It is crucial that appropriate data measuring instruments are calibrated at all times in order to eliminate the likelihood of errors occurring and be compliant with the Occupational Health and Safety Act (OHSAct, 1993) under the general machinery regulation. South African Legal Trade Metrology Act No. 9 of 2014 stipulates that online and offline measuring instruments must also be regularly calibrated in the prescribed manner by the accredited bodies [42] and [43]. This involves measurement traceability (See Table 6), which according to [16], has made it possible to conduct commercial trade globally and compete with the other power plants internationally on plant performance indices.

Table 6: Measurement traceability chain showing magnitudes of measurement uncertainty. Source: [16]

Level	Uncertainty
National standard accurate	0.002%
Calibration laboratory	0.01%
Company “master” item	0.07%
Company production equipment	1%
Produced product	10%

A study in a power plant found that online measuring instrument accuracy was low [44]. They have made use of the global test, serial elimination strategy and data reconciliation methods to detect and identify gross errors with the objective of improving the accuracy of measured data. Keithley [45] defines error as the “deviation (difference or ratio) of a measurement from its true value”. There are two common errors in the measurement system according to [32]; see Table 7 below for details.

Table 7: Systematic and random error source(s). Source: [32]

Systematic or Controllable error source(s)	Random error source (s)
Calibration errors	Presence of transient fluctuation in friction in the measuring instrument
Ambient conditions (Jones [16])	Play in the linkages of the measuring instrument
Deformation of workpiece	Operator’s judgement in reading the fractional part of the engraved scale divisions
Avoidable errors (E.g. Reading, Parallax effect, etc.)	The positional error associated with the measured object and standard arising due to small variations in setting

5 DISCUSSION OF THE RESULTS

According to [46], 70% of online or offline data that is generated is never used, and this lead to subjective decision-making rather than objective-based, which is data-driven [47]. Condition monitoring, operating, and maintenance data collection tests that are regularly done in the power plants are not optimally used as argued by [46] and reported. A team [48] conducted an 18-month analysis on 45375 job cards with the goal of identifying critical data quality problems that delayed efficient after-market maintenance services inside the two Finnish enterprises. Their findings revealed that plant data was stored in silos, data integrity was poor, and this hampered decision-making. Refer to the proposed offline measuring instruments hypothetical model under Table 8 that is based on these silos as per [48].

The offline measuring device tests are mainly done by the condition monitoring team, plant maintenance tasks and offline testing are done by the maintenance team while operating the plant, and offline testing is done by the operating team. Each of these teams has different reporting lines, and the test results were not shared amongst these teams in order to enhance the quality plant decision-making process (See Table 9 for details). Owing to these gaps, the potential failures (**P**) are not addressed on time, thus allowing plant item/s to deteriorate towards functional failure (**F**). This type of delay is classified under general maintenance time delays (**D0**) under Table 9 below, and this is claimed to be one of the contributing factors to a **REDUCED** power generation calendar as illustrated with obese **RODENT D** below in Figure 5.

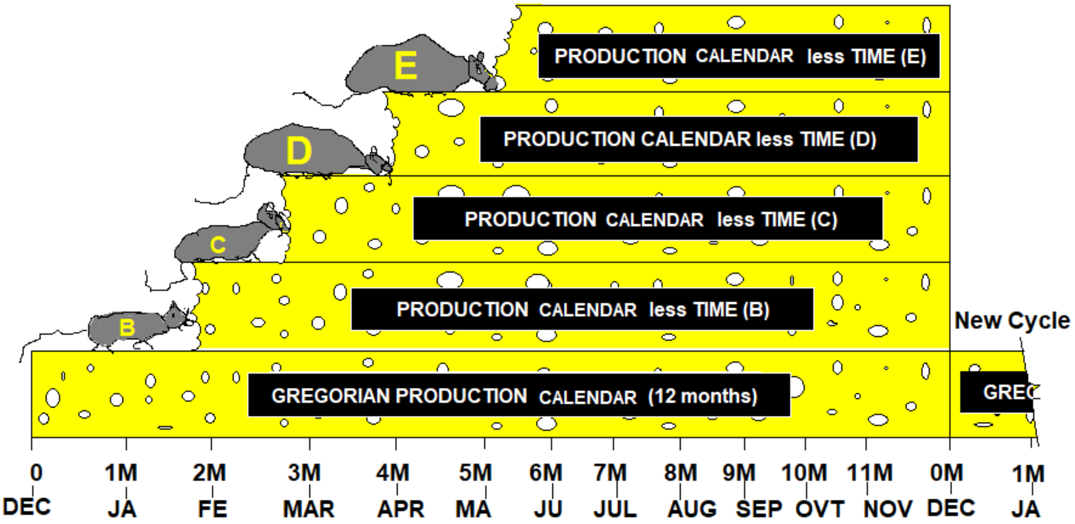
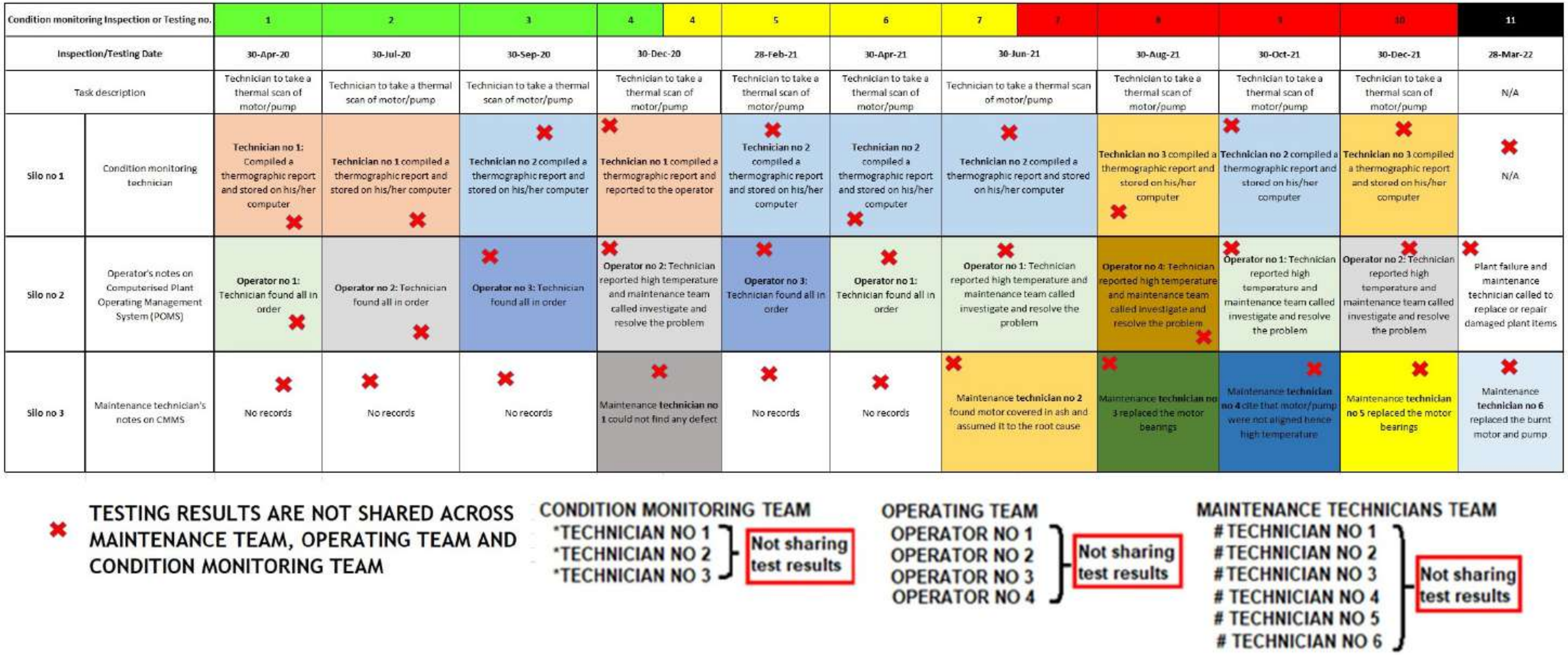


Figure 5: Annual production and maintenance plant times with constant capacity and fewer time losses. Source: Adapted from [49] and [50]

Tables 8,9 and 10 represent the hypothetical model that will be evaluated and validated through a case study in the future; this will be conducted in a dust and plant system so that levers of high plant uptime can be identified and optimised.

Table 8: Hand-held condition monitoring devices feedback, CMMS database and POMS database dynamics involved in maintaining the power plant by different teams with poor communication within the teams and departments *(Hypothetical). NB: Testing no 1 to 10 done by different members within the same team*



Condition monitoring Inspection or Testing no.		1	2	3	4 4	5	6	7 7	8	9	10	11
Inspection/Testing Date		30-Apr-20	30-Jul-20	30-Sep-20	30-Dec-20	28-Feb-21	30-Apr-21	30-Jun-21	30-Aug-21	30-Oct-21	30-Dec-21	28-Mar-22
Task description		Technician to take a thermal scan of motor/pump	Technician to take a thermal scan of motor/pump	Technician to take a thermal scan of motor/pump	Technician to take a thermal scan of motor/pump	Technician to take a thermal scan of motor/pump	Technician to take a thermal scan of motor/pump	Technician to take a thermal scan of motor/pump	Technician to take a thermal scan of motor/pump	Technician to take a thermal scan of motor/pump	Technician to take a thermal scan of motor/pump	N/A
Silo no 1	Condition monitoring technician	**Technician no 1:** Compiled a thermographic report and stored on his/her computer ✖	**Technician no 1** compiled a thermographic report and stored on his/her computer ✖	✖ **Technician no 2** compiled a thermographic report and stored on his/her computer	✖ **Technician no 1** compiled a thermographic report and reported to the operator	✖ **Technician no 2** compiled a thermographic report and stored on his/her computer	**Technician no 2** compiled a thermographic report and stored on his/her computer ✖	✖ **Technician no 2** compiled a thermographic report and stored on his/her computer	**Technician no 3** compiled a thermographic report and stored on his/her computer ✖	✖ **Technician no 2** compiled a thermographic report and stored on his/her computer	✖ **Technician no 3** compiled a thermographic report and stored on his/her computer	✖ N/A
Silo no 2	Operator's notes on Computerised Plant Operating Management System (POMS)	**Operator no 1:** Technician found all in order ✖	**Operator no 2:** Technician found all in order ✖	✖ **Operator no 3:** Technician found all in order	✖ **Operator no 2:** Technician reported high temperature and maintenance team called investigate and resolve the problem	✖ **Operator no 3:** Technician found all in order	✖ **Operator no 1:** Technician found all in order	✖ **Operator no 1:** Technician reported high temperature and maintenance team called investigate and resolve the problem	**Operator no 4:** Technician reported high temperature and maintenance team called investigate and resolve the problem ✖	✖ **Operator no 1:** Technician reported high temperature and maintenance team called investigate and resolve the problem	✖ **Operator no 2:** Technician reported high temperature and maintenance team called investigate and resolve the problem	✖ Plant failure and maintenance technician called to replace or repair damaged plant items
Silo no 3	Maintenance technician's notes on CMMS	✖ No records	✖ No records	✖ No records	✖ Maintenance **technician no 1** could not find any defect	✖ No records	✖ No records	✖ Maintenance **technician no 2** found motor covered in ash and assumed it to the root cause	✖ Maintenance **technician no 3** replaced the motor bearings	✖ Maintenance **technician no 4** cite that motor/pump were not aligned hence high temperature	✖ Maintenance **technician no 5** replaced the motor bearings	✖ Maintenance **technician no 6** replaced the burnt motor and pump

✖ TESTING RESULTS ARE NOT SHARED ACROSS MAINTENANCE TEAM, OPERATING TEAM AND CONDITION MONITORING TEAM

CONDITION MONITORING TEAM
*TECHNICIAN NO 1
*TECHNICIAN NO 2
*TECHNICIAN NO 3
Not sharing test results

OPERATING TEAM
OPERATOR NO 1
OPERATOR NO 2
OPERATOR NO 3
OPERATOR NO 4
Not sharing test results

MAINTENANCE TECHNICIANS TEAM
TECHNICIAN NO 1
TECHNICIAN NO 2
TECHNICIAN NO 3
TECHNICIAN NO 4
TECHNICIAN NO 5
TECHNICIAN NO 6
Not sharing test results

Table 9: Factors affecting production and plant recovery times.

Production Interruption factor (s)	**Description**
General public holidays (**B**)	Remaining production calendar time when statutory public holidays have been subtracted (**B**). These are the days that are legislated in the republic as holidays.
Statutory and non-statutory maintenance times (**C**)	Remaining production calendar time after deduction of statutory and non-statutory maintenance times (**C**). This measure is based on statutory and non-statutory maintenance of the plant. Statutory could be based on the Occupation Health and Safety Act, Act 85 of 1993 – For example, pressure equipment regulation that requires pressure testing of the pressure vessels every 36 months. Non-statutory could be based on the OEM recommendations and operational experience gained in maintaining a particular system or assembly or sub-assembly or plant item by the maintenance manager.
General maintenance delay times (**D = D0+D1+D2+D3+D4**)	The remaining production calendar time after deduction of the following delays (**D**): • Condition monitoring technician has conducted plant item test (**point no. 4**) and after analysis of data in the office, load a request to maintenance manager after the time (**D0**) upon the conclusion that plant failure is imminent. In the meantime, plant failure has deteriorated towards functional failure (**point no. 11**) shown in Figure 1. • The maintenance technician who was on standby had to travel from home to the industrial site, and it took one time (**D1**) for travelling. • The maintenance technician has to get the toolbox in time (**D2**). • The maintenance technician has to obtain the necessary spares or special equipment in time (**D3**). • The maintenance technician has to conduct the troubleshooting in time (**D4**) before one can start with the repair of the defective plant item.
Repair or spanner and post-repair testing times (**E**)	The remaining production calendar time after reinstating the plant to a healthy state. This is after deducting the repair or spanner and post-repair testing times (**E**). This is the period that differentiates maintenance leaders from the laggards in terms of efficiency and effectiveness. Measures that are used to evaluate this include: Mean Taken to Repair (MTTR), Rework and so on.
True production time (**F**)	The is the true production calendar time (**F**) after the deduction of **A, B, C, D** and **E** times. The period between plant item *testing* and *repairs* or *recovery time*s is the area that this exploratory research is focused on with the objective of understanding the condition monitoring dynamics involved with the use of hand-held measuring instruments.

6 CONCLUSION

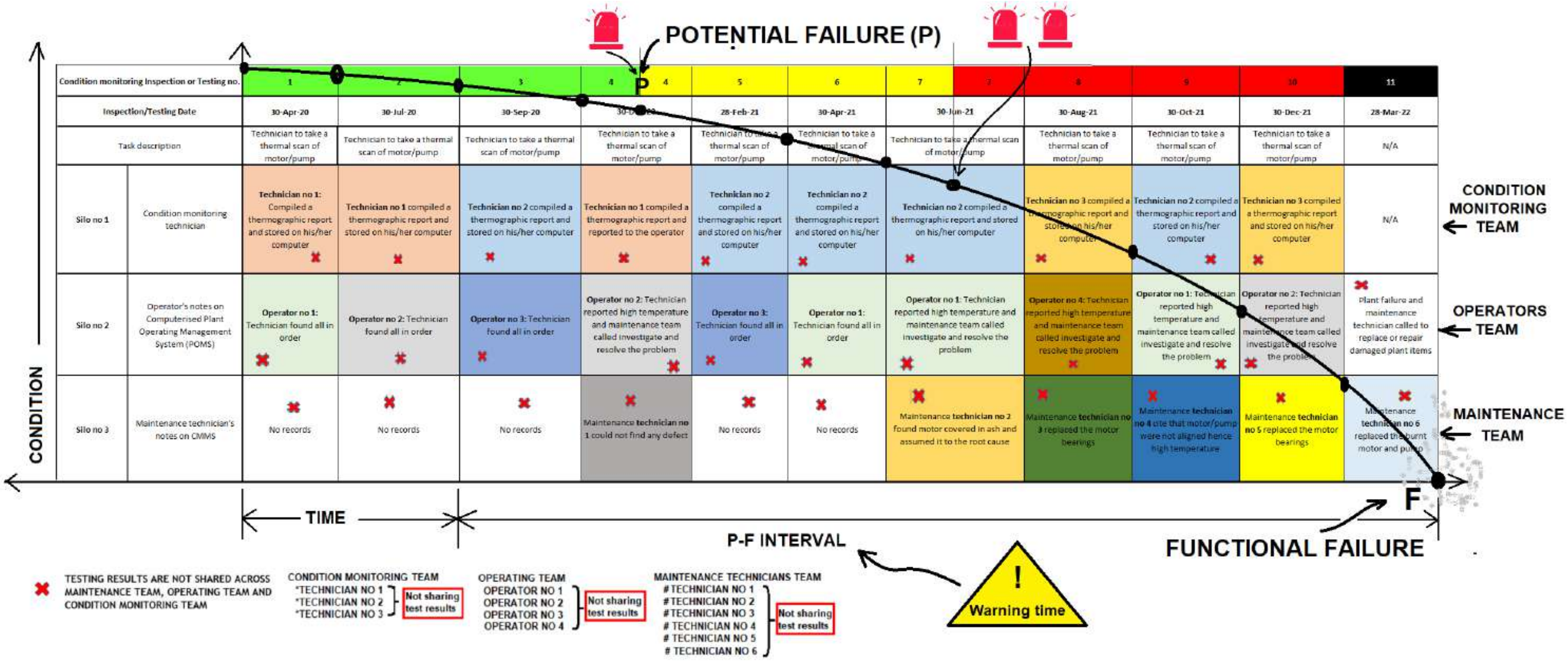
Offline or hand-held measuring instruments that are in the silos have been identified.

Offline measuring instruments data has been identified as a back-up to the online measuring instruments that have low accuracy when conducting data integrity investigations.

CMMS and POMS software developers need to develop a tool that will combine the POMS, CMMS and hand-held measuring instruments results into one platform so that MTBF can be increased and ultimately increase dust and ash plant uptime. This will assist the plant decision makers to have a richer view and assist in reducing plant recovery times.

The hypothetical condition-time graph/communication (condition monitoring, maintenance and operating teams) framework (Table 10) below has been developed, and factors affecting production and plant recovery times have been identified for the future case study. The outcome of the case study shall be applied to the dust and ash plant maintenance system dynamics model with the objective of enhancing plant uptime.

Table 10: Imperfect communication system of condition monitoring data, plant maintenance data and operating data (*Hypothetical*). This is based on superimposition of figure 3 and table 8 in order to illustrate the negative effect of poor communication



Condition monitoring Inspection or Testing no.		1	2	3	4 P 4	5	6	7 7	8	9	10	11
Inspection/Testing Date		30-Apr-20	30-Jul-20	30-Sep-20	30-Dec-20	28-Feb-21	30-Apr-21	30-Jun-21	30-Aug-21	30-Oct-21	30-Dec-21	28-Mar-22
Task description		Technician to take a thermal scan of motor/pump	Technician to take a thermal scan of motor/pump	Technician to take a thermal scan of motor/pump	Technician to take a thermal scan of motor/pump	Technician to take a thermal scan of motor/pump	Technician to take a thermal scan of motor/pump	Technician to take a thermal scan of motor/pump	Technician to take a thermal scan of motor/pump	Technician to take a thermal scan of motor/pump	Technician to take a thermal scan of motor/pump	N/A
Silo no 1	Condition monitoring technician	**Technician no 1:** Compiled a thermographic report and stored on his/her computer ✖	**Technician no 1** compiled a thermographic report and stored on his/her computer ✖	**Technician no 2** compiled a thermographic report and stored on his/her computer ✖	**Technician no 1** compiled a thermographic report and reported to the operator ✖	**Technician no 2** compiled a thermographic report and stored on his/her computer ✖	**Technician no 2** compiled a thermographic report and stored on his/her computer ✖	**Technician no 2** compiled a thermographic report and stored on his/her computer ✖	**Technician no 3** compiled a thermographic report and stored on his/her computer ✖	**Technician no 2** compiled a thermographic report and stored on his/her computer ✖	**Technician no 3** compiled a thermographic report and stored on his/her computer ✖	N/A
Silo no 2	Operator's notes on Computerised Plant Operating Management System (POMS)	**Operator no 1:** Technician found all in order ✖	**Operator no 2:** Technician found all in order ✖	**Operator no 3:** Technician found all in order ✖	**Operator no 2:** Technician reported high temperature and maintenance team called investigate and resolve the problem ✖	**Operator no 3:** Technician found all in order ✖	**Operator no 1:** Technician found all in order ✖	**Operator no 1:** Technician reported high temperature and maintenance team called investigate and resolve the problem ✖	**Operator no 4:** Technician reported high temperature and maintenance team called investigate and resolve the problem ✖	**Operator no 1:** Technician reported high temperature and maintenance team called investigate and resolve the problem ✖	**Operator no 2:** Technician reported high temperature and maintenance team called investigate and resolve the problem ✖	✖ Plant failure and maintenance technician called to replace or repair damaged plant items
Silo no 3	Maintenance technician's notes on CMMS	✖ No records	✖ No records	✖ No records	✖ Maintenance **technician no 1** could not find any defect	✖ No records	✖ No records	✖ Maintenance **technician no 2** found motor covered in ash and assumed it to the root cause	✖ Maintenance **technician no 3** replaced the motor bearings	✖ Maintenance **technician no 4** cite that motor/pump were not aligned hence high temperature	✖ Maintenance **technician no 5** replaced the motor bearings	✖ Maintenance **technician no 6** replaced the burnt motor and pump

7 FUTURE RESEARCH

In the future, a case study research instrument shall be developed, and tests shall be conducted based on this hypothetical model using observation, interviews and focus group instruments in order to quantify the effects of poor communication in the dust and ash plant. The research output of the case study shall be used to validate the plant recovery delays (Figure 5) and relationships between delays and plant downtime in the dust and ash maintenance plant system dynamics model so that their true effect(s) can be established and ultimately make use of the results to enhance dust and ash plant uptime.

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COMPARING CLASSICAL AND HEURISTIC OPTIMISATION TECHNIQUES THROUGH A DEEP-LEVEL MINING APPLICATION

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ABSTRACT

Deep-level mine dewatering systems are large contributors to industrial energy consumption. The associated electricity costs can be reduced by utilising time-of-use electricity tariffs. Classical methods use static dam levels for cost optimisation, which often results in costly and inefficient pump operation. A need was identified for more dynamic methods to be assessed for use. Heuristic optimisation techniques are compared to classical optimisation techniques in this study with the purpose of varying these set-points dynamically by using the present water demand and volume of water in circulation as inputs. The techniques compared in this study include genetic algorithm, particle swarm optimisation, linear programming, and quadratic programming. The result is an achieved cost saving of more than R945 000 per annum by using the classic methods, which were found to result in a more viable solution than heuristic techniques.

Keywords: energy management, deep-level mining, heuristic techniques, dynamic load shift, comparison, optimisation techniques

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1 INTRODUCTION

Deep-level mines are facing narrowing profit margins as operating costs continue to increase [1]. Energy consumption is the second largest cost in a typical deep-level mine, of which electricity is the largest contributor [2]. Further, the electricity costs for the South African deep-level mines have been increasing faster than commodity prices [3], [4]. Table 1 summarises the 10-year price increases for gold and platinum (the two main commodities extracted from South African deep-level mining) compared to electricity cost increases and inflation over the same period.

Table 1: 10-year (2012-2021) percentage price increase for commodities and electricity versus inflation

Commodity and electricity	10-year increase
Gold	119%[†]
Platinum	35%[‡]
Electricity	186%[§]
Inflation	63%[**]

Table 1 indicates that the platinum price increased by significantly less than inflation did the past 10 years, while electricity costs increased by almost three times the inflationary increase. This places the platinum mining industry under pressure to reduce its electricity usage to maintain profitability amidst these changes.

Furthermore, deep-level mine development extends further from the initial central infrastructure as the mine's life progresses. This results in inefficiencies in the large energy-consuming systems. Figure 1 summarises the largest energy consumers and their respective contribution to a typical mine's energy consumption [5], [6]. Pumping alone accounts for 16% of a typical mine's energy consumption [5].

The pumping system, commonly referred to as the dewatering system, is needed to extract water from the underground environment [7]. The water accumulates in dams from mining operations and underground water sources [8].

[†] "Gold Price in South African Rand - South Africa," GoldBroker, Accessed on 8 May 2022, https://goldbroker.com/charts/gold-price/zar

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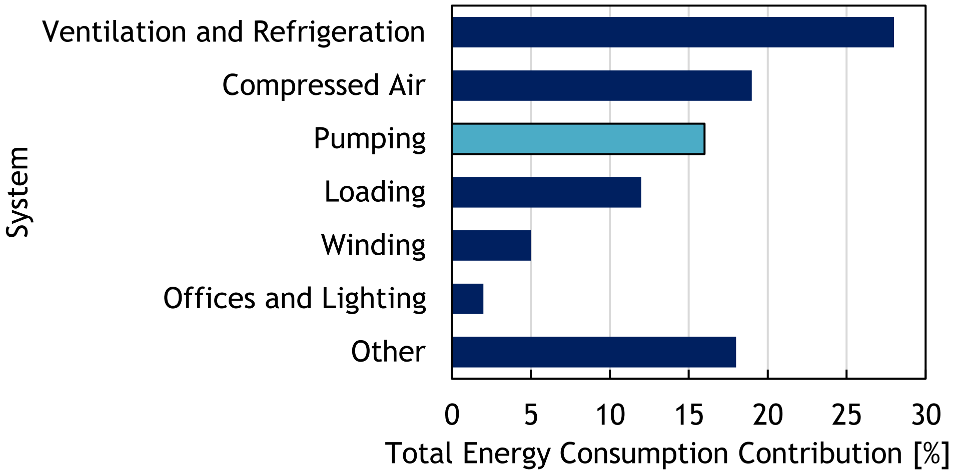

Figure 1: Energy system contribution towards a typical mine's energy consumption [5], [6]

The current methods applied to reduce the operating cost of the dewatering system include:

- Energy recovery [9]–[11]:
    - Utilising the height displacement of flowing water between surface and underground to generate energy.
- Demand reduction [12]:
    - Reducing the water required for mining activities and, consequently, reducing the amount of water that needs to be pumped from underground to surface.
- Load shifting [13]–[15]:
    - Utilising dam capacities to pump water to surface outside of the Eskom peak electricity tariff periods.

The present control philosophy for load shifting on the dewatering system entails scheduled pumping to ensure dam levels are maintained within a specific range for various times of the day [7], [15]. However, this control philosophy does not adequately utilise dam capacities to account for fluctuations in mining water consumption, largely due to changes in mining activity. Predictive control techniques and continuous optimisation is required in the control philosophy to utilise dam capacity and reduce electricity consumption [16].

From previous research, predictive control techniques have been used to optimise system design, ensuring the maximum benefit of load shifts [13]. However, this did not account for changes in water inflows. Further, optimal operation for load shifts has been determined through various solvers [14], [17] but various optimisation techniques were not compared to determine the most suited technique to be applied to the control system.

From literature it was also found that the load shift of the dewatering system has been modelled as a minimisation problem [14]. Various optimisation techniques can then be used to solve for the minimum of the problem, resulting in the largest possible load shift benefit [18], [19]. However, optimisation techniques can be categorised into two groups: classical optimisation techniques, and heuristic optimisation techniques. The use of heuristic optimisation techniques has not been evaluated or compared for mining applications.

Classical optimisation techniques include numerical methods to solve for a minimum within a defined problem [20], [21]. An example of a problem defined by a cost function and constraints is depicted in Figure 2. The constraints define the constrained area (shaded in Figure 2) and the minimum is determined with the constrained area (indicated with a marker in Figure 2).

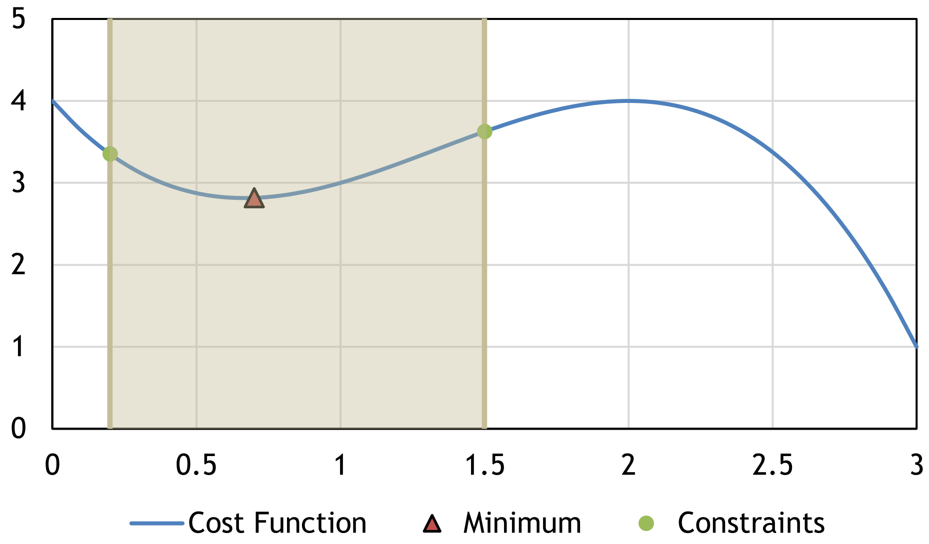

Figure 2: Visual example of a defined problem and minimum within constraints

The most common classical optimisation techniques include non-linear programming and linear programming [22]. These algorithms can consistently determine the function minimum of constrained problems but have difficulty solving discrete and large-scale integrated problems [23]. However, linear programming is more robust and should be selected before non-linear programming should the application be linearly defined.

Heuristic optimisation techniques utilise a form of intelligence to converge on a minimum [24], [25]. The majority of these algorithms mimic a population to explore a constrained area and determine the minimum for the defined problem [26]. The most commonly used algorithms are Genetic Algorithms and Particle Swarm Optimisation [27]. These algorithms can solve larger integrated problems, but are found to be unreliable in determining the function minimum [23].

Both classical optimisation techniques and heuristic optimisation techniques have been used to solve load shifting problems [28]–[30], but have not been compared for ideal control implementation for a mine dewatering system.

This study compares the two most common techniques within each category (i.e., classical optimisation techniques and heuristic optimisation techniques) and evaluates the techniques according to the solution minimum obtained as well as solution time. The novel contribution is the analysis and comparison of various optimisation techniques for a deep-level mine's dewatering load shift control system to establish what the most appropriate solution would be.

The algorithms are linear programming, non-linear programming, Genetic Algorithm, and Particle Swarm Optimisation. The optimal parameters for each optimisation technique are determined and used in the evaluation and comparison. Further, a simulation model is used to verify the solution results and the adherence to the determined constraints.

2 OPTIMISATION MODEL DEVELOPMENT

Various optimisation models will be used to solve for the ideal economic dispatch of a sequential dewatering system of a specific mine. Two classical optimisation techniques as well as two heuristic techniques will form the optimisation algorithms (identified and discussed in Section 1), namely:

- Classical optimisation techniques:
    - Linear programming
    - Non-linear programming
- Heuristic optimisation techniques:
    - Genetic Algorithm (GA)
    - Particle Swarm Optimisation (PSO)

The solutions of the various optimisation algorithms are verified through simulation to ensure that the solution is within practical and defined limits. The various solutions are then compared. The two parameters identified in Section 1 are used as a basis for comparison between the various optimisation algorithms: solution time and obtaining the problem minimum. The process flow is depicted in Figure 3.

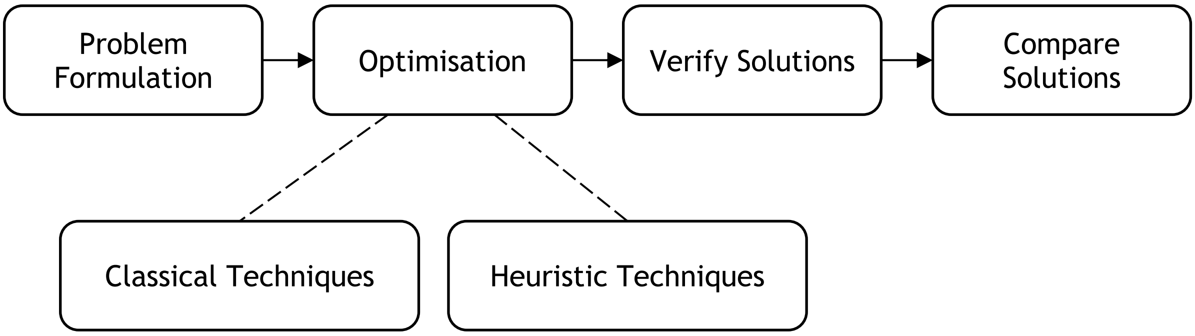

Figure 3: Optimisation and comparison process

The solutions will be compared by using a case study mine as the basis for the application. The dewatering system of the mine used as a case study consists of two dams, each with two pumps, with a basic illustration of the layout presented in Figure 4. The water flows from the mining operation into the lowest dam, Dam_1. The water is then pumped to an intermediate dam, Dam_2, before it is pumped to surface. One of the pumps at each dam is for redundancy and thus the optimisation problem should optimise to operate a maximum of one pump at each dam.

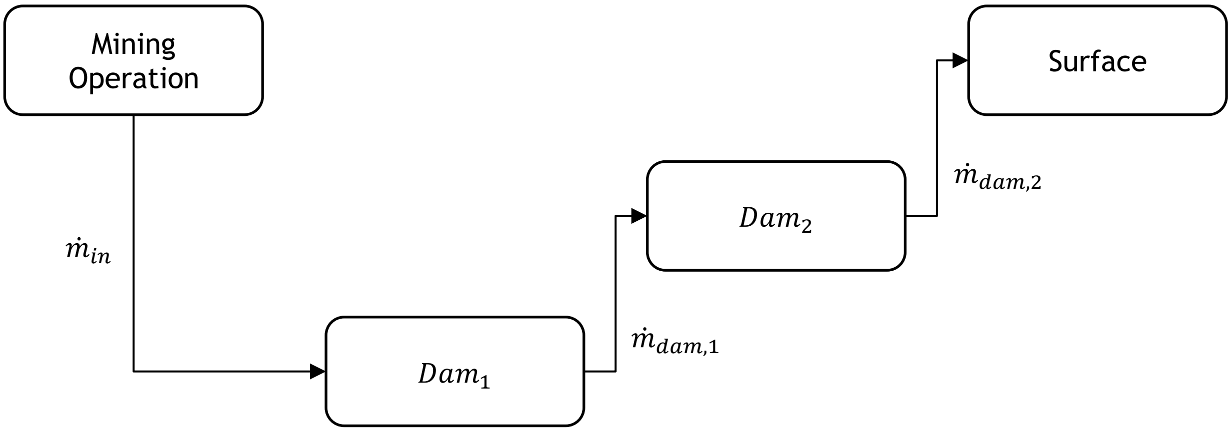

Figure 4: Simplified dewatering layout of the case study mine

2.1 Problem Formulation

The various optimisation algorithms are required to solve for the optimal flow rates of the two pumping stations ($\dot{m}_{dam,1}$ and $\dot{m}_{dam,2}$) as well as the optimal initial mass of water in the dams ($\dot{m}_{dam,1,init}$ and $\dot{m}_{dam,2,init}$). The present control philosophy operates in intervals of 15-minutes. This is done to reduce machine cycling and thus increase maintenance intervals on the machinery. As a result, the optimal solution for the flow rates will be a 96-point profile, indicating the flow rate at each 15-minute interval of the day.

The mine is subject to a variable electricity cost structure. Thus, to obtain the electricity cost for the dewatering system, an energy profile is determined from the flow profile and respective pump head. The energy profile is then converted to an electricity cost using the variable cost profile. The electricity cost is used as the fitness function for the various optimisation techniques, solving for the minimum. The electricity cost function is depicted in Equation 1.

$$Cost = \sum_{n=1}^{k} \sum_{i=1}^{j} \frac{\rho \cdot \dot{m}_{dam,n}(i) \cdot g \cdot h_{dam,n} \cdot tariff(i)}{4 \cdot \eta_{pump,n}} \tag{1}$$

For Equation 1:

$Cost$ - Electricity cost in R.
n - Arbitrary counter variable.
k - Number of pump stations.
i - Arbitrary counter variable.
j - Number of time periods.
ρ - Density of water in kg/m^3.
$\dot{m}_{dam,n}(i)$ - Mass flow rate of pump station n at time period i in L/s.
g - Gravitational acceleration in m/s^2.
$h_{dam,n}$ - Differential pump head of pump station n in m.
$tariff(i)$ - Cost of electricity at time period i in R/Wh.
$\eta_{pump,n}$ - Efficiency of pumps at pump station n.

The independent variable is the mass flow rates and the present operating flow rates are used as initial values in the various optimisation models. The mass flow rates for the various pump stations are restricted by the maximum pumping capacity for the installed pumps. Further, the pumps are not designed to handle reverse flow and as such the mass flow needs to be a positive number. These restrictions are described in Equations 2 and 3.

$$0 \le \dot{m}_{dam,1}(i) \le \dot{m}_{dam,1,max} \tag{2}$$

$$0 \le \dot{m}_{dam,2}(i) \le \dot{m}_{dam,2,max} \tag{3}$$

For Equations 2 and 3:

$\dot{m}_{dam,\mathrm{X}}(i)$ - Mass flow rate of pump station X at time period i in L/s.
$\dot{m}_{dam,\mathrm{X,max}}$ - Maximum flow rate of installed pump at pump station X in L/s.

The minimum and maximum dam levels are not 0% and 100%, as would be expected. This is due to possible mud in the dams and to allow for capacity to ensure storage to prevent dam overflow in emergency situations. The dam level is calculated as the sum of flow into the dam and the initial dam volume, subtracting the outgoing flow. As a result, these limits are dam dependent and the constraints determining the dam levels are detailed in Equations 4 and 5.

$$m_{dam,1,min} \le m_{dam,1,init} + 90 \times \sum_{i=1}^{j} \dot{m}_{in}(i) - 90 \times \sum_{i=1}^{j} \dot{m}_{dam,1}(i) \le m_{dam,1,max} \tag{4}$$

$$m_{dam,2,min} \leq m_{dam,2,init} + 90 \times \sum_{i=1}^{j} \dot{m}_{dam,1}(i) - 90 \times \sum_{i=1}^{j} \dot{m}_{dam,2}(i) \leq m_{dam,2,max} \tag{5}$$

For Equations 4 and 5:

$m_{dam,X,max}$ - Maximum volume of water allowable in dam X at time period i in L.
$m_{dam,X,min}$ - Minimum volume of water allowable in dam X at time period i in L.
$m_{dam,X,init}$ - Initial volume of water in dam X at time period i in L.
$\dot{m}_{in}(i)$ - Mass flow rate of mining operation water at time period i in L/s.

Lastly, to ensure day-to-day continuity, the dam levels at the end of each day need to be consistent with the dam levels at the beginning of each day. Thus, the total volume of water that enters the dam each day needs to be consistent with the volume of water that is pumped out from the dam. This is described by Equations 6 and 7.

$$\sum_{i=1}^{n} \dot{m}_{dam,1}(i) = \sum_{i=1}^{n} \dot{m}_{in}(i) \tag{6}$$

$$\sum_{i=1}^{n} \dot{m}_{dam,1}(i) = \sum_{i=1}^{n} \dot{m}_{dam,2}(i) \tag{7}$$

2.2 Optimisation

The defined problem was formulated to be utilised in constrained solver variations of the various algorithms (Linear programming, Fmincon, GA, PSO). The solution to the optimisation problem would be two initial dam levels, two 96-point pumping profiles, and a cost per day for the obtained solution. Further, the time taken to solve for the solution would be measured using MATLAB's built-in timer and using the same computer to run the solutions for comparison purposes. All the optimisation algorithms were implemented in MATLAB [31] using the "Optimisation Toolbox" to ensure that the solution times can be compared accurately. The various algorithms were configured as discussed below.

2.2.1 Linear Programming

Linear programming is a classical optimisation technique within mathematical optimisation. Linear programming solves for the minimum of a formulated problem with linear constraints. Due to the simplicity of the formulated problems, linear programming is robust in determining the minimum.

Linear programming was implemented in MATLAB using the 'linprog' function. Both the 'interior-point' and 'simplex' algorithms were tested. For the defined problem, both algorithms provided the same solution, but the 'interior-point' algorithm had a lower solution time. Thus, for the 'interior-point' algorithm was selected for comparison purposes.

2.2.2 Non-linear Programming

Similarly, non-linear programming is a classical optimisation technique within mathematical optimisation. However, non-linear programming is used to solve for a minimum of a formulated problem with linear or non-linear constraints. Due to the increase complexity, increased solution times is expected for non-linear programming compared to linear programming.

Non-linear programming was implemented in MATLAB using the 'fmincon' function. 'Fmincon' is a constrained nonlinear multivariable solver found in MATLAB's Optimisation Toolbox [31]. Similarly, to 'linprog', various algorithms were tested. The various algorithms are suited to the type of problem and have different solution times. For the formulated problem, the algorithms tested include ‘interior-point’, ‘sqp’, and ‘active-set’. The ‘sqp’ algorithm (Sequential Quadratic Programming) found the solution minimum in the lowest solution time and was used for further comparisons.

2.2.3 Genetic Algorithm

A GA is an optimisation technique that mimics the evolution of a generation to solve a problem. An initial population is evaluated and a new generation is developed from a combination of the best of the initial population, crossover and mutation. The GA thus provides multiple solutions to a defined problem and a final solution is obtained when the population converges to the same solution.

The GA was implemented using the ‘ga’ function in MATLAB’s Optimisation Toolbox. Numerous settings were tested for the GA to determine the best combination of settings. The settings were selected based on the solution energy cost and solution time. The solution energy cost was used as the primary selection criterion. Table 2 depict the various options tested for the various algorithm parameters (the finally selected options are underlined in Table 2). Further dependency information is included in brackets. Convergence was consistently obtained using the parameters listed in Table 2.

Table 2: Genetic Algorithm parameters

Parameter	Options
Creation function	Random distribution that satisfies all constraints (largely dependent) Random uniform distribution
Crossover function	Intermediate (negligibly dependent) Laplace
Mutation function	Random direction adaption based on previous successful generations (largely dependent) Power mutation

2.2.4 Particle Swarm Optimisation

PSO is an optimisation technique that mimics a swarm of particles to search a constraint area. The velocity of the particles is determined through a combination of the global best solution as well as the particle best solution. A final solution is obtained when all the particles converge to the same point within the defined constraint area.

The PSO was implemented in MATLAB using the “Constrained Particle Swarm Optimisation” library [32]. Varying the adaptive inertia weight, self-adjusting weight, and social adjusting weight had no effect on the solution electricity cost and negligible effect on the solution time. Thus, the default values for the various weights were used, as depicted in Table 3.

Table 3: Particle Swarm Optimisation weights

Parameter	Value
Adaptive inertia weight range	[0.1, 1.1]
Self-adjusting weight	1.49
Social adjusting weight	1.49

2.3 Verification

A transient thermohydraulic software ("Process Toolbox" [33]-[35]) was used to build and calibrate a simulation model of the system, depicted in Figure 4. The simulation was developed from the design specifications and layouts. The developed simulation was compared to operating data and an average absolute error of less than 5% was obtained. As a result, the developed simulation can be used as a characteristic model to verify the optimisation solution flow profiles and dam levels.

The simulation model is used to identify whether the solution is within the defined constraints, such as the minimum and maximum dam levels, the consistent initial and final dam levels, and practical pump flow rates. Should one of the conditions not be met, either there was a problem in the optimisation and problem setup, or the algorithm was not able to obtain a minimum within of the defined constraints.

3 RESULTS AND DISCUSSION

The various optimisation algorithms solved the problem for a minimum electricity cost, providing a solution for the initial dam levels and pump station flow profiles. The initial dam levels and pump station flow profiles are used as inputs in the developed simulation model and the dam level profiles and electricity costs are the outputs. An example of the optimised pump station flow profiles is depicted in Figure 5.

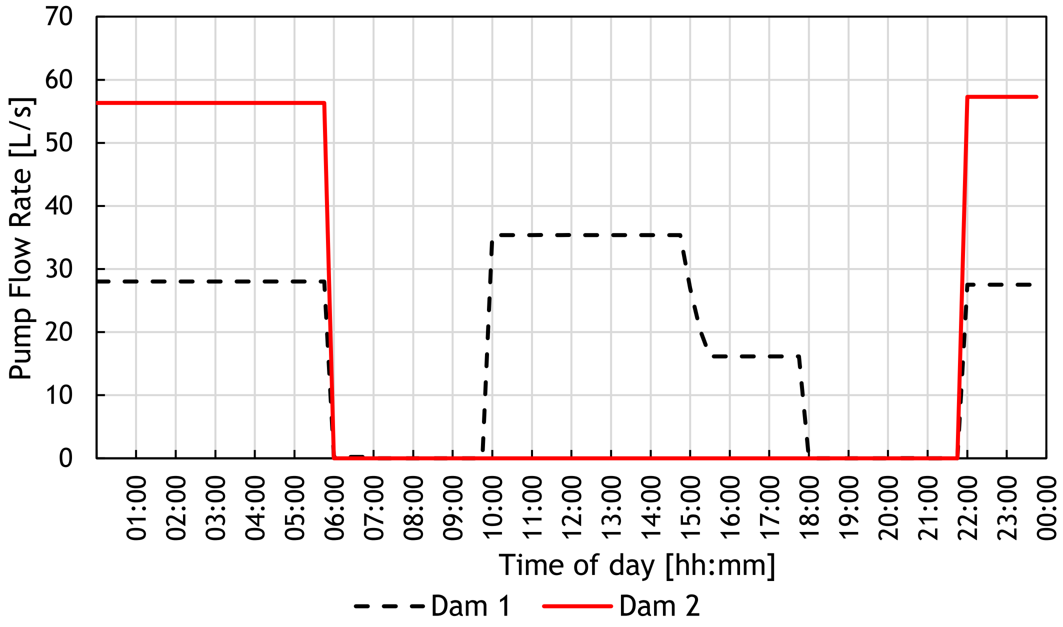

Figure 5: Example of optimisation solution pump station flow profiles

The optimisation algorithms aim to shift the pumping energy from the peak tariff periods (from 07:00 to 10:00 and 18:00 to 20:00) to the off-peak tariff periods (from 22:00 to 06:00). However, the maximum allowable dam levels prevent all the pumping energy to be moved and some energy must be used in the standard tariff periods (from 06:00 to 07:00, 10:00 to 18:00, and 20:00 to 22:00).

The electricity cost of the optimisation algorithm is compared to the simulated electricity cost as a verification of the electricity cost function. The simulation model further verifies the adherence to the allowable minimum and maximum dam levels. The levels are dependent on the pump station flows as well as the optimised initial dam level. An example of the simulated dam level profiles is depicted in Figure 6.

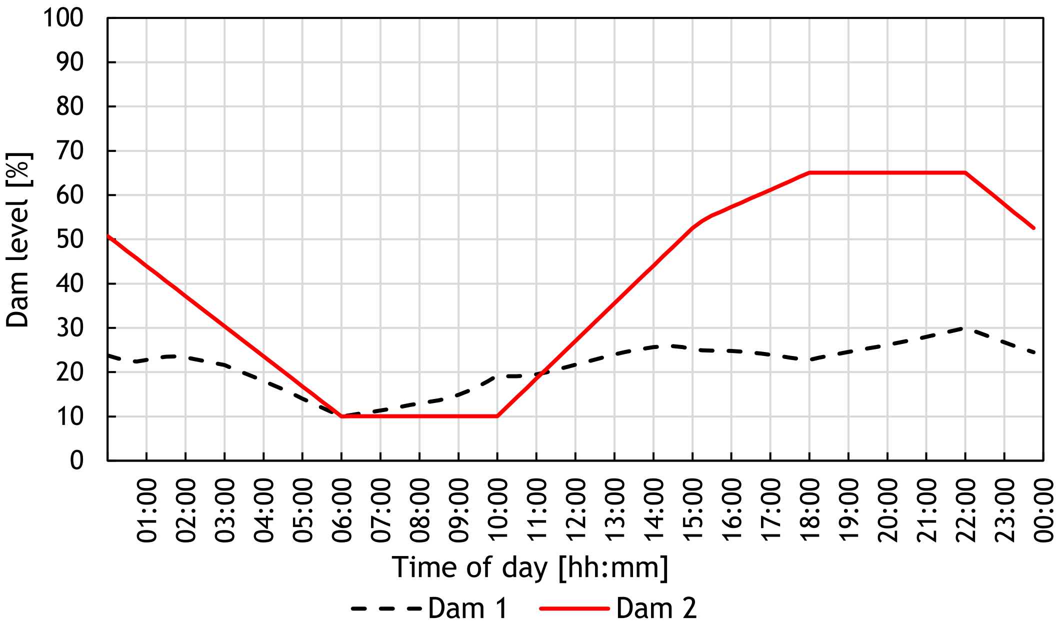

Figure 6: Example of optimisation solution dam level profiles

The various optimisation algorithms provide the initial dam volumes as well as the electricity cost per day. The daily electricity cost is converted to a cost per year and compared to a baseline to obtain an electricity cost saving per year. Further, the time taken to solve for the various algorithms is noted. Table 4 depicts these parameters for the various algorithms.

Table 4: Detailed optimisation results

Optimisation algorithm	Initial volume [ML]	Saving [R/year]	Solution time [s]
Linprog	1.58	R946 161.84	0.19
Fmincon	1.61	R946 161.84	0.38
Genetic Algorithm	0.59	R659 373.58	56.49
Particle Swarm Optimisation	1.27	R508 404.46	0.13

As seen in Table 4, the Fmincon and Linprog algorithms found the same minimum to the defined solution. Linear programming should be selected before non-linear programming should the problem be linearly defined. The two heuristic algorithms were not able to find the minimum of the defined problem but still converged to a solution that resulted in an electricity cost saving.

The PSO algorithm converged to a solution in the shortest time but has similar solution times to the Fmincon and Linprog algorithms. The GA had a solution time of order magnitude larger than the other algorithms (including the other heuristic algorithm). The primary comparison parameters for the various algorithms are solution time and annual benefit. Figure 7 provides a visual comparison of the results.

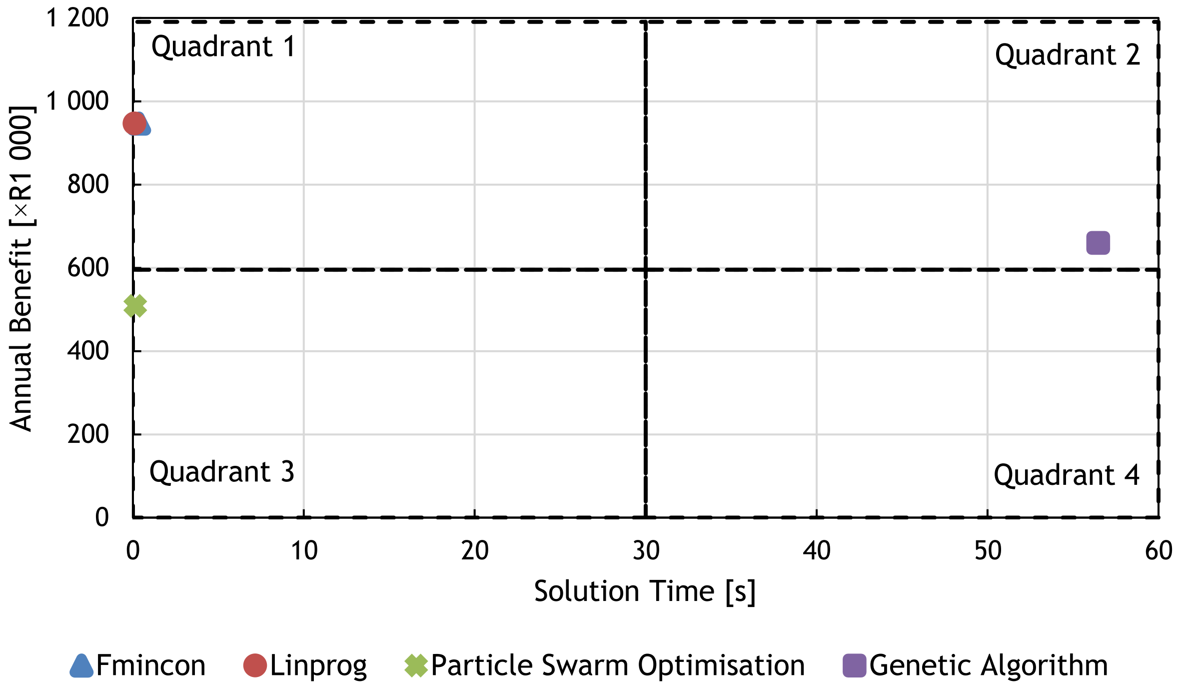

Figure 7: Comparison of various optimisation results

Figure 7 separates the result area (defined by annual benefit and solution time) into four quadrants:

- **Quadrant 1:** The most ideal algorithms will be placed in this quadrant and exhibit shorter solution times with higher annual benefits.
- **Quadrant 2:** This quadrant is the second-best quadrant exhibiting the same benefit as quadrant 1 with longer solution times. The solution times in this quadrant are still adequate for mine dewatering systems as the resolution of periods (15 minutes) is of order magnitude larger than the solution time.
- **Quadrant 3:** An optimisation algorithm in this quadrant is less desirable than quadrant 2 due to the lower annual benefit. However, the solution time is faster and might be required in situations with higher resolution of time periods.
- **Quadrant 4:** An optimisation algorithm in this quadrant is the least desirable due to the slower solution times and lower annual benefits.

Following the characterisation, the least desirable optimisation algorithm is PSO and the most ideal is Linprog and Fmincon. The difference in solution time between Linprog and Fmincon is negligible compared to the resolution of control time periods (15 minutes) for the mine dewatering system. The implementation of either of the most ideal algorithms will result in an annual benefit of R946 161.84.

Based on these results for the case study mine, it is seen that heuristic optimisation techniques are not expected to increase cost saving of mine dewatering load shift projects, and are therefore not recommended for use over classical optimisation techniques. However, these results could vary for more complex pumping systems or for pumping systems with integer or non-linear constraints.

4 CONCLUSION

To prevent narrowing profit margins, optimisation of large energy systems in deep-level mines is required. Load shifts are often used to reduce the operating costs of mine dewatering systems but have not been evaluated with the emergence of heuristic optimisation techniques.

This study modelled a deep-level mine's dewatering system to determine what effect the use of heuristic would have on the optimal load shift. The developed model formed the basis of comparison between two classical- and two heuristic optimisation techniques.

The linear programming and sequential quadratic programming (classical) algorithms solved the defined problem in similar times with the same annual benefit (due to load shift). The Particle Swarm Optimisation (heuristic) had a faster solution time compared to the classical techniques, but resulted in an annual benefit just over half that of the classical techniques. The Genetic Algorithm (heuristic) has a solution time of order magnitude larger than the other techniques.

The solutions of the various optimisation algorithms were verified through simulation. The implementation of either classical optimisation technique is expected to result in an annual benefit of more than R945 000. All optimisation techniques (including the Genetic Algorithm) were applicable to be implemented in the control system as the solution time (maximum 56 s) was shorter than the control resolution (15 minutes).

Further improvement on the accuracy of the system modelling can be achieved. This will however result in a more complex, non-linear system. It is recommended that various techniques be compared for these models and evaluate the effect on the optimisation techniques by the increased accuracy. Another recommendation is to compare optimisation techniques for large integrated systems, such as between dewatering and refrigeration, as opposed to a single system. This will improve dynamic control of a mine's systems and further reduce inefficiencies.

5 ACKNOWLEDGMENTS

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INVESTIGATING THE PERFORMANCE OF DIFFERENT MACHINE LEARNING ALGORITHMS FOR OPTIMAL DECISION-MAKING

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ABSTRACT

Machine learning algorithms are identified as the key to unlocking the value in customer data and using this data to make optimal predictions and decisions. This paper contributes to the machine learning application domain by evaluating the performance of four machine learning algorithms to address a direct marketing campaign problem. The models include the Random Forest, the Decision tree, the Gaussian Naïve Bayes, and the K-neighbor. A literature study is conducted on data handling, cross-validation, hyperparameter tuning and machine learning algorithms. The four algorithms are trained to prevent overfitting or underfitting. After the models are trained, the performance of the four models is tested using five performance metrics. The random forest performed the best and was optimised using a grid search function in Python and recall as a scoring metric. The optimised model estimated a 5.66% higher recall value than the base model. Conclusions are provided, followed by future recommendations.

Keywords: Machine learning, random forest, decision tree, k-neighbor, naïve bayes, hyperparameter tuning, cross-validation, grid search.

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1 INTRODUCTION

Machine learning algorithms are identified as key to unlocking the value in customer data and using this data to make optimal predictions to stay ahead of competitors [1]. Therefore, machine learning algorithms are essential since it facilitates data-driven decisions. Thus, if companies do not apply machine learning to make optimal data-driven decisions or predictions, they could fall further behind due to uncertainty or rapid technology changes.

It is essential to note that not all machine learning models apply to all problems [2]. Some algorithms are best suited for specific problems, and the correct process must be followed to select the best algorithm. This paper contributes to the machine learning application domain by evaluating four machine learning algorithms and identifying the best performing model.

Machine learning is a subset of artificial intelligence (AI) which can be applied to analyse data and interpret patterns for optimal decision-making [1]. Subsequently, data is fed to a computer algorithm that analyses and makes data-driven suggestions and decisions based on the input data. There are four machine learning algorithms [3]: supervised, unsupervised, semi-supervised and reinforcement learning. In a supervised learning algorithm, the machine is trained using test data. A known data set is used with all the required input and output variables. The operator trains the model until a high accuracy or precision is achieved. A semi-supervised learning algorithm uses both labelled and unlabelled data sets. The machine learning algorithms learn to label unlabelled data.

An unsupervised learning algorithm recognises the patterns in a data set. For this reason, there is no human operator providing instructions and changing input parameter values. The machine identifies the patterns and relationships between various variables and addresses the problem accordingly. In a reinforcement learning algorithm, parameters, end values, and actions are provided as input. The machine learns the rules and explores various possibilities to make optimal predictions. This process is also known as trail-and-error enabling the machine to make predictions using historical data [3].

Machine learning algorithms are applied to various industries [1]. Prominent applications include the manufacturing industry [4], retail industry [5], healthcare [6], finance [7], the travel industry [8], and the energy sector [9, 10].

This study focuses on direct marketing campaigns of a banking institution using open-access data from Kaggle [11]. The campaign aims to target potential customers that would subscribe to a term deposit in the banking industry. Therefore, the problem or output variable would be: "Will the client subscribe to a term deposit (yes or no)." The following four machine learning models are investigated: The random forest, the decision tree, the Gaussian Naïve Bayes algorithm and the K-neighbor algorithm. To achieve the aim, the following objectives are formulated:

1. To conduct a literature study on data cleaning, machine learning models, overfitting and underfitting, cross-validation, hyperparameter tuning and model optimisation.
2. To train the four machine learning models using cross-validation and hyperparameter tuning.
3. To test the four machine learning models and to identify the best performing algorithm.
4. To optimise the best performing machine learning model using a grid search and k-fold cross-validation.

This study focuses only on selecting the best performing algorithm (part 1) and excludes the actual predictions (part 2). Section 2 provides a detailed overview of the theory related to machine learning and the various types of algorithms. In Section 3, the research method and the techniques applied in this study are defined and explained.

In Section 4, the study results are demonstrated. First, an overview is provided on the data handling, the training, and the testing of all four algorithms. Last, the best performing algorithm is identified and optimised accordingly. Conclusions and future recommendations are provided in Section 5.

2 LITERATURE STUDY

Machine learning is applied to solve different problems, including classification problems, regression problems, reinforcement learning problems, anomaly detection problems and clustering problems [2]. A classification problem is defined if the output is identified as part of a class, i.e., true/false or yes/no. The output classes can be binary or multi-class classification problems. A regression model addresses an issue that contains any numerical or continuous output, typically how many or how much. An anomaly detection model finds an unusual pattern in a data set. For example, credit card companies use this algorithm to detect suspicious behaviour and notify customers to prevent fraud. A reinforcement learning problem is concerned with what to do next by analysing historical data. A classification problem is explored in this study. A generic machine learning model consists of five components, as demonstrated in Figure 1 [2].

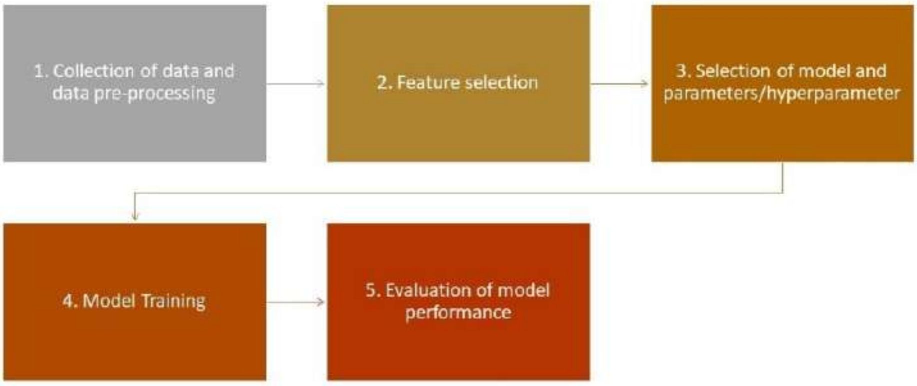


Figure 1: The six components of machine learning [2]

A machine learning model learns from the data; therefore, the data must be structured in a specific format before applying it to an algorithm. For this reason, data first needs to be cleaned and pre-processed. Brownlee [12] stated that errors, including missing data points, duplication, or mistyped data, can be eliminated by cleaning the data first. There are different methods used to prepare the data. These include removing unnecessary columns, identifying any null/missing values in the data set, encoding categorical data, scaling numerical data, and splitting the data in the correct format [12]. All these methods will be applied in Section 4. Feature / variable selection also forms part of the data cleaning process. Not all the data points present in the data are applicable to the problem. For this reason, some data points can be removed [2].

A suitable machine learning algorithm needs to be selected after cleaning the data. Before running the algorithm, specific hyperparameters need to be tuned or adjusted. An overview of the four algorithms with the hyperparameters are provided in Sections (2.1 – 2.4).

2.1 The Random Forest model

Leo Breiman and Adele Cutler first proposed the random forest model [13]. This method is defined as a supervised machine learning algorithm widely used for classification and regression. This method integrates the bootstrap aggregating and random subspace methods. A set of decision trees are formulated and contains decision tree classifiers. The categories are classified based on the mode of the decision tree result.

Two random selection processes are defined for a single decision tree. First, the training samples are selected randomly, followed by the random selection of the characteristic attributes of the sample. The final classification results are selected based on equal-weight voting [13]. Bagging is a method where random samples are selected from a data set, and each model is generated from the different samples, also known as row sampling [14]. The row sampling step with a replacement is known as bootstrap. Subsequently, the models are trained, and the majority vote generates the final output after combining all the results of the models. Aggregation is the step where the results are combined, and an output is generated based on the majority voting.

The following hyperparameters enhance the performance and predictive power of the model [14]:

1. **The number of estimator (n_estimators)** - This is the number of trees the model formulates before averaging the results.
2. **The maximum features (max_features)** - The maximum features the model considers before splitting the node.
3. **The minimum samples leaf (Mini_sample_leaf)** - is the minimum number of leaves the model requires before splitting an internal node.
4. **The number of jobs (n_jobs)** - This hyperparameter indicates how many processors the engine should use.
5. **The random state (Random_state)** - This hyperparameter controls the randomness in the sample.
6. **Out of the bag (OBB)(obb_score)** - A cross-validation method for the random forest model. In cross-validation, a specific sample of the data set is used to test the model's performance. These samples are referred to as out of the bag samples.

2.2 The Decision tree

This algorithm is regarded as a divide-and-conquer approach when dealing with a classification problem and is used to discover various features and patterns in large data sets [15]. The method was first introduced in 1960 and is considered one of the most effective methods in data mining. Decision trees are used for various purposes, including, and not limited to variable selection, handling of missing data, prediction, and data manipulation [16]. Like the random forest model, there are various hyperparameters to consider [16]:

1. **The maximum depth (Max_depth)** - This hyperparameter will prevent the tree from expanding until all the leaf nodes are pure.
2. **The minimum samples split (Min_samples_split)** - This is the minimum samples the tree requires to split the internal nodes.
3. **The minimum samples leaf (Min_sample_leaf)** - This is the minimum required sample at a specific leaf node.
4. **The maximum features (Max_features)** - These are considered the maximum features when looking for the optimal split.

The random forest and the decision tree are two different algorithms but are also considered similar since both models are in the form of a tree. A decision tree is prone to overfitting if there are no stopping criteria, whereas a random forest model averages the results resulting in very little overfitting. Overall, a decision tree will formulate some rules to make predictions. The random forest model randomly selects the observations, builds the tree, and averages the results [14]. Therefore, no set of formula is used.

2.3 The Gaussian Naïve Bayes

The Naïve Bayes method is based on Bayes' theorem and is known to be very efficient, fast, and accurate. This theorem assumes that all features in a data set are mutually exclusive and are applied to solve various classification problems.

Raschka [17] indicated that the Naïve Bayes consists of three different models: The multi-variate Bernoulli, the multinomial, and the Gaussian Naïve Bayes model. The multinomial Naïve Bayes is an event-based model, where features are represented as vectors, and each feature represents a frequency for each occurred event. The Bernoulli model is also considered an event-based model where features are mutually exclusive, and these values are represented in binary form [17]. The Gaussian Naïve Bayes assumes that the classes are normally distributed. This study will specifically focus on the Gaussian Naïve Bayes model. The Gaussian processes are applied in multiple industries and to solve different problems including classification, regression, and reinforcement learning. The Gaussian Naïve Bayes consists of different parameters: Priors and variance smoothing (var_smooting). Priors demonstrate the prior probabilities of the classes, and the variance smoothing shows the most significant variable of all features [18].

2.4 The K-neighbor algorithm

The K-neighbors (KNN) algorithm is defined as a supervised learning algorithm. This algorithm assumes that similar data points are near each other and is known for capturing the idea of proximity. The main advantage of this algorithm is that it is simple and versatile, which means that it can be applied to classification and regression problems [19]. However, one disadvantage of this algorithm is that the computational time increases as the number of examples or variables increases.

The KNN algorithm determines the distance between a query and finds a specific number (k) closest to that point. The algorithm then votes for the most frequent label. The KNN classifier consists of the following hyperparameters [19]:

1. **The number of neighbors (n_neighbors)** - This hyperparameter indicates the number of neighbors to use by default.
2. **The number of jobs (n_jobs)** - This integer number demonstrates the number of parallel jobs to run for the neighbors search.
3. **The leaf size (leaf_size)** - This hyperparameter affects the speed for the query and influence the memory required for the tree.
4. **P_value** - The p-value is defined as the power parameter.

Other hyperparameters not applicable to this study include weights, algorithm, and metric.

A machine-learning algorithm uses various optimisation methods to solve a problem [20]. An optimisation function consists of different hyperparameters, and these values are set before the training phase. The aim is to find the best hyperparameter values to obtain the best performance when the algorithm is applied to data. This process is referred to as hyperparameter tuning. Wu et al. [20] stated that in practice, it is essential to adjust and combine the hyperparameter values continuously when training the models. Hyperparameter tuning can be conducted using a manual search or an automatic search. For a manual search, different values are selected, and the relationship between various parameters is analysed using visualisation tools [21].

For this study, a manual search is conducted in the training phase (Section 4.2) and an automatic grid search is used when optimising the best performing model (Section 4.4). An automatic search algorithm known as the grid search is proposed to prevent the challenges experienced with a manual search [22]. A grid search is also known as exhaustive searching.

A grid search evaluates all possible values of hyperparameters to obtain the best performance when training the model.

The automatic search often suffers from the curse of dimensionality, which means that the model's efficiency decreases as the hyperparameter values increase. The random search algorithm has been introduced to address this challenge, which indicates that only some of the hyperparameters matter. The model's efficiency is increased by only considering a few hyperparameters. A random search is more efficient when applied to high-dimensional space [22].

After selecting the appropriate hyperparameter values, the machine learning models need to be trained [2]. The data used to train the model is normally only a portion of the entire data set. Cross-validation is a method used to determine the performance of a machine learning model on unseen data. Various cross-validation techniques exist, including ShuffleSplit, K-fold, GroupKFold, and LeavePOut [23]. For this study, the LeavePOut and the K-fold techniques are used. The LeavePOut cross-validation technique is conducted by training the model only on one portion of the data and testing the model on the portion that was left out. This technique provides a good indication of how the model will perform on unseen data.

The K-fold cross-validation technique estimates the performance of a machine learning model on unseen data [23]. This technique splits the data implemented with (K>1) folds. This technique is also known as a resampling technique without replacement and can be implemented using Python (Sklearn) package. In each iteration, hyperparameter tuning is done on only a portion of the data. For example, if K=5, the data is trained on a 4/5 fold, and the final fold is left for validation. This process is repeated five times until all the folds are used on the validation data [24].

Typically, the data is split into training, validation, and testing. To verify the models correctness, the hyperparameter tuning is conducted on only the training and validation data sets. Cross-validation is also applied to avoid overfitting [23]. Overfitting occurs when the model learns the data too well, resulting in poor performance on unseen data [12]. For this reason, the model is unable to produce sensible results.

On the contrary, underfitting is when the model is not complex enough and typically has a high bias towards one output variable. For this reason, methods including cross-validation, data augmentation and regularisation are applied to prevent overfitting and underfitting [12]. After the hyperparameter tuning, the model is tested using the unseen data set. This forms part of validating the models. It is essential to note that no hyperparameters are tuned when testing the data. The performance of the models is evaluated using a confusion matrix [26].

Table 1: An example of the confusion matrix

	Actual Positive	Actual Negative
Predicted Positive	True Positive (TP)	False Positive (FP)
Predicted Negative	False Negative (FN)	True Negative (TN)

First, a confusion matrix is used to evaluate a model's performance. Based on the confusion matrix, the following performance parameters are measured [24]:

1. **Accuracy:** Classification accuracy indicates the perceived positive events among the total positive events.

$$Accuracy = \frac{TP+TN}{TP+TN+FP+FN} \qquad (1)$$

2. **Precision:** The precision ratio indicates which proportion of the predicted positive values were positive.

$$Precision = \frac{TP}{TP+FP} \qquad (2)$$

3. **Recall:** The recall value indicates how much the model correctly classified the ratio of actual positives.

$$Recall = \frac{TP}{TP+FN} \tag{3}$$

4. **F1-Score:** This score presents the mean among the recall value and the precision value.

$$F1 = \frac{2TP}{2TP+FP+FN} \tag{4}$$

5. **Cohen Kappa score:** This score measures how frequently two rates agree if they measure the same quantity. Subsequently, it measures the reliability of the two raters.

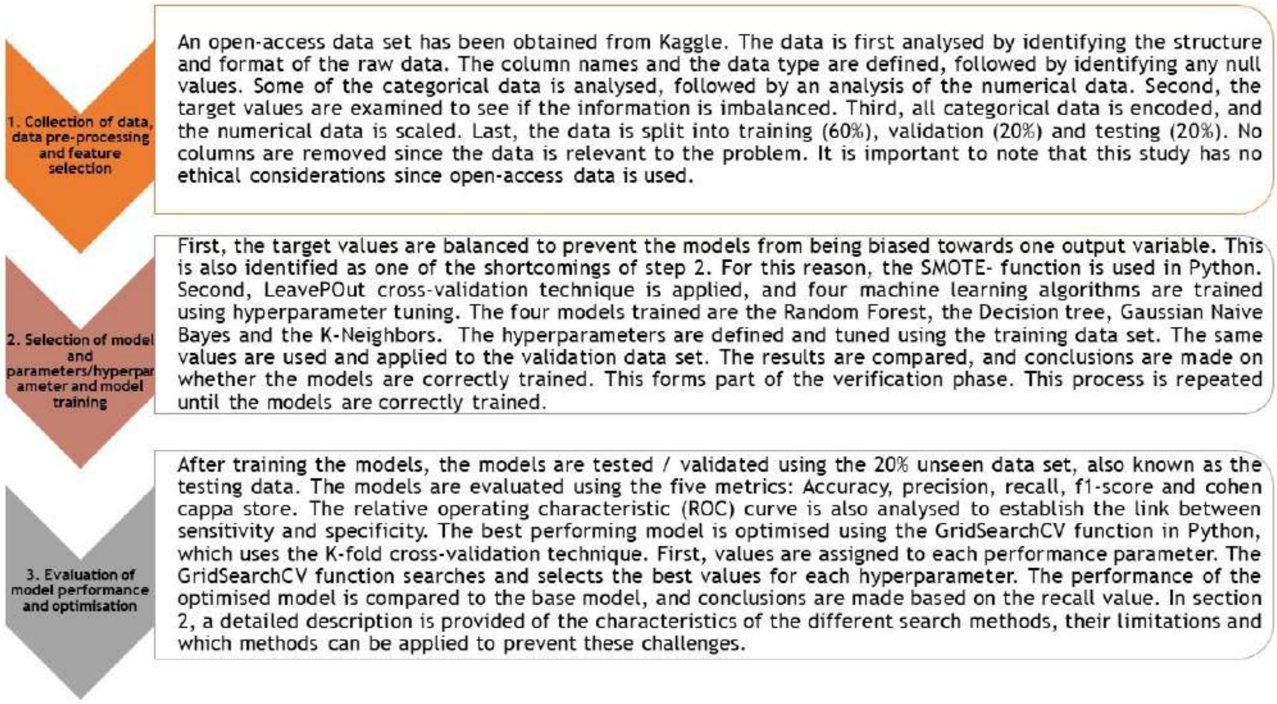
$$k = \frac{p_o-p_e}{1-p_e} \tag{5}$$

   - The variable (p_o) is defined as the probability of agreement on the label assign to a sample. The variable (p_e) is defined as the expected agreement when both raters assign labels randomly.

6. **The area under Curve (AUC):** This curve demonstrates how sufficient the model distinguishes the positive and negative probabilities from each other.

3 RESEARCH METHOD

This section provides an overview of the research method and software used in this study. The following methods and techniques are applied, as outlined by Alzubi et al. [2]:



An open-access data set has been obtained from Kaggle. The data is first analysed by identifying the structure and format of the raw data. The column names and the data type are defined, followed by identifying any null values. Some of the categorical data is analysed, followed by an analysis of the numerical data. Second, the target values are examined to see if the information is imbalanced. Third, all categorical data is encoded, and the numerical data is scaled. Last, the data is split into training (60%), validation (20%) and testing (20%). No columns are removed since the data is relevant to the problem. It is important to note that this study has no ethical considerations since open-access data is used.

First, the target values are balanced to prevent the models from being biased towards one output variable. This is also identified as one of the shortcomings of step 2. For this reason, the SMOTE- function is used in Python. Second, LeavePOut cross-validation technique is applied, and four machine learning algorithms are trained using hyperparameter tuning. The four models trained are the Random Forest, the Decision tree, Gaussian Naive Bayes and the K-Neighbors. The hyperparameters are defined and tuned using the training data set. The same values are used and applied to the validation data set. The results are compared, and conclusions are made on whether the models are correctly trained. This forms part of the verification phase. This process is repeated until the models are correctly trained.

After training the models, the models are tested / validated using the 20% unseen data set, also known as the testing data. The models are evaluated using the five metrics: Accuracy, precision, recall, f1-score and cohen cappa store. The relative operating characteristic (ROC) curve is also analysed to establish the link between sensitivity and specificity. The best performing model is optimised using the GridSearchCV function in Python, which uses the K-fold cross-validation technique. First, values are assigned to each performance parameter. The GridSearchCV function searches and selects the best values for each hyperparameter. The performance of the optimised model is compared to the base model, and conclusions are made based on the recall value. In section 2, a detailed description is provided of the characteristics of the different search methods, their limitations and which methods can be applied to prevent these challenges.

Figure 2: Research method and techniques applied in this study

Spyder, which is defined as an open-source scientific environment in python, is used for this study. Python (V3.10) was used to prepare the data and to train and test the machine learning models. An HP EliteBook 850 was used with the following specifications:

a) Processor: Intel(R) Core(TM) i7-8565U CPU @ 1.80GHz 1.99 GHz

b) Operating System Type: Windows 10 Pro, 64- bit operating system, x64-based processor.

c) Installed Memory (RAM) 8.00 GB

4 DISCUSSION OF RESULTS

In this section, the data is prepared, and the four machine learning algorithms are trained and tested and the best performing model is optimised.

4.1 Data Handling

As discussed in Section 2, the data must first be prepared. Before the data can be prepared, a detailed analysis must be conducted on the characteristics of the data. This analysis includes the name of the columns and the type of data available in each column. A summary of the data is provided in Table 2.

Table 2: A description of the data

Column name	Column description	Column's data type	Is the data presented in each column categorical or numerical?	Are there any missing values in each column? (False = no, True = yes)
Age	The age of the customer	Integer	Numerical	False
Job	The job type of the customers	Object	Categorical	False
Marital	The marital status of each customer: married, single or divorced.	Object	Categorical	False
Education	The educational level of the customers: Secondary, tertiary, primary or unknown.	Object	Categorical	False
Default	The default column demonstrates if the customer has credit in default.	Object	Categorical	False
Balance	The balance column indicates a customer's balance.	Integer	numerical	False
Housing	This column indicates if a customer has a housing loan.	Object	Categorical	False
Loan	This column indicates if a customer has a personal loan.	Object	Categorical	False
Contact	This column demonstrates the type of communication the customer received in the past.	Object	Categorical	False
Day	This column indicates the last contact day of the week.	Integer	Numerical	False
Month	This column indicates the last contact month of the year.	Object	Categorical	False
Duration	The duration column suggests the duration of the contact session (in seconds)	Integer	Numerical	False
Campaign	This column represented the number of contacts performed during the campaign.	Integer	Numerical	False
Pdays	This column demonstrates the number of days that passed after the client was last contacted.	Integer	Numerical	False
Previous	This column indicates the number of contacts performed before the launch of this campaign.	Integer	Numerical	False
Poutcome	This column indicates the outcome of the previous campaign	Object	Categorical	False
Target value (y)	These are the target values. This column represents if the customer would subscribe for a term deposit.	Object	Categorical	False

There are 17 columns in the data set. The most important column is column 17, which indicates whether a customer would subscribe for a loan deposit. It is important to note that machine learning models are sensitive to the data, and all columns and rows must contain an integer value or an object. Further analysis is conducted by evaluating some of the columns to understand the relationships between variables. To gain more perspective on some of the categorical data, the type of jobs, the marital status, and the educational level of the customers are analysed, as presented in Figure 3.

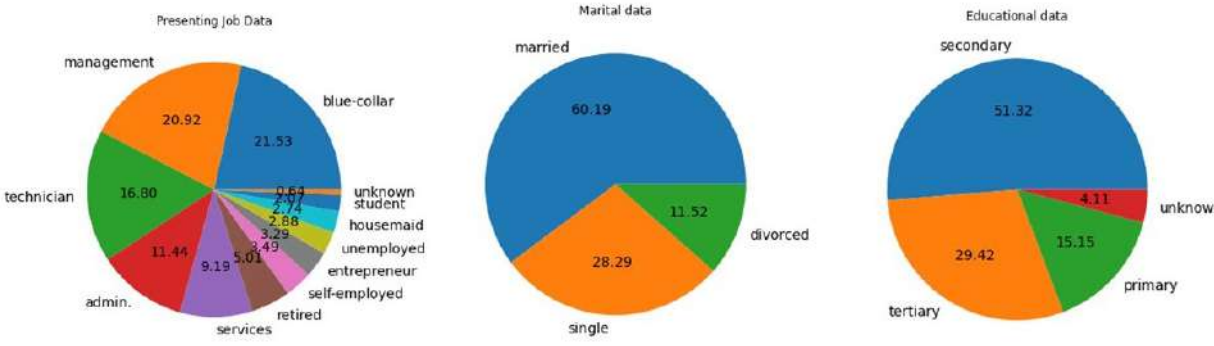


Figure 3: A demonstration of some of the categorical data

From Figure 3, it is evident that the customers are in different types of job industries. The top three job types are as follows: 21.53% are blue collars, 20.92% are in management positions and 16.80% are technicians. The second pie chart shows that 60.19% are married, 28.29% are single, and 11.52% are divorced. The third pie chart demonstrates that 51.32% have a secondary education, 29.42% have tertiary education, 15.15% have primary, and 4.11% are unknown. Figure 4 demonstrates three bar charts on some of the numerical data.

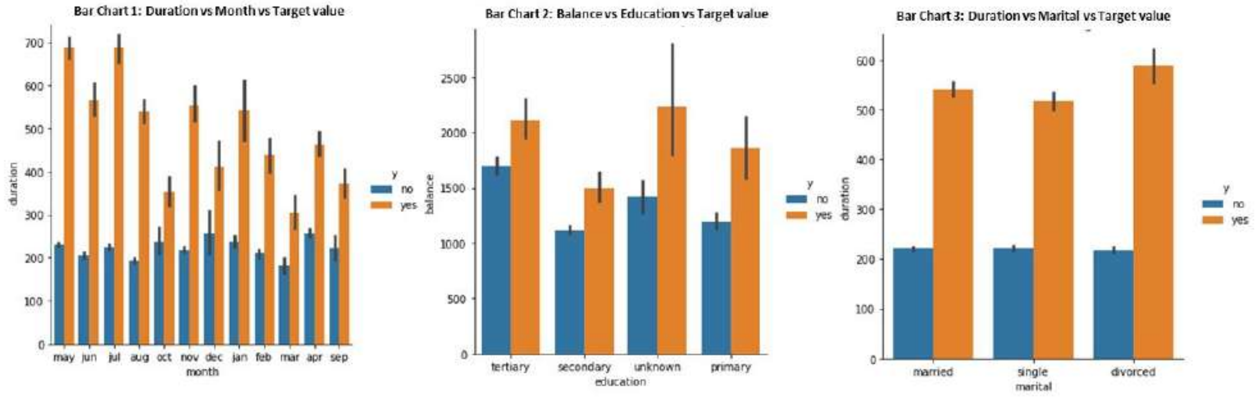


Figure 4: A demonstration of some of the numerical data

The first bar-chart shows that the longer the contact session (in seconds), the higher the customer's probability of subscribing. This also shows the effectiveness of the phone calls and direct marketing. It is also indicated that most of the customers subscribed in May and July, and during these months, the most prolonged duration of phone calls happened.

The second bar-chart shows that the higher a customer's balance, the higher the customer's probability of subscribing. Customers with tertiary education are more likely to subscribe for a loan deposit. The third bar-chart provides insight into the duration of the phone calls, the customers' marital status, and whether the customers with these characteristics have subscribed for a loan deposit. It is evident that divorced customers are more likely to subscribe for a loan deposit, and these also had the most prolonged duration of phone calls. Figures 3 and 4 show valuable information which the bank can use for future planning.

The target value determines whether a customer would subscribe to a loan deposit. These values are presented in column 17. Before the data can be split, it is essential to evaluate the class distribution of these values. The class distribution of the target values is presented in Figure 5.

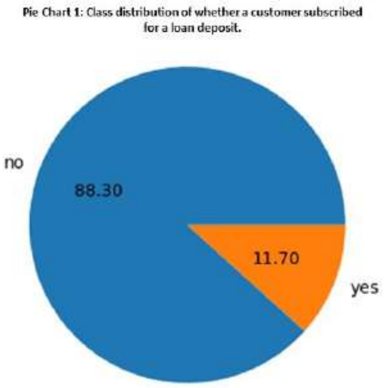


Figure 5: The class distribution of the target group

Figure 5 shows that 88.30% of customers have not subscribed for a loan deposit, and 11.70% have subscribed. It is important to note that the data is imbalanced. If the data is not balanced, the models might be biased towards one output variable. This process is conducted in Section 4.2.

After evaluating the data and the relationship between different variables, it is important to encode the categorical data into numerical data. Figure 4 demonstrates that the target values are represented as "yes" or "no". It is important that these values are also encoded to binary variables defined as "1" or "0". All categorical data including the target values are encoded into numerical values. All numerical data is scaled to avoid outlier presence. The StandardScaler function from sklearn in python is used to scale the data. Last, the data is split into training (60%), validation (20%) and testing data (20%).

4.2 Training of the machine learning algorithms

The SMOTE-function is used in python, which serves as an oversampling technique to prevent the model from being biased towards one output variable. First, the hyperparameters are identified and these values are tuned and used on the training data set. The same values are then applied to the unseen data set, the validation data set. These results are compared, and a conclusion is made on whether the model is overfitting, underfitting or correctly trained. If the model is overfitting, a new set of values is provided for the hyperparameters, and the results are compared. This process is followed until a decision is made on whether the model is correctly trained.

4.2.1 The random forest model

Four hyperparameter tuning attempts are made for the random forest model. The results are demonstrated in Table 3.

Table 3: The random forest model results

Attempt	Hyperparameters	Training Results	Validation Results
1	(random state = 0)	Accuracy: 1.0 Precision: 1.0 Recall: 1.0 F1 Score: 1.0 Cohens Kappa Score: 1.0 Area Under Curve: 1.0 Confusion Matrix: [[23913 0] [0 23913]]	Accuracy: 0.94 Precision: 0.97 Recall: 0.92 F1 Score: 0.94 Cohens Kappa Score: 0.88 Area Under Curve: 0.99 Confusion Matrix: [[7765 259] [667 7357]]
2	(n_estimators=10, max_features=10 , min_samples_leaf =10 , n_jobs=10 , random_state=0)	Accuracy: 0.96 Precision: 0.97 Recall: 0.95 F1 Score: 0.96 Cohens Kappa Score: 0.92 Area Under Curve: 0.99 Confusion Matrix: [[23183 730] [1249 22664]]	Accuracy: 0.94 Precision: 0.95 Recall: 0.93 F1 Score: 0.94 Cohens Kappa Score: 0.88 Area Under Curve: 0.99 Confusion Matrix: [[7637 387] [601 7423]]
3	(n_estimators=100, max_features=30 , min_samples_leaf =104 , n_jobs=101 ,random_state=0)	Accuracy: 0.93 Precision: 0.94 Recall: 0.92 F1 Score: 0.93 Cohens Kappa Score: 0.86 Area Under Curve: 0.98 Confusion Matrix: [[22381 1532] [1848 22065]]	Accuracy: 0.92 Precision: 0.93 Recall: 0.91 F1 Score: 0.92 Cohens Kappa Score: 0.85 Area Under Curve: 0.98 Confusion Matrix: [[7488 536] [685 7339]]
4	(n_estimators=5, max_features=3 , min_samples_leaf =50 , n_jobs=16, random_state=0)	Accuracy: 0.93 Precision: 0.96 Recall: 0.89 F1 Score: 0.93 Cohens Kappa Score: 0.86 Area Under Curve: 0.98 Confusion Matrix: [[23102 811] [2586 21327]]	Accuracy: 0.92 Precision: 0.96 Recall: 0.88 F1 Score: 0.92 Cohens Kappa Score: 0.85 Area Under Curve: 0.98 Confusion Matrix: [[7721 303] [936 7088]]

In the first attempt, no hyperparameters are tuned except for the random state. The training results show that the model is overfitting since it provides a 100% accuracy, precision, recall, f1 score, cohen kappa score, and AUC.

The validation results are very different from the training results. This is also an indication of overfitting, and the hyperparameters must be tuned. If overfitting is not addressed, the model will not provide accurate results on an unseen testing data.

All five hyperparameters are tuned in the second attempt, and a value is assigned. From the training results, it is evident that the model provided good results and is not overfitting. The validation results are now more similar to the training results. In attempt three, the values of four of the five hyperparameters are increased, which resulted in poorer performance on both data sets. In attempt four, some hyperparameters are decreased, and others are increased, resulting in better results than in attempt 3. From Table 3, it is decided that attempt 2 provided the best results, and the model is not overfitting. For this reason, these hyperparameter values are selected to test the random forest model on the unseen testing data in Section 4.3.

4.2.2 The decision tree

This section makes four attempts to ensure that the decision tree model is correctly trained before testing the model. The results are demonstrated in Table 4:

Table 4: The decision tree results

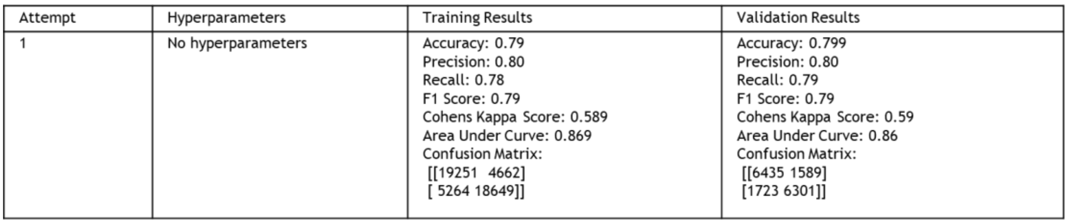
Attempt	Hyperparameters	Training Results	Validation Results
1	(random state = 0)	Accuracy: 1.0 Precision: 1.0 Recall: 1.0 F1 Score: 1.0 Cohens Kappa Score: 1.0 Area Under Curve: 1.0 Confusion Matrix: [[23913 0] [0 23913]]	Accuracy: 0.91 Precision: 0.92 Recall: 0.90 F1 Score: 0.91 Cohens Kappa Score: 0.82 Area Under Curve: 0.91 Confusion Matrix: [[7437 587] [833 7191]]
2	(random_state=0, max_depth=10, min_samples_leaf=20, min_samples_split= 15, max_features=20)	Accuracy: 0.92 Precision: 0.93 Recall: 0.91 F1 Score: 0.92 Cohens Kappa Score: 0.84 Area Under Curve: 0.98 Confusion Matrix: [[22283 1630] [2082 21831]]	Accuracy: 0.92 Precision: 0.93 Recall: 0.91 F1 Score: 0.92 Cohens Kappa Score: 0.84 Area Under Curve: 0.98 Confusion Matrix: [[22283 1630] [2082 21831]]
3	(random_state=0, max_depth=100, min_samples_leaf=27, min_samples_split= 18, max_features=29)	Accuracy: 0.94 Precision: 0.95 Recall: 0.93 F1 Score: 0.94 Cohens Kappa Score: 0.88 Area Under Curve: 0.99 Confusion Matrix: [[22720 1193] [1628 22285]]	Accuracy: 0.92 Precision: 0.94 Recall: 0.90 F1 Score: 0.92 Cohens Kappa Score: 0.84 Area Under Curve: 0.98 Confusion Matrix: [[7531 493] [766 7258]]
4	(random_state=0, max_depth=300, min_samples_leaf=10, min_samples_split= 10, max_features=50)	Accuracy: 0.96 Precision: 0.96 Recall: 0.95 F1 Score: 0.96 Cohens Kappa Score: 0.91 Area Under Curve: 0.99 Confusion Matrix: [[23085 828] [1212 22701]]	Accuracy: 0.96 Precision: 0.96 Recall: 0.95 F1 Score: 0.96 Cohens Kappa Score: 0.9 Area Under Curve: 0.99 Confusion Matrix: [[23085 828] [1212 22701]]

In the first attempt, no hyperparameters are tuned except for the random state. From the training results, it is evident that the model is also overfitting. The validation results are very different from the training results. All five hyperparameters are tuned in the second attempt, and a value is assigned. From the training results, it is evident that the model provided good results and is not overfitting. In attempt three, the values of four of the five hyperparameters are increased, which resulted in poorer performance on both data sets. In attempt four, some hyperparameters are decreased, and others are increased, resulting in better results than in attempt 2 and 3. Table 4 shows that attempt 4 provided the best results, and the model is not overfitting or underfitting. For this reason, these hyperparameter values are selected to test the decision tree model on the unseen testing data in Section 4.3.

4.2.3 The Gaussian naïve bayes

The Gaussian Naïve Bayes model was trained by first including no hyperparameters. The training and validation results are depicted in Table 5.

Table 5: The Gaussian Naïve Bayes results



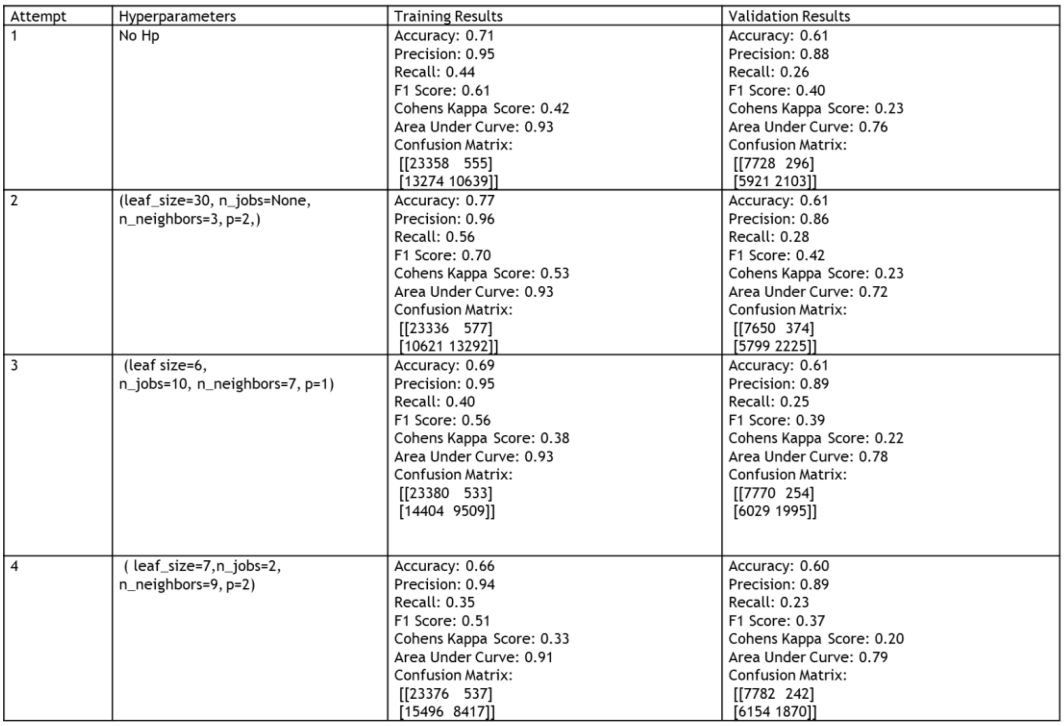
Attempt	Hyperparameters	Training Results	Validation Results
1	No hyperparameters	Accuracy: 0.79 Precision: 0.80 Recall: 0.78 F1 Score: 0.79 Cohens Kappa Score: 0.589 Area Under Curve: 0.869 Confusion Matrix: [[19251 4662] [5264 18649]]	Accuracy: 0.799 Precision: 0.80 Recall: 0.79 F1 Score: 0.79 Cohens Kappa Score: 0.59 Area Under Curve: 0.86 Confusion Matrix: [[6435 1589] [1723 6301]]

From Table 5, most of the values obtained from the training data set are very similar to those obtained from the validation data set. It is also clear that the model is not overfitting or underfitting. For this reason, it was not necessary to do hyperparameter tuning on this model. The model is tested on the unseen testing data as is.

4.2.4 The K-neighbor

This section makes four attempts to ensure that the KNN model is correctly trained. The results are demonstrated in Table 6.

Table 6: The K-neigbor results



Attempt	Hyperparameters	Training Results	Validation Results
1	No Hp	Accuracy: 0.71 Precision: 0.95 Recall: 0.44 F1 Score: 0.61 Cohens Kappa Score: 0.42 Area Under Curve: 0.93 Confusion Matrix: [[23358 555] [13274 10639]]	Accuracy: 0.61 Precision: 0.88 Recall: 0.26 F1 Score: 0.40 Cohens Kappa Score: 0.23 Area Under Curve: 0.76 Confusion Matrix: [[7728 296] [5921 2103]]
2	(leaf_size=30, n_jobs=None, n_neighbors=3, p=2,)	Accuracy: 0.77 Precision: 0.96 Recall: 0.56 F1 Score: 0.70 Cohens Kappa Score: 0.53 Area Under Curve: 0.93 Confusion Matrix: [[23336 577] [10621 13292]]	Accuracy: 0.61 Precision: 0.86 Recall: 0.28 F1 Score: 0.42 Cohens Kappa Score: 0.23 Area Under Curve: 0.72 Confusion Matrix: [[7650 374] [5799 2225]]
3	(leaf size=6, n_jobs=10, n_neighbors=7, p=1)	Accuracy: 0.69 Precision: 0.95 Recall: 0.40 F1 Score: 0.56 Cohens Kappa Score: 0.38 Area Under Curve: 0.93 Confusion Matrix: [[23380 533] [14404 9509]]	Accuracy: 0.61 Precision: 0.89 Recall: 0.25 F1 Score: 0.39 Cohens Kappa Score: 0.22 Area Under Curve: 0.78 Confusion Matrix: [[7770 254] [6029 1995]]
4	(leaf_size=7,n_jobs=2, n_neighbors=9, p=2)	Accuracy: 0.66 Precision: 0.94 Recall: 0.35 F1 Score: 0.51 Cohens Kappa Score: 0.33 Area Under Curve: 0.91 Confusion Matrix: [[23376 537] [15496 8417]]	Accuracy: 0.60 Precision: 0.89 Recall: 0.23 F1 Score: 0.37 Cohens Kappa Score: 0.20 Area Under Curve: 0.79 Confusion Matrix: [[7782 242] [6154 1870]]

In the first attempt, no hyperparameters are tuned. Subsequently, it is evident that the model is not overfitting or underfitting. More hyperparameters are added in attempt two, and it is clear that the model performed better on both the training and validation data sets. From the results of attempt 3 and 4, it is evident that the model performed best in attempt 2. For this reason, attempt two's hyperparameter values are selected to test the KNN model on the unseen testing data in Section 4.3.

4.3 Testing of the machine learning algorithms

As demonstrated in Tables 3,4,5, and 6, the models are trained correctly. The best hyperparameter values are selected for each model, and the models are tested using the 20% unseen testing data. It is important to note that the target values were not balanced for the testing part, and no hyperparameters were tuned. The purpose of the testing is to validate the performance of each model when applied to unfamiliar and unseen data. This is also an indication of how the models will perform when applied to imbalanced industry data. Each model's results with the selected hyperparameter values are depicted in Table 7.

Table 7: The training results

Machine learning model	The Random Forest	The Decision Tree	The Gaussian Model	The K-Neighbors model
Hyperparameters	(n_estimators=10, max_features=10 , min_samples_leaf =10 , n_jobs=10 , random_state=0)	(random_state=0, max_depth=300, min_samples_leaf=10, min_samples_split=10, max_features=50)	No Hyperparamater tuning	(leaf_size=6, n_jobs=10, n_neighbors=7, p=1)
Testing results	Accuracy: 0.90 Precision: 0.59 Recall: 0.50 F1 Score: 0.54 Cohens Kappa Score: 0.49 Area Under Curve: 0.92 Confusion Matrix: [[7624 361] [528 530]]	Accuracy: 0.89 Precision: 0.546 Recall: 0.52 F1 Score: 0.53 Cohens Kappa Score: 0.47 Area Under Curve: 0.87 Confusion Matrix: [[7531 454] [512 546]]	Accuracy: 0.80 Precision: 0.33 Recall: 0.70 F1 Score: 0.44 Cohens Kappa Score: 0.34 Area Under Curve: 0.81 Confusion Matrix: [[6462 1523] [321 737]]	Accuracy: 0.88 Precision: 0.51 Recall: 0.26 F1 Score: 0.35 Cohens Kappa Score: 0.29 Area Under Curve: 0.79 Confusion Matrix: [[7725 260] [782 276]]

The results provided in Table 7 are demonstrated in Figure 6.

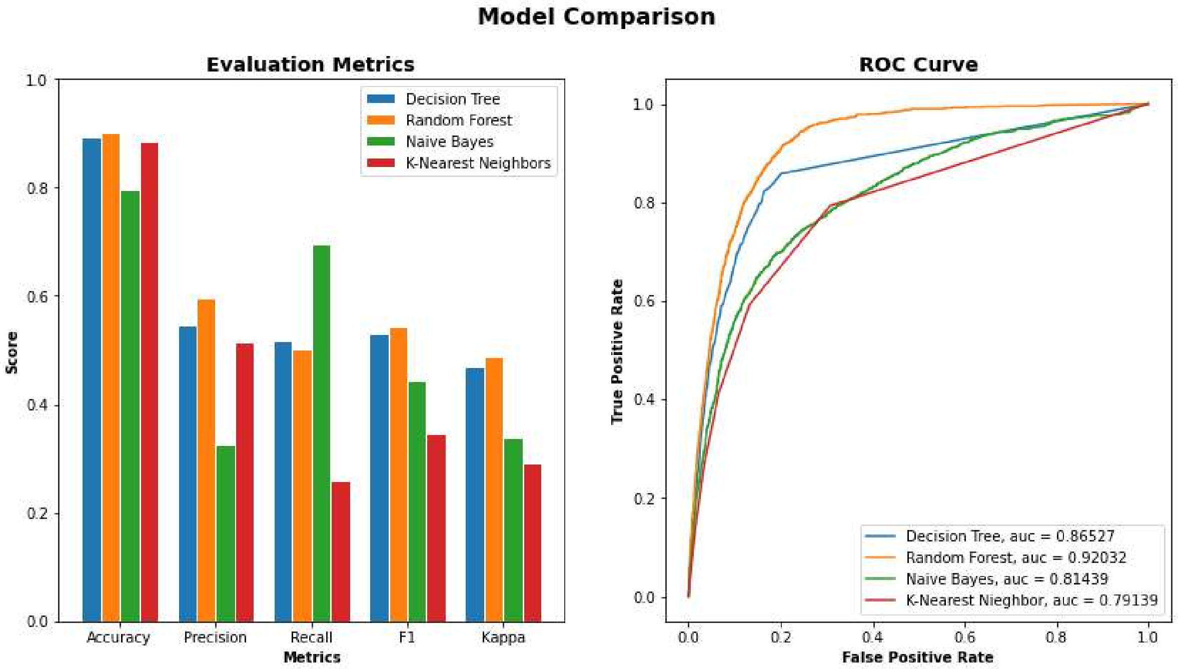


Figure 6: The testing results

Figure 6 shows that the random forest model achieved the highest values in four metrics: accuracy, precision, f1-score and the kappa score. The Naïve Bayes model achieved the highest recall value. The ROC curve demonstrates the relationship between the sensitivity and the specificity. The higher the curve is to the top left corner, the higher true-positives and low false-negatives are predicted. Figure 5 shows that the random forest model performed best, followed by the decision tree, the Naïve Bayes and the KNN model.

4.4 Model optimisation

An attempt is made to optimise the random forest model [24]. The grid search (GridSearchCV) functionality from sklearn in Python is used to find the best optimal parameters for the model [24]. A base model is created, and the recall is used as a scoring method. The recall is used as a scoring metric since the main aim is to predict as many actual positive values as possible. Values are assigned to the hyperparameters, and a GridSearchCV function is used. This function iterates through all the values to find the best optimal scoring hyperparameters. The GridSearchCV uses cross-validation to train the model, and each iteration is divided into five folds. Four out of the five folds are trained, and the rest is left for validation. This process is repeated five times until all the folds are used for validation [24].

As stated in Section 3.2, the computational time increases as the model searches through all combinations. Subsequently, the random search can be used to decrease the computational time. In this section, only the grid search is used, which means that the model took longer to solve. The results of the grid search are depicted in Table 8.

Table 8: The optimisation results for the random forest model

Hyperparameter	Hyperparameter input values (combinations)	Best value selected for each hyperparameter using GridSearchCV
Maximum depth	[20, 30, 40]	20
Maximum features	[2, 10, 12]	10
Minimum samples leaf	[2, 4, 5]	4
Minimum samples split	[2, 30, 40]	40
N_estimator	[10, 50, 100]	10

The best hyperparameter values are selected, and the optimised model is compared with the base model using five metrics as shown in Table 7. The results are demonstrated in Figure 7.

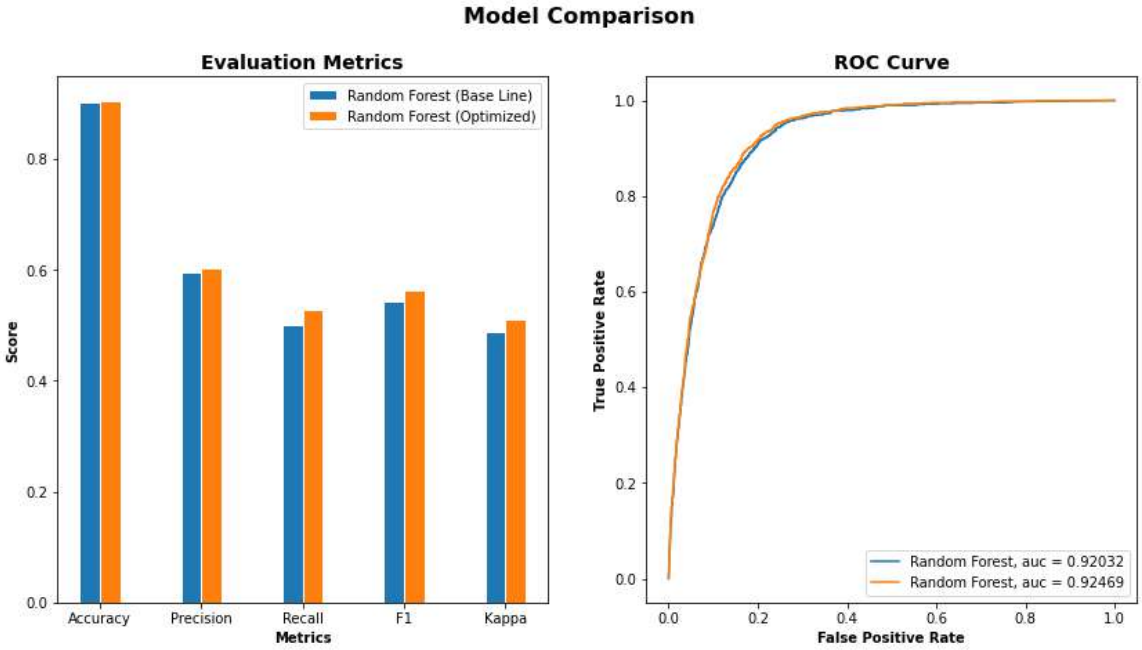


Figure 7: The optimisation results

From Figure 7, it is shown that the optimised model performed better in all five metrics. The optimised model also has a higher true positive rate and a lower false negative rate. The recall was used as a scoring method, and Figure 7 shows that the optimised model estimated a 5.66% higher recall value than the base model. For this reason, when using the model for prediction, the optimised model must be used.

5 CONCLUSIONS AND FUTURE RECOMMENDATIONS

Machine learning algorithms are identified as the key to unlocking the value in customer data and using this data to make optimal predictions. Subsequently, not all machine learning models are applicable to all types of problems. Some algorithms are best suited for specific problems, and the correct algorithm must be selected to address the problem.

This paper contributes to the machine learning application domain by evaluating four machine learning algorithms and identifying the best performing algorithm to solve a direct marketing problem. These four algorithms included the random forest, the decision tree, the gaussian Naïve Bayes and the K-neighbor algorithms.

Open-access direct marketing campaign data was obtained from Kaggle. The problem or output variable was specified: "Will, the client, subscribe to a term deposit (yes or no)?". First, a literature study was conducted on data cleaning, the types of machine learning algorithms, cross-validation, hyperparameter tuning, overfitting and underfitting and various performance parameters. Second, the data set was investigated. The relationship between the variables was evaluated using various bar-charts and pie-charts. The conclusions are seen as valuable information that the bank can use for future planning. The unnecessary column was removed, the categorical data was encoded, and the numerical data was scaled. Last, the class distribution of the target values was balanced using the oversampling function (SMOTE) in Python.

After cleaning the data, the four models were trained using LeavePOut cross-validation and hyperparameter tuning. The results concluded that the random forest model achieved the highest values in four metrics: accuracy, precision, f1-score and the kappa score. The Naïve Bayes model achieved the highest recall value. The ROC curves were also demonstrated. An attempt was made to optimise the random forest model by using the grid search (GridSearchCV) in Python. A few potential hyperparameter values were provided, and the best values were selected. From the results, it was concluded that the optimised model performed best with a 5.66% higher recall value than the base model. Thus, it will be recommended that the optimised model be used when making predictions.

This study aimed to select the best performing machine learning algorithm to make predictions for a direct marketing campaign. The first part, which focused on choosing the best algorithm, was explored in this study. For future research, it will be recommended to explore the second part (part 2), which focuses on the actual predictions. Thus, using the random forest model to predict whether a customer will subscribe to a loan deposit or not. This algorithm can plan and improve direct marketing strategies to assist the banking industry with optimal decision-making. It will also be recommended that the performance of other deep learning models, including artificial neural networks (ANN) or support vector machines (SVM), are compared to the random forest model. By conducting these investigations, the overall strategies and planning of marketing campaigns can be optimised.

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IMPLEMENTATION OF SYSTEM DYNAMICS MODELS IN INFRASTRUCTURE CONSTRUCTION PROJECTS WITHIN AN ELECTRICITY SECTOR: A LITERATURE REVIEW

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ABSTRACT

Energy plays a fundamental role in sustainable development and poverty alleviation efforts. Over the past decades, South African state-owned enterprises have registered a greater demand for power supplies in response to economic growth. These enterprises are currently engaged in capital expansion building programmes to overcome the supply constraints. The purpose of the study reported on was to conduct a systematic literature review relating to the utilisation of system dynamics models in infrastructure construction projects within the energy sector. The Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) methodology was used to conduct a search, which resulted in the identification of 130 journal articles, of which 15 fell within the scope of the review. The literature review suggested that projects in the electricity sector can be framed as complex dynamic systems and system dynamics is the best modelling tool for infrastructure projects within the energy sector.

Keywords: Electricity, Infrastructure, System dynamics modelling

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1 INTRODUCTION

According to the International Energy Agency (IEA), 1.1 billion people do not have access to electricity majority of whom reside in rural regions. It further confirmed energy to be a key global challenge experienced by both the African continent and the entire world, with noting that in many countries, including South Africa, economic growth and social needs are resulting in substantially greater energy demands, despite continued and accelerated energy efficiency advancements [1] .The relationship between the supply of and demand for electricity has changed over the most recent economic cycles [2]. It further points out that conventionally, as the demand for electricity increases, so does the production of electricity. Thus, in the view of [2], new generating capacity must be installed to cater for the growth in energy demand. In late 2009, South Africa recorded a growth in the number of large infrastructure projects intended to resolve the energy crisis. There was pressure to increase power capacity to meet the needs of their populations over such projects as per the graph below.

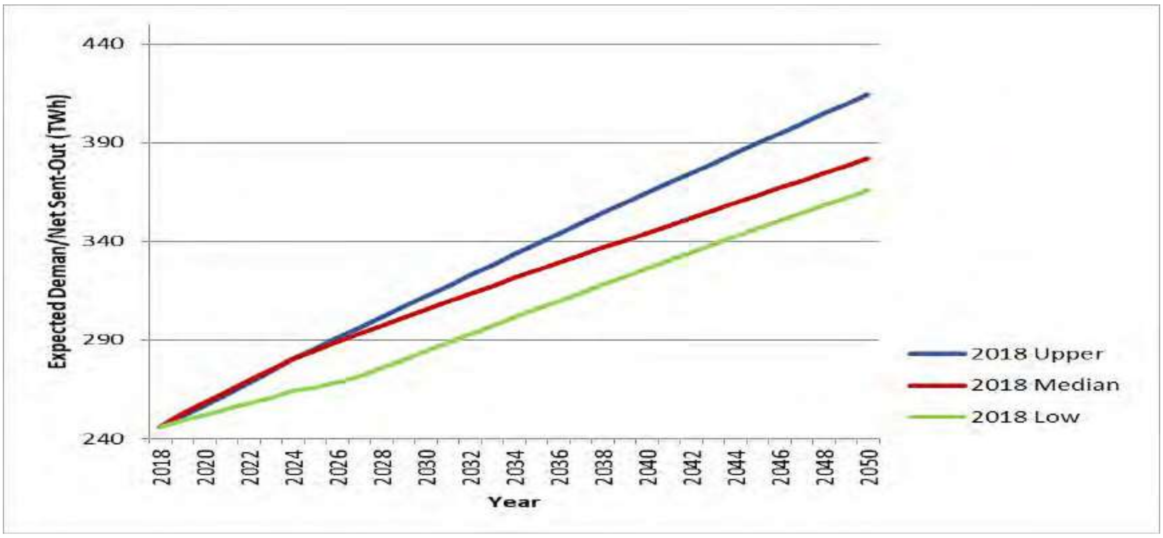

Figure 1: Projected electricity requirements for South Africa to 2034

Construction activities are an index of the economic and social progress of a country, and management of these projects inevitably requires dealing with uncertainties that may arise. They identify possible sources of uncertainties related to infrastructure construction as technology choice, pollution and environmental concerns, and regulatory and political risks.These uncertainties, along with many other documented problems, are the root causes of project delays and decline in organizational performance [3].

Schedule delays and cost overruns are common in construction projects in spite of advances in construction equipment and management techniques, electricity sector is dynamic in nature, and has been classified as a complex matter due to its interaction with other sectors of the society. A recent survey undertaken by Massachusetts Institute of Technology(MIT) revealed that more than 50% of large technological development projects fail to meet their cost and schedule targets. In this context, report that system dynamics (SD) methods have been used extensively over the past 35 years on complex projects and have a proven project management track record in terms of the project lifecyle [4].

Fast-paced technological advancements have resulted in unprecedented, dynamic customer demands, as well as ever-changing legal frameworks in the twenty-first century [5].The electricity industry is not immune to these dynamics as it continuously evolves over time. Sterman [6] argues that the nature of electrical industry projects can be framed as complex dynamic systems, because these projects are part of a system that includes several interdependent and dynamic components, as well as multiple feedback loops and non-linear interactions.SD is a simulation-based modelling technique that excels at dealing with complexities and their consequences for decision-making.

SD was first developed during the late 1950s at The Massachusetts Institute of Technology under Prof. J.W. Forrester as a method for modelling and analysing the behavior of complex social systems, particularly in an industrial context [7]. The SD model has been employed by a large number of construction management researchers during the last 20 years. However, there is a scarcity of systematic reviews of SD articles in this subject, preventing researchers from gaining a thorough and systematic grasp of research focuses and trends. Furthermore, some researchers erred in their application of SD. The use of SD in construction management lags behind other fields, such as economic development, rural and urban planning, environmental sciences, and the energy sector [8].

2 OBJECTIVES

The objective of the proposed study was to review existing literature related to SD models within the electricity sector .With the goal of focussing on the contribution of system dynamics modelling in the electricity sector infrastructure projects and shortfalls in the literature to enhance on-time delivery of projects.

3 LITERATURE REVIEW

Project management is one of the most important and most poorly understood areas of management. Delays and cost overruns are the rule rather than exception in construction, defence,power generation, aerospace, product development, software and other areas. Projects often appear to be going smoothly until near the end, when errors made earlier are discovered, necessitating costly rework, expediting, overtime, hiring, schedule slippage, or reductions in project scope or quality [9].

SD modelling, which is based on systems thinking, aims to capture the systemic collection of elements and interactions that result in the observed problem behaviour. SD models can also be used to identify which components are important in the problem, as well as tools like causal loop diagrams and stock-flow diagrams that help organizations convey outcomes to stakeholders more effectively [7].

Ahmad et al. [10] divided the main efforts to improve the construction industry into the four major categories of resources development, enterprise development, documentation and procedure development, and appropriate policies. However, what constitutes a successful combination of policies in one country might not be applicable to or successful in another.

3.1 System Dynamics Approach

Ahmad et al. [10] stated that SD modelling is useful for the management and simulation of processes with two important characteristics: (1) they involve changes over time and (2) they allow feedback – the transmission and receipt of information.The SD approach describes cause-effect relationships involving stock flows and feedback loops. This approach makes it possible to describe the dynamic structures of construction organizations before and after the implementation of policies.

Sterman [11] argues that recently, SD modelling has been applied to construction research, and the literature on its application to project management is extensive. Specifically, he justifies the utility of SD for construction for the following reasons: construction projects are extremely complex and consist of multiple interdependent components, they are highly dynamic, they entail multiple feedback processes, and they involve nonlinear relationships. According to Xu and Zou [8] SD has the potential to effectively create a learning laboratory for the simulation of policies through its modelling process. Sterman [9] justified the utility of SD to construction as follows, construction projects:

- Are extremely complex and consist of multiple interdependent components
- Are highly dynamic
- Involve multiple feedbacks processes
- Involve nonlinear relationships, and
- Involve both hard (quantintative) and soft (qualitative) data

In recent decades ,there has been a remarkable growth in the number, size, and complexity of large –scale infrastructure projects in many developing countries.The late completion of projects is a problem faced by many institutions globally, in both developed and developing countries [12]. The challenge of the late delivery of projects affects not only the construction sites of state-owned enterprises (SOEs), but also those of other organisations around the world. The history of the construction industry globally reveals that most projects face significant time and cost overruns [13]. In 2011, the schedule for the Medupi build programme was running far behind the original schedule, and the cost of the project had escalated from R80-billion to R120-billion. He further noted that President Ramaphosa had acknowledged that the factors causing the delays in the construction of the Medupi and Kusile power stations were state capture, corruption, mismanagement, and a shortage of essential skills.

3.2 Generation Capacity Expansion

Articles covering this area deal with models that were developed to solve problems relating to generation capacity expansion (GCE) in the electricity sector. Rigorous analyses are needed before committing to generation capacity expansion. Identify the focus of GCE models as being to find out which technologies for power generation will make up the system in the long run.

Discuss GCE decisions as being based on the profitability assessment of a particular investment and incorporating variable efficiencies. Simulations show a cyclical pattern in the total operational capacity and the price of electricity, attributed to power plant construction delays, and limitations in the ability of investors to predict market trends. Models reviewed in this category indicated the difficulty of balancing supply and demand in the electricity sector, with identifying planning and construction delays in the expansion of generation capacity to be critical and requiring consideration [10].

Leopold [14] developed a preliminary SD model for the Mauritius power sector. This particular study documented the first iteration in the development of a power sector model for Mauritius based on Threshold 21 models developed by the Millennium Institute. These authors suggested that future work might include the expansion of the model to cover the whole of the energy system in Mauritius and policy analysis.He further developed an SD model to evaluate electricity generation expansion in New Zealand, and made projections as to whether capacity cycles would occur in the future. Similarly Qudrat-Ullah and Seong [15] state that SD based simulation models are becoming increasingly popular in the analysis of important energy policy issues including global warming, deregulation, conservation and efficiency. They note that the usefulness of these models is predicted on their ability to link observable patterns of behaviour of a system to micro-level structures.

Qudrat-Ullah and Davidsen [16] developed an SD model in electricity generation sector of Pakistan. The model investigated the impact of government's policy of boosting private sector investments in power generation. Demand, investments, resources, production capital, production, environmental, and finally the financial sub-sectors were modelled. The interaction of these sub-sectors with the GDP driving electricity demand was assumed to produce dynamic behaviour of industry. Simulations revealed that with a new policy in place, hydroelectric development will be impeded. The model effectively showed the side effects of a policy. However, overly relying on a single exogenous variable (GDP) as the driver of long term demand seems not to be appropriate. Other macro-economic factors, like population and electrification rate could be more appropriate for inclusion in a model of a developing country.

3.3 Modelling Project Dynamics using System Dynamics

Richardson and Pugh [17] argues that project modelling has been one of the mainstays of SD practice for many years. Modelling has been used in projects ranging from military and commercial shipbuilding projects to aerospace and weapons systems, power plants, civil works and software projects. By way of an illustration, SD has been used to model a communication tool that would allow the project team to illustrate potential project results to customers, and to better understand their expectations, while [18] used the SD modelling approach in designing, building, testing, and implementing a model-based system to aid project management at Fluor Corporation.

Ford and Lyneis [19] argues that major electricity infrastructure projects are known to be complex in nature, involving construction of power lines over huge stretches of various types of terrain, and taking numerous stakeholders into account. They expresses the view that project planning is a successful SD application field. The model in Figure 2 below is an SD model devised by [20] that shows the project dynamics linked endogenously.

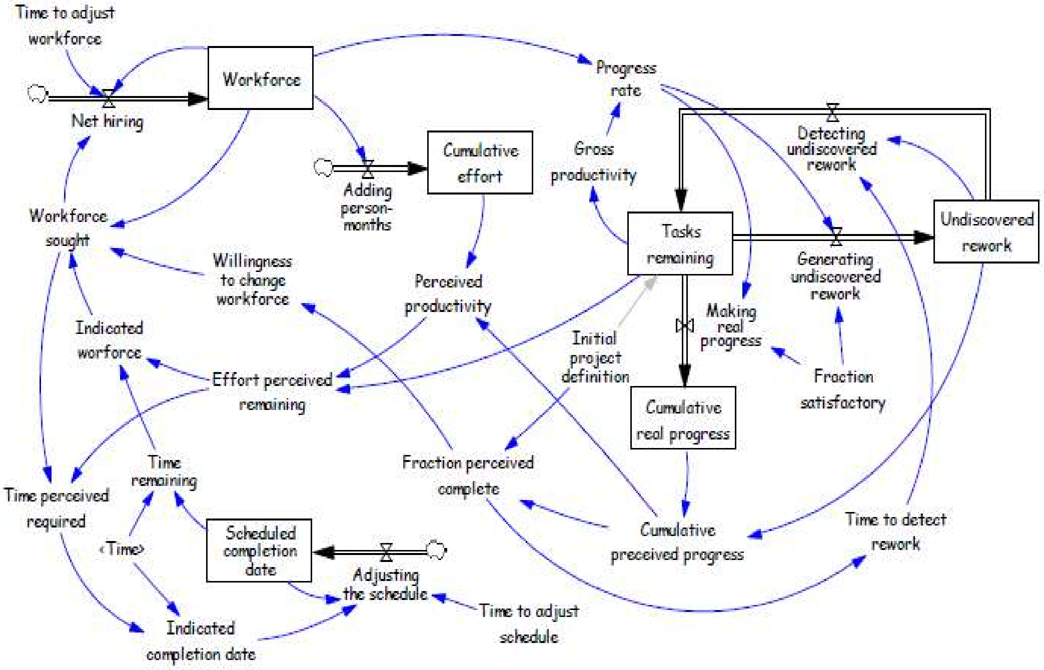

Figure 2: A typical SD model of project dynamics

According to Richardson [20], the model has the rework cycle at its core, showing how rework is generated and dealt with in projects; and includes the workforce component, showing how the project dynamics at play would result in variations in the size of workforce needed at a particular time. It also shows how the workforce size affects the cumulative effort on the project, and how the cumulative effort in turn affects and influences the perceived productivity.

The rework cycle is the most important single feature of system dynamics project models in which rework generates more rework that further generates even more rework [19]. It is the source of many project management challenges, and was first developed by Pugh Roberts Associates. The majority of system dynamics studies that focus on project dynamics include a simulation model of project evolution and the core feature of these models is the rework cycle [21]. While most of the original work in projects is usually finished early in the project, delays are usually caused by the need to rework that original work. By considering defects, quality and testing through rework cycle; many path-dependent reinforcing loops are generated that critically impact the fate of projects. Almost all dynamic project models have a rework cycle in some form [22].

3.4 System Dynamics in the Project Management Environment

Rodrigues and Bowers [23] states that SD has been implemented in many fields, but that only a limited number of studies have been conducted in the project environment relating to construction. He further note that while the traditional project management approach encounters difficulties relating to analytical techniques such as Program Evaluation and Review Technique (PERT) scheduling, risk assessment and contract management, the new approach employing SD assumes a holistic view of the project organization, focusing on the behaviour of projects and its relation to managerial strategies.Ford and Lyneis [19] report that project management researchers have explained that one reason project goals are often not met is that the project management concepts and tools used today are too linear and deterministic. The systems in which project management occurs are too complex and volatile and contain too much apparent randomness to be managed effectively by linear, deterministic tools that focus on one portion of the system at a time. These researchers have suggested that SD concepts and tools such as causal loop diagrams and detailed models should be integrated into project management practices to allow project managers to better understand the structure of the system in which project management occurs, and consequently plan and control projects better.

Love et al. [24] notes that the types of decisions made on projects are often categorised as being either strategic, tactical, or operational. This author states that the use of system dynamics most naturally occurs at the strategic/tactical end of the spectrum, and defines strategic project management as decisions that are taken up front in designing the project.

According to Ford and Lyneis [19], the first description of the use of SD in understanding projects appeared in 1964, but it was not until the 1980s that the first project-specific applications began to be reported. Since 1990 there have been many more reported examples of the use of system dynamics in project management. The first models were developed to examine the dynamics of research and development projects.

Chritamara, Ogunlana and Bach [3] argues that SD suggests that it is not the detail that determines the outcome of the project, but rather the powerful underlying influences and the insidious feedback loops that can, if not managed properly, result in unexpected overrun and overspend.

According to Rodrigues and Bowers [23] construction projects are extremely complex and involve nonlinear relationships as well as hard (quantitative) and soft (qualitative) data. SD is better suited to dealing with these situations than any other modelling tool. Nasirzadeh and Nojedehi [25] share a similar view, stating that project performance in terms of schedule, cost and quality evolves through time, and therefore is a dynamic concept that lends itself to the application of SD modelling.

Leopold [4] point out that many factors that result in projects not meeting their schedule or cost targets are not covered by the PMBOK-type model; these include client-driven changes to specifications, technology problems, poor design management, external price changes, environmental issues, community or political issues, and labour problems.

Sterman [7] state that during its early days project management covered the overall project life cycle, from initial phase to execution. In the 80s, however, this changed, and the discipline came to be seen as an execution function, focusing on delivering projects on time, within scope and on budget; this missed the fact that most of the causes of project failure are to be found in the front-end stage of the project. In their conclusion, these authors state that during the early stages of the project things are complex, intangible and uncertain, and hence people tend not to focus on them.

Chritamara, Ogunlana and Bach [3] report other causes of project failure to be inadequate scoping by owners such that the project scope does not fully fulfil organizational business requirements, an inexperienced or unqualified project team that lacks the appropriate skills and expertise to manage the project, lack of proactive risk management, unrealistic schedules, and project tolls and infrastructure that are not set up to effectively plan, deliver, track, and report performance. These authors add that if these issues are attended to, projects will always run late and excessive costs will be incurred. SD modelling has also been applied in design management, disruptions and delay, design and building and quality and change management.

4 RESEARCH METHODOLOGY

The research methodology entailed the systematic review approach. A systematic literature review comprises a thorough examination of the literature on the subject at hand. To enhance the analysis of the reviewed literature, the process began with the identification of the key ideas that related to the research question. The criteria included a generic review of the area under research, as well as limiting reviewed papers to those in English, and ensuring the relevance of the reviewed articles to the area under study. To obtain relevant information consent with the purpose and direction of the research, a keyword search of online databases was conducted on the following topics: Modelling the dynamics of infrastructure projects, performance enhancement in a construction organization and system dynamics modelling and electricity.

Filters based on the PRISMA technique were constructed according to [26] in order to determine the degree of relevance of the articles to the topic under investigation. According to the PRISMA technique divides the article extraction procedure into four stages: (1) identification; (2) selection; (3) eligibility; and (4) inclusion. Keywords and complementary terms were employed in all the database searches during the identification step, and all articles identified were extracted for the second stage (selection). In the second stage, the following filters were used: The article type, peer-reviewed status, and English language. Titles and abstracts were read in the third step (eligibility), and papers with content directly linked to the topic were selected, with all others being discarded.

An initial search using the search string was conducted which yielded 130 articles. The researchers conducted a preliminary assessment based on reading the abstracts of all selected papers in order to concentrate on the most pertinent literature. According to the database, the earliest description of the use of SD in understanding projects was published in 1964, although the first project-specific applications were not recorded until the 1980s. Many more examples of the usage of SD in project management have been recorded since 1990 [18].The findings of the literature review led to a number of conclusions. The first is that the number of articles published on SD modelling in infrastructure projects in the electrical industry has increased in recent years as shown in figure 4. According to figure 3, this study starts with the initial collection as step number one of four steps. Collecting from various publishers, i.e., Science direct , Emerald, Springer Link, Google scholar, Elsevier within the year from 2001 until 2021.

4.1 Selection and criteria inclusion of the analyzed studies

The research methodology is represented in Figure 3. We used the systematic review principles proposed by [26]. The literature was searched via the search engines of major publishers, including Google Scholar, Elsevier, Science Direct, Emerald, Springer Link, other worldwide publishers. An iterative process, s was used to derive information from the abstracts of published papers. After the first search, a total of 130 studies were identified for our systematic review. To select the final studies to be included in this review, a practical screening was conducted that consisted of the following two steps: 1) the setting of inclusion criteria and 2) the strategy for selecting the potential studies.

4.1.1 Inclusion criteria

To be included in our systematic review, first, a practical screening of the titles and abstracts was conducted following the next inclusion criteria. A study had to meet the following criteria to be included:

- The study must be an article published in a peer review journal in the English language within the last twenty years (2001-2021).Thus, other publication forms (conference proceedings, books, newspaper articles, unpublished works) were not included
- Mentioning in a categorical manner of system dynamics model in infrastructure model within electricity industry (methodology, approach, analysis)

4.2 Studies selection

In the second stage, the identified articles were subjected to a double screening. A first sorting of the articles' titles and abstracts allowed us to include 130 potentially relevant studies. Each of these 130 articles were reviewed and assessed according to the inclusion criteria. The second screening went beyond the title and abstract into the full text of the papers. 117 studies did not fulfil the inclusion criteria. Therefore, after the two-step practical screening, the literature review on finally involves 15 potentially relevant studies that met all the inclusion criteria.All the papers that fulfilled the practical and methodological inclusion criteria were analysed [20].

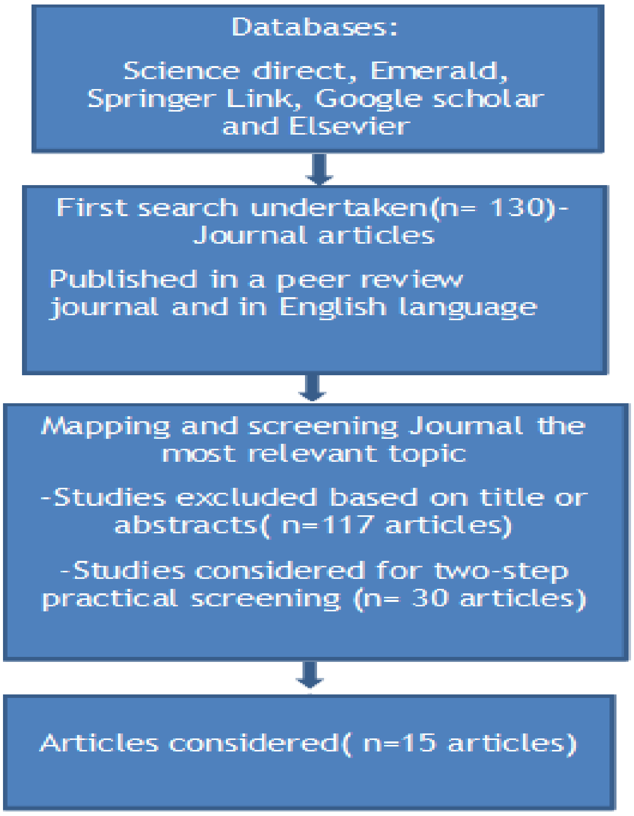

Figure 3: Systematic Review Flow Diagram

5 RESULTS AND DISCUSSION

According to the findings of the literature review, there is a growing corpus of knowledge on the subject of the application of SD in the energy sector. SD modelling has been used in design management. A number of scholars have used SD modelling to do research on construction project management, as shown in table 1 below, with SD being a valuable tool for understanding situations involving dynamic complexity and policy opposition, since SD is a dynamic field in and of itself. The analysis of the literature review conducted yields the conclusion that SD modelling has been applied in design management, with a number of researchers having carried out research related to construction project management with the use of SD modelling, as shown in table 1 below:

Table 1: SD related to Construction Projects – Model Summary

Published	Authors	Title	Purpose	Conclusion
2001	Qudrat-Ullah and Davidsen	Understanding the dynamics of electricity supply, resources and pollution: Pakistan's Case	An assessment of the existing resource policy	The current energy policy is unsustainable in terms of attracting investments.
2002	Chritamara and Ogunlana	System dynamics modelling of design and build construction projects	Design and build construction projects modelled in order to optimise time and cost performance.	In design and build construction projects, a system dynamics model is constructed that integrates significant subsystems (such as different phases or human resources input to projects) and their interactions.
2002	Love *et al.*	Using SD to better understand change and rework in engineering project management systems	The requirement for an awareness of how certain dynamics can obstruct the performance of a project management system.	Love constructed an SD model to describe how construction changes and rework can affect the project management system. This was also the first study to take a quantitative look at project management.
2003	Ogunlana *et al.*	System dynamics approach to exploring performance enhancement in a construction organization	Performance enhancement in a construction organisation	A model is created to investigate policies that can improve a construction firm's performance.
2005	Nguyen and Ogunlana	Modelling the dynamics of an infrastructure project	Modelling the dynamics of an infrastructure project	To capture the dynamism of construction projects in the construction phase, a dynamic simulation model is built. As dynamic hypotheses, eight essential feedback structures from earlier project dynamics models and the specific characteristics of building projects are identified. They cover labour structures, equipment, material, labour-equipment interaction,

Published	Authors	Title	Purpose	Conclusion
				schedule, rework, safety, and quality.
2005	Park	A model-based dynamic approach for construction resource	He notes that excess resource idling can result in cost overruns, while low resource coverage or long lead time in resource acquisition can delay the project schedule.	For building resource management, he created an SD model. In addition, policy implications for the main variables of goal material level, target workforce level, material acquisition rate, and workforce based engineering rate were explored without any mention of outsourcing.
2007	Motawa	A systematic approach to modelling change processes in construction projects	Modelling changes in construction projects	An SD model with an integrated fuzzy logic-based change prediction model. He demonstrated how SD could be used in conjunction with other research approaches.
2007	Dimitrovski *et al.*	An interdisciplinary approach to long-term modelling for power system expansion	Interdisciplinary modelling approach of large-scale power systems over a long-term horizon	The value of simulation models that may be used interactively.
2012	Boateng *et al.*	A conceptual system dynamic model to describe the impacts of critical weather conditions in megaproject construction	Modelling the impacts of critical weather conditions in megaproject construction.	An SD model was created to characterise the effects of key weather conditions in megaproject development, allowing for more precise construction planning to avoid project delays, cost overruns, and increased rework.
2013	Han *et al.*	A system dynamics model for assessing the impacts of design errors in construction projects	They pointed out that design errors, which result in rework and/or design revisions, are the biggest cause of schedule delays and cost overruns in design and construction projects.	They created an SD model to capture the dynamics of design errors and assess their negative consequences in a methodical way.
2013	Richardson	System dynamics applications with impact	A typical SD model for project dynamics	The workforce component of the model has the rework cycle at its heart, indicating how the project dynamics at play would result in variations in the size of the workforce required at any given time.

Published	Authors	Title	Purpose	Conclusion
2014	Lisse	Applying SD for nuclear power plant design	Analysed an SD model for outsourcing engineering services in a large and complex project organisational structure	SD model for outsourcing design services in a project.
2016	Ogano	A system dynamics approach to managing project risks in the electricity industry in Sub-Saharan Africa	An SD approach to managing project risks	The model is an expansion of Richardson incorporating political risk, project management competence, unforeseen technical challenges, and an insurance index to generate scenarios that can be utilized to reduce project delays and increase project quality.
2019	Mingqiang LIU *et al.*	System dynamics modelling for construction management research: Critical review and future trends	Critical review on system dynamics for construction projecs and future trends	This systematic review indicates that SDM has been in-creasingly advocated by researchers over the past two decades to explore nonlinear and dynamic complexity issues involved in CM
2021	Xiaoxiao XU, Patrick X. W. ZOU	System dynamics analytical modeling approach for construction project management research: A critical review and future directions	A critical review and future directions	The results show that SD has received increasing attention from construction management researchers over the past five years.

To some extent, these studies attempted to resolve a number of dynamics problems encountered on complex construction projects. However, and despite these efforts, little or no research has been done on understanding the dynamics at play in ensuring on-time delivery of infrastructure projects within the power utility and minimising cost caused by project delays. From the literature, it is clear that certain variables relating to ensuring on-time delivery of infrastructure projects have not been covered such as scope change, resource competency and project management skills.

5.1 Number of publications

The number of SD-related articles published annually from 2001 to 2021 is presented in Figure 4. Although the absolute quantity of articles is small, it demonstrates an increasing trend, from 4 in 2001 to a maximum of 13 in 2021. This trend indicates the increasing amount attention the SD in the construction management field received from researchers. Interestingly, a slow growth trend occurred in the two decade 2001– 2004, where an average of one article was published annually. Since 2007, SD has gradually been valued by construction management-related researchers and plays an important role in construction management.

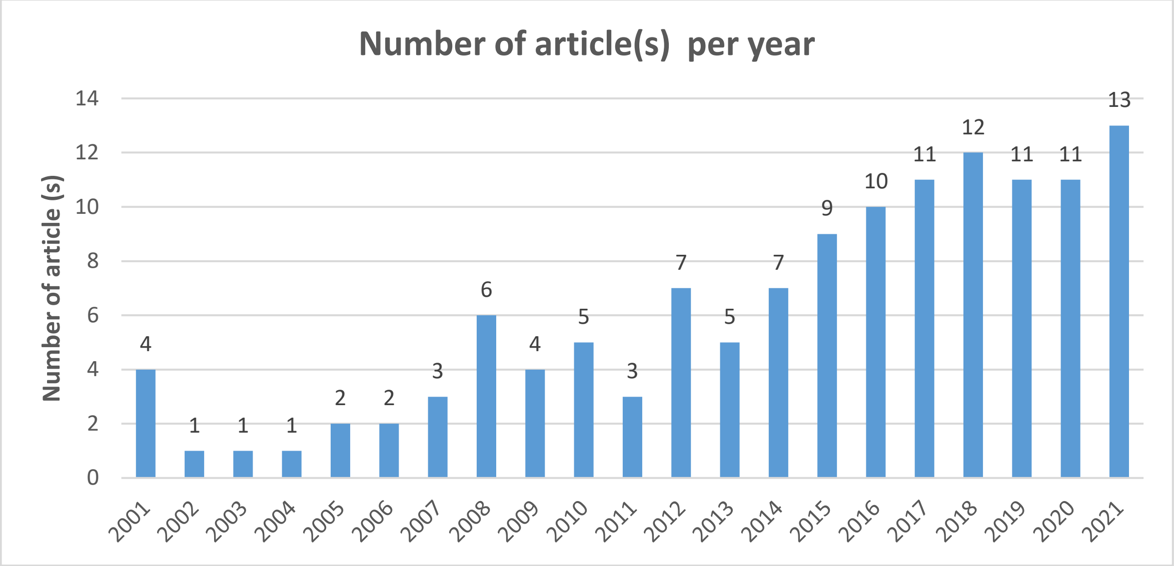

Figure 4: Number of SD-based construction management articles published annually from 2001 to 2021

According to Boateng, Chen and Ogunlana [27], SD suggests that it is not the detail that determines the outcome of the project, but rather the powerful underlying influences and the insidious feedback loops that, if not managed properly, can result in unexpected overrun and overspend. The results display that SD has received increasing attention from construction management researchers over the past ten years. Furthermore, several issues exist in SD application, which include model boundary, model development, model test, and model simulation. This study has certain limitations. As noted by Zheng [28] the categories of identified articles may be influenced by the subjective judgments of authors to an extent. Four significant feedback structures from earlier SD models of project dynamics and distinctive characteristics of construction projects have been recognized as major trends, according to the findings of the current review. Design errors, rework, and change management are among them, as well as performance and effectiveness, resource management, and project planning and control.

These studies have attempted to address a number of dynamics issues that arise in complicated construction projects to some extent. Despite these efforts, little or no study has been done to understand the dynamics at play in guaranteeing on-time delivery of infrastructure projects in the energy sector, as well as to reduce the costs associated with project delays.

6 CONCLUSION

Globally, the electricity industry faces numerous challenges. The research undertaken identified literature showing the way in which a dynamic model can improve on-time delivery of infrastructure projects and minimise costs within the power utility in South Africa. The literature survey conducted revealed SD modelling to have made a significant contribution to the electrical sector. However, additional effort is needed to fully realise the benefits of SD modelling in the electricity industry. More research into developing a dynamic model to improve on-time delivery of infrastructure projects and minimise costs within the power utility in South Africa needs to be undertaken.

The focus was on gap on literature that were not included in the models developed by other researchers to see how they affect on-time delivery of projects. A theoretical framework is the first step towards the development of a dynamic model based on the insights gained from the South African power utility, followed by validation of the model in this context. It is very difficult to sum up all aspects of electricity-based SD models including their variety of intentions, time horizons and goals, depending on the region taken into account. However, the research on electricity SD models reveals a degree of similarity across the world, demonstrating the need for optimization of planning, production and use of power plants.

7 FUTURE RESEARCH

Future research should be to investigate the effect of changes in variables such as scope change, resource competency and project management skills both individually and collectively on the overall project performance of the model. The focus should be on how these changes affect the overall project completion and quality of completed project tasks.

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AN INVESTIGATION INTO ENERGY SAVING OPPORTUNITIES FOR PHARMACEUTICAL COMPANIES IN SOUTH AFRICA

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ABSTRACT

The global manufacturing industry faces a considerable challenge in maintaining profitability due to the excessive rise in energy costs. The rise in costs of electricity consumption clearly emphasises the importance for the manufacturing industry to increase its energy efficiency. Industrial Engineering principles are proven productivity improvement methods, which focus on determining and removing sources of wastes. These principles focus on productivity improvements and were never intended as a form of improvement mechanism or framework for the identification and reduction of energy consumption. The qualitative research study was done at a leading pharmaceutical organisation and the undertaking reveals the relationship between Industrial engineering, energy and the implementation of a framework to support it. The results yielded a positive outcome, confirming that the implementation of the framework will lead to improved energy efficiency in the manufacturing industry.

Keywords: energy, industrial engineering, framework

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1 INTRODUCTION

Business performance is challenged by energy cost increases and availability to users. The cost of electricity in South Africa (SA) has increased from an average annual selling price of 19.80 cents per kilowatt hour in 2007 to 110.93 cents per kilowatt hour in 2020 [1].

The Department of Minerals Resources and Energy (DMRE) of the Republic of South Africa revealed a new strategy with new policies to improve energy supply for 2020-2025. One of which was to extend its nuclear lifespan of the Koeberg nuclear plant by an additional 20 years. Data from the International Atomic Energy Agency (IAEA) illustrates that global energy produced by nuclear currently stands at 396 GW, however only 2 GW of that is produced in Africa, in this case, South Africa. Egypt is currently developing a 5 GW capacity, and there are other projects underway of unreported sizes in Kenya, Ghana and Nigeria. Experts believe that by the year 2050, global supply from nuclear power could potentially be as high as 750 GW, of which Africa would potentially contribute 15 GW [2].

Troublesome operational issues at Eskom attributed to rolling blackouts and continuous load shedding schedules from 2008 up until and including the release of this article in June 2022. This has a crippling effect on the supply to industry and general users within SA. This is mainly attributed to its ageing facilities within their coal burning plants that cannot keep up with the designed capacity, with the addition of a continuous increase in overall demand. Another factor is the high level of corruption and fund displacement that cripple the projects undertaken by the SA government [3].

SA further voluntarily announced the intent to reduce its greenhouse gas (GHG) emissions with 34% by 2020 and 42% by 2025 from a business-as-usual perspective [4]. In contrast to the green energy platforms, it seems that SA and to some extent global strategy has shifted, leaning towards demand side management. Therefore, the interim solution for the energy problem lies in demand side management. Demand side management projects include the processes of load shifting, load scheduling, energy efficiency and strategic growth to realise impacts on energy demand [5].

In the past organisations were ambiguous about their energy use, and the impact it had on the environment. However, with the current change in global culture governments are forcing organisations to rethink and adapt and consider their energy footprint. In SA this is amplified by the spiralling increase of energy costs and lack of capacity to supply from the government.

A research study was undertaken at a leading global manufacturer in South Africa to understand what the preferred method would be and how energy could be reduced following the developed method.

2 OBJECTIVE

The purpose of this research study was to investigate the relationship between Industrial Engineering, Waste, and the potential development of a framework to assist with energy saving initiatives. The intended framework was created to assist the author in finding a structured way to save energy by breaking down complexity of challenges into manageable steps.

3 LITERATURE REVIEW

Sustainability means the ability to maintain at a certain rate or level [6]. Thus, in relation to humanity, it means that we need to meet our own needs without compromising the ability of future generations to meet their needs. In addition to natural resources, we also need social and economic resources. Sustainability is not just environmentalism. Sustainable development is increasingly becoming a goal to which countries aspire. Overall sustainability has been defined in many ways, and is often considered to have three distinct components: environmental, economic and social [7]. Thus, embedded in most definitions of sustainability we also find concerns for social equity and economic development.

3.1 Energy Sustainability

In some ways, the concept of energy sustainability is simply the application of new technologies to the sustainability of energy, such as using the latest energy saving appliances. In other ways, energy sustainability is far more complex and involved. Energy sustainability involves the provision of energy services in a sustainable manner, which in turn necessitates that energy be provided for all people in ways that, now and in the future, are sufficient to provide basic necessities, affordable, not detrimental to the environment, and acceptable to communities, and people [8].

For clarification below are some definitions of Energy Efficiency and Energy Intensity:

Energy Efficiency, improves when a given level of output is provided with reduced amounts of energy inputs [9].

Energy Intensity, is measured by the quantity of energy required per unit output or activity so that using less energy to produce a product reduces the intensity [10].

3.2 Why Energy Sustainability is Important

In summary, energy sustainability relates to the limited amount of non-renewable energy sources on Earth, it is important to conserve our current supply or to use alternative renewable sources so that our natural resources will be available for the future generations. Energy conservation is very important as overconsumption of non-renewable sources creates an impact on the environment. Case-specific, our use of fossil fuels, these are ultimately the largest contributor to air and water pollution. Among various sustainability aspects, energy sustainability is arguably the most pressing socio-environmental concern of modern times [11]. The ever-increasing energy demand across the globe is generally satisfied with the elevated consumption of fossil fuels, leading to undesirable conditions such as acidification, global warming, air pollution, and land degradation [12]. On a different note, and viewed from the socioeconomic sustainability perspective, the capacity and efficiency of energy systems and widespread access to affordable energy, particularly electricity, are imperative components of socioeconomic equality. Countries with higher energy supply security and more efficient and extensive energy delivery networks have been more successful in pursuing national development, improving human wellbeing, and reducing poverty [13]. These concerns, collectively, contribute to the importance of the energy sustainability concept and the need for supplying more accessible, economically viable, environmentally friendly supplies of energy while increasing energy efficiency and eliminating energy waste [14], [15].

3.3 Industrial Engineering

The focus of Industrial Engineering is how to improve processes or design things that are more efficient and waste less: money, time, raw resources, man-power and energy while following safety standards and regulations. Industrial engineers may use knowledge of Maths, Physics but also Social Sciences to analyse, design, predict and evaluate the results and roadblocks of processes and devices [16]. In the Automotive manufacturing Industry Lean methods have been extensively implemented. Over time, the efficiency and reliability of these methods have been proven and thus adopted by other industries such as other manufacturing industries, construction, and even service industries. Most of these industries have realised that the elimination of 'waste' has become a fundamental requirement for operational performance and profitability [17]. Waste or 'muda' in Japanese is simply defined as anything other than the minimum amount of parts, materials, equipment, and work time specific to production [18].

3.3.1 The Seven types of waste

Taiichi Ohno (1912-1990) identified the first seven Lean wastes, also known as "Muda", in the Japanese Language. These wastes are excess inventory, overproduction, waiting time, unnecessary transportation, excessive processing waste, inefficient work methods, and product defects [19]. Waste can also be defined as something that is used or expended carelessly.

3.3.2 Waste and Energy focus in Manufacturing

A pilot study done at Columbia Paints- a paint manufacturer based in the United States revealed reduced production lead and cycle times, overproduction, material scrap, operator travel time, and downtime through an Energy focused project [20].

Agasthya [21] found through his studies on an Energy focused projects in Asia, that they highlight several kinds of wastes such as, operators and machines waiting for material to arrive (idle time), inventory of excess material, Overproduction, improper flow of materials between operations, and finally the effective use of equipment to optimize inputs such as labour and energy.

Bantowsky [22] in accordance with the Washington State Department of Ecology and Washington Manufacturing Services collaborated in a project to provide lean and environmental technical assistance to Canyon Creek Cabinet Company, and Lasco Bathware products. Certain Governments are clearly involved in assisting organisations through cleaner production methods that protect the environment.

Berghans [23] implies that the majority of Energy Efficiency improvements will materialise through the implementation of standards, regulations, manufacturing techniques, and management tools, which at the end of the day lead to short payback periods for the individual enterprises.

Riddleberger [24] investigated the establishment of a new system by IBM named “Green Sigma”. Green Sigma applies Lean Six Sigma principles to measuring and monitoring energy and water usage throughout an organisation's operations, and the Carbon Trade-off Modeller, which helps evaluate and balance carbon dioxide emissions and energy usage with other key factors throughout the supply chain costs, service and quality. He further explored the use of Green Sigma and found that robust green initiatives, resources and intellectual capital across the company are greatly improved.

The Federal Energy Management Program in the US conducted two pilot studies to demonstrate that behaviour-based programs can help reduce energy use and expenditures [25].

More business leaders agree that the shift to Green is necessary and, when done well, can be profitable, and that Lean, Lean Six Sigma, and other Continuous Improvement strategies could possibly be applied to integrated management systems as a framework for the shift to Green [26].

ISO 50001 ia an Energy Management system, designed to support organisations to improve energy use by developing their own energy management system (EnMS) [27]. However, if the organisations’ goal is to comply with a standard to “get the certificate”, the standard is the master and also a costly and time consuming annoyance [28].

4 METHODOLOGY

A Quantitative research project was undertaken in a leading pharmaceutical company in South Africa (which chose to remain anonymous) to investigate energy usage, and utilise Industrial Engineering techniques to support it.

The aim was to fully understand energy consumers within the facility and find potential energy saving projects to optimise the use of energy. Interviews with both internal and external contractor consultants, local municipalities, and energy proficient experts were carried out to better understand the overall dynamics for the organisation. In addition metering equipment was installed and the trending data was analysed to illustrate the behavioural aspects and dynamics of the equipment related to energy.

Given the large and open ended nature of the task, a framework was created to improve the scope and to fully understand where potential areas for improvement could be.The framework encompasses the relationship between Industrial Engineering and Energy. It also outlines the need for a comprehensive structured approach steering towards a starting point, the need for measurement, and other related criteria to practitioners wanting to undertake similar energy saving investigations.

5 RESULTS

The research found that a systematic approach was required in order to investigate the energy consumers within the organisation.

5.1 Step 1: Installed Capacity

The first step was to understand what the installed capacity was for the facility. In order to assist with this step site drawings were created and improved upon by detailing the incoming supply of both electrical energy and water. Illustrating the main meters for each (Figure 6, Appendix A).

In addition, the investigation into installed capacity yielded that complexity of billing scenarios exist under municipalities for each rate of consumer.

Such examples include the billing of electricity supply categories include Domestic usage, small business, prepaid, and commercial. Under each consumption is billed based on selective rates for usage per month. In addition, charges could be broken into summer vs winter categories and importantly as is the case with South African municipalities and Eskom, Standard, Peak and Off-peak rates are charged. Normal consumption rates are charges such as Kilowatt usage per hour(Kwh) as well as demand charges based on Kilovolt Amps (KVa), of which the peak number is billed. Another example is that of water, these include treated vs untreated water as a supply within a municipal area, residential vs commercial distinguishing rates, as well as Raw water charges outside the municipal area [29].

5.2 Step 2: Conduct Energy Audit

The second step was to carry out an Energy Audit. As an indication an Energy Audit is a form of analysing equipment to establish their theoretical consumption rate, and thus categorising them from high to low consumers. These efforts would then give an indication as to where efforts could potentially be focused to improve Energy consumption. The audit also has the benefit and serves as a guide toward investment in metering equipment (covered in the next step) in that to ensure relevant areas are measured which would lead to more significant savings. Most equipment suppliers provide equipment master data sheets from which theoretical energy consumption rates can be derived to assist with the energy audit.

Table 1. Theoretical Energy Consumption Data as per Energy Audit (Nov-2015 to Oct 2016)

Process	Theoretical Electricity kWh	%
Admin, Other	2708	0,25%
Air Compressor	55655	5,06%
Cooling	376366	34,20%
Equipment	4589	0,42%
Fans	285669	25,96%

Process	Theoretical Electricity kWh	%
Heating	167491	15,22%
Lighting	49501	4,50%
Smaller Drive Motors (Conveyors etc.)	44595	4,05%
Pumps	113968	10,36%
Total	1100542	100,00%

From the data obtained it was found that data needed to be segregated in order to establish the "vital few" segregated from the "trivial many" in order to select and shift the focus to the most important [30].

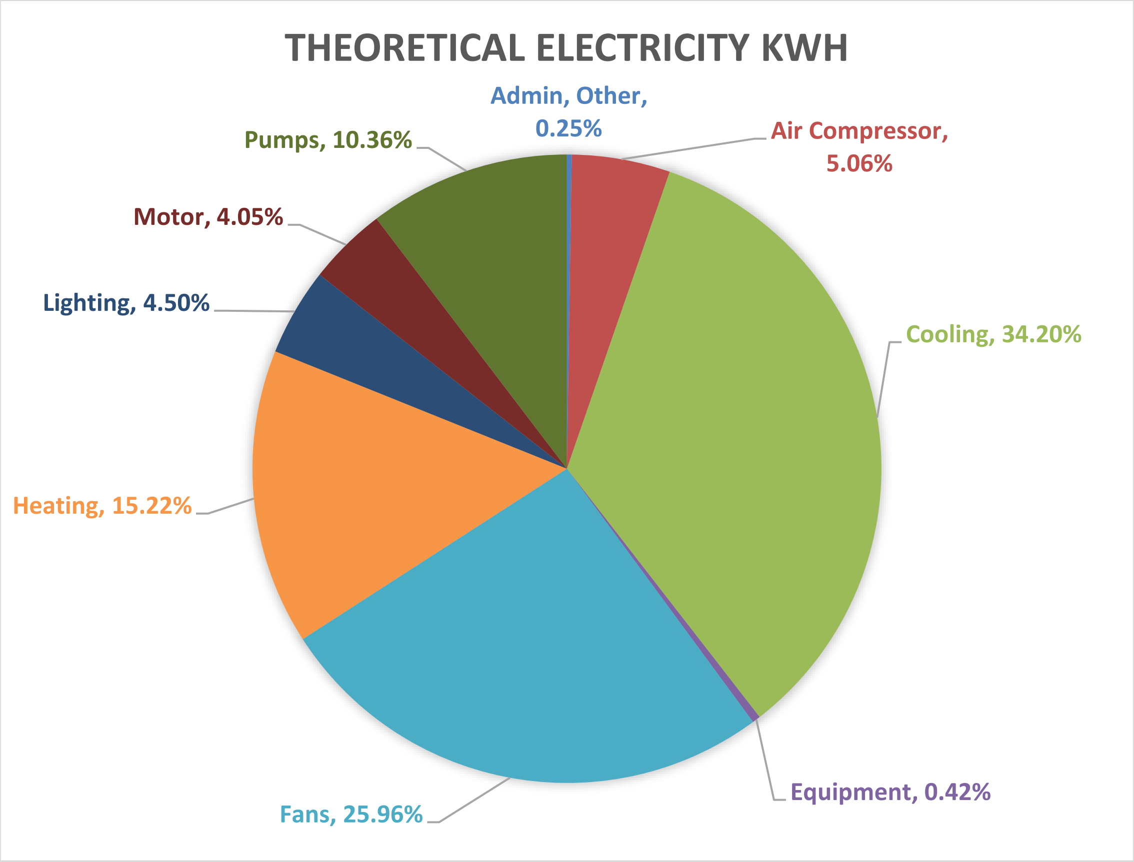

Figure 1: Pie Chart showing theoretical balance of energy use

It can be seen from the previous pie chart that the Significant energy consumers (electrical) are;

- Cooling - 34.20%
- Fans - 25.96%
- Heating - 15.22%
- Pumps - 10.36%
- Compressed Air - 5.06%

There are a multitude of smaller consumers such as lighting, administrative equipment and smaller drive motors ~10%, but the highest individual consumers are those listed above. In order to achieve significant energy savings it is generally accepted that the higher power consumers should be tackled first as even a small percentage saving on these large items would result in good benefits.

5.3 Step 3: Install Metering Equipment and Analyse results

The third step in the process is to install metering equipment and obtain real time data. Peter Drucker, an Austrian-American management consultant, educator, and author, whose publications and consultations has significantly contributed to the philosophical and practical foundations of the modern business corporation, Is famous for coining the term “What gets measured gets improved” [31].

Metering Equipment and subsequent software applications can selectively be installed based on the Highest users, at this pharmaceutical supplier cooling related to air conditioning indicated to be one of the biggest contributors. The pareto chart mentioned in the previous step assisted and provided an indication to where meters should be installed for the manufacturing site, Thus due to budgetery concerns, Theoretical Highest consumers were selected first and ultimately meters were rolled out to the rest of the site. In addition, return on investment calculations were made when selective meters were chosen. Following the success of illustrating the advantage of having real time data the decision was made and metering equipment was installed in all indicative areas as outlined by the Energy Audit for the pharmaceutical supplier.

There are numerous electrical meters on the market measuring many different components of electrical efficiency. In the most basic form and as an indicative measure, meters should be selected based on the consumption rate (Watts or Kwh) as well as demand rate (VA or KVA). These two basic measurements will give a good indication as to how much electricity is consumed as well as peak demand rates of equipment [32]. It was found beneficial to link these meters to the software databases that document the consumption rate over a period. Reports were drawn to indicate usage and peak demand rates at various points in time. The results in Figure 2 below illustrates that peak demand usage was during the facility start-up in the early mornings, with an average demand stemming during the day and then ultimately dropping off as the end of the day approached.

5.4 Step 4: What to Save?

The fourth step is to establish what can be done to save energy. There are multiple energy saving applications related to each selective equipment category available for intedened research and application. Energy saving projects are not unlimited and thus numerous options were investigated and decisions were made based on the largest return on investment [33].

However, it’s important to focus the energy saving initiatives on the data that is available and that served as an indicative measure in the previous steps.

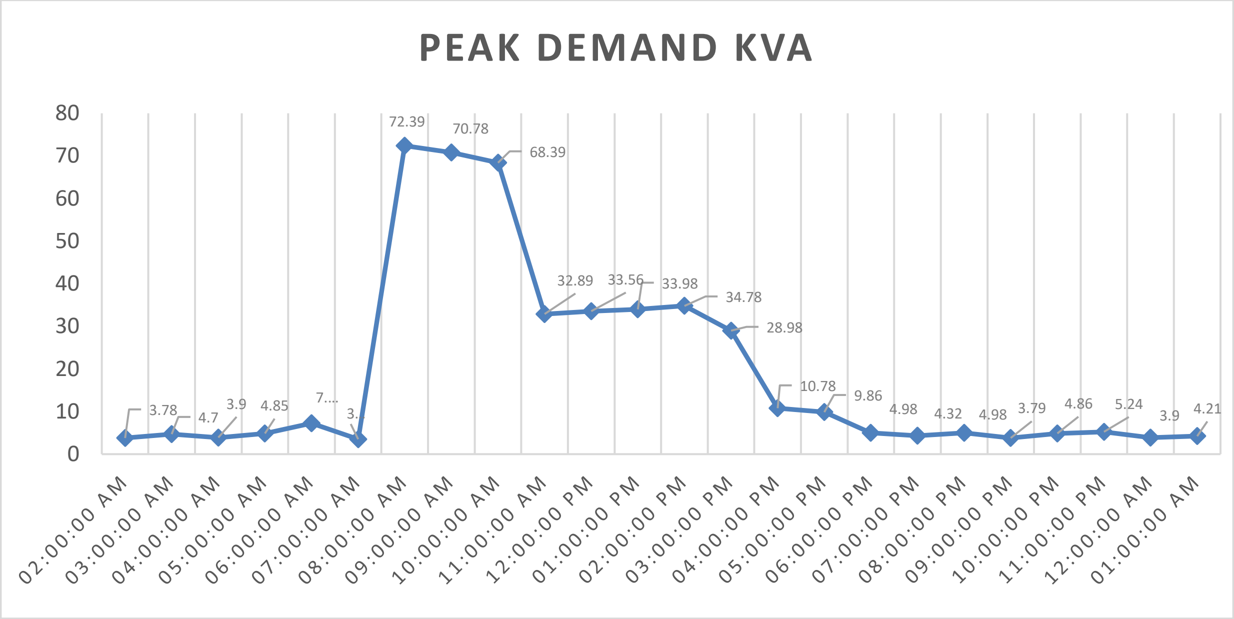

Figure 2: Chart illustrating Peak Demand (KVA) of power use at time of day

The organisation undertook multiple energy saving initiatives. The highest consumers were tackled first:

5.4.1 Cooling Tower Air Compressor & Ambient temperatures

Using the metering systems and graphical software mentioned in the previous step an analysis was made, the example below indicates how intricate measurement is related to energy savings. It discusses the impact of ambient temperatures and humidity related to energy consumed for AC compressors;

During the winter period the A/C compressors are not operating continuously however they are 'hunting', (starting and stopping) on a regular basis. Where there is a requirement to supply cooling during the winter period, due to high internal loads, the low ambient temperature and humidity at certain times should meet the internal temperatures. The graphs below provide an indication of the average and peak humidity and temperature experienced for weather data collected for the city of Port Elizabeth in the year 2016 [34]. The link between the weather data and the Energy usage is further discussed below.

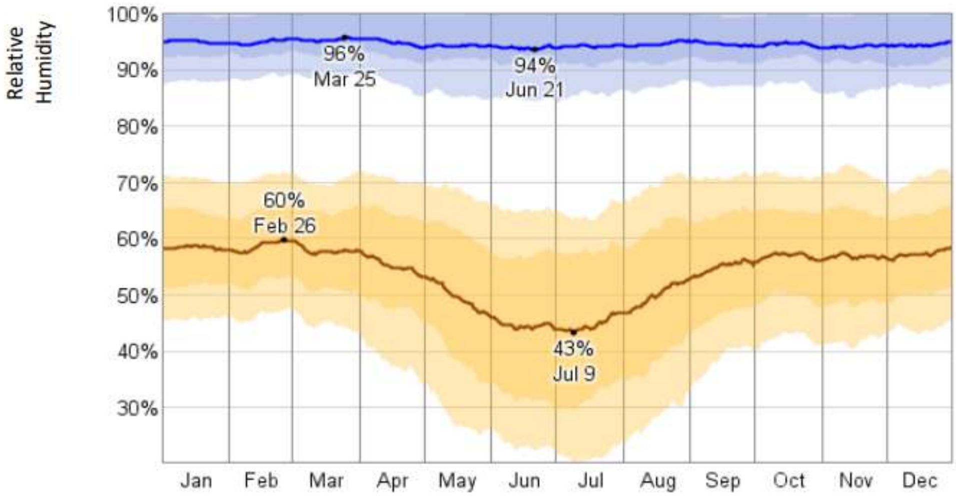

Figure 3: Chart illustrating the average daily high (blue) and low (brown) relative humidity with percentile bands

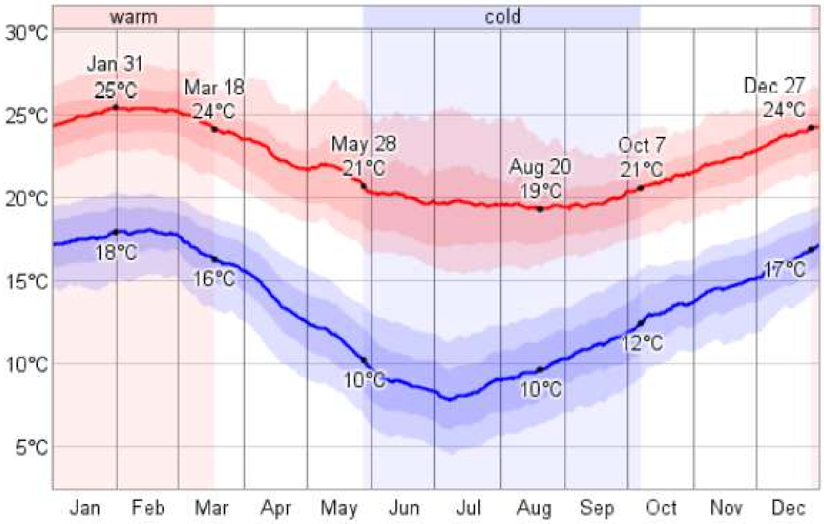

Figure 4: Chart illustrating The daily average low (blue) and high (red) temperature with percentile bands

5.4.2 Cooling Tower Air Compressor & Ambient temperatures

Free cooling is a method of using low external air temperatures to assist in chilling water, which can then be used for industrial process, or air conditioning systems. When the ambient air temperature drops to a set temperature, a modulating valve allows all or part of the chilled water to by-pass an existing chiller and run through the Free Cooling system, which uses less power and uses the lower ambient air temperature to cool the water in the system. Referring to (Figure 5) a bypass has been installed in a typical A/C system layout. During the winter periods this system is in operation. The tower fans and circulating pumps operate as per usual however the main compressors are not operated. The water towers provide the cooling requirement.

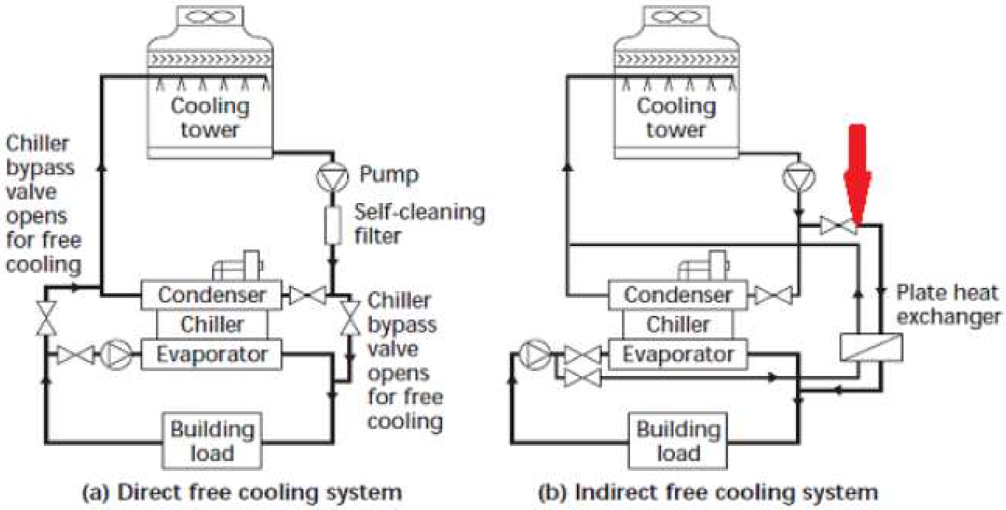

Figure 5: Alternative arrangements for free cooling in Cooling towers

The results obtained from the metering software by comparing the previous year's energy usage to that of the year after installation of the modulating valve and subsequent advantage taken by the ambient temperatures, has indicated a 12% Saving on Cooling electricity billing.

5.4.3 Equipment running when not in use

Subsequent energy savings were undertaken to take advantage of the metering of equipment installed indicating equipment that was running when not in use. Waste is defined as anything that does not add value [35].

5.4.4 Peak vs Off Peak running costs

In addition, Peak, Off Peak and standard rates were investigated.

Eskom and subsequent municipalities define the different Time of Use as follows [29];

Weekdays

- Peak Times: 08:00-10:00 and, 18:00-20:00
- Standard Times: 07:00-08:00, 10:00-18:00
- Off Peak Times: 22:00-07:00

Saturday

- Standard Times: 07:00-12:00, 18:00-20:00
- Off Peak Times: 22:00-07:00, 12:00-18:00

Sunday

- Off Peak Times: 00:00-24:00

It was found that equipment can be started up during the Off Peak times, thus resulting in a lower billing rate as opposed the having equipment started during peak times. A subsequent 6% saving was obtained in overall demand (KVA) billing [29], due to starting equipment during Sundays and the Off-Peak slot on Mondays.

5.5 Step 4: Key Performance Indicators & Reporting

As a final step the pharmaceutical supplier introduced daily, weekly and monthly energy reporting Key Performance Indicator (KPI) in addition to their current production performance monitoring metrics [10]. Each of these KPI's were then followed through with selected annual energy saving targets and subsequent budgets, which in turn were broken down into monthly targets for each category as part of the continuous improvement culture.

It must be mentioned that energy reporting and the results can vary, and in cases energy consumption might even increase even though energy saving initiatives are in place. This was indeed a finding at the pharmaceutical supplier. This was due to various factors such as an increase in demand, overtime worked in non-standard hours, Rework of parts requiring extra effort and energy, and new projects being launched.

5.5.1 Energy Intensity

It is for this reason that a popular way of measuring and reflecting energy consumption was investigated and thus the Energy Intensity ratio was introduced. The ratio consists of energy used in relation to the volume of product produced. The KPI serves to have an advantage over traditional energy only metrics such as Kilowatt hours (KWh) or Kilovolt amps (KVa), as Energy consumption can directly be linked to units produced [36].

Energy Intensity formulae:

$$EI_t = \frac{E_t}{Q_t} \qquad \textbf{\textit{(1)}}$$

Where;

EI_t is the Energy Intensity for manufacturing

E_t is the Total energy consumed measured in each Energy entities respective unit (Kwh, Litres, kg etc.)

Q_t is the Total number of units produced

6 CONCLUSION

The literature review suggest that both energy sustainability and industrial engineering focus on optimising and reducing waste where possible or finding potential ways to do so. It also points to the focus of effective, and efficient use and development of future technologies to further ensure long term sustainability. The Industrial Engineering, lean strategies, and framework adopted by the pharmaceutical supplier has found to be effective at illustrating the relationship between energy and industrial engineering. An Energy Management process was further suggested to be created and embedded as part of the organisations overall Operational Excellence and Lean Manufacturing culture [37], [27].

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APPENDIX A

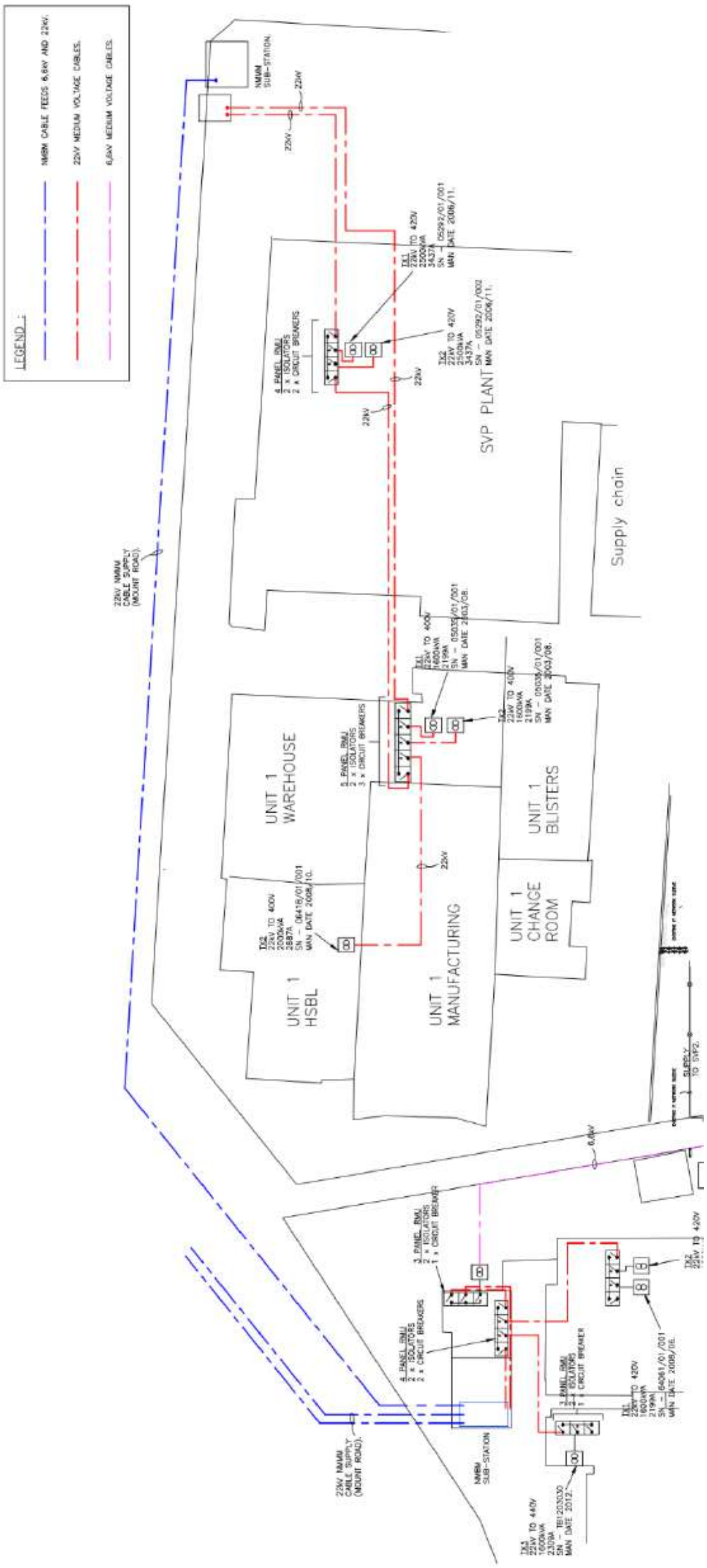

Figure 6: Installed Electrical capacity at a facility.

IMPLEMENTATION OF A QUALITY ASSURANCE SYSTEM FOR THE PRODUCTION OF CHROMITE SAND FOR RAPID SAND CASTING APPLICATIONS

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ABSTRACT

Rapid sand casting is the manufacturing of sand moulds and cores using three-dimensional printing. The binder-jetting process based on the furfuryl alcohol resin bonded sand casting method is the most popular method for rapid sand casting. Silica sand has been the de facto refractory sand used for rapid sand casting applications. However, recent investigations have shown that South African chromite sand could also be an alternative for special applications. To that end, laboratory tests have been conducted to optimise the production of furfuryl alcohol resin-coated chromite sand. The next step is to ensure that bulk production of the chromite sand consistently meets the required specifications. This paper presents and discusses the implementation of quality assurance for the production of chromite sand based on Quality by Design (QbD), theoretically developed for chemical-coated sand used in Additive Manufacturing (AM) technologies.

Keywords: rapid sand casting, chromite sand, furfuryl alcohol resin, quality by design

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1 INTRODUCTION

Additive manufacturing (AM), commonly known as three-dimensional printing (3DP), is a technique that uses digital three-dimensional data to produce a part by layering raw material successively until the part is complete [1]. This manufacturing technique, termed rapid prototyping, was originally used for fabricating models and prototypes as opposed to user functional components.

However, additive manufacturing has evolved significantly over the years in major manufacturing industries, such as aerospace, medicine, transportation, energy and consumer products, with the latter becoming popular as 3DP allows individuals to take control of and tailor products to their own requirements from the comfort of their home [2], in line with the principles of the Fourth Industrial Revolution (4IR).

3DP makes use of a binder jetting process that starts with the application of a chemical coated sand on a building platform using a re-coater, with binder jetted after each successive layer of sand, effectively gluing the layers together [3]. Figure 1 provides a diagrammatic summary of the process. Materials commonly used are metals, sands and ceramics. Owing to its low cost and improved production speeds, the production of large sand-casting moulds and cores is one of the most common uses for binder jetting [4].

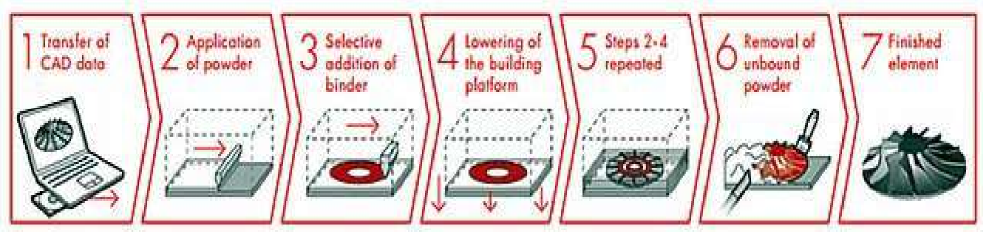


Figure 1: AM printing process summary [5].

Different sand properties, including but not limited to flowability, acid-demand-value, AFS clay content and sand moisture greatly influence the quality of moulds and cores, which ultimately affect their mechanical, chemical as well as final casting properties. Thus it is imperative that we characterize the refractory moulding sands by using methods such as quality management and design systems [6], [7]. Other aspects to be considered are friability, loss on ignition, fine aggregate angularity, mechanical strengths (transverse, tensile & compression), grain fineness and particle size distribution of the moulding raw materials.

A number of studies have been undertaken on the use of both silica and chromite sands as refractory materials for rapid sand casting and conventional moulding, with silica sand being the more popular owing to its low cost and greater abundance [8]. More recently, locally sourced chromite sands have been evaluated as alternative refractory materials to silica sand due to their technical advantages, which include high refractoriness and metal penetration resistance, excellent chilling ability and superior dimensional strength [9].

South Africa is the number one international producer and supplier of chromite sand essentially manufactured from Ferro-chrome production. Chromite sand is predominantly found in the Bushveld Complex, which houses approximately 70% of chromite reserves in the world [10]. It is being proposed that this chromite sand can be effectively beneficiated to produce a high value product, namely chemical coated chromite sand that can be used for 3DP in the era of 4IR.

In a paper presented at the 22nd Annual RAPDASA International Conference, Tshabalala et al. [11] shared their work on the optimization of process parameters for the manufacturing of a resin-coated chromite sand for use in a Voxeljet VX1000 3D printer based on certain criteria such as acid demand value and pH, angle of repose, flowability based on the angle of repose and transverse strength. The study demonstrated that a locally sourced chromite sand from a major South African supplier could be used for rapid sand casting.

Chauke et al. [12] investigated the suitability of five locally sourced chromite sands for their use in a Voxeljet VX1000 3D printer, with optimized parameters. They coated the sand with a sulphonic acid catalyst supplied by the original equipment manufacturer (OEM) and 3D printed mechanical testing specimens. The sand recoating behaviour and foundry sand properties were analysed. The study concluded that four out of five of the locally sourced chromite sands from major South African suppliers could be used for rapid sand casting.

Tshabalala et al. [13] looked into whether or not a locally acquired chromite sand could be used in a 3D printing process and determined the optimal additions of furfuryl alcohol resin and sulphonic acid catalyst for the foundry industry with the hope of localizing the sand coating process that could potentially play a major role in the local industry as the process requires a chemically coated sand which is currently imported from the OEM. The addition of sulphonic acid that proved to be optimal was 4wt% and 0.3wt% respectively based on sand weight.

QbD can be defined as “a systematic approach to development that begins with predefined objectives and emphasizes product and process understanding and process control, based on sound science and quality risk management”. It was introduced in 1992 by Juran in his book, *Juran on Quality by Design: The New Steps for Planning Quality into Goods and Services* [14]. Juran's process seeks to create customer satisfaction and guarantee the reliability of the product to avoid customer dissatisfaction. The aim is quality improvement, that Juran termed the Juran or Quality Trilogy.

This approach is utilized in different manufacturing industries (automotive, pharmaceutical, aerospace etc.) for its unique approach which advances the product improvement practice that leads to systematic product and process awareness, effective scale-up, control strategy and recurrent development [15].

QbD is used in order to lower risks while nurturing coherent design thought processes to eliminate a trial-and-error status quo. It has demonstrated a decrease in development costs as well as research lead times [16].

Recently this methodology was used as a guideline for the development of a QA framework for the production of a chemical coated sand used in AM technologies by van Tonder in his master’s research dissertation for locally sourced sands [6].

The overall goal was to decrease operational costs for the South African foundry industry as no QA procedures existed for chemical coated sand used for 3D printing of moulds and cores due to the high manufacturing cost involved with the purchasing of 3DP silica sand provided by the OEM Voxeljet AG, which comes pre-coated with sulphonic acid catalyst ready to use with the Voxeljet VX1000 3D printer.

Now that it has been scientifically established that South African chromite sand can be successfully as a raw material for additive manufacturing, the logical way forward is to produce the material in large quantity while meeting stringent specifications.

The main objective of this study is to ensure the development of a quality assurance (QA) framework, which will allow the bulk production of a chemical coated chromite sand that continuously meets required specifications for 3DP applications. In this paper, Quality by Design (QbD) is adopted as the methodology to develop such a framework.

2 METHODOLOGY

Several quality frameworks and presenting existing models that are extensively utilized globally like the Common Assessment Framework, Six Sigma, EFQM Excellence Model, IS0 20252:2006 Market, Opinion and Social Research, Balanced Scorecards as well as the ISO 9000 series that form part of the philosophies of total quality management (TQM) model [17]. TQM models present the idea of organized, all-inclusive methods to evaluate the quality of products produced. This model provides continuous improvement of overall production that comprise of support processes as well as management systems.

In this research paper, QbD has been selected as the methodology best suited for the development of a QA framework as it is a popular system for the production of new material, service or procedure development, more especially in the pharmaceutical and biopharmaceutical processes [18], in this case chemical coated chromite sand for 3DP.

Figure 2: QbD framework flow diagram.

This QbD practice consists of eight major components that function as the QA framework which could be utilized as guidelines for developing processes, procedures or work instructions for product and service development. These components are outlined in the flow diagram Figure 2 above and summarized below in Table 2 [6].

Table 1: Definitions of QbD framework components.

QbD Component	**Definition**
1. Quality Target Product Profile (QTTP)	Refers to the product information like ideal characteristics and features relating to safety and functioning of that product.
2. Critical Quality Attributes (CQA)	Refers to the product characteristics that should be within specific parameters to ensure that they meet the desired level of quality outlined in the QTPP.
3. Process Flow Diagram (PFD)	Assists in representing processes visually via the identification of the essential steps, contributors and resolutions within a process.
4. Critical Process Parameters (CPP) and Material Attributes (CMA)	Refers to the determining of CPP and CMA whose variability might possibly modify CQA. These attributes must be observed and controlled all through the process to ascertain process consistency, repeatability and accuracy.
5. Quality Risk Assessment (QRA)	Refers to the identification and control of potential quality risks during the improvement and manufacturing procedure to safeguard a high-quality product.
6. Design Space (DS)	Refers to the connection between process inputs and CQAs. Therefore it is used to determine the multidimensional arrangement and relations of input variables like CMAs and CPPs that have been validated to give assurance of quality.

7. Control Strategy (CS)	Refers to the listing of the identified monitoring or control actions to guarantee that the processes will stay within the predefined CPP and CMA range.
8. Continuous Improvement Strategies (CIS)	Refers to a list of plans with tasks designed to effect gradual and continuing development of products, services or processes through constant assessment, measurement and action.

The QbD components have been applied for the manufacturing of a furfuryl alcohol coated sand to be used for the production of sand moulds and cores by binder jetting process using a Voxeljet VX 1000.

The QA framework developed by van Tonder et al. in 2019 [6] served as a guideline for the development of chemical coating processes, procedures and work instructions in this research paper. Several QbD requirements addressed in van Tonder's study do apply to chromite sand. This investigation deals with the QbD requirements supplementary in the case of chromite sand.

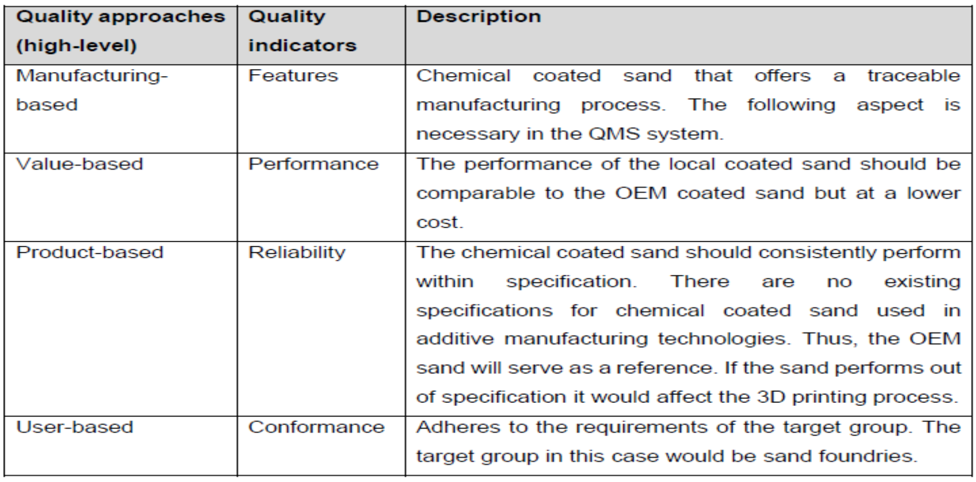
3 DISCUSSION

In this section, the QbD framework is discussed in the context of the production of a chromite sand for rapid sand casting applications.

3.1 Quality Target Product Profile (QTTP)

The product is the chemical coated chromite sand, the target/customer is the Foundry industry, in South Africa (S.A) or international. In the case of S.A, the industry involved will generally be foundry producing special types of manganese-steel components for the mining industry such as grinding media, pumps, etc. The QTTP identified in the Van Tonder et al. [6] study so apply and is presented in the table below.

Table 2: QTTP identified in the research paper.



Quality approaches (high-level)	Quality indicators	Description
Manufacturing-based	Features	Chemical coated sand that offers a traceable manufacturing process. The following aspect is necessary in the QMS system.
Value-based	Performance	The performance of the local coated sand should be comparable to the OEM coated sand but at a lower cost.
Product-based	Reliability	The chemical coated sand should consistently perform within specification. There are no existing specifications for chemical coated sand used in additive manufacturing technologies. Thus, the OEM sand will serve as a reference. If the sand performs out of specification it would affect the 3D printing process.
User-based	Conformance	Adheres to the requirements of the target group. The target group in this case would be sand foundries.

3.2 Critical Quality Attributes (CQA)

The procedure and key findings will be used to highlight the crucial aspects of the QA framework that will be used to ensure the quality of the chemical coated locally sourced chromite sands [9]. These characteristics are outlined in Table 4 below. The CQA of special importance to the chromite sand are the following:

Table 3: Chromite sand material sand selection checklist.

CQA	**Requirements**	**Specification**
Refractory Material	Grain shape	Chromite sand is angular sand by contrast to most silica sand. This could pose a challenge during the layer by layer manufacturing, thereby producing smoother surface finishes in castings.
	Chemical composition and Cleanliness	Cleanliness and Chemical composition affects the refractoriness. Only specific grade of chromite sand could be used for metal casing applications.
Chemical coating	Flowability	Sand with a low flowability could result in recoating errors causing mould defects or printing failures which could lead to clogging and re-coater issues.

3.3 Process Flow Diagram (PFD)

A process flow diagram (PFD) displays the processes visually by identifying the essential steps, contributors and resolutions within a process. It enriches the comprehension of the current process and aids in identifying problem areas that could affect the product's functionality and CQA. They are displayed in Table 6.

Table 4: Critical quality attributes.

Procedure	**Critical Attribute**
Physical Classification	Grain shape
Cleanliness	Turbidity meter will be used
Chemical Composition	X-ray fluorescence (XRF)
Flowability Verification	Flowability

In this research paper, the PFDs for the CQA that were suggested in the quality approach for chemical coated silica sand QA framework by van Tonder [6] were found to be applicable when it comes to locally sourced chromite sands as well in order to achieve the required QTTPs.

3.4 Critical Process Parameters (CPP) and Critical Material Attributes (CMA)

3.4.1 Physical classification procedure

These critical attributes are influenced by the method of mining as well as screening processes, with CMAs indicated in Table 7.

Table 5: Physical classification procedures.

Critical attributes	**Considerations**	**CMA**
Grain shape	Medium to high sphericity, allowing for good permeability as well as good flowability. This provides a high sand-packing density, which in turn allows for high strength at low binder content [19].	Medium to high sphericity [20].

Fine aggregate angularity	The fine aggregate angularity determines the amount in percentage voids in un-compacted fine aggregate material that fall within 1.18 mm, 600 µm, 300 µm and 150 µm standard sieve sizes [12].	32-34% (very-rounded) 35-38% (sub-rounded) 38-45% (sub-angular) >45% (angular) [4].

3.4.2 Cleanliness procedure

This critical attribute is determined by the moisture of the sand, with CMA indicated in Table 8.

Table 6: Cleanliness procedure attributes.

Critical attributes	Considerations	CMA
Turbidity	Turbidity or the amount of impurities in chromite sand has an impact on the sintering temperature of chromite sand. These impurities are low melting silicates and other trump material liberated from the chromite grain [10].	<0.05 NTU and 400 NTU [21]

3.4.3 Chemical composition procedure

These critical attributes are used to determine whether or not the chromite sand can be be used with an acid-cured furan no-bake binder system, the CMAs are indicated in Table 9.

Table 7: Chemical composition procedure.

Critical attributes	Considerations	CMA
Sintering temperature	The critical temperature for sintering is reached when 60 % of the chromite sand sample's total mass undergoes sintering. A study done in 2021 by Kabasele and Nyembwe 2021 on local chromite sands [10].	Sintering temperature >1577.55 °C [10].
X-ray fluorescence chemical analysis	The composition of sand affects the refractoriness of the moulding sand, the pH and the acid demand value, hence they need to be quantified [7]. If not done, its chilling properties will be inadequate	Silica (SiO_2) <1%, [19].

3.4.4 Resting period procedure

This critical attribute is influenced by the method used to store the acid-coated chromite sand, with CPP included.

Table 8: Resting period procedure.

Critical attributes	Considerations	CPP
Resting period	Studies conducted in 2021 by Chauke et al. and Tshabalala et al. proved that the flowability of sulphonic acid coated chromite sand improves after a storage period of 2 days [12], [11].	Minimum 48 hours storage.

3.4.5 Catalyst verification procedure

These critical attributes are influenced by the method of determining the amount of acid used to coat the chromite sand processes, with CMAs included.

Table 9: Catalyst level verification procedure.

Critical attribute	**Considerations**	**CMA**
% acid/sand weight	A study conducted by Tshabalala et al. in 2021 entailed an optimization of sulphonic acid coated chromite sand between 0.1 and 0.5wt% BOS with 0.3wt% being optimal [11]. The optimal percentage of coating weight was later confirmed in 2021 by Chauke et al. on 5 locally sourced chromite sands [12].	Minimum 48 hours storage.

3.4.6 Flowability procedure

This critical attribute is influenced by how long the chemical coated chromite sand was rested/stored, as well as the type of container used for storage with CMA included.

Table 10: Flowability procedure.

Critical attribute	**Considerations**	**CMA**
Flowability - angle of repose	Studies conducted by Chauke et al. and Tshabalala et al. proved that the flowability of sulphonic acid coated chromite sand improved after a storage period of 2 days [12], [11].	Minimum 48 hours storage.

3.5 Quality Risk Assessment (QRA)

Refers to the identification and control of potential quality risks during the improvement and manufacturing procedure to safeguard a high quality product. The risks were discovered and are displayed in an Ishikawa diagram methodology in Figure 5.

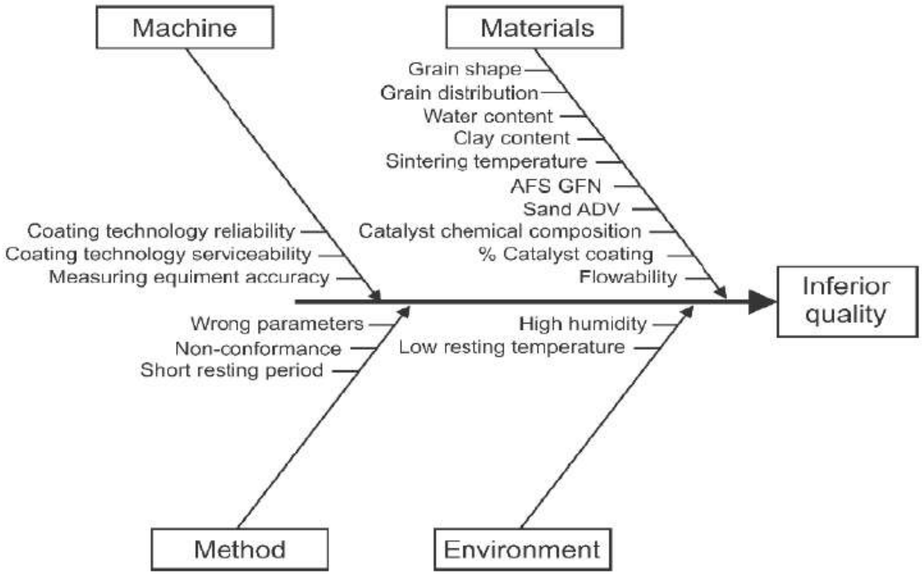


Figure 3: Chemical coating process risks [6].

3.6 Design Space (DS)

The performance of the refractory material used in moulds and cores plays a crucial role in producing high quality castings. A quality assurance checklist was compiled for the chemical coating process design space as it was identified as a potential area of risk that could influence the quality of the chemical coating process specific to chromite sand.

Table 11: A refractory material quality checklist.

Process	Consideration	Specification
Chemical coating	Fine-aggregate angularity	32-34% (very rounded) 35-38% (sub rounded) 38-45% (sub angular) > 45% (angular)
	Grain shape	Medium to high sphericity
	Resting period	Min 2 days
	Coating ratio	0.3% BOS
	Angle of repose	$\leq 45^o$
	XRF	$SiO_2 < 1\%$
	Turbidity	< 0.05 NTU and 400 NTU

3.7 Control Strategy (CS)

Refers to the listing of the identified monitoring or control actions to guarantee that the processes will stay within the predefined CPP and CMA ranges. The in situ monitoring systems that were highlighted to designate whether or not the chemical coated chromite sand adheres to specification are shown in Table 14.

Table 12: Control strategy critical attributes.

Critical attributes	Monitoring systems/standards	Specifications
Fine-aggregate angularity	ASTM C1252	Test for determining the amount in percentage voids in un-compacted fine aggregate material.
Grain shape	AFS 1107-00-S	Test for determining shape of sand grains.
Sintering Temperature	German VDG procedure 26.	Test for measuring temperature at which 60% of sand will be sintered.
Angle of repose	ASTM C1444-00	Standard test for measuring the flowability of powders.
X-ray fluorescence (XRF)	ASTM E1621-21	Machine used to measure the silica (SiO_2) content.
Turbidity	ISO 7027-1:2016	Test used to measure water quality.

3.8 Continuous Improvement Strategies (CIS)

The ISO 9001 standard stresses 6 techniques to guarantee continuous development in a process, which comprise:

- Design and development review
- Control of design and development changes
- Monitoring and measurement of processes
- Control of non-conforming products
- Corrective actions
- Preventive actions

4 CONCLUSION

This study aimed to develop a quality assurance framework based on the QbD method for producing high-quality chemical-coated local chromite sand for rapid sand casting. The refractory material's bulk production will meet the specifications for 3DP applications using a Voxeljet VX1000 printer. The study has extracted the properties of particular importance for foundry chromite sand. It also added new features previously not considered by previous researchers on this sand moulding raw material. This research anticipates the successful beneficiation of local chromite sand for three-dimensional printing applications, providing South Africa with an additional competitive advantage globally.

5 FUTURE WORK

Future work will include the implementation of QA in the case of a small production of chromite sand in one of the SA local mines. Moreover, viability studies are being carried out to foster the adoption of rapid sand casting in the local foundry industry, especially with the Voxeljet VX1000 3D printer.

6 LIMITATIONS

This study's limitations include using a single binder jetting process based on the Voxeljet VX1000 3D printing machine and the limited number of local chromite sand samples.

7 RECOMMENDATIONS

The angle of repose should be tested thoroughly to ensure good quality sand is being used. This ensures that clogging of the re-coater is prevented. A resting period of a minimum of two days for the coated sand is essential to allow the carrier fluids to evaporate. This reduces the capillary forces between the chromite sand particles, allowing for improved flowability of the chemically coated sand.

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AN ASSESSEMENT OF RAPID SAND CASTING THROUGH THE LENSES OF RESOURCE EFFICIENT AND CLEANER PRODUCTION (RECP) FRAMEWORK

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ABSTRACT

The South African metal casting industry is required to align with resource efficient and cleaner production (RECP) approaches to reduce the cost of operations and comply with the United Nations' sustainable development goals. One way to achieve RECP is the adoption of rapid sand casting processes. Rapid sand casting is based on the additive manufacturing of sand moulds and cores from which castings are produced. Rapid sand casting related systems, including EOS laser sintering and Voxeljet binder jetting, have been locally available for the last decade. It is regarded as the green alternative process as it can develop and promote economically viable and socially desirable development alternatives while protecting the environment. This paper discusses the rapid sand casting processes through the lenses of the RECP framework.

Keywords: Resource efficient and cleaner production, Carbon footprint, Metal casting, Rapid sand casting

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1 INTRODUCTION

Throughout the second half of the 20th century a growing worldwide movement has attempted to change the way industry interacts with the environment and to reduce its environmental impact by changing industrial behaviour and technology [2]. Researchers are continually trying to find green alternative processes in order to reduce environmental impact, improve resource efficiency and save costs. The main objective is to meet the needs of the present without compromising the ability of future generations to meet their needs, in other words, creating a balance between the environment, society and the economy. This led to the development of the concept of resource efficient and cleaner production (RECP).

RECP is a sustainable development strategy aimed at minimizing waste and emissions by managing energy, water, and environmental and financial resources in a sustainable and cost-effective way. RECP practices look at improving the means to meet human needs while respecting ecological carrying capacity. The RECP method is a continuous application of preventive environmental strategies to processes, products and services in order to increase efficiency and reduce the risks to humans and the environment [2]. RECP covers the application of preventive management strategies used to increase the productive use of natural resources and minimize waste generation.

Metal casting is the process of manufacturing metal parts by pouring molten metal into a mould cavity where it is allowed to cool and solidify, and then extracted. The metal casting industry, also referred to as the foundry industry, is one of the most important manufacturing industries since castings are essential in almost all engineering sectors. Castings are most often used in mining, automobile and train locomotive manufacture, the power industry, and the manufacture of electrical equipment, machine tools and parts for other kinds of equipment **[1]**. Due to its high levels of pollution, the metal casting industry is under pressure to reduce its environmental impact. The government together with metal casting associations has set up new norms and guidelines to be followed in order to reduce the industry's pollution levels. Rapid sand casting is one of the green alternative technologies able to contribute to achieving the RECP requirements.

Rapid sand casting is the process of manufacturing sand moulds and cores without utilizing patterns. The metal casting manufacturing process is divided into five parts, namely pattern making[1], mould and core making[2], melting and metal processing[3], casting[4] and finishing[5]. Rapid sand casting not only eliminates pattern making but also minimizes the amount of waste generated during the sand moulding process. It uses additive manufacturing technology to fabricate sand moulds layer by layer through a process called binder jetting [3]. Binder jetting is a process where liquid binder is jetted onto layers of powdered material in accordance with the CAD design of the 3D part being made [4]. Applications of new technologies such as binder jetting in the metal casting industry lower greenhouse gas emissions, including carbon dioxide.

South Africa promotes the application of the RECP practices through a national programme called the National Cleaner Production Centre of South Africa (NCPC-SA). The metal casting industry, being one of the industries that consumes large amounts of water and energy, and produces various by products and emissions that cause serious water, air and soil contamination, needs to adopt RECP **[4]**. The adoption of rapid sand casting technology could be one way of achieving RECP in the metal casting industry.

2 ENVIRONMENTAL IMPACT OF METAL CASTING

Metal casting is characterized as an energy-intensive process because of the large amount of energy required for manufacturing one item and its resultant high carbon footprint [2]. The majority of emissions in metal casting come from processes such as mould and core making, metal melting, pouring, cooling and shakeout [3]. Some of the emissions associated with metal casting are harmful and poisonous gases, dust particles and waste pollutants. The major environmental issues associated with foundry industries are disposal of solid wastes, high electricity usage and melting of ferrous materials [4]. Foundries are required to align with environmental management legislation. This is largely achieved through sustainable manufacturing. Sustainable manufacturing is defined as a manufacturing process with reduced energy use, water use and waste generation. This, in general, is what is known as resource efficient and cleaner production.

The overall environmental impact of foundry industries is determined by part design, material used, choice of melting furnace, percentage of secondary (recycled) material and usage of cast products. Process parameters, such as pouring temperature, core and mould making, and casting yield, also have an immense impact on the environment [5]. Metal casting is classified as an energy-intensive process because of the large amount of energy required for manufacturing [6]. Since this paper is focused on how rapid sand casting can meet the RECP requirements, the main environmental issues that will be discussed are those associated with conventional sand moulding process.

Key environmental concerns with sand moulds in metal casting are the emissions of harmful poisonous gases, generation of dust and waste pollutants. Sand waste from foundries in conventional sand moulding has been recognised as the most persistent waste problem in foundries. Mould mixtures lose their properties after several uses resulting in large amounts of sand waste. Even though sand reclamation processes are recommended, a proportion of new sand is required for the production of quality moulds therefore it is inevitable that some sand will be lost from the system. The waste sand is normally discarded in landfills, reclaimed for off-site use or put to beneficial re-use [1]. The sand tends to produce dust containing binder remains which has a negative environmental effect.

3 RECP REQUIREMENTS IN THE RAPID SAND CASTING PROCESS

RECP is measured by the reduced resource consumption and the reduced environmental impact from materials, emissions and accidental releases per unit of production, trade and consumption of goods and services over their full life cycles. Production efficiency is the optimization of the productive use of natural resources (materials, energy and water) [7]. The three dimensions of sustainable development are production efficiency, environmental management and human development, as shown in Figure 1.

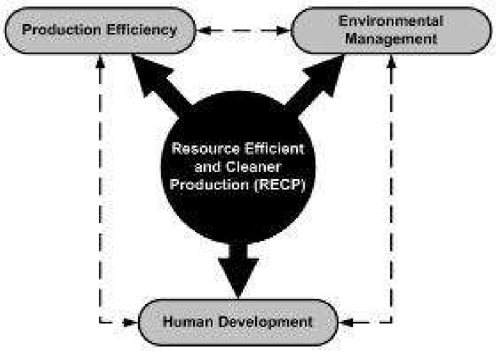

Figure 1: The resource efficient and cleaner production dimensions of sustainable development [3]

3.1 Production efficiency

Production efficiency is the optimization of the productive use of natural resources (materials, energy and water) by enterprises and other organisations. The conventional moulding process constitutes 7–20% of the overall energy consumption of a foundry [8]. Rapid sand casting is regarded as a resource efficient process due to the fact that it offers reduced energy consumption, cost savings and reduced production lead time.

3.1.1 Energy consumption reduction

The energy consumption in rapid sand casting depends on the type of 3D printer used. The power consumption of 3D printers ranges from 5000 W to 10 300 W. A study was performed in which a printer with a 10 300 W energy consumption was evaluated in order to determine the maximum energy consumed while manufacturing rapid sand moulds. In this work, the VX500 Voxeljet 3D printer was considered. It was determined that if the density of the parts to be produced is 1.738 kg/m^3, the specific energy consumption for printing a mould is 1.08 MJ/kg [6].

3.1.2 Cost savings

The implementation of RECP methods offers reduced operational costs and improved profitability. The costs involved in conventional sand moulding processes are generated from the labour, tooling, manufacturing and energy costs. 3D printing of sand moulds and cores saves up to 75% in costs. In direct comparison to conventional production, rapid sand castings show a clear cost saving [9]. Rapid sand castings are the direct fabrication of sand moulds using the additive manufacturing technique, where the pattern fabrication is completely eliminated unlike conventional moulding. Production of complex parts, such engine blocks, is difficult in a single mould cavity, as an intricate internal shape is desired. A secondary element, called a core, is thus required inside the sand mould. In contrast, the binder jetting technique can incorporate the core design within the mould thus, in most cases, eliminating the need for a separate core design. The core is positioned inside the mould cavity allowing it to cast an internal feature [6]. Since the rapid sand-casting process eliminates the pattern and core making steps, the concomitant costs are removed, thus reducing the final production costs. Conventional moulding is also a labour-intensive process, whereas rapid sand casting uses new technologies and artificial intelligence which only require a few operators. In this way rapid sand casting saves on labour costs.

3.1.3 Production lead time reduction

One of the main advantages of rapid sand casting over conventional sand moulding is the reduction of production time. The overall time spent on conventional moulding is a combination of core making time, mould making time and fettling time. As discussed in the previous section, rapid sand casting is a patternless process and due to its ability to design more complex shapes, some complex sand castings can be produced without a core. This tends to reduce the lead time of the overall manufacturing process significantly. Furthermore, in rapid sand casting multiple mould components can be produced in a single operation [6]. However, one of the disadvantages of rapid sand casting is the limitation of the mould size. Each 3D printer model has a print size limit. Rapid sand casting is therefore advantageous for small production runs and small castings.

3.2 Environmental management

Environmental management is minimizing the impact on the environment and nature by preventing the generation of waste and emissions, and improving the management and productive use of chemicals. Rapid sand casting offers reduced waste generation and a reduction in the overall carbon footprint of the process.

3.2.1 Waste reduction

The moulds utilized for both rapid and conventional sand casting are used only once as they are destroyed when the cast part is removed. Rapid sand casting, however, has been proven to save on the resource (sand) usage. With conventional sand casting, one tonne out of every two tonnes of casting sand used is disposed in landfills. With the incorporation of rapid sand casting in the conventional mould making process, around 60% of the sand can be saved, thereby reducing the environmental impact **[6]**. In 2018 Hawadar and Zhang compared the fabrication of sand moulds using rapid sand casting with those made using conventional moulding. The overall weights of the sand moulds of the conventional moulding and rapid sand casting were found to be 34 kg and 23 kg respectively. The used sand weights for mould and core in conventional casting were found to be 301 kg and 7.7 kg and for rapid sand casting were 90 kg and 3.3 kg for the same type of casting **[10]**. The conventional sand mould process produces large amounts of harmful silica dust that causes silicosis or lung cancer **[11]**.

3.2.2 Carbon footprint

The carbon footprint is the amount of greenhouse gases emitted, mainly carbon dioxide (CO_2), during an activity or by an organization. South Africa is one of the highest emitters of CO_2 in the world, the reason being that coal, due to its great abundance, is the predominant fuel used for energy generation [12]. Most studies have found that foundry operations consume high amounts of energy and that most of the energy wastage lies there. Foundry energy efficiency can be improved by implementing more environmentally sustainable processes. On average 1.9 tonnes of CO_2 are emitted for every tonne of steel produced and the iron and steel industry accounts for approximately 4-5% of the total world CO_2 emissions [12]. The introduction of more energy-efficient processes in foundries plays an important role in energy saving and the reduction of carbon emissions.

Different processes account for different carbon emissions, choosing appropriate design parameters guarantees reduced emissions and improved production quality. Zheng et al. [11] studied the carbon emissions from different sources of foundry operations, the results are shown in Figure 3. Foundry carbon emissions are a combination of emissions from the material processing, energy consumption and pollutants. The results revealed that the greatest contributor to the foundry carbon footprint is energy consumption, accounting for 26.53%, material resources, 1.87%, and emissions from pollutants, 1.30%, as shown in Figure 3 [11].

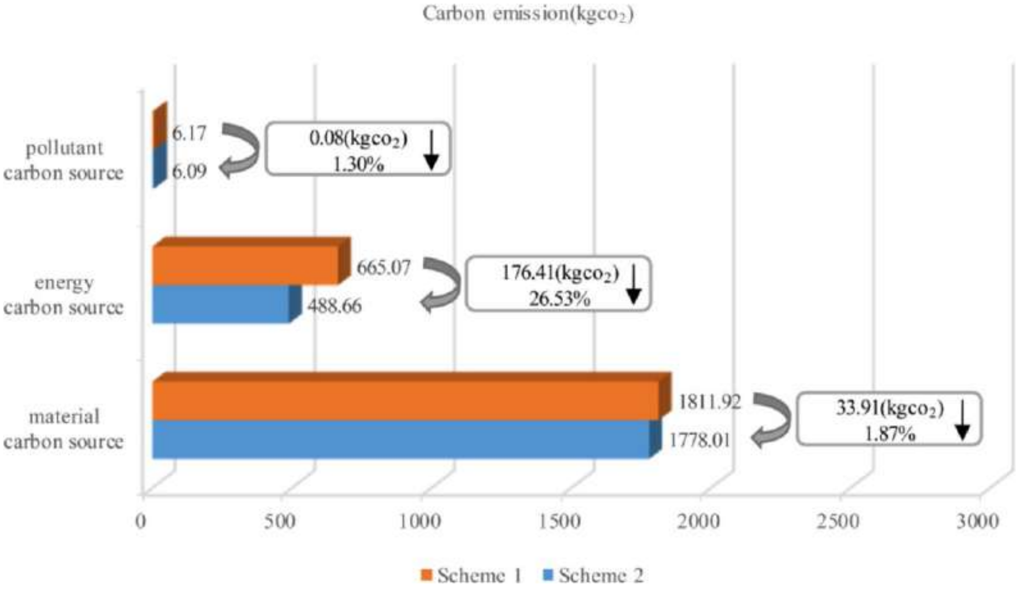

Figure 2: Foundry carbon emissions (Adapted [11])

Rapid sand casting is known for reducing overall energy consumption, material usage and waste generation, which are the main contributors to carbon emissions or the carbon footprint of the metal casting industry.

3.3 Human development

Human development is the minimizing of the risks to people and communities from enterprises and other organizations, and supporting people's own development. Surrounding communities are often exposed to emissions generated by these companies which greatly affects their health and the environment as a whole. As rapid sand casting is known to reduce pollution, adoption of rapid sand casting reduces the risks the metal casting industry imposes on the surrounding communities.

4 CONCLUSION

The main aim of this theoritical exercise was to analyse if rapid sand casting meets the resource efficient and cleaner production (RECP) requirements. The sustainability dimensions of the RECP framework included resource efficiency, environmental protection and social enhancement. Rapid sand casting has the potential to be a resource-efficient mould production process due to its reduced energy requirements, which reduce metal casting's carbon footprint and its reduced material consumption, which is achieved by sand waste reduction. Rapid sand casting also could reduce the production cost and the lead time of the manufacturing process, thus improving total productivity efficiency. The adoption of additive manufacturing in the foundry industry should therefore be encouraged in South Africa. Future studies will quantify the gains that can be achieved by adopting rapid sand casting in compliance with the RECP process.

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DETERMINATION OF TURNAROUND TIME FOR MAIZE RAIL WAGONS

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ABSTRACT

The maize export process is important as it affects food provision processes. For the year 2020-2021, South Africa exported 2,867,790 tons of maize. It is therefore important that export processes be efficiently managed to handle maize carried through the port operations. Currently, the standard time to unload a shunt of wagons needs to be re-evaluated, as there have been major operational changes, hence the need to determine new turnaround times. This will assist in proper planning for human resources, plant machinery and other resources needed for the unloading operation. The turnaround time (TAT) for rail wagons is an important key performance indicator, especially for a congested agricultural terminal with capacity constraints. Process mapping and flowcharts were utilized, and historical process data was analysed to determine the activity times. This paper shows the determination of TAT, identifies inefficiencies & issues that impact on the performance of the wagon unloading.

Keywords: Turnaround Time, Process Flow, Standard Time

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1. INTRODUCTION

The maize export process is important as it affects the food provision processes of the receiving country. For the year 2019/2020, South Africa exported 1,809,573 tons of maize [1], and for 2020/2021, this value increased to 2,867,790 tons. It is therefore important that the export processes be efficiently managed to handle an increase of maize carried through the port operations. The maize come from the farmer's storage through road trucks and rail wagons, depending on the volumes that need to be transported from inland to the agricultural terminal. Once the required volumes have been attained, the vessel calls in at the seaport so that maize can be loaded onto the vessel/ship for export, through the conveyer belt. For this paper, the focus is on unloading of maize rail wagons into grain silos (landside operation).

At the moment, the standard time to unload a shunt of 26 wagons needs to be re-evaluated, as there are major operational changes and the previous times are outdated, hence the need to determine new turnaround times. This will assist in proper planning for human resources, plant machinery and other resources needed for the unloading of maize operation. The turnaround time (TAT) for rail wagons is an important key performance indicator a port terminal, especially for a congested agricultural port terminal with capacity constraints. Having minimal turnaround time and less delays means that more rail wagons can be unloaded, thus affecting the whole value chain of the maize export process.

The agricultural port terminal is a principal element of the export process for maize. The agricultural port operations provide an important link in between rail freight and maritime supply chains [2]. Goedhals-Gerber [2], further stresses that efficiency and performance can contribute fundamentally to a country's competitiveness. It is therefore important that all inland operations of the terminal are efficient as export vessel volumes can be reached quicker, thereby allowing ships to call in earlier and load cargo, so that more cargo can be exported. Figure 1 below shows export volumes from 2017 to 2021. For the year 2020/2021, there has been an increase in export volumes of maize [1], and this value is estimated to slightly decrease to 2,191,456 tons. This affords the agricultural port terminals the opportunity to be more competent and utilize the limited temporary storage area efficiency to accommodate increasing export volumes of maize.

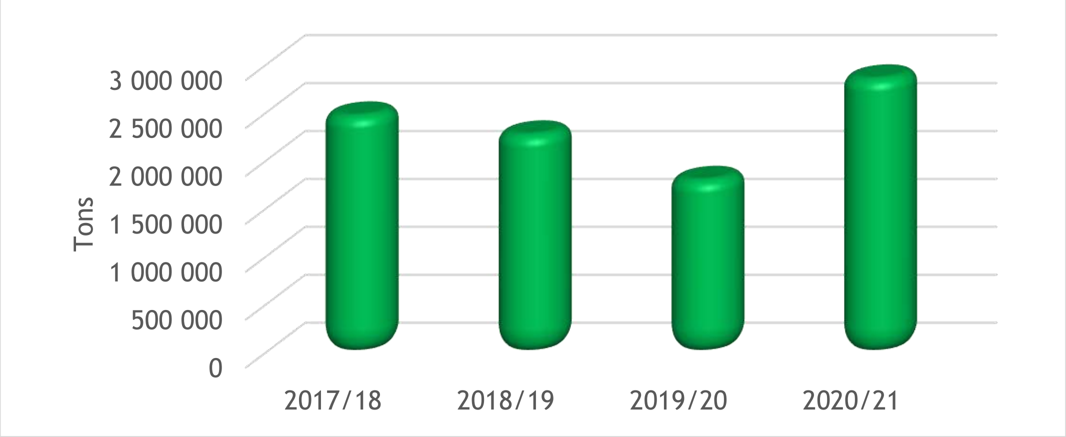

Figure 1: Export volumes for maize for South Africa

Source: [1]

The turnaround time is a critical indicator in port operations, both on the land and seaside operations. The most common land-side performance indicator is the average wagon turnaround time [3]. It can be defined as to the time it takes a wagon to complete the delivery and essentially a difference between the gate time in and the gate out time at the terminal [4]. Among other key performance indicators of the terminal, the rail wagons turnaround time is measured daily to make sure that there is a strong focus on efficiency, as to ensure that the terminal is competitive and able to compete with other bulk terminals in the vicinity of the port. Many factors may affect the TAT including communication from the freight rail office, which is under a different entity. The availability of freight wagon drivers is also an important contributor because only the freight train drivers can remove the wagons once the unloading operations have been completed at the agricultural terminal. This means that efficient communication systems are critical in ensuring that there is minimal time where the terminal is waiting for the rail wagons to be removed.

Figure 2 below summarizes the steps in the maize export process from the time of harvest until it is loaded into the vessel for export. The focus of this paper is the time between the rail wagons are called in from the transit area, unloading of cargo and when they leave to the transit area.

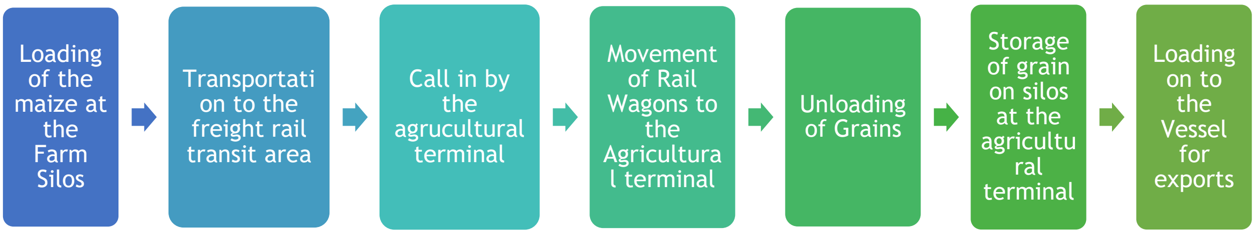

Figure 2: The overall export process from the farm to the vessel.

The operation is characterised by manual processes of rail wagon shunting by cargo workers. After the wagons have been shunted into the system of conveyer belts, they are then unloaded into silos. The machinery of the conveyer belt controls this process. Once each rail wagon has been emptied into the conveyer system, cargo operators move the rail wagon from the system so that other wagons can be emptied as well. The weighing system is built into the conveyer system, thereby limiting the unloading of multiple rail wagons. Therefore, the unloading process allows one rail wagon at a time. The average number of wagons per shunt is 26.

2. LITERATURE REVIEW

In his article, van de Vyer [5], stated that transporting maize from inland South Africa to the harbour via the rail wagons is still cheaper than using road trucks. The rate per ton by rail wagon for approximately 410 km’s (Reitz to Durban) is estimated at 255 rand per ton, and the estimated road truck’s rate 420 rand per ton [5]. This means that it is cheaper by 165 rand per ton to transport maize via the rail wagons. The other reason that rail is preferred for transportation of maize to the harbour is that road trucks have created congestion in the harbour precinct, causing an increase in road maintenance costs [5]. This raises the importance of efficient operations at the agricultural terminal. The terminals need to utilize techniques such as lean management, material flow analysis process mapping and measuring of key performance indicators such as overall equipment efficiency to improve efficiency. The concepts that will be explored in the literature review include lean management, value stream mapping, and process mapping.

2.1. Lean Management

Santos [6] asserts that that lean thinking organizations have lean manufacturing with the aim of eliminating waste in production processes. The use of lean management tools such as Value

Stream Mapping can assist in further identifying non-value adding activities that may improve the efficiency of the maize export process.

There are various points of improvement ranging from shunting delays to waiting for preparation of statuary papers. The types of wastes that are being reduced can in this process also include, waiting, unnecessary transporting, excess motion, defects as described by Ferciq et al [7]. To provide a structured solution for the inefficiencies challenge, a lean management initiative of DMAIC can be used systematically and structurally, to analyse and eliminate all inefficiencies in the maize export process. Figure 3 shows the cycle of the DMAIC problem solving method and the main points of each step.

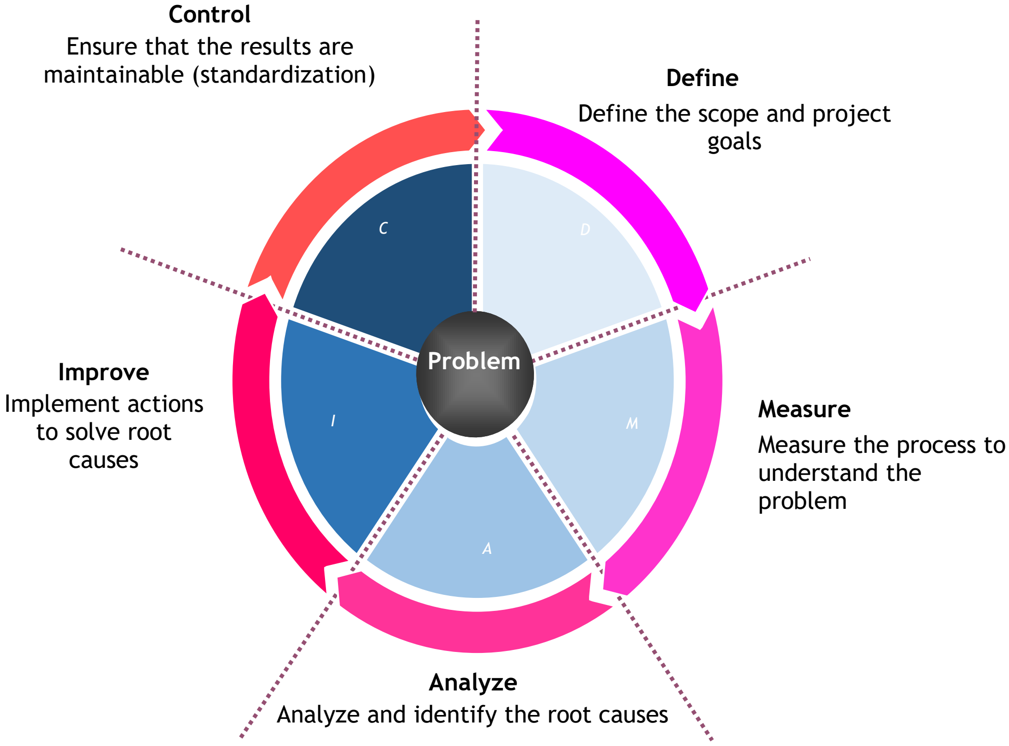

Figure 3: The cycle of the DMAIC problem solving method

Source: [8]

Figure 4 below shows the activities that need to be completed in each step of the DMAIC process. This guides the problem-solving methodology to be valid and easily understood.

Define	• Formulate project team for improvement and goals • Assess financial & efficiency impact • Set target or deliverables
Measure	• Collect data using work studies, historical process data • Identify problems and map the process
Analyze	• Analyse each step of the maize unloading process for validity and identify root causes
Improve	• Formulate and rank improvement solutions • Check data to see if the goals and deliverables have been met
Control	• Observe the process for progress and stabilize the improvements

Figure 4: Five Steps for DMAIC Process

Sources: [9] and [8]

2.2. Process Mapping and Flowcharts

In order to understand the process clearly, it is important to map the process so that the flow is identified, and each specific step is defined. Process mapping is a systems thinking approach used to understand, analyse, and optimise processes within complex systems [10]. A process map is a diagrammatic representation of a sequence of actions for a given activity [11]. This exercise assists in explaining and visualizing steps in a clear manner. The process mapping assisted in understanding the role of the agricultural terminals' employees versus the role of the freight rail entity. It assisted in obtaining clear data collection points and duration for each activity in the maize export process, from the time the rail wagons are called into the premises of the terminal, until all the unloading has been complete, and the wagons are collected by freight rail entity's drivers.

2.3. Value Stream Mapping

Value Stream Mapping can be described as an analytical technique of the process' current status [12], and a value stream mapping exercise assists to identify the gaps and inefficiencies in the process. In a study by Chen et al. [13], value stream mapping was used to realize increased inventory leanness by 60.90% through cost efficient procurement. Through the use of tools such as value stream mapping, the total operation time was reduced by 81%.

In another study, Nandakumar [14] , used Six Sigma DMAIC in a food processing company to reduce bottlenecks and non-conformance in production and packaging processes. During the measure phase, they utilised Value Stream Mapping to indicated nonvalue adding activities. From these studies, it can be seen that VSM is a powerful tool that can be used to improve efficiencies by identifying nonvalue activities and can be implemented further to improve the efficiency of the in the unloading process of maize.

3. METHODOLOGY

A method study was conducted prior to the observation to map the possible scenarios of the process. The observation of the actual process was conducted over a period of a week to ascertain the correct working procedures. The standard operating procedures had not been updated over the years and therefore the actual observation was needed. The existing standard operating procedures manual was revisited to confirm if there were additional processes that were added on the observed process.

Historical data for the unloading process was obtained from the records. This is data collected over months; however, the date range of 3 months was selected to be the appropriate period for the study. This includes invoices from the weighbridge, clocking times for staff, grading notes, unloading times and other related data. The data was then analysed, and standard times were obtained from the analyses. Turnaround time of maize rail wagons was obtained from operations template and analysed.

4. RESULTS & FINDINGS

4.1. Process Flow

Figure 5 below, is an overall process for offloading the maize rail wagons at the agricultural terminal from inland to the silo (grain storage). The important part is the time delays in between the process, which have an impact on the process efficiency and overall plant availability.

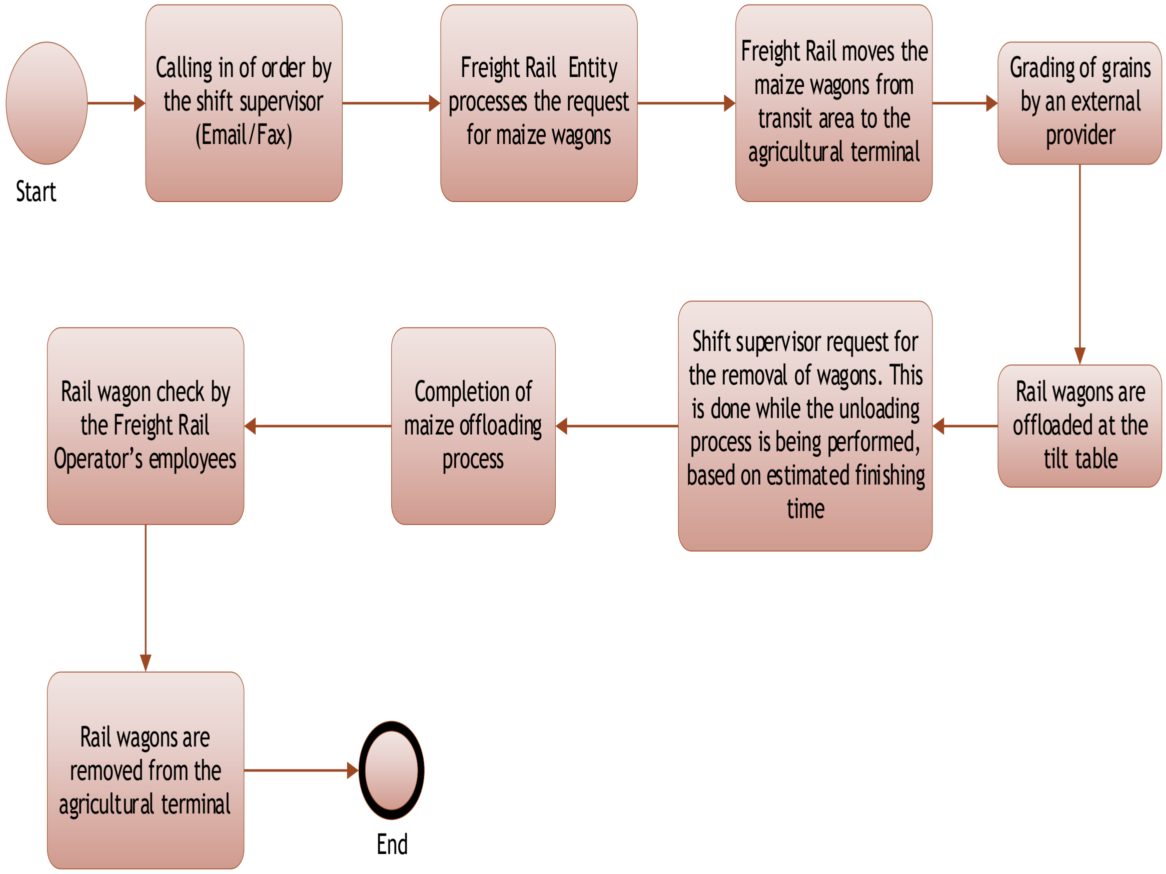

Figure 5: Process flow for the maize offloading process at the agricultural terminal (landside)

4.2. Breakdown of Turnaround Time

As stated in the introduction section, the window period for the data was 3 months. The terminal works for 24 hours a day using a 3-shift system of 8 hours. Therefore, the total available time for working in the 3-month period was 2160 hrs. The following table explains the breakdown of the time into different activities. Furthermore, the bullet points below show how the time was accounted in the three-month period.

- Waiting time for wagons to arrive after sending order request (WTR)
- Time spent grading the maize (TSG)
- Time spent on preparation of receipt notes (TSP)
- Offloading time (OT)
- Waiting time for wagons to arrive after sending wagons removal request (WTRR)
- Mandatory Breaks (MT)
- Unaccounted idle time (UIT)

Figure 6 below shows the total time spent on each activity. This data was obtained after the analysis of historical data and observation of the process. The majority of the time was spent waiting for the wagons to arrive from the transit area of the freight rail operator which shows that there is a need to look at reducing this time so that the process can be more efficient.

Activity	**Total activity time during the 3 month period (hours)**
WTR	705
TSG	203
TSP	208
OT	504
WTRR	404
MT	132
UIT	4
TOTAL	**2160 hours**

Figure 6: Breakdown of total working time for the 3-month period

Further statistical analyses were done to determine the turnaround time per shunt of 26 rail wagons. The time taken to unload a rail wagon was found to be 8.63 minutes per wagon. On average, the WTR time per shunt is 2.60 hours and grading (TSG) was 0.75 hours. The WTR time varies from time to time. It takes an average of 0.77 hours for the maize to be graded per shunt. On average, the waiting time for wagons to arrive after sending wagons removal request (WTRR) is 1.5 hours. In order to calculate the total turnaround time, we first calculate the operational turnaround time related to a shunt of 26 rail wagons. Thereafter, the mandatory breaks are factored in to get the total TAT of a set of wagons. This means that TAT will be impacted by the issues such as when the mandatory breaks are taken, and whether the shunt commenced at the beginning or middle of the shift.

So, the terminal has one dedicated line of maize unloading. There is a major project for development of the second line. With these capacity constraints, there is usually a consistent flow of wagons that need to be unloaded. The equation to calculate the turnaround time

Turnaround Time (TAT) = TSG + TSP+ OT x number of rail wagons + WTRR
= 0.75 + 0.77 + 8.63 min per wagon x 26 wagons + 1.5 hours
= 6.76 hours.

The total turnaround time = operational turnaround time + mandatory breaks. After obtaining this value, the terminal management can then use this for tactical and strategic planning of volumes and capacities that the terminal can handle in an appropriate horizon. Notably, there is a considerable time of 2.60 hours that the terminal is not working because they are waiting for the rail wagons to be shunted to the agricultural terminal. Since the freight rail operator and the agricultural terminal are separate operating organizations, an initiative of continuous improvement such as DMAIC can be utilized to improve efficiency of this process.

5. RECOMMENDATIONS

In the interim, before the DMAIC process is introduced to address inefficiencies, the following is recommended:

5.1. Regular tracking of WTR time at the Central Logistics Committee.

From Figure 6, it can be seen that 32% of the time was spent waiting for the wagons to arrive. Furthermore, the average WTR time per shunt was 2.6 hours. There is a need for centralized planning of all the rail wagon flow along the entire logistics chain. The establishment of a central planning committee involving the rail operator and the agricultural terminal is essential. The actions from this committee can impact the turnaround time and address issues such as

- Operational schedules not aligning between the freight operator and agricultural terminal
- Incomprehensive visibility of train movements and delays
- Clashing schedules between the freight operator and agricultural terminal, resulting in shift personnel and equipment

The key performance indicator that can be measured on this aspect is WTR time and can be measured fortnightly, at a tactical level of the central planning office.

5.2. Re-evaluation of freight service design to include the agricultural terminal

The current train service design is insufficient, and processes are variable. For example, the time taken to receive wagon orders by the train operator varies from 10 min to 2 hours, and these further impact train and shunt crew availability. Regular tracking of the time taken to receive wagon orders may assist in improving the service and this can be measured at weekly, at a tactical level.

5.3. Realignment of Key Performance Indicators between the freight and the agricultural terminal.

There needs to be KPI alignment between two entities in the landside unloading of maize process and this will require transparent restructuring of KPIs between two entities. Table 1 represents some of the key performance indicators that can be tracked at both the operational, tactical, and strategic levels.

Table 1: Activities and possible actions that can be implemented

KPI	Entity	Impact	Horizon	Frequency
Time taken to grade maize	Agricultural terminal	Tracking this performance measure can assist with information visibility and provide data to identify opportunities of improving this time to less than current 0.75 hours.	Operational	Daily, for every set of wagons
			Tactical	Weekly
WTR Time	Central Logistics Committee	Close monitoring of WTR will provide a better view of factors that cause delays. The quick wins items such as alignment of clashing shift schedules between the agricultural terminal and freight rail operator can be looked at in a more strategic manner.	Operational	Daily, for every set of wagons
			Tactical	Weekly
Time taken to prepare receipt notes	Agricultural terminal	This is one of the areas where improvements can be easily implemented, including digitization of the preparation of receipt notes.	Operational	Daily , for every set of wagons
			Tactical	Weekly

5.4. Focus on other enabling activities that will support productivity

5.4.1. Information Visibility

The wagon turnaround performance and time spent in different parts of the agricultural terminal needs to tracked and visible. This includes location of offloaded and unloaded rail wagons, as well as the visibility of en-route train traffic for the agricultural terminal and the freight rail operator. This can be achieved through the use of spreadsheets and dashboards. The agricultural terminal is already using an enterprise resource planning (ERP) system for other operational functions such as procurement and human resources. It is therefore critical that spreadsheets tracking these KPI's be integrated into the ERP system (SAP ERP System), so that powerful reporting tools such as SAP Business One Dashboard or Microsoft Power BI can be fully utilised to assist with information visibility in the terminal.

5.4.2. Communication

There needs to be a co-location of planners between the two entities. This includes agreed and documented communication roles, responsibilities, and communication of anticipated problems, performance targets and KPIs for each shift. Tracking of performance targets is already being done as an imperative in all business levels, from shift to executive management level, however, the integration of this tracking to an ERP system-linked dashboard is lacking. In the future work, this will be prioritised.

5.4.3. Mindset

There needs to be a sense of urgency in turning around wagons. Furthermore, interpersonal relationship and team building across the different entities need to be employed as to inculcate the culture of working together.

6. FUTURE WORK

The next stages of this research will focus on the digitization of some processes. The current manual process for preparation of receipt notes can be done digitally as there are handheld terminal scanners that have already been purchased. The full integration with the ERP system will be further explored. The DMAIC process will be used analyse and eliminate all inefficiencies in the maize export process and the savings will be measure. The new improvements will bring in improvements in the terminal operations, and a change in standard operating procedures. Therefore, new training needs for the employees will be identified.

7. CONCLUSION

The turnaround time is a critical indicator for this process. Among other key performance indicators of the terminal, the rail wagons turnaround time needs to be tracked to make sure that there is a strong focus on efficiency. The tracking mechanism for the TAT will be through Business Intelligence tools such as Microsoft Power BI or SAP Business One Dashboard. The times will be captured on the tools such as spreadsheet and integrated on the ERP system. It was important to determine the standard time for turning around a 26-wagon set . The TAT for each shunt is 6.75 hours. This will assist in planning for employees, plant machinery and other resources needed for the unloading of maize operation. This paper suggests possible actions that need to be conducted to address the issues of information visibility communication and mind-sets. The WTR time per shunt is 2.60 hours per shunt and WTRR is 1.5 hours. These times are controlled partly by the freight operator, and continuous improvement techniques such as DMAIC are utilized to recommend for the issues identified in the study. Further work needs to be done to address the inefficiencies and the next step is to explore the DMAIC processes on the WTR and WTRR times.

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USING LEAN MANAGEMENT TO ADVANCE SUPPLY CHAIN EFFICIENCY

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ABSTRACT

Lean management has been traditionally used in the manufacturing world but recently there has been a move to apply lean manufacturing principles in the supply chain management. There is an ever-growing pressure for organisations to achieve shorter lead times, lower costs, and better quality. Lean provides a systematic approach to optimize value stream from suppliers to consumers through elimination of non-value adding activities. This paper looks at the benefits of implementing lean in supply chain, supply chain performance review tools, evolution of lean in other sectors out of manufacturing and how it can be implemented in an integrative manner with other approaches such as Industry 4.0. It further reviews the peer reviewed case studies where lean has been implemented successfully and how can the results be amplified further.

Keywords: Lean management, Lean Supply Chains, SCOR

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1 INTRODUCTION

The term 'lean' was used in 1980's as authors attempted to describe the success of Japanese manufacturing corporations, the most prominent being the Toyota Production System (TPS) [1]. In general, the literature defines lean management as a set of tools and methods that improve customer value through the reduction of non-value adding tasks and actions at an operational level [2]; [3], maintained by a strategic organisational philosophy of continuous improvement and culture [4]; [5] and [6].

Lean management offers a customer-centric philosophy grounded on five ideologies (define value, identify the value stream, flow creation, introduce pull to customer and pursue perfection) with the goal of waste reduction from of the process [6].

Traditionally lean has been used in the manufacturing world but recently there has been a move to apply lean manufacturing principles in the supply chain management. The indication by Santos [7], further stresses the point that lean thinking organisations have lean manufacturing with the aim of eliminating waste in production processes.

Waste can take form of anything over than the minimum required amount of equipment, materials, parts, and working time that are essential to production [7]. The types of wastes that are being reduced are, overproduction, waiting, transporting, overprocessing, unnecessary inventory, excess motion, defects as described by Fercoq et al. [8].

The aim of this paper is to highlight the implementation of lean management in supply chain, and it further reviews the successful cases of lean supply chain and importance of supply chain performance tools. The critical key performance indicators are presented as a blueprint/template for organisations to adapt. The paper looks at integrative approach of implementing lean management as there have been major advances in business management philosophies, practices, and industrial revolutions such as Industry 4.0. The implementation of these new advances is being adopted while there are existing business improvement approaches such as lean management, and there is a need for an integrated approach.

2 METHODOLOGY

For this study, a qualitative approach was adopted. This type of research enables the researcher to focus in a particular area and gather information through various means. The use of secondary research was adopted, to analyse the existing data and connect with the objectives of the new study. In this case study, data was collected through the review of existing literature.

3 LEAN MANAGEMENT IMPLEMENTATION IN THE SERVICE INDUSTRY

Lean management has been implemented dominantly in the manufacturing sector. However, there have been successful implementation of lean management in other sectors such as the higher education sector. Kazancoglu and Ozkan-Ozen [9], investigated the eight wastes in higher education institutions (HEIs). The authors utilized a decision-making method which included fuzzy decision-making trial and evaluation laboratory. The study identified that most occurring wastes in business schools were repeated tasks, unnecessary bureaucracy, errors because of communication problems, excessive number of academic units and creation of an excessive amount of information.

According to Robinson and Yorkstone [10], the University of St Andrews (UK), saved over £130 000 pounds by developing a new software for process management. As one of the outcomes manifested by implanting lean, the university also saved money by removing job adverts from external websites. The resources used to procure job-advertising services were redirected to the university's treasury. The internal staff benefited by being capacitated with new skills to manage this process.

Arlbjørn et al. (Arlbjørn, Freytag, & de Haas, 2011) investigated the lean practices in the Danish municipal sector through two questionnaire surveys and three case studies and to elaborate on whether it makes sense to apply the lean concept in a service SCM context. They found out that customers' demands in the municipal sector are driven by public political processes such as elections that shape the customer value and add more complexity when compared to the private sector.

In their exploratory study, Habib and Jungthirapanich [11], found out that there is not much literature addressing the supply chain management for the universities let alone research supply chain as a major element in the academic supply chain for the universities. They provided a new dimension to understand the contribution of supply chain management for prosperity of university processes. They further developed a conceptual model focusing on two main contributions to the end customer of the university such as the society including human resource contribution and research contribution.

Kress and Wisner [12], analysed a supply chain for a library with the view to assess and improve its efficiency. The authors employed an action research methodology to map the supply chain of the University of Nevada, Las Vegas Lied Libraries' information resources. They then developed a supply chain model, analysing it and developing linked performance measures. The major advantage of this journal article is that the model was developed and implemented successfully.

These cases confirm that lean has been implemented successfully in many sectors that are not involved in traditional manufacturing. This shows that lean has evolved from the conventional applications and can be transferred as an enterprise model that can be emulated by the non-automotive and non-Japanese environments based upon the premise that manufacturing problems and technologies were "universal problems" facing management [13].

4 LEAN SUPPLY CHAIN

Lean has been implemented in many organisations and there is a wealth of knowledge within published in journal articles. The focus of this literature review will be on lean in supply chain related activities. There is growing pressure for organisations to achieve shorter lead times, lower costs, and better quality. This is supported by the research conducted by Al-Aomar and Hussain [14], where the principles of lean management have been incorporated into the supply chain integrative approaches in the hotel industry.

Therefore, in supply chain, lean provides a systematic approach to optimize value stream from suppliers to consumers through elimination of non-value adding activities. Iyer et al. [15] suggest that firms need to focus on the determinants of superior supply chain performance to be more cost efficient and responsive to dynamic business targets.

a. Lean Supply Chain Cases

Lean supply chains are constituted by a set of organisations directly linked by upstream and downstream flows of materials and data that work in a concerted manner to reduce costs and waste through efficient focus on customer needs [16]. It is important to further look into how lean has been implemented in the supply chain environment as it will assist in grounding the research to the concept of lean supply chain. This section will provide a highlight of case studies where lean supply chain was implemented successfully.

In a study by Chen et al. [17], lean inventory management was used to realize increased inventory leanness by 60.90% through cost efficient procurement. Inventory leanness is a company's minimization of its inventory comparative to counterparts in the same sector [18]. In this case, customer service levels were also increased with ominously less inventory costs. The total operation time was reduced by 81% by using lean initiatives and radio frequency identification (RFID) technologies to improve the efficiency and effectiveness of the supply chain process. Major tools such as value stream mapping (VSM) were used in this case.

In the aerospace industry, there has been many cases where lean has been implemented effectively and benefits realized. Garre et al. [19] published a paper where the benefits of lean were tabled. The cycle time for the welding process was reduced by 25% for pressure vessel capacity of 500 L (from 48 min to 36 min) and by 26 % for 220L pressure vessel (from 54 min to 40 min.)

In a study by Rahman et al. [20], a manufacturing company through implementing the Kanban system (one of the lean tools), reduced operational costs, wastes and scrap. The company minimized losses and overproduction of stock was controlled with flexible workstations. Although this study was completed when the company was still on the infant stages of implementing lean, it demonstrated the benefits of using lean to optimize the value stream of the company.

In their paper, Afonso and Cabrita [21], proposed a conceptual framework for management of lean supply chains which focused on integrating monetary and non-monetary performance dimensions. This conceptual framework expands the current data on lean supply chains and provides indication of how lean supply chain performance assessment [21].The proposed framework was implemented in a small medium enterprise operating in the fast-moving consumer goods (FMCG) sector in order to better understand the suitability of this conceptual framework.

A study by Farsi et al. [22] validated an optimization framework for improving service supply chain performance using DMAIC cycle. They used a bespoke service provider to test the applicability of the framework. This included identifying KPIs for different supply chain elements and links. This study contributed to the current research by developing a performance optimization framework for service supply chain using DMAIC cycle. In another study, Acero et al. [23] used value stream mapping and DMAIC to reduce the order processing time.

5 BENEFITS OF IMPLEMENTING LEAN IN SUPPLY CHAIN

Lean manufacturing has been used effectively by organisations as a wholly new way of thinking the organisations roles in the value chain and improve organisational performance [24]. The lean management strategies are aimed on how to deliver cost effective good quality products quickly [25]. Successful lean management approaches include

- Toyota's TPS (Toyota Production System)
- Nestlé's NCE (Nestle Continuous Excellence)
- Heineken's World Class Manufacturing

Further research has shown that there are great benefits for supply chain when it adopts lean techniques; such as sustainability of the industries increasing unit outputs with less inputs through elimination of non-value-added activities to maintain effectiveness and profitability [26]. Gunasekaran et al. [27] also studied the e-procurement adoption in the small medium enterprises (SME's) in the South Coast area of Massachusetts. The survey employed revealed that when the SME's adopted greater use of e-procurement, there were visible benefits and positive organisational performance such as improved process efficiency, revenue increase and process effectiveness. This affirms that the e-procurement is an important component of general procurement in a supply chain hub.

Arif-Uz-Zaman and Nazmul Ahsan [28] proposed a set of metrics, based on lean management, to evaluate supply chain performance. The study used a fuzzy model to assess the performance of cost competitive supply chains [28]. This further shows that, when implemented supply chains, lean provides measurable benefits.

In their study, Wee and Wu [29] investigated how value stream mapping supports lean supply chain. The study further identified opportunities for continuous improvement for waste elimination [29]. These opportunities include

- Standardized operations
- Improved overall equipment efficiency
- Reduced inventory costs and variability.

6 SUPPLY CHAIN PERFORMANCE REVIEW TOOLS: SCOR OVERVIEW

Mazzola et al [30], suggested that the supply chain review tools such as, Supply Chain Operations Reference (SCOR) and lean management are successful methodologies that have a common objective of achieving customer satisfaction, through optimization of processes, while ensuring that the business is profitable. While each aspect of these philosophies operate on different organisational levels, their objectives are similar [30]. This suggests that they can be integrated together, through the SCOR supply chain strategic methodology [30].

Research by Anham et al [31], used a SCOR model as a medium of performance measurement metrics that control the implementation of lean supply chain management. This further supports that there is a causal relationship between lean and supply chain review tools in supporting successful implementation of lean supply chain.

The Supply Chain Operations Reference (SCOR) is naturally a tool released by the Supply Chain Council (SCC, now APICS) in 1996 to integrate business process reengineering, benchmarking, operations measurement into a an integrated framework for businesses to use [32]. The model offers a logical method for identifying, evaluating, and monitoring supply chain performance. According to Huan et al. [32], the framework contains the following aspects:

- Standard descriptions of management process
- A framework of relationships among the relationships
- Standard metrics to measure process performance (e.g., inventory turnover, productivity ratio, customer fill rates, order to cash cycle time etc.
- Management processes that produce best in class performance
- Standard alignment to software features and functionality

As described by Apics [33], SCOR identifies five core supply chain performance attributes: reliability, responsiveness, agility, costs, and asset management. SCOR model contains a modelling tool, a set of Key Performance Indicators (KPI's) and benchmarking. The model's generic scope has five distinct process elements for management activity namely:

- Plan
- Source
- Make
- Deliver
- Return

Curbelo and Delgado [34] stated that there is a need for a proper management of supply chain, and this will assist businesses to improve their competitiveness by increasing supply chain efficiency, through optimal use of resources that fulfil customer needs. They further stated that better accuracy in planning and control of flow of materials and data in the whole value chain, improves relationships among segments of the chain, reduce inventory levels and shorten delivery time. The typical traditional categories of supply chain performance measures of the company include 3 metrics such as service measurement, cost measurement, and return-on-assets [35]. These metrics are described as short-term financial performance measures. In the 2000's Brewer & Speh [36], stated that there is a need to achieve the balance between non-financial and financial results across short-term and long-term time horizons.

Then SCOR model provides a unique framework that links business processes, management indicators, best practices and technologies in a unified structure to support communication between partners in the supply chain and improve the effectiveness of management and supply chain improvement activities [34]. The SCC has a large number of companies including Collins Aerospace, Weir, Express Point, DuPont and many others which are utilizing the SCOR model for strategic performance [37]. The table below shows examples of key performance indicators that can be integrated in the SCOR model, as a cascading to the operational level of the company. These are based on a case study looking at the procurement system of research equipment for an HEI in South Africa.

Table 1: Typical Key Performance Indicators for Procurement in an HEI

Key Performance Indicator	Frequency	Tracking Level	Person Responsible
Number of reminders sent to researchers	Quarterly	Tactical	Procurement Department Head
Number of queries solved via the chatbot	Weekly	Operational	Procurement Officers
Number of requisitions and orders with incorrect specifications	Weekly	Operational	Procurement Officers
% Accuracy for requisitions and orders	Weekly	Operational	Procurement Officers
Number of unsigned requisitions on the ERP System by Management	Every 2 days	Operational	HOD in which the requisition is raised as per delegation system
The time between capturing of the approved requisition system to when there it is converted to a purchase order.	Biweekly	Tactical	Procurement Team Head of Sections
% incomplete requisitions	Weekly	Operational	Administrative Staff for respective department
% of orders completed via digital ITSS module	Monthly	Tactical	Procurement Team Head of Sections
% of manual orders completed	Monthly	Tactical	Procurement Team Head of Sections
possible KPI's to be tracked: time take to complete the requisitions	Monthly	Tactical	DMAIC Project Team

Key Performance Indicator	Frequency	Tracking Level	Person Responsible
number of requisitions with incomplete quotations	Fortnightly	Operational	Procurement Performance Analyst
number of requisitions with incomplete documentation (excluding quotations)	Fortnightly	Operational	Procurement Performance Analyst
Number of workflows not approved within the day	Daily	Operational	Procurement Performance Analyst
Time between capturing of the approved requisition system to when there it is converted to a purchase order.	Weekly	Operational	Procurement Officers
Time taken to release purchase order to supplier after entry	Weekly	Operational and Tactical	Budget Officers, Procurement Officers, Finance Managers for respective heads
% Tagged Items on the items	Daily	Operational	Maintenance Team
% Untagged Items on the items	Daily	Operational	Maintenance Team

7 INTEGRATIVE IMPLEMENTATION OF LEAN AND INDUSTRY 4.0

There have been major advances in business management philosophies, practices and industrial revolutions. This includes Industry 4.0. The implementation of these new advances is being adopted while there are existing business improvement approaches such as lean management, and there is a need for an integrated approach. There is a need to do more research on this area of lean management and Industry 4.0 as to provide ways for organisations to implement both these initiatives without interrupting supply chain objectives and focusing on efficiencies needed.

There has been a vast attentiveness in government and private sector approach in 4IR. However, there are existing management approaches in organisations. Therefore, it is important to identify synergies in implementing both Industry 4.0 and lean management as to avoid contrasting actions.

Sony [38], proposed models where lean management and Industry 4.0 can be integrated. They are vertical integration and lean management, horizontal integration and lean management and end-to-end engineering integration and lean management.

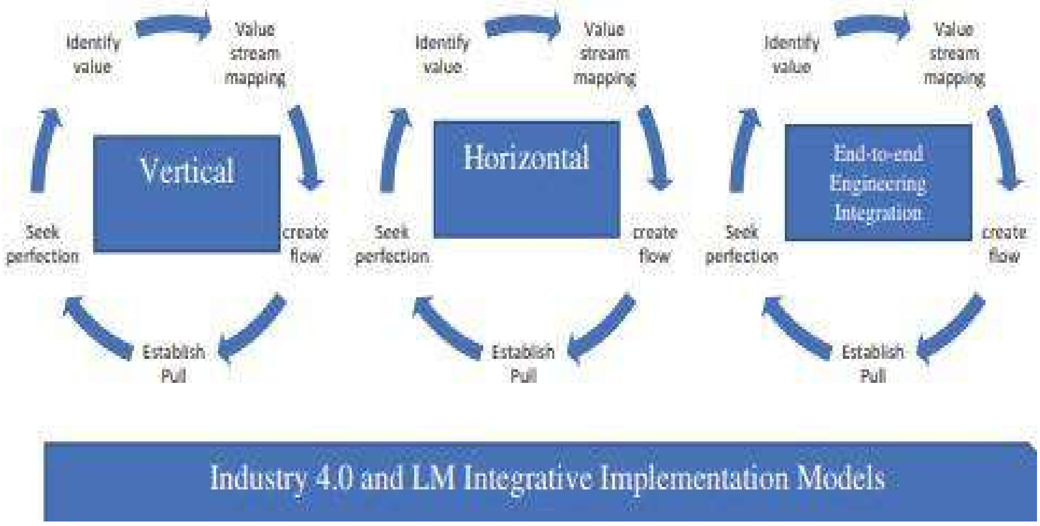

Figure 1: Lean Management and Industry 4.0 Integration

Source: [38]

Sony [38] proposes a model of integrations for lean and Industry 4.0 and propositions for implementation to test its robustness. The 15 propositions provide a solid base for implementation and recommendation on how these integrations can assist the business with a blueprint for implementing both lean and industry 4.0 simultaneously. They are further presented in Table 2 below.

Table 2: Integration models of Industry 4.0 and Lean with propositions **Source:** [38]

No	**Proposition by M Sony 2018**	**Integration**
1	While designing the vertical integration architecture through Industry 4.0 for implementing Industry 4.0, defining the value in terms of customer needs for products and services will form the underlying principle for vertical integration [38].	Vertical Integration and Lean
2	Value stream mapping of products and services before designing architecture for vertical integration thorough Industry 4.0 of hierarchical subsystems within an organisation will help in removing waste in the integration of Cyber Physical Systems (CPS) which will represent all machines, products, and resources within the organisation [38].	
3	The vertical integration of various hierarchical subsystems within the organisation will create a smooth flow process leading to cross-functional cooperation between departments by integration of CPS within each department in a strategic manner using a self-regulated system [38]	
4	The vertical integration though Industry 4.0 of hierarchical subsystems within the organisation will drastically reduce the time taken to bring the product into the market enabling a customer created pull system [38].	
5	The vertical integration of hierarchical subsystems should create a continuous improvement culture within the overall integrating	

No	Proposition by M Sony 2018	Integration
	subsystems within the organisation to improve value to the customer [38].	
6	Horizontal integration of various organisations is designed based on the common and mutually agreed perception of the customer value among the integrating organisations, which the commonly agreed integration strategy is supposed to accomplish [38].	
7	The horizontal integration mechanism can be designed by incorporating Value Stream Mapping (VSM), to map the value to the customer by identification of waste (Muda) in the horizontal integration mechanism [38].	Horizontal Integration and Lean
8	The horizontal integration mechanism using industry 4.0 will improve the flow across the cooperating organisation to deliver value to the customer by incorporating smart coordination and regulation systems[38].	
9	The horizontal integration mechanisms using Industry 4.0 will enable the delivery of customized products and services in a shortest possible time based on customer created a pull system resulting in new industry level benchmarks[38].	
10	Continuous improvement culture should be the benchmark across all the horizontally integrated organisations to create a perfect system to deliver optimum customer value by using minimum resources [38].	
11	End -to-end engineering integration requires identifying the value of the product in terms of customer requirements which are further translated into the CPS requirements[38].	End-to-end engineering integration
12	For end-to-end engineering integration the value stream of CPS system requirements using the product-service-system will help to identify the non-value added activities [38].	
13	For end-to-end engineering integration the data from the smart products can be used to design the smooth flow using the CPS [38].	
14	The data from the smart products can be used to create a pull system design using end-to-end engineering integration in a shortest possible time within and external to the organisation[38].	
15	The self-regulating mechanism through smart data from the products in end-to-end engineering will create a culture of continuous improvement[38].	

The integration model of lean and Industry 4.0 proposed by Sony [38] is built on Wang et al. [39] model, and includes integration points of lean management with all the three integration of industry 4.0 which are vertical, horizontal integration as well as end-to-end engineering integration models. Sony's theoretical model is more structured and robust. The application of this model industry may be modified for practical implementation since organisations have already implemented lean management, they may adopt the digitalization solutions that come with Industry 4.0. The propositions provide in Table 2 can be used to implement lean and Industry 4.0 applications in an integrated manner.

8 DISCUSSION

Lean management has evolved from being manufacturing based and has been implemented successfully in many sectors that are not involved in traditional manufacturing. This positions lean management as a transferrable enterprise model that has been largely emulated by many organisations in service. These include higher education institutions that have realised major monetary savings and supply chain process efficiency. The case studies presented in this review, show that lean management has had a major positive impact in large multinational companies' supply chains.

Although lean and SCOR are different management philosophies, they have one common goal of profitability and customer service prioritization. With each aspect of these philosophies operating on different organisational levels, their objectives are similar [30]. Therefore, it is important that an organisation focuses on integrative implementation of these philosophies for amplified supply chain efficiency.

An important dimension is that there has also been in industrial revolutions and advancement of Industry 4.0. The implementation of these new advances is being adopted while there lean and supply chain review tools are integral business improvement philosophies, and this raises a need for an integrated approach. Sony [38] proposes a model of integrations for lean and Industry 4.0. This integration model with its propositions for implementation provide a solid base for implementation both lean and industry 4.0 simultaneously. When implemented in a supply chain environment as an integrated business management philosophy, there are good prospects for improving the supply chain efficiency, and this can be measured through key performance indicators in the SCOR model.

9 CONCLUSION

In this paper, we look at the evolution of lean management from being a philosophy linked to manufacturing, to being transferable to almost any type of industry, whether service or manufacturing. The cases reviewed confirm that lean has been implemented successfully in various sectors that are not involved in traditional manufacturing. This shows that lean has evolved from the conventional applications and can be transferred as an enterprise model in all sectors.

The paper further looks at successful implementation of lean management supply chain environments and quantifiable results in supply chain efficiency improvement. The importance of an integrative approach of lean management and supply chain review tools such as SCOR is highlighted as there is a causal relationship between both constructs in improving supply chain efficiency. While implementing lean management and SCOR in an integrative approach, there is a compelling need to further integrate Industry 4.0 initiatives, as the world is moving towards digitalization. The integration models by Sony [38] form a critical foundation that an organisation can implement lean and industry 4.0 initiatives. Future work for this paper includes a practical utilisation of this model of integration.

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FACTORS THAT INFLUENCE THE SUCCESS OF CODING AND ROBOTICS IMPLEMENTATION IN SOUTH AFRICAN SCHOOLS

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ABSTRACT

The 4IR created a demand for 21st-century skills in the workplace, introducing a need for the education system to equip students with these skills. STEM education is one approach that prepares students for the digitally driven workplace of the future, with the subject of Coding and Robotics forming an important part of STEM learning. The South African Department of Education plans to include Coding and Robotics in the grade R to 9 school curricula to ensure that students are prepared for the workplace and for further education in technical fields such as Industrial Engineering. Disparities exist between schools in rural and urban areas in South Africa, which will pose challenges in the introduction of the subject. Literature was reviewed and subject matter experts were interviewed to identify relevant factors, such as teachers and infrastructure, that a school will need to consider to overcome these practical challenges when implementing the subject.

Keywords: 21st-century skills, 4IR, Basic Education, Coding and Robotics, Curriculum Development, Education, South Africa

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1 INTRODUCTION

The Fourth Industrial Revolution (4IR) introduced rapid advancement in science and technology [1]. This created a skills gap for digital and computational thinking skills in the workplace and increased the demand for specialists in fields such as Industrial Engineering. Early Coding and Robotics education ensures that scholars' skills stay relevant in the digital economy as the 4IR progresses [2].

The Faculty of Engineering at Stellenbosch University recognises the value of applying an engineering approach to many of the challenges faced in the education sector [3]. This research work was supported through a Subcommittee B grant from Stellenbosch University for engineering research into the impact of the 4IR on Education in South Africa.

The Department of Basic Education (DBE) in South Africa plans to add Coding and Robotics as a new subject to the curriculum of grades R to 9. This aims to help students adapt to a rapidly transforming society and equip them with the basic thinking skills required to pursue further education in technical disciplines such as Industrial Engineering [4]. The challenge for education specialists in implementing these subjects in basic education is the technical nature of the curriculum content and delivery mechanisms. If done correctly, the knowledge and skills scholars obtain could benefit their success in technical higher education streams and future workplace environments.

However, the South African context poses a unique challenge in terms of the disparities that exist between schools in rural and urban areas [3]. The proposed curriculum might require adjustment to achieve the desired learning outcomes in the subject if the infrastructure available varies. This reality suggests that each school needs to do an analysis of their facilities and support structures before introducing the proposed Coding and Robotics curriculum. Understanding and utilising the systemic relationships between the teachers, infrastructure, curriculum and supporting environment would be the key to successful broad-based implementation. This paper determines relevant factors that need to be considered to ensure that the Coding and Robotics subject is introduced successfully in a school.

2 METHODOLOGY

The objective of this paper is to identify factors that a South African school should consider when introducing Coding and Robotics as a new subject. An engineering approach was followed to investigate and define the systemic relationships between these factors and how they could influence the successful implementation of the subject. The approach aims to assist schools to better prepare for potential challenges and leverage existing identified factors that are in place to offset factors where a school are weaker in implementation. It would also ensure that the approach would benefit scholars who would be interested in following a career into a technical field, such as engineering.

The first stage of the paper consists of a literature review. The background of Coding and Robotics education in the STEM context is presented. The DBE's vision for the subject as stated in the Draft Curriculum is presented. The current version of their curriculum includes a broad scope of topics, that will be filtered in future versions to ensure that technical quality of the content is adequate to support future 4IR requirements, but it already suggests practical aspects a school will have to consider to support the implementation of the future national curriculum.

Secondly, potential factors a school should consider were identified from reviewed literature and policy statements from other countries that already teach Coding and Robotics-related subjects in schools. These preliminary factors were discussed with relevant subject matter experts during semi-structured interviews to ensure their validity and to expand the description of the factors. Data gathered from these interviews are presented to give a practical perspective of the attributes describing each factor with regard to teaching Coding and Robotics in the South African context. The relationships between the factors were investigated in an exploratory manner to determine whether structures or rankings exist among the factors.

3 LITERATURE REVIEW

Relevant literature is reviewed to present background for the inclusion of the Coding and Robotics subject in the curriculum.

3.1 Background

4IR is characterised as an era of automation by producing several emerging technologies. The introduction of 4IR technology caused a disruption in business, education and many other sectors of the economy [5]. These technological advances created a professional skills gap, since technology is now a key player in the workplace. In order to qualify for competitive job opportunities, people need to be comfortable with adapting to new innovations [6]. The technological skills gap is widened further by the demand for advanced engineering talent in the innovative sector. Skills in robotics and electronics are in high demand due to the new market gap created by 4IR development, adding to the necessity of educating South African youth in these fields [7].

One educational approach that ensures the technical literacy required for an innovation-driven occupation is STEM [6]. STEM stands for Science, Technology, Engineering and Mathematics [8]. Coding and Robotics form an important part of STEM subjects, linking to the Technology and Engineering branches [9].

The current South African education system does not offer students adequate STEM tuition and there is a need for skilled professionals in these fields [10]. Studies show that South Africans are not yet equipped with the information technology skills needed to keep up with the 4IR and the curriculum of early grades does not yet include digital skills [11].

South African Minister of Basic Education, Angie Motshekga, addressed this shortcoming in 2020 by confirming that a new Coding and Robotics subject will be introduced to schools by 2023 [12]. The subject will be incorporated into the curriculum of grades R to 9 and a draft curriculum was compiled and submitted to Umalusi, the Council for Quality Assurance in General and Further Education and Training, for evaluation. President Ramaphosa announced in February 2021 that the DBE will launch a pilot program during that year to test the draft curriculum to allow possible amendments to be made before all public schools in the country present the material [13]. No further formal notices could be found on the progress of the rollout of the Coding and Robotics curriculum.

The inclusion of the Coding and Robotics subject to the curriculum from as early as grade R aims to equip students with relevant skills [11]. However, very little information is available on the practicalities of the rollout of this subject and the infrastructure needed to present the subject in a meaningful way.

The South African context poses a unique challenge in terms of the variety of public schools in the country. High disparities exist between schools in rural and urban areas [3]. This might present a challenge to achieve the same learning outcomes in teaching the subject if available infrastructure differs. This reality suggests that each school needs to assess facilities and support before attempting to introduce the new Coding and Robotics subject.

3.2 Learning outcomes suggested by Department of Basic Education

The DBE named the new subject “Coding and Robotics”, but it is important to define the topics included in the content to better understand what literature and studies are relevant to this subject.

The official curriculum for Coding and Robotics is not yet available, but the Draft Curriculum released on 19 March 2021 stated that the Coding and Robotics subject aims to guide students to solve problems, think critically, work collaboratively, function in a digital and information-driven world, and apply digital and Information and Communications Technologies skills. Students will be guided to transfer these skills to thrive in a rapidly changing society [4].

The study areas suggested in the draft curricula are summarised in Table 1 to indicate the aimed scope of the subject [3], [14], [15].

Table 1: Study areas suggested in the draft curriculum.

Study Areas	Foundation phase Grades R - 3	Intermediate phase Grades 4 - 6	Senior phase Grades 7 - 9
Algorithms and coding	Includes fun coding activities where students get to engage with digital platforms.	Block-based coding platforms used to teach basic programming skills.	Line-based programming interface used to develop programming skills.
Robotics skills	Introduces fundamental electrical and mechanical engineering systems and circuits used in robotics.	Introduces microcontrollers by programming them with the block-based coding platforms.	Microcontrollers are programmed with line-based programming platforms.
Internet and e-communicating	Safe ways to browse the web in search of information as well as digital identities and safety on digital platforms.	Topics such as digital citizenship, piracy and copyrights are covered.	Skills that ensure the student's safe use of online platforms covered.
Application skills	Basic text editing skills and the use of spreadsheet applications are introduced.	Multimedia editing, spreadsheets and computer-aided drawing are covered.	End-user skills are developed to familiarise students with various digital platforms. Website development and data analysis are introduced
Pattern recognition	Identification of geometric and abstract patterns to develop computational thinking skills.		

The complexity of these topics suggested in the draft curriculum are still not specified and it is not confirmed whether all of these topics will be included in the final curriculum. However, it does suggest the broad spectrum of the subject and implies that the subject will comprise of more than the limited term of "Coding". This paper's assumption from studying the draft curriculum is that literature related to Computer Science, software development, electronics and robotics education are relevant to the aims set out in the draft curriculum of Coding and Robotics.

3.3 South African education context

South Africa today is one of the most unequal countries in the world, which is mirrored in the education system [16]. The disparities between the situations in rural and urban areas can largely be attributed to the historic context of the country [17].

The 2017/18 School Monitoring Survey and 2017 National Senior Certificate pass rates revealed that there was a more than 30 percentage point difference between quintiles with just 56% of learners in Quintile 1–3 schools passing Grade 12 with an NSC, in contrast to 87% of learners in Quintile 5 schools [18].

The PIRLS (Progress in International Reading Literacy Study) revealed in 2017 that 97% of Grade 4 children in South Africa scored the lowest of the 50 countries participating in a reading and literacy test, with 78% of Grade 4 students unable to read for meaning. Rural provinces performed significantly worse [19].

These performance results are not surprising when thousands of students and teachers have to learn and teach in schools that have inadequate infrastructure and an absence of basic essential facilities [20].

Government statistics for 2018 revealed that out of 23,471 public schools 19% still only had illegal pit latrines for sanitation while another 37 schools had no sanitation facilities at all. 86% of schools had no laboratory, 77% no library and 72% no internet access. 269 schools lacked any electricity access and 1,027 schools had no perimeter fencing, which is essential to ensure teacher and student safety [20]. South African head teachers report that a shortage of physical infrastructure is hindering their school’s capacity to provide quality instruction [21].

4 EDUCATION FACTOR IDENTIFICATION

Factors that influence the success of Coding and Robotics implementation is explored.

4.1 Introducing the new subject to schools

The increased prevalence of information and communication technologies in society has placed an imperative on schools to adapt to these new norms [22].

Tucker *et al*. suggest that school computer science education will face unique challenges because the subject is still relatively new. For schools to introduce the subject, work is needed in three important areas: teacher preparation, government-issued content standards, and curriculum materials development. Persons in leadership positions must acknowledge the importance of computer science [23].

Dr Mmaki Jantjies mentioned five elements that are important to ensure an effective rollout of the new Coding subject, namely localised learning content, infrastructure, teacher training and support, technical support, and safety [24].

The inclusion of computer science to the curriculum will require more consideration than simply adding content [25]. Smith [2] suggested that basic tools such as teachers, infrastructure and Wi-Fi will be necessary. Technical infrastructure and support from stakeholders such as administrators, parents, teachers, and support staff will also be important [25].

The magnitude of inequities is in South African schools is considerable [16]. Each school has its own constraints with regard to student scheduling, availability of knowledgeable staff, and computer resources, and will have to make adjustments according to their situation [25].

4.2 Factors identified from literature

Possible factors that could influence the success of Coding and Robotics education were identified by reviewing relevant literature.

4.2.1 Teacher

Classroom teachers play a critical role in the learning experience of the student in computer science curricula [26]. The effectiveness of the new Coding and Robotics subject's learning progressions will be significantly influenced by teachers' pedagogical practices [25] since teacher quality is one of the most important factors in the success of student learning [27].

Tucker *et al*. suggests that for students to master this new subject, teachers must acquire both an understanding of the subject matter as well as the pedagogical skills that will allow them to present the material to students at appropriate levels. It is understood that there must be a match between the skills and knowledge defined for the students and the acquired skills and knowledge of the teachers. At the same time, teachers must have a greater depth of knowledge than that embodied in the topics they are teaching to provide students with adequate context [23].

Many teachers are in need of professional development to enhance their effectiveness to teach STEM subjects [28]. Buchter *et al*. [27] agrees that it is critical that early childhood educators are highly trained, competent and qualified to support young children, as the period of early childhood is crucial for cultivating interest. Delivery of high-quality teacher professional development has demonstrated significant improvement in student achievement for young children. Professional development should be ongoing, appropriate to the subject matter being taught, include opportunities for teachers to actively participate, and have some relevance to what is happening in industry.

Tucker *et al*. [23] suggests that the teacher needs to invest in opportunities for professional development with regard to the new subject. In-service education is important to help current teachers adopt and integrate new curriculum elements. Provisions must be made to retrain teachers already in the school systems, so that they may also develop the skills and knowledge necessary to obtain new certifications as needed for the new subject [23].

4.2.2 Infrastructure

The foundations of computer science have a major information technology component; therefore, it is important to reaffirm the need for technical support in the classroom. There needs to be access to physical resources (hardware and software). The physical arrangement of those resources in accessible learning spaces also influences the success of computer science education [23]. The Coding and Robotics resources and need to be stored securely [24].

A lack of computers and internet access does indeed continue to be a disadvantage for reaching all students, but many computer science topics, such as algorithmic thinking, searching, sorting, and logic, can be learned without computers. "Unplugged" computer science is an approach to learning computer science concepts through physical and kinesthetic experiences where the students develop certain important thinking skills through structured play. These basic concepts can be taught independent of computer or online access. Teachers can combine these unplugged experiences with programming exercises to provide even richer experiences for young students [25].

4.2.3 Artefacts

Sullivan *et al*. [28] suggest that children can learn programming from a very young age if they are supported with the developmentally appropriate tools that allow integration of technical skills with arts, literacy and maths.

A variety of approaches exist to make programming accessible to young learners and beginners. Programming environments on tablets have made programming even more accessible to younger children by reducing the number of available commands. Games and other applications teaching programming skills are available on smartphones. Visual, block-based programming languages are designed for students to program without the obstacle of syntax errors found in traditional text-based languages. These languages and environments are suitable for inexperienced programmers, but still allow students to build complex programs and games. The social communities that have evolved around these platforms allow students to co-develop by sharing and reusing others' creations [25].

Fessakis *et al*. [29] point out that apart from software programming environments, systems that include tangible objects are effective in aiding the learning of programming and robotics skills. The interaction between student and robot amplifies the magnitude of knowledge and problem-solving skills since the presence of robots in the classroom increases student engagement and provides a practical learning experience [9]. Sullivan *et al*. [28] add that the new generation of learning manipulatives include educational robotics kits to support the development of mathematical concepts such as size, number and shape. Some of these robotics kits are standalone devices, while other systems require a computer or tablet as an external controller [29].

4.2.4 Curriculum

The success of Computer Science teaching is also dependent upon a clear vision of what expectations are necessary and appropriate at every level [23].

Fessakis *et al*. [29] suggest that programming learning activities for young children should be structured to keep the following remarks in mind. The activities should be challenging to keep the children's interest but should also be achievable to ensure that the children do not become discouraged. Teachers play a very important role in the social organisation of the participants if multiple children are engaged in a classroom setup. Group activities could help to hold children's interest by reinforcing interaction and allowing suggestions when difficulties arise.

Concepts included in the curriculum should be curated carefully. The concepts should be scaffolded, meaning that the topic should be simple enough to introduce to young students, but build in complexity as they advance through the curriculum. The concepts should also be relevant in other subjects and disciplines, to move away from the "silo" approach to education. The topics included in the curriculum should also remain relevant in computer science for at least the next five to ten years, to ensure that students are being prepared for the workplace of the future [25].

4.2.5 Support network

Any sustainable effort to include computer science-related education will require support from leadership positions at the state and district levels [25].

Successful integration of technology to support learning goals depends, among others, on the vision of the specific school's leadership for successful implementation and long-term success. The school leadership needs to support incentives to allow the relevant teacher access to professional development opportunities as well as support in terms of the time the educator will need to invest in the new subject matter [23]. Trained subject advisors will also play an important role in supporting the implementation of the new subject curriculum [30]. Mtshali [24] emphasises the necessity of adequate technical support for the introduction of the Coding and Robotics subject.

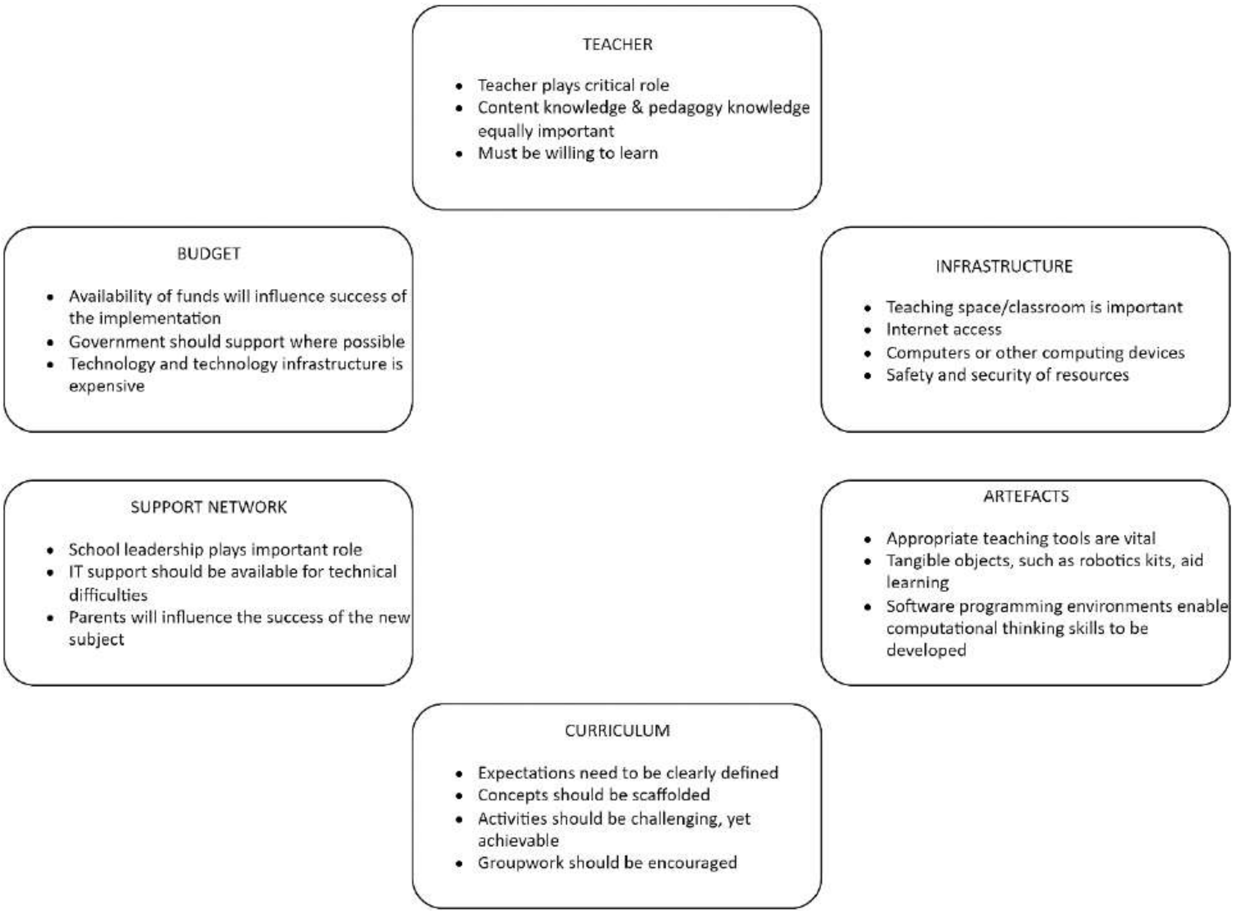
Parents and family also play an active role in mediating a new education policy and should be regarded as important stakeholders with their part to play in realising students' full potential [31].

4.2.6 Budget

Funding is an important factor in introducing a new subject and government should allocate funds toward course materials, technical infrastructure and professional teacher development [25]. A big factor in the success of Computer Science implementation is ongoing financial support for sustained technology and technological infrastructure [23]. The price of the robot is often the main consideration of a school when adopting Coding and Robotic education in their classroom [9].

4.2.7 Summary of factors identified from literature

The reviewed literature revealed possible factors and their attributes and considerations that a school will need to evaluate when implementing the subject of Coding and Robotics, as illustrated in Figure 1.



TEACHER

- Teacher plays critical role
- Content knowledge & pedagogy knowledge equally important
- Must be willing to learn

BUDGET

- Availability of funds will influence success of the implementation
- Government should support where possible
- Technology and technology infrastructure is expensive

INFRASTRUCTURE

- Teaching space/classroom is important
- Internet access
- Computers or other computing devices
- Safety and security of resources

SUPPORT NETWORK

- School leadership plays important role
- IT support should be available for technical difficulties
- Parents will influence the success of the new subject

ARTEFACTS

- Appropriate teaching tools are vital
- Tangible objects, such as robotics kits, aid learning
- Software programming environments enable computational thinking skills to be developed

CURRICULUM

- Expectations need to be clearly defined
- Concepts should be scaffolded
- Activities should be challenging, yet achievable
- Groupwork should be encouraged

Figure 1: Factors identified from literature with preliminary attributes and considerations

4.3 Factor Identification Interviews

To identify valid factors, a practical perspective on Coding and Robotics teaching was needed. Some schools in South Africa already teach Coding and Robotics-related lessons to introduce their students to these topics, even though the subject has not formally been included in the National Curriculum and Assessment Policy Statement. A few of these schools in the Western Cape were identified and their Coding and Robotics teachers were contacted to determine whether they would add value to this study. Three participants were selected that teach at local quintile 5 public schools, have at least 10 years of experience teaching and at least 1.5 years of experience teaching Coding and Robotics. Their identifiers are stated in

Table 2.

Table 2: Data collection participants

Participant Identifier	Position	Coding and Robotics Teaching Context
One	Deputy Principle	Coding and Robotics class teacher
Two	Head of Technology and Learning	Coding and Robotics teacher at extracurricular school Robotics club
Three	Head of Information and Communications Technology; Head of Robotics	Coding and Robotics class teacher and extracurricular school Robotics club teacher

They participated in the exploratory semi-structured interviews where they shared their findings from their experience teaching the new subject. The draft factors identified from the literature as expanded in Section 4.2 were presented to the participants and they were asked to comment on the significance and practical considerations of these factors. The findings from the conversations with these three participants are summarised in the same structure identified as factors during the literature analysis.

4.3.1 Teacher

All participants agreed that it is important that the appropriate teacher is selected to present Coding and Robotics. The teacher will have to be someone who takes initiative and has creative problem-solving skills. Every school's situation is different, and it is often the teacher's responsibility to find unique ways to present the subject and make do with the resources at hand. The appropriate teacher for the subject is someone who at least has some basic digital skills, but most importantly the person must be motivated and enthusiastic. Participant One was adamant that the most important attribute of the teacher is their self-motivation and willingness to learn. Participant Two agreed, adding that they must be interested in the subject and in new technologies and ICT topics in order to succeed at teaching Coding and Robotics.

They emphasised a requirement for life-long learning, since the field of Coding and Robotics is ever-changing. The teacher will have to continue to learn as they teach the subject. It is important that the teacher is equipped with skills and pedagogical knowledge about the subject before they start teaching the subject. However, the curriculum content taught in Coding and Robotics will not stay the same for long, therefore teachers will need to continue attending training and refresher courses throughout their careers in teaching. Infrastructure and artefacts available also continue to evolve and increase, meaning teachers will need to stay informed about these new technologies, to ensure that their students are always exposed to the best possible learning materials available within their means.

4.3.2 Infrastructure

The participants mentioned a few elements with regards to the infrastructure that support Coding and Robotics education.

4.3.2.1 Robotics Lab

The participants all emphasised the importance of having an appropriate space to teach the subject. Participant One explained that they initially used their Technology class to start teaching Coding and Robotics but recently equipped a space specifically for Coding and Robotics teaching. Participant Two uses their Technology classroom for the Coding and Robotics club since it takes place after school and does not interfere with the Technology timetable. Participant Three also has a classroom that is specifically equipped for Coding and Robotics.

They all agree that one of the most important attributes of an appropriate classroom is the size. The learning of Coding and Robotics involves a lot of interaction and group work, especially while the students are working with a certain artefact or robotics kit, therefore the more spacious the location the better. Participant One added that if they had the opportunity to build a class specifically with Coding and Robotics in mind, they would prefer to have enough room for robotics tables and set computer tables, but also have space for students to play with bigger teaching artefacts and robots on the floor.

4.3.2.2 Devices

The robotics lab should be equipped with standard tables, the traditional wooden school benches are not appropriate, for they are sloped, and the robots need to move on a flat surface. Participant One elaborated that it is useful to have the tables mounted on wheels so that the layout of the classroom can be adjusted according to the specific assignment.

It is advisable that the robotics lab be equipped with digital devices to code with, such as desktop computers, laptops, or tablets. These devices should preferably be Bluetooth and Wi-fi connected to ensure compatibility with educational robots so that robotics lessons, as well as coding lessons, can be taught using the same devices.

4.3.2.3 Security

The equipment used in the teaching of Coding and Robotics is often quite expensive and measures should be put in place to ensure their safekeeping. The participants elaborated on the respective security measures they put in place, but all led with the importance of storing the robotics kits in a locked cupboard in a storeroom or classroom that can be locked securely. Burglar bars on the windows as well as secure locks on the doors were mentioned. All participants commented on the importance of having a security surveillance alarm system installed in the classroom where the robotics kits and equipment are stored. Two of the participants mentioned that their computers and laptops used for Coding and Robotics are insured to protect them against losses in the case of theft or damages.

4.3.2.4 Electricity and Wi-fi

The participants agreed that it is preferable to have electricity points in the Coding and Robotics classroom. If the assigned space does not have power points, it may just result in desktop computers not being used but rather laptops or tablets that can be charged at a separate location. Many robotics kits have long battery life and can also be used in a space that does not have power points but also be charged at a separate location when not in use.

The participants strongly recommend that the school should try to organise Wi-fi access for the Coding and Robotics class. Ideally, the internet connection should have adequate bandwidth allowing students to work on connected devices at the same time. If this is not possible, it is strongly recommended that the teacher at least have internet access to be able to download applications to the devices that the students can use offline. The teacher should also preferably have access to the abundant resources available on the internet about Coding and Robotics related topics to help them with lesson planning and staying informed of the relevant developments in the field. If no internet access is available at all, it is recommended that the school purchase a robotics kit with a pre-designed lesson plan to ensure that the teacher has a curriculum to follow without having to improvise from ideas found online.

4.3.3 Artefacts

All participants agreed that it is possible to teach Coding and Robotics on a very low level without robotics kits, using “unplugged” methods. However, they commented that in their opinion the ceiling for the robotics content that can be taught without the availability of a robot or programmable device is quite limiting.

All participants currently use the LEGO Education Spike sets in their Coding and Robotics classes. Participant One has experimented with a few different kinds of robotics kits through the course of teaching the subject, among which are the Cubroid Coding Blocks, LEGO Education WeDo 2.0 Robotics Core Set, LEGO Mindstorms EV3 set, as well as the LEGO Education Spike set. Participant One still uses all these robots in the class, rotating the groups of students to ensure that they all get a chance to work with the different robots throughout the year. This rotational method also ensures that the students get exposure to different difficulty levels of assignments, since some of the robots limit lesson complexity.

The robots aid the “learning-through-play” method of teaching the participants currently employ. The assignments involve a certain “mission” that must be accomplished with the robot to give students the freedom to practice problem-solving and computational thinking skills at their own pace. Participant Two mentioned that it is important to not have the students work in very large groups when completing assignments with the robotics kits. Group work is encouraged, but smaller groups are preferable to prevent “less enthusiastic” students from losing interest and becoming spectators.

The participants mentioned that the robotics kits that are selected as teaching artefacts should be researched properly since they can have a significant financial implication. The robots must be age-appropriate, ensuring that younger students work with robots that have larger components that are easily handled. It is also useful to consider whether the assignments completed with a certain robot can be scaffolded, for if the complexity of the assignments cannot be increased with the same robot, more advanced robots will have to be acquired once a class have mastered the lessons taught with a certain robot, which can become expensive to sustain learning.

They believe robots should preferably be compatible with multiple types of devices (laptops, desktop computers or tablets) and different apps. For example, the robots are much more versatile when they can be instructed through block-based coding as well as line-based coding platforms.

4.3.4 Curriculum

Participants believe the teacher should follow a lesson plan, to ensure that the skills that are taught are scaffolded.

Participant Two uses the lessons provided with the LEGO kits they bought. The lessons are presented in the format of an instructional video or tutorial document that can be downloaded to explain the specific assignment scenario. Participant Two added that there are many resources available online for the LEGO kits, since they are very popular in the educational robotics field.

There are external educational robotics companies that sell a robotics curriculum, often along with a uniquely designed robot. This ensures that the teacher does not have to be creative in designing unique assignments for the students with their given robot, but rather that a lesson plan with learning outcomes can be followed. This is advisable for a less experienced robotics teacher but can be more expensive.

Participant One suggests that the DBE design a fitting Coding and Robotics curriculum with appropriate learning outcomes and lesson plans to communicate the specific requirements of the subject before it is formally included in all school curricula.

4.3.5 Support Network

The participants mentioned a few role players that support the teaching of Coding and Robotics.

4.3.5.1 School Leadership

The participants emphasised the importance of having the support of the school management to succeed in introducing Coding and Robotics to the school. Participant One stated that the Principal and School Governing Body (SGB) ultimately have the final say in what goes on in the school since they control the school funds. Funds from the school budget will more easily be allocated towards the inclusion of the subject if the Principal and SGB advocate for the initiative. If the school budget does not allow the expense, the support of the Principal and SGB can go a long way to help the school get an external grant for the teaching of Coding and Robotics. The school leadership also must support the decision where certain adjustments need to be made to the infrastructure or the setup of the Coding and Robotics classroom.

4.3.5.2 Parents

Participant Three mentioned that it is preferable to have the parents' support with teaching Coding and Robotics, especially if the inclusion of the subject depends on the "bring-your-own-device" policy where students are allowed to use their own tablets or laptops, or even their smartphones to aid learning. If these devices are used for Coding and Robotics education, parents need to support this.

4.3.5.3 IT support

All participants commented on the usefulness of having an IT staff member that is responsible for the maintenance of relevant infrastructure. IT support is very useful in Coding and Robotics teaching since the subject may involve connected devices and depend upon the functionality of the infrastructure.

4.3.6 Budget

The participants agree that the introduction of Coding and Robotics is an endeavour that can be quite expensive, for there are many elements in the process that could be costly.

Firstly, infrastructure upgrades might need to be made if the school does not already have computer or laptop devices that are used for other digital literacy classes or adequate Wi-fi provision. The robotics lab will need to be set up with furniture fitting for Coding and Robotics education. Secondly, if an appropriate teacher can be identified from the current staff, training for the teacher will have to be funded. If there is no appropriate teacher, another teacher may need to be recruited which could mean additional salary expenses. The artefacts used in the teaching of the subject are often expensive. The specifications of the required robotics kits will have to be determined critically, for there is a range of products available at different prices. Participant One offered that it may be worth to invest in a curriculum from an external robotics company to assist with lesson planning if the teacher is not very experienced or confident with Coding and Robotics education. Another aspect to consider with regards to budget is whether students will be encouraged to enter educational robotics competitions, like the World Robotics Olympiad, dependent on the availability of funds.

If the Coding and Robotics related expenses cannot be covered by the school budget, alternate sources may need to be considered. Participant Two explained that they decided to introduce Coding and Robotics teaching as an extracurricular activity for this reason. The students in the club pay a term fee, which allowed the school to fund the robotics kits. This means that fewer kits are needed for only the interested students who join the club. Another option for funding is to make use of external grants or sponsors from community stakeholders. These can be individuals who wish to invest in community advancement or businesses who wish to meet their social responsibility requirements.

4.3.7 Summary of factors identified from interviews

Figure 2 illustrates the factors and their attributes and considerations as expanded from the interviews with subject matter experts.

The relationships between the factors and importance of the factors were discussed with the participants in order to explore the possibility of structuring their systemic influence in a certain hierarchy. However, it was discovered that the interrelationships are more complex than initially expected and that the influence of the different factors on one another are tightly interwoven.

The factor of teacher effectively shows the range of influence, as its connection to all the other factors can be explained with simple examples. The quality of the teacher will influence the complexity of the infrastructure and artefacts required. A creative and motivated teacher will be able to teach the required skills and ways of thinking without access to sophisticated equipment. The factors of teacher and curriculum are also connected, for if the teacher is not very experienced and confident, there will be a need for a lesson plan that provides more practical guidance to the teacher. The teacher will need the support of the school management with regards to the attendance of teacher training and the IT support will directly influence the teacher’s ability to focus on the students without being distracted by possible technical difficulties. The budget will also have an effect on the teacher’s decision making, since the acquisition of resources relies on funds.

It was suggested by various interviewees that the factors all influence one another, but the strength and cause-and-effect direction of these influences cannot be concluded from a sample size of three participants and should be investigated in further research outside of the scope of this paper.

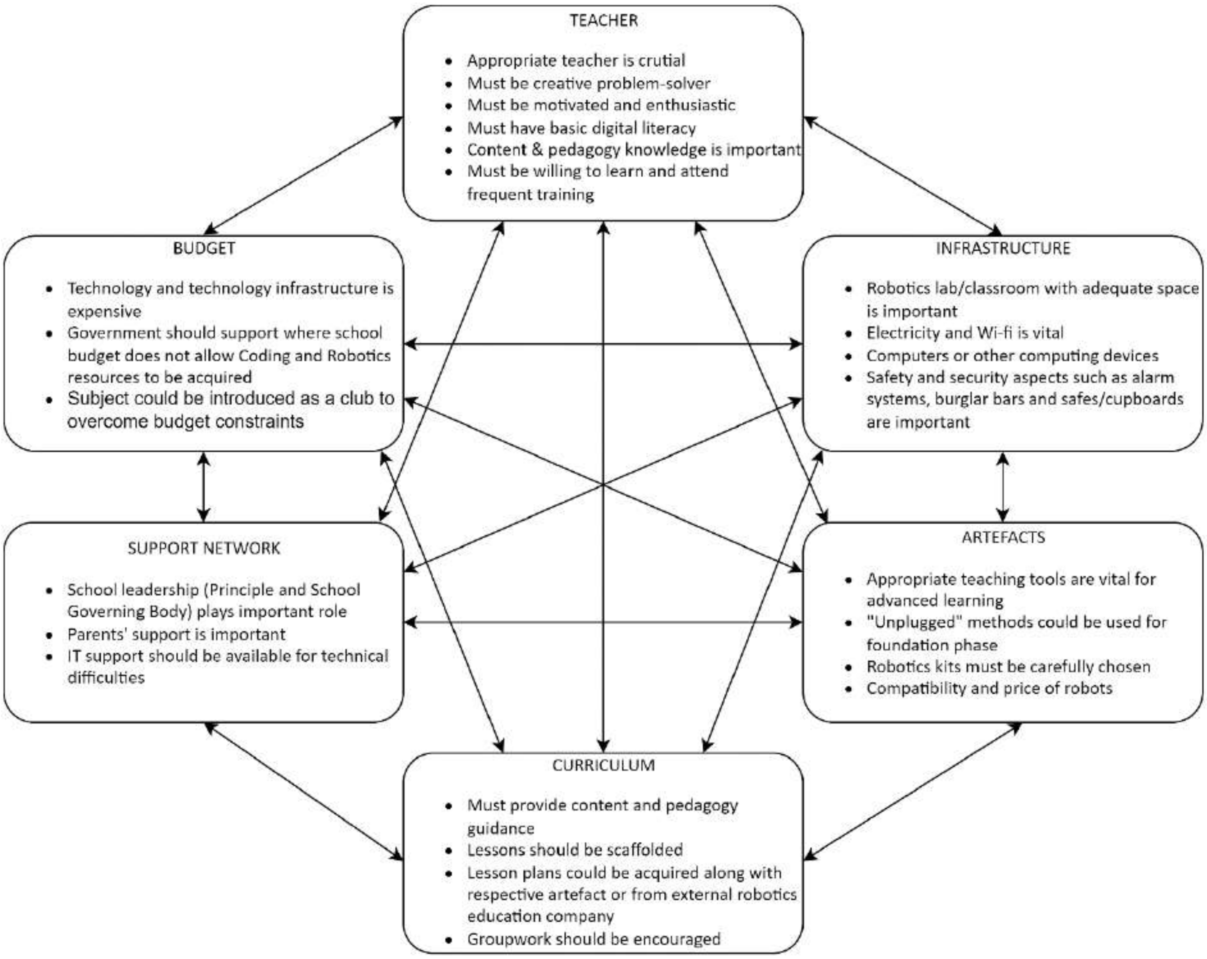


Figure 2: Factors identified from interviews with attributes and considerations

5 CONCLUSION AND FUTURE WORK

This paper aimed to contribute to the preparation of future Industrial Engineers by determining relevant factors that a school should consider when introducing Coding and Robotics as a subject, to ensure that the subject succeeds in equipping students with 21st-century skills. The factors identified from literature were confirmed as relevant findings by the interviews. The factors identified as the teacher, infrastructure, artefacts, curriculum, support network and budget were described by the participants to paint a picture of the practical considerations when teaching Coding and Robotics in a school.

The next stage of this project will be to determine attributes for each factor that can be linked to measurable criteria. The findings also suggested the existence of complex interrelationships between the factors. This can be used to build a framework of factors that a school can use as a benchmark when assessing its own situation. The framework will be tailored to the South African context to allow any school to assess readiness and appropriately prepare for introducing the subject.

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PROCESS IMPROVEMENT FOR THE MANUFACTURE OF EXCAVATOR BUCKET FOR A CONSTRUCTION EQUIPMENT MANUFACTURER

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ABSTRACT

A construction equipment manufacturer procured the SK220 excavator machine from Japan without the bucket. Given the poor quality of outsourced buckets, the company considered manufacturing its own strong and reliable excavator buckets. However, due to Covid 19 pandemic, the company failed to deliver the buckets on time, which affected committed customer orders. The aim of the paper is to pinpoint the bottlenecks within the supply chain and institute some corrective and preventive actions to improve the manufacture of excavator bucket for the construction equipment manufacturer. Capacity planning was conducted to establish the weekly production capacity for the excavator bucket, considering the number of workers and equipment. Root cause analysis was conducted to pinpoint all the waste that characterised the supply chain and significant counter-measures were implemented. The results demonstrated significant productivity improvement, waste reduction and average in monthly sales amounting to R6 250 000.

Keywords: Excavator bucket, Supply chain, Lean, Six sigma

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1 INTRODUCTION

A construction equipment manufacturer is one of the key industrial pillar of South African economy that has a significant economic impact through contribution to agricultural machines, forestry machines, construction machines and providing decent jobs to about 10 000 employees. The new competition is in terms of improved quality, products with higher performance, reduced cost, a wider range of products and better service, all delivered simultaneously [1]. To secure the companies competitiveness, it is necessary to increase the flexibility in the customer order fulfilling process.

The construction equipment manufacturer is the exclusive distributor of Kobelco excavator machines in Southern Africa. The SK220 excavator buckets are manufactured by the company because of customers consider them as strong and reliable. Due to Covid 19 pandemic, the company failed to deliver the buckets on time. The aim of this study is to identify the root causes of inefficiency in the manufacture of excavator buckets and develop measures to ensure excavator buckets are delivered on time.

The Covid 19 pandemic is an infectious disease which was originated in China December 2019, it provoked serious social and economic disruption global. The strong equipment manufacturer was affected due to Covid 19 pandemic. The construction equipment manufacturer was struggling to meet the customer demand, delivery dates and expectation. The late delivery of material at earth moving equipment manufacturer from their suppliers and production constraints has affected the commitment which they already made with customers.

Business organizations have faced huge challenges due to unprecedented disease outbreaks in recent decades. The scope of the challenges faced by these organizations largely depends on the severity of the outbreaks in question. A widespread public health incident such as an epidemic or pandemic can have substantial negative impacts on businesses and supply chains, including reducing their efficiency and performance.

Under the COVID-19 pandemic, the labour resources and supply chain framework are disturbed. The quality of being trustworthy to your customers is significant due to market demand has become more combative and managing supply chain uncertainty is crucial. Covid 19 pandemic has posed a significant challenge for supply chain and logistic execution globally. Multiple national lockdowns continue to slow or even temporarily stop the flow of raw materials and finished goods, disrupting manufacturing as a result.

Time studies will be used to establish daily production capacity of excavator buckets considering number of workers and equipment. Value stream mapping will be conducted to visualize entire process, demonstrates links between operations and to remove non-value-added activities from the process. Cause and effect diagram will be conducted to pinpoint all the wastes that characterised the supply chain and significant countermeasures will be implemented. Implementation of the forecast will also help to set the goal and ensure that the target is achievable.

2 LITERATURE REVIEW

Lean tools have to be applied to increase the SK220 excavator buckets efficiency of the industry. Kanban serves as a tool to control the levels of buffer inventories in the production; in simpler terms to regulate production quantities. When a buffer reaches its present maximum level, the upstream machine is directed to stop producing that part type. Hence, in the manufacturing environment, Kanban are signals used to replenish the inventory of items used repetitively within a facility.

Six-Sigma is described as a data-driven approach to improve business processes by reducing variability, defects and errors in all process that are critical to the customer [2]. Its adoption has now evolved further in service sectors [3]. Six sigma approach improves on time delivery, reduce cycle time for hiring new employers, reducing complaint resolution, and improving the average order fulfilment lead time for sales orders [4]. The approach could be used to improve the company inability to deliver the buckets on time hence the study aim was to pinpoint causes on inefficiency and develop controllable measures.

Roots cause analysis incorporates a broad range of approaches, tools, and techniques to uncover causes of problems, ranging from standard problem-solving paradigms, business process improvement, benchmarking, and continuous improvement [5]. Roots cause analysis is used in different organisations for process improvements of processes and reducing the quality problems. Root cause analysis can be performed with a collection of principles, techniques, and methodologies that can all be leveraged to identify the root causes of an event or trend.

Lean manufacturing defined as a group of tools aimed at minimizing wastes and non-value-added activities in a production setup [6]. It has also been defined as a multidimensional approach that includes Just in Time, quality system, different management practices, work teams, cellular manufacturing, and supplier management in an integrated system to reduce waste [7]. Manufacturing companies are now operating in a highly complex and competitive environment and should engage in Lean thinking initiatives to improve their manufacturing processes. The rate at which new product are being released into the market is increasing. Lean application promotes the production of high-quality products at reduces lead time, thus products are produced at the pace of customer demand.

JIT production can be described as manufacturing the right product at the correct time in its rightful quantity [8]. The JIT principle states the production should be initiated when a customer downstream orders for a product. The benefits realized by the customer pulling the product is that it lowers inventory, throughput time and process variability [9]. The major tools that help JIT construct are pull, Kanban and Production levelling. The pull principles ensure that resources are not dedicated to production before the customer demands for a product [10]. Kanbans are used to initiate the production process and these visual cards or electronic mechanisms carry information about the number of parts to be transmitted to the proceeding process. Production levelling is done to avoid peaks and troughs in the workload of employees thus ensuring that daily production volume is kept constant.

Excavator buckets are digging attachments with teeth that can be fixed to the arm of an excavator. The buckets are controlled by the excavator operator using controls in the cabin. There are different types of excavator buckets that are used depending on where the digging has to be done. Excavator buckets can also be used to move dirt or load dump trucks for transportation to dumping sites. Excavators are used in conventional trenching methods for laying pipelines and also used for digging trial pits for geotechnical investigation [11].

Excavator buckets is a bulk material handling component or specialized container attached to a machine. The bucket has an inner volume as compared to other types of machine attachments like blades or shovels. The bucket could be attached to the lifting hook of a crane, at the end of the arm of an excavating machine, to the wires of a dragline excavator, to the arms of a power shovel or a tractor equipped with a backhoe loader or to a loader, or to a dredge. Excavator bucket is the important part which is responsible for work and excavator bucket life is the very important factor since the bucket may fail to complete its designed life [12]. The major reason behind this failure is its working environment and modes of operations. Excavator buckets are designed to work in worst conditions, situations for long duration of time. During operation, the bucket undergoes excessive stresses, loads, jerks, deformations, and it would be have to be robust enough to withstand such operating conditions [13].

3 METHODOLOGY

After gathering all the necessary problems concerning the current SK220 excavator buckets delays, the project was divided into different phases.

- Phase 1 - The current process was studied and represented in graph forms for simplification and to be able to visualize the impacts as a whole.
- Phase 2 – Conducting of root cause analysis to mitigate factors while also providing the control plan to ensure the project would have positive impact and beneficial to the company
- Phase 3 –Capacity planning were conducted to determine how many excavator buckets can be manufactured a week.
- Phase 4 – Excavator buckets forecast was designed and shared with production department to plan according as per weekly requirement.

4 CASE STUDY BACKGROUND

Given the poor quality of outsourced buckets, the company considered manufacturing its own strong and reliable excavator buckets. However, due to Covid 19 pandemic, the company failed to deliver the buckets on time. The supplied excavator machines that were shipped from Japan to South Africa faced a deficit of excavator buckets which affected committed customer orders. The quality of being trustworthy to your customers is significant due to market demand has become more combative and managing supply chain uncertainty is crucial. The customers were complaining about delays, and hence it was imperative to initiate a project for process improvement.

The information of excavator buckets delivered date versus the required date was obtained from the range of 2020 to 2021. Table 1 represent the bill of materials for the various parts required to manufacture SK220 Excavator bucket.

Table 1: Bill of materials for parts required for Excavator bucket

Part No.	Description	Quantity
TB00595/0	Belly	1
TB00595/13	Side Cover	2
TB00595/04	Middle Cover	1
TB00595/02	Half Round	1
TB00595/05	Lug	1
TB00595/01	Side Plate	2
TB00595/19	Back UO Bar	1
TB00595/16	Fish Plate	1
TB00595/09	Back Rib	1
TB00595/08	8mm Washer	4
TB00595/14	6mm Washer	4
TB00595/07	L Plate	1

TB00595/15	Gasket Plate	2
X4278137	14mm Boss	8
X4197029	Stopper	1
X4218627	3 Hole Boss	3
X4278138	4mm 3 Hole Washer	3
TE02918	Lip Plate	1
TE01741	Pin	2
X4278139	Shim	2
T3053596	Side Cutter	2

The delivery of buckets has been extremely bad, and the organisation struggling to achieve the targets and fulfilling the customer orders.

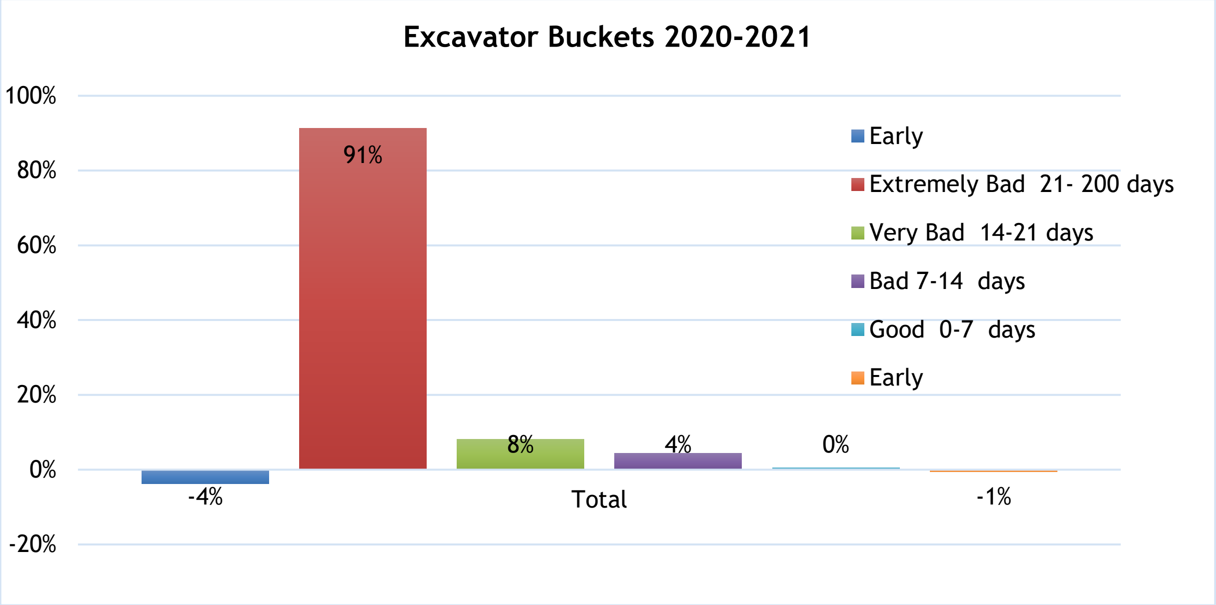


Figure 1: Delivery performance of excavator buckets

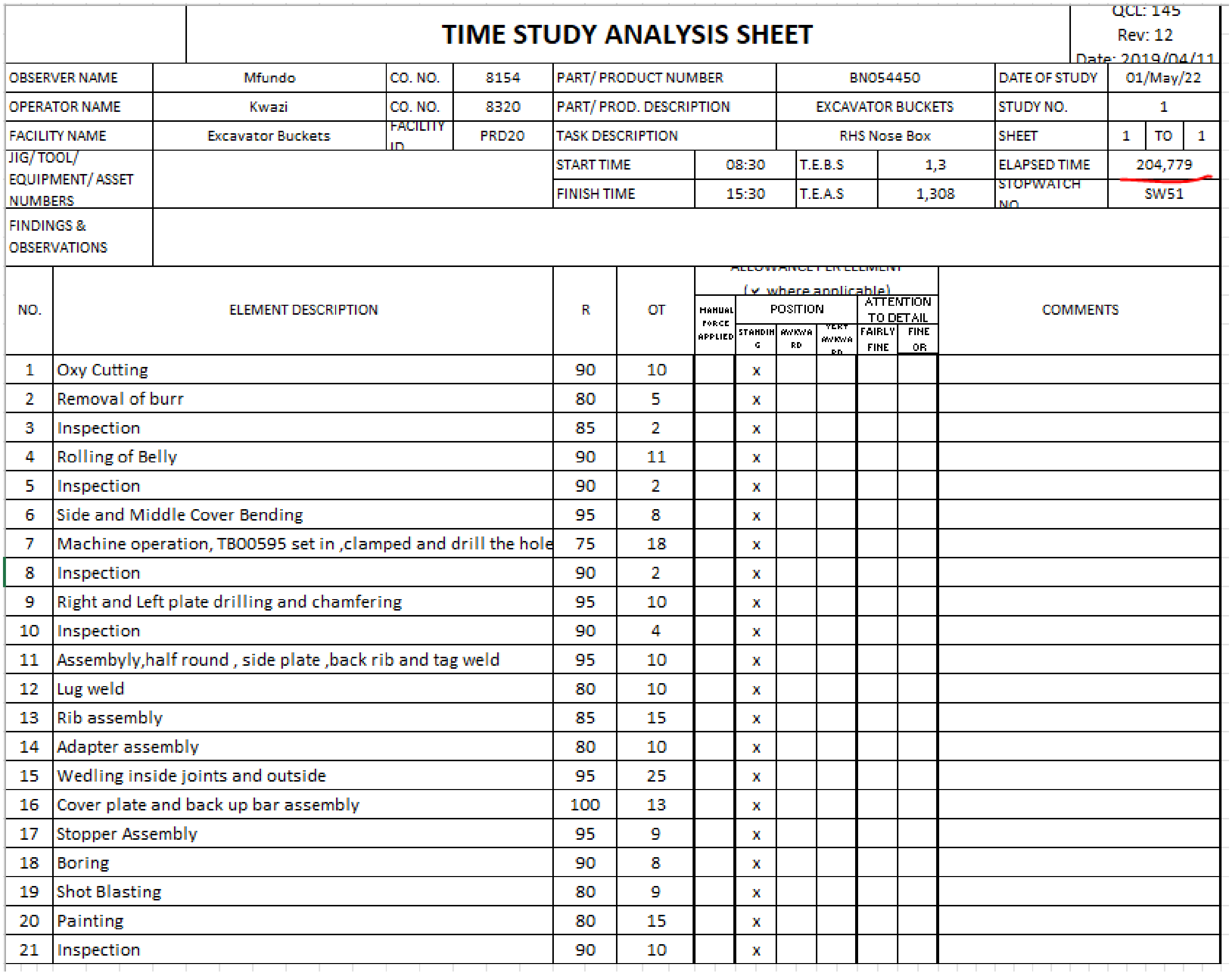
From the graph analysis of Figure 1, the indication is that the current process in not working effectively and efficiently in terms of meeting the primary targets. Figure 1 demonstrates that there was that the buckets were never delivered on time, it either delivered too early or too late and this analysis is raising a concerned about currently strategy that used by production department.

Bar graphs represent the poor performance of the production department failing to meet customer expectation. The bar graph analysis highlighted the production constraints which need to be pinpointed to find the root cause of the problem.

5 RESULTS AND DISCUSSION

5.1 Time Studies

The cycle time taken by all the processes involved in manufacturing of bucket is studied and the time taken by them is discussed below. Time study for all the workstations is carried out and the total time is estimated. The time includes the loading, clamping, or fitting and unloading.



TIME STUDY ANALYSIS SHEET

QCL: 145
Rev: 12
Date: 2019/04/11

OBSERVER NAME	Mfundo	CO. NO.	8154	PART/ PRODUCT NUMBER	BN054450			DATE OF STUDY	01/May/22
OPERATOR NAME	Kwazi	CO. NO.	8320	PART/ PROD. DESCRIPTION	EXCAVATOR BUCKETS			STUDY NO.	1
FACILITY NAME	Excavator Buckets	FACILITY ID	PRD20	TASK DESCRIPTION	RHS Nose Box			SHEET	1 TO 1
JIG/ TOOL/ EQUIPMENT/ ASSET NUMBERS				START TIME	08:30	T.E.B.S	1,3	ELAPSED TIME	204,779
				FINISH TIME	15:30	T.E.A.S	1,308	STOPWATCH NO.	SW51
FINDINGS & OBSERVATIONS									

NO.	ELEMENT DESCRIPTION	R	OT	ALLOWANCE PER ELEMENT (x where applicable)						COMMENTS
				MANUAL FORCE APPLIED	POSITION			ATTENTION TO DETAIL		
					STANDING	AWKWARD	VERY AWKWARD	FAIRLY FINE	FINE OR	
1	Oxy Cutting	90	10		x					
2	Removal of burr	80	5		x					
3	Inspection	85	2		x					
4	Rolling of Belly	90	11		x					
5	Inspection	90	2		x					
6	Side and Middle Cover Bending	95	8		x					
7	Machine operation, TB00595 set in ,clamped and drill the hole	75	18		x					
8	Inspection	90	2		x					
9	Right and Left plate drilling and chamfering	95	10		x					
10	Inspection	90	4		x					
11	Assembyly,half round , side plate ,back rib and tag weld	95	10		x					
12	Lug weld	80	10		x					
13	Rib assembly	85	15		x					
14	Adapter assembly	80	10		x					
15	Wedling inside joints and outside	95	25		x					
16	Cover plate and back up bar assembly	100	13		x					
17	Stopper Assembly	95	9		x					
18	Boring	90	8		x					
19	Shot Blasting	80	9		x					
20	Painting	80	15		x					
21	Inspection	90	10		x					

Figure 2: Time studies results for excavator bucket

5.2 Value Stream mapping

Value stream mapping was conducted to analyse how current process operates and to see a process in a holistic view for identifying linkages between information and material flow for the improvement to be implemented.

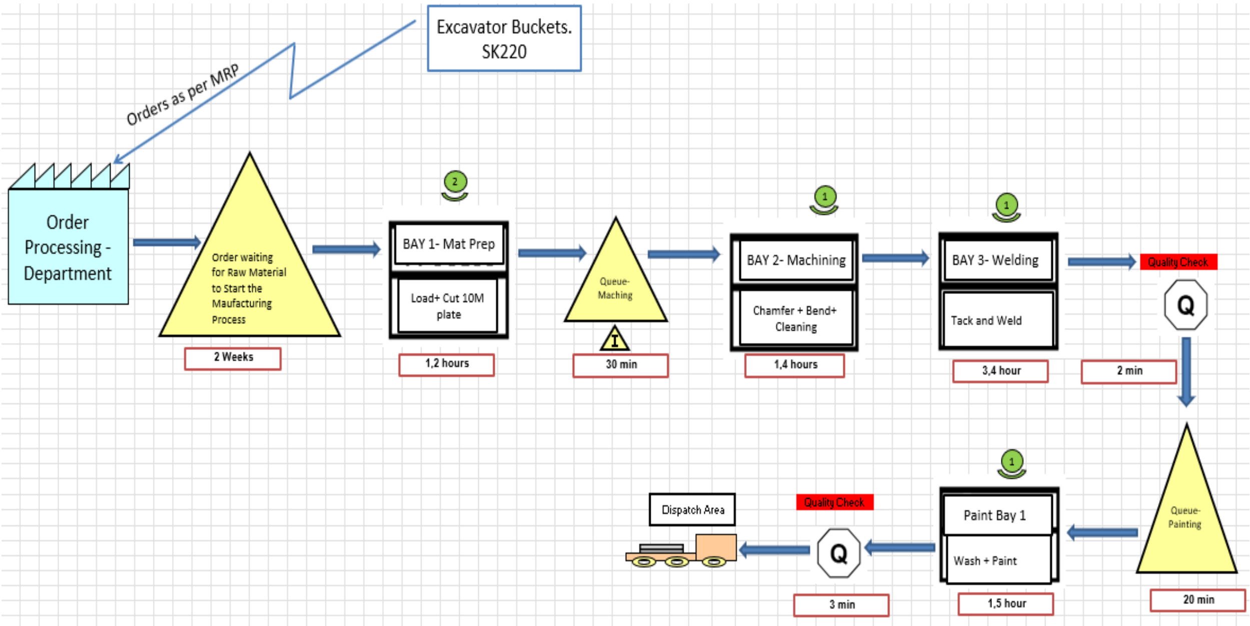


Figure 3: Value Stream Map for Excavator bucket

Figure 3 shows the value stream map for excavator bucket, and it highlighted the area of concern where the waiting time is 4 weeks. The root cause analysis will be conducted below to pinpoint the reason for the delays.

5.3 Cause and Effect Diagram

A cause-and-effect diagram shown in Figure 4 was constructed to identify problems and areas of change of the above value stream mapping. To the right of the diagram the problem is identified as the head of the fish. Then possible causes are identified as the bones of the fish with further causes linked to the main causes.

Facts gathered during preliminary investigation:

- Unskilled operator: could happen the operator requires certain skill or formal education.
- Incorrect material: could happen incorrect tools are used and thereafter rework need to be done which contribute to time delays.
- Not follows customer requirements: specifications or features of the product that are deemed necessary by customers are not being done on time and being done on a later stage.
- Outdated machines and setting time: machine downtime and decrement in production rate due to frequent setup changes being down done and use of old machine which is not effectively and efficient.
- Uncalibrated instruments: Leads to increase down time and unexpected failures as it can affect and damage parts and lead to wastage.
- Incorrect operation and no inspection: inadequate upfront planning which reduced productivity and lot of mistakes being done with inspection.

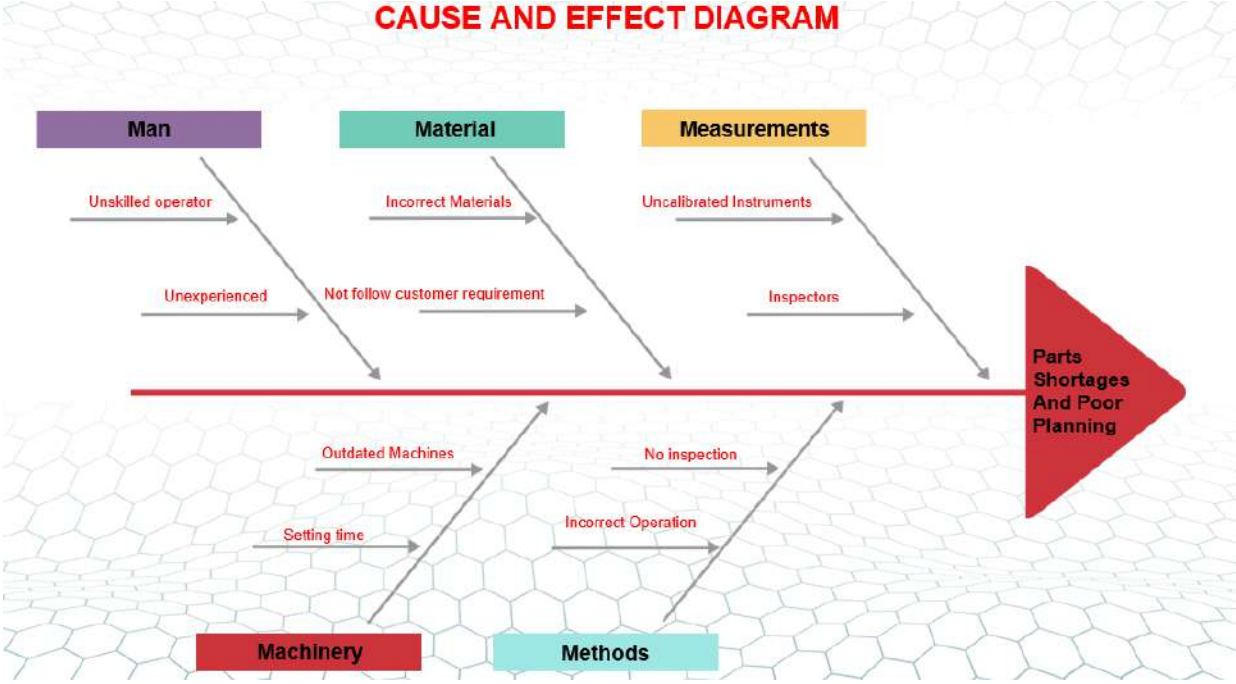


Figure 4: Cause and effect diagram depicting problems with current system

After preliminary investigation and issues being raised it was evident that are great opportunities for improvement of SK220 excavator bucket and many causes that can be addressed. Parts shortages and poor planning are the main course behind the delays of excavator buckets. Shortages were pinpointed as causes of the line stop of more than 3 to 4 days which was attributed to the poor planning. After roots cause analysis, time studies were conducted to plan future of the buckets and to determine how many excavator buckets can be build a week. The production department is operating 40hrs a week and 8 hours a day, upon time study finding it took 5 hours to fabricate a bucket a day. The results shows that only one bucket can be done a day. It was also identified that based on the capacity of production only 5 to 6 excavator buckets can be build a week, that information was used to design the excavator buckets forecast and staggered buckets per week.

5.4 Adjustment of Material Requirements Plans

Table 2 shows a report representing customer orders and required date. The forecast of the customer orders was designed as an improvement to see the customer orders in the 6-month horizons for the material to be order in advance and planned properly as how may buckets we will build per week. The company uses the MRP system to load the customer order requirement for production to react on the demand. The report was run and populated in the excel sheet. The report includes model of the bucket, quantity, order number, required date, serial number and required week for production to react to. The excel pivot table used to make a forecasted based on the information obtained from the report.

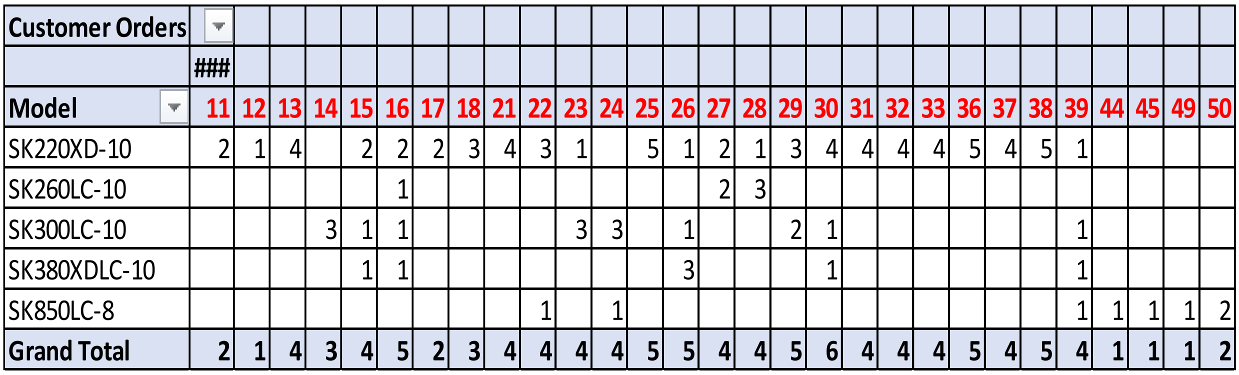
Table 2: Report representing customer orders and required date

Model	Order No	Qty	Serial No	Required date	Week
SK220XD-10	M030180	1	JFL3018	25/01/2021	5
SK220XD-10	M030120	1	JFL3012	27/01/2021	5
SK220XD-10	M048530	1	PF4853B	29/01/2021	5
SK220XD-10	M048770	1	PF4877B	01/02/2021	6
SK220XD-10	M048780	1	PF4878B	02/02/2021	6
SK220XD-10	M048860	1	PF4886B	04/02/2021	6
SK220XD-10	M048870	1	PF4887B	05/02/2021	6
SK220XD-10	M048790	1	PF4879B	09/02/2021	7
SK220XD-10	M048800	1	PF4880B	10/02/2021	7
SK220XD-10	M048660	1	PF4866B	11/02/2021	7
SK220XD-10	M048650	1	PF4865B	12/02/2021	7
SK220XD-10	MO48830	1	PF4883C	18/02/2021	8
SK220XD-10	M148850	1	PM4855B	19/02/2021	8
SK220XD-10	M030090	1	JFL3009	22/02/2021	9
SK220XD-10	M030110	1	JFL3011	23/02/2021	9
SK220XD-10	M030170	1	JFL3017	25/02/2021	9
SK220XD-10	M148760	1	PM4876B	26/02/2021	9
SK220XD-10	MO48970	1	PF4897B	03/03/2021	10

5.5 Weekly requirement forecast

Table 3 represent the customer orders in weeks, the customer forecast requirement was staggered as per the capacity planning which was identify by the time studies that only 5 to 6 buckets can be manufactured a week if it happens the demand was more that the capacity planning the requirement were move to the following week. The forecast was shared with production department to have a holistic view of how many buckets required in weeks in order for the production department to confirm in the plan is achievable and also the organisation to commit to the customer.

Table 3: Revised customer orders in weeks



Customer Orders																													
	###																												
Model	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**36**	**37**	**38**	**39**	**44**	**45**	**49**	**50**
SK220XD-10	2	1	4		2	2	2	3	4	3	1		5	1	2	1	3	4	4	4	4	5	4	5	1				
SK260LC-10						1									2	3													
SK300LC-10				3	1	1					3	3		1			2	1							1				
SK380XDLC-10					1	1								3				1							1				
SK850LC-8										1		1													1	1	1	1	2
Grand Total	**2**	**1**	**4**	**3**	**4**	**5**	**2**	**3**	**4**	**4**	**4**	**4**	**5**	**5**	**4**	**4**	**5**	**6**	**4**	**4**	**4**	**5**	**4**	**5**	**4**	**1**	**1**	**1**	**2**

5.6 Ordering Material in Advance

Due to Covid 19 pandemic the lead time of the material increased significantly, the construction equipment manufacturer's sub-suppliers were struggling to get material from their suppliers on time. The construction equipment manufacturer decided to place orders of excavator buckets material in advance to hold the 40 percentage of inventory to ensure that there is enough material to cater for customer requirement because excavator buckets are on demand. The strategy really contributes to meeting the customer expectations.

6 CONCLUSION

In conclusion the aim of the project was achieved because the bottleneck within supply chain was identified, root cause of the problem was pinpoint and new strategy of determining the demand forecast in advance a based on the production capacity was implemented. The weekly requirement forecast improved the planning process, the production department was able to plan accordingly. The organisation experienced significant improvement of excavator buckets after implementation of the new strategy and customer demand were met on time. The organisation benefited from more sales that were made on time, hence more profit was generated. The monthly sales of R12 500 000 were achievable after implementing the new strategies.

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REDUCTION OF EXCESSIVE CLAIM COSTS ASSOCIATED WITH DAMAGED CARDBOARD CARTONS IN DISTRIBUTION

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ABSTRACT

Courier services suffer a severe problem of experiencing parcel damages that lead to customer complaints and carton claims. Cardboard cartons are easily prone to being damaged during transition and courier companies are not always accountable for parcel damages but still endure consequences as claim costs continue to rise every financial year. The Plan-Do-Check-Action system was used to collect and analyze data intending to prioritize problems, and a parcel inspection was conducted for 22 suppliers to measure variables. Correlation analysis was conducted, and results showed a strong correlation between weight, size, internal carton utilization, and flute corrugated size used on a cardboard. A fish-bone diagram was used to represent the potential root-causes, as a result the relationship between these variables has proven to have the most impact on parcels being damaged. The correlation between the flute corrugated size and internal carton utilization along with mishandling of stock impacted damages the most. During the movement, the durability of the carton is highly depended on these variables. An implementation of training and awareness on how to handle stock with care was conducted to reduce damages during distribution while optimising operations.

Keywords: PDCA cycle, Distribution, Root-cause analysis

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1 INTRODUCTION

Logistics distribution is a highly integrated supply chain network that is generally focusing on the optimal operation of movement from consignor to consignee. The supply chain can be described by pointing to such features as: process object of flow, structure, goals - functional scope and areas of cooperation of the participating entities [1]. The expected business threat in logistics is known to be high fuel cost, fuel cost has emerged as one of the top ten challenges in the truck transport industry [2] however that is not always the case. The business process operations design is currently the most vital and impactful function in the supply-chain of goods by courier services.

Consumers are no longer willing to accept poor service offerings [3]. Service failures arise when perceptions of performance are lower than expectations, resulting in dissatisfaction [4, 5]. Therefor, the number of complaints across the globe is steadily rising. With the current state of increase in number of customer complaints and cardboard packaging claims due to parcels being damaged within the network, distribution services lose 34% of revenues due to product damages every financial year. This paper adopts a focused improvement approach to optimize logistics operations by developing a framework for reduction of excessive claim costs associated with damaged cardboard packaging in distribution. The deployment of plan-do-check-action, root cause analysis, correlation analysis and development of training solutions was used to address packaging damages. Lean manufacturing does enhance logistics by getting the right product, in the right quantity, in the right condition, at the right place, at the right time, to the right customer, at the right price [6].

2 LITERATURE REVIEW

Courier services are an intermediary that distribute finished products from business to consumer (B2C) and consumer to consumer (C2C). At one place of shipment couriers pick up shipments for many recipients, and thus B2C service is implemented [7]. The distribution leg can be short, like in the same city, or long like exporting overseas. However, during the supply-chain reliable packaging is vital and plays a huge role in the distribution process. According to Pongrácz [8], the only way between production and consumption is by making use of packaging. Moreover, Pongrácz [8] stated that during urbanisation, the transportation of products will be crucial and therefore packaging will play an enormous role. In addition to this, another source stated that packaging plays an immense role in the business world, as a result of globalization where all companies are in constant competition with each other [9]. Moreover, Gunasekaran [9] explains that packaging does not receive as much attention as it deserves. However, when the package reaches the consumer and it is destroyed or wasted, this is when packaging is brought into attention [8]. This study will focus on improving controllable factors that influence reduction of packaging claims.

Yu et al. [10] used a decision tree combined with clustering method to develop real time logistics monitoring system of packages during transportation, that has inertial measurement units (IMUs) which can be easily installed and can detect states of packages correctly, the system can distinguish different states of packages with different weights.

Optimisation is an action of making the best out of the situation or a resource, and in logistics, the aim of optimisation is focused on a more effective utilisation of transport means, technologies, and human resource. A typical parcel movement line for inducted stock in the distribution network as shown in Figure 1 is characterised by the movement of load vehicles from the warehouse, conveyor belt system, cross belt sorter, palletisation and loading vehicle for dispatch. Since this is a cross dock operation, stock is not stored for a long period in the warehouse.

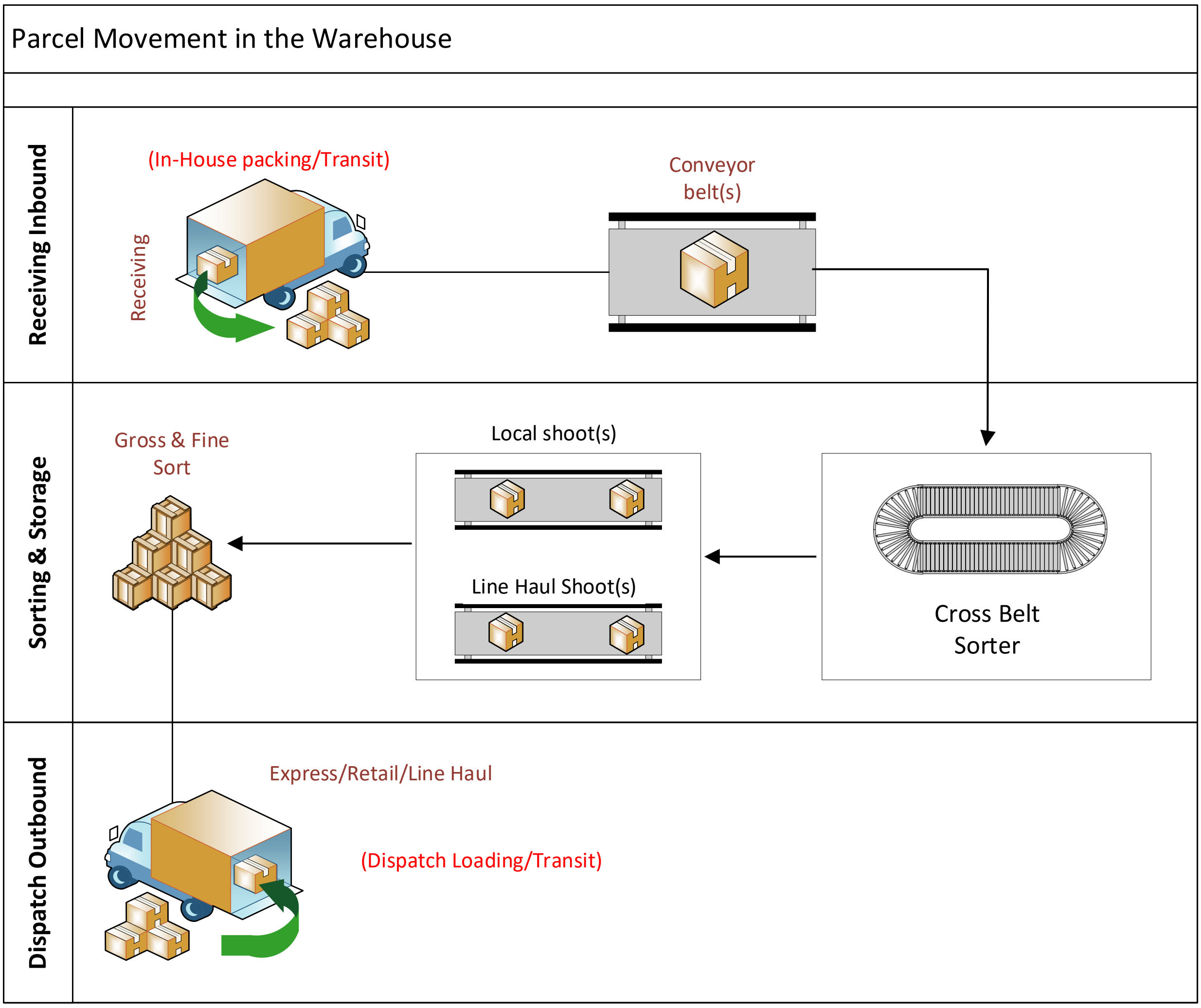

Figure 1: Flow diagram for distribution operations

Dominic [11] mentioned that excellent and reliable packaging is mandatory to protect goods during transportation. Moreover, courier service internal staff are responsible for handling stock with care until the last mile delivery. There are many aspects and guidelines to consider with handling and packing goods to enable safe transport [12]. This study focused on the problem of cardboard packaging damages that lead to poor service delivery, excessive claims and increase in operational expenses.

Reverse logistics can also be recognised as optimisation because it refers to the reverse logistics system, the layout of the various logistics facilities and transport facilities between the arrangements. The distribution of transport nodes using transport logistics makes it possible to reduce transport difficulty. In relation to freight transport the reduction of transport as well as shipping happens [13]. Operations research can be understood as a resource to find an optimal solution while evaluating various factors [14], for example the routes can be chosen for several vehicles from the same location or from several independent locations [15].

3 RESEARCH APPROACH

The Plan-Do-Check-Action (PDCA) system was used to collect, analyse data, improve, and control operational processes continuously. This methodology is the most effective technique to look for better effects or improvement [16]. During the Plan phase, a parcel inspection document was developed and used to collect information and data of the variables influencing claims for each damaged cardboard in terms of parcel specifications. In the Do phase, the correlation analysis was performed on measured variables and the results of the study was used to design required operational processes by identifying process parameters which are resulting to cardboard packaging damages. To accurately describe the problem, a fishbone diagram was developed to identify the root-cause to improve controllable factors that influence reduction of packaging claims.

Mishandling = Stacking misalignment of corrugated cardboard due to lack of awareness

In the Check phase, a database was created for capturing structured information related to damages received within the distribution network with an aim of understanding a detailed description of the damaged cardboard. In the Action phase, the results were validated through statistical analysis and used to develop training solutions to empower employees for sustained optimisation of logistics and distribution of parcels. Lastly, cardboard packaging damages were tracked to verify if there were improvements in reduction of packaging claims after the implementation of the PDCA cycle and training solutions.

4 DEFINITION OF PROBLEM AND IMPLEMENTATION OF SOLUTIONS

4.1 Problem definition

Historical data of the breakages enquired within the distribution network was retrieved from packaging damages records. Data was drawn from the Logidata ERP system for the freight and Figure 2 shows a summary of cardboard packaging damages resulting to excessive claims. Over a period of 6 months, the distribution service experienced a total of 85 745 parcel breakages during the consignment of goods from B2C or C2C within the regions of South Africa. In this study, attention was paid for every damaged parcel since it results to excessive claims and loss in business revenue.

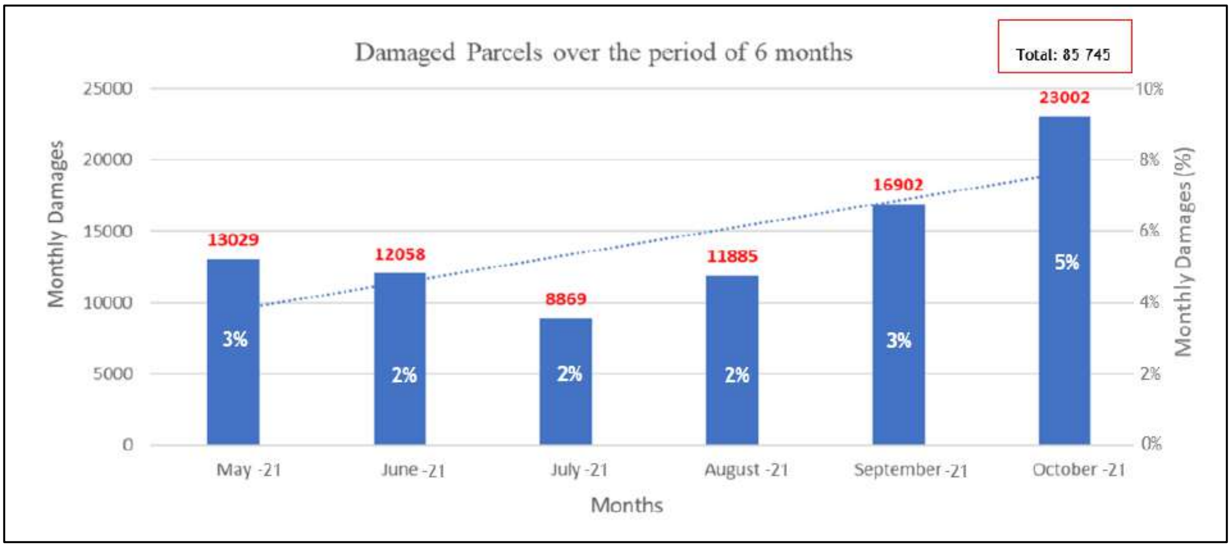

Figure 2: Summary of cardboard packaging damages resulting to excessive claims

Figure 3 shows a summary of packaging damages per customer that were assessed in one month, that had >100 damages. Out of the 22 suppliers measured, only 11 suppliers had damages >100. The highest number of damages assesed was 3484 by customer 1 followed by 3109 by customer 2. As a result, the assessment checks performed included packaging size, weight of parcel, internal packaging utilization, flute corrugated size used and type of adhesives used for the package. The database was created for capturing structured information related to damages received within the distribution network, it is capable of capturing and storing up to 1000 cardboards per day.

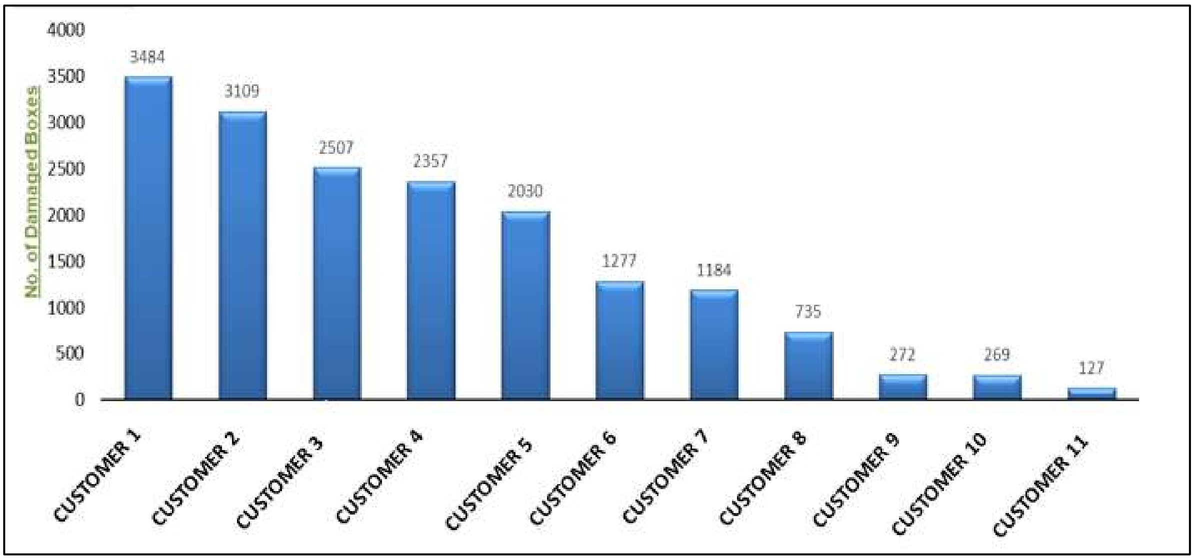

Figure 3: Summary for packaging damages per customer

Figure 4 shows a summary of factors that contribute to cardboard packaging damages in the distribution network. The highest number of damages were experienced due to staff mishandling cardboards followed by receiving cardboards from suppliers that are internally over or under utilized.

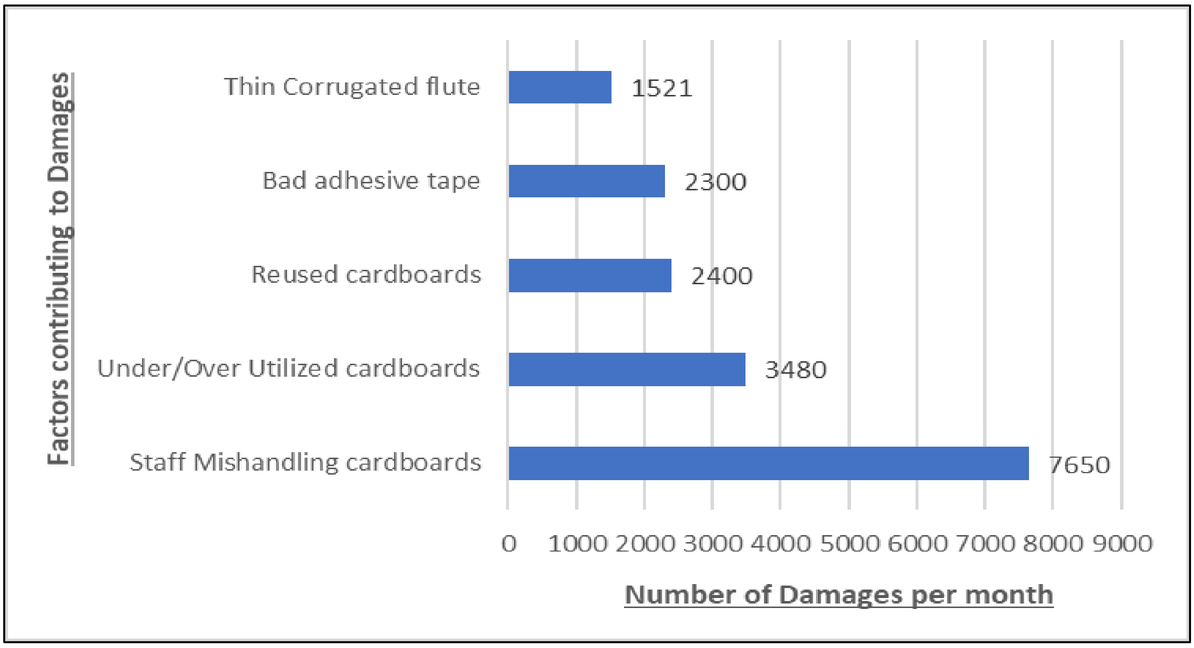

Figure 4: Summary for factors that contribute to cardboard packaging damages

Therefore, in line with proper problem definition, the problem was found to be mishandling of packaging that were resulting to damages.

4.2 Potential causes for packaging damages

A root-cause diagram was used as a tool to identify and display possible causes for packaging breakages. As shown in Figure 5, it represents the deepest underlying cause of positive or negative symptoms within the logistics process that would result in elimination, or substantial reduction, of the symptom [17]. The causal factors were established from brainstorming sessions and information obtained from operations project department. Some of the correlating factors that contribute to packaging damages were revealed to be specifications such as packaging size, weight of parcel, internal packaging utilization, flute corrugated size used for the package. It was also revealed that man-power is struggling with heavy parcels hence resulting in more breakages. The foundation point for parcel damage prevention is the packaging, keep in mind that each good requires different packaging materials. So, take the necessary time to choose the ideal packaging for your type of product, so that it reaches the customer in perfect conditions.

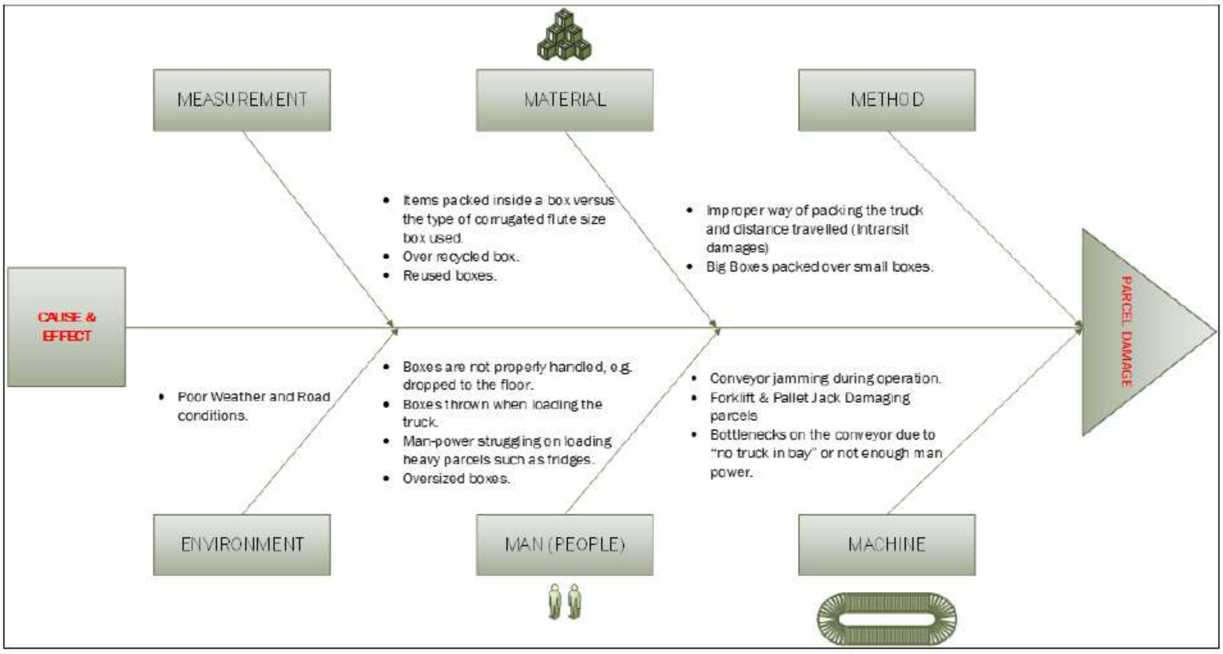

Figure 5: Root cause analysis for packaging damages

The next step was to check if the standards were taken into consideration for each of the causes. Table 1 shows a summary of troubleshooting the potential root causes, the inspection procedures to be followed, and the observations that were made. Concerning poor handling of cardboards, the development of training solutions such as handling parcels in a vertical flute direction (VFD) will enhance the strength of the cardboard, develop a parcel inspection document (PID) and use it to collect information and data of the variables influencing claims and also empower employees for sustained framework while optimising distribution services. The team leader and supervisor use a parcel handling evaluation sheet (PHES) to observe employees as they are executing their duties doing a job. The PHES is a customised job description for each of the jobs that are executed within the cross dock facility.

Table 1: Troubleshooting potential causes for packaging damages

Potential root cause	**Inspection**	**Observation**
Incorrect method of handling	Perform PHES to check VFD on handled cardboard packaging	Lack of awareness on handling packaging correctly
Incorrect cardboard size used for packaging item	Perform PID to check cardboard size used against packaged item	Some packaging found to be underutilized
Conveyor jamming during operations	Check if there is enough chain lube on the inbound and discharge conveyor	No issues were observed

Incorrect adhesive tape	Perform PID to check adhesive tape used on cardboard packaging	No issues were observed
Incorrect stacking strength	Perform PHES to check VFD on cardboard packaging ensuring stacking strength	Some cardboard stacked incorrectly
Reused cardboards for packaging	Check for worn cardboard packaging	Some cardboards were worn

4.3 Implementation of possible solutions

These solutions included developing training solutions for parcel handling methods and stacking strength guides. It was also imperative to check if the packages are still getting damaged after the implementation of training and awareness on handling packaging correctly. Table 2 shows the steps which were followed for the implementation of possible solutions.

Table 2: Steps for the PDCA cycle

Description	**Responsible**	**Status**
• Develop a parcel inspection document to collect data of the variables influencing packaging claims.	Industrial Engineer	Completed
• Develop a fishbone diagram to identify the underlying root-cause to packaging damages • Measure the correlation of variables influencing packaging damages	Industrial Engineer	Completed
• Check detailed description of captured structed information related to damages	Industrial Engineer	Completed
• Develop training solutions through validated statistical analysis	Industrial Engineer	Completed

To close the loop, it was vital to do the following tasks:

- Generate an incessant schedule to check packaging variables or review the frequency;
- Generate an incessant schedule to check handling methods or review the frequency.

5 RESULTS AND DISCUSSION

The implementation of possible solutions led to the improvement of parcel handling in terms of reduction of packaging damages. These include stacking corrugated cardboard in a vertical flute direction always as this increases the stacking strength of the cardboard and continuously perform feasibility study on packaging. Figure 6 shows a comparison of before and after scenarios for packaging damages. A successful consignment of delivering 100 000 parcels to a consignee is equivalent to generating a R1 million rands sale. In the before scenario, the highest number of cardboards damages in a month was 23 000 which is 5% of the delivered parcels. The results demonstrate that there is a noteworthy improvement after the interventions on issues that were highlighted by the root-cause diagram for cardboard packaging damages and reduced the number of damages drastically to 5000 which is 1% of the delivered parcels in the month of May-22.

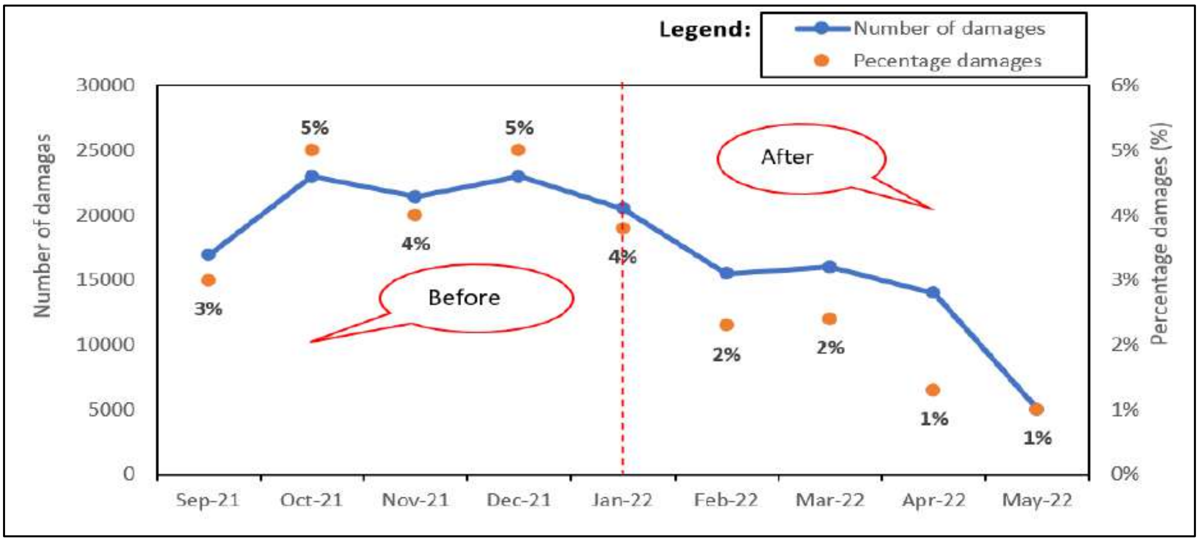

Figure 6: Comparison of before and after scenarios for cardboard packaging damages

6 CONCLUSION

The study focused on the improvement of cardboard packaging damages through the deployment of PDCA system and root cause analysis. It was noted that damages during distribution service is a challenge given the escalation of logistics costs associated with supplier claims. Lean manufacturing tools can be used to provide structure to solve problems and measure performance, and thereafter provide solutions to optimise distribution operations while reducing packaging damages. It was also noted that the PDCA is an iterative technique for continuous improvement and can be exploited to improve the distribution operations. The root causes of packaging damages during the distribution operations as a result of mishandling packaging were identified and cost-effective measures were instituted to reduce excessive claims associated with damaged cardboard cartons in distribution. Future research would embrace the impact of Industry 4.0 and other related technology will influence quality and efficiency of packaging solution in distribution.

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ANALYSIS ON THE IMPACT OF REDUCED MEAT CONSUMPTION ON THE SOUTH AFRICAN ECONOMY

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ABSTRACT

Statistics show an increasing trend towards the adoption of meat-free and meat-reduced diets motivated by environmental sustainability, personal health, and animal welfare. The tremendous growth in sales revenue of plant-based foods further proves this shift towards reduced meat consumption. The impact of this change in lifestyle among a large population size will affect many industries. This project identifies the economic impact of a large-scale reduction in meat consumption on the agricultural sector, food industry, and healthcare sector, and analyses how these combined impacts will affect the South African economy. This is achieved by building a predictive model that is able to predict the GDP per capita based on the behaviour of features from specified key industries.

Keywords: predictive models, human factors, economy,

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*Corresponding Author

1 INTRODUCTION

The benefits of meat reduced, or meat free diets are not limited to their impact on the environment, animal welfare and human health. Recent statistics and studies have shown that these lifestyles have also resulted in many economic benefits. An example of this is the predicted 2026 global plant-based food industry market value of $16 billion [1]. Furthermore, the Plant Based Foods Association in the USA reported that in 2016 the plant-based food industry created over 60 000 jobs that paid a total of $3.6 billion in income [2]. The report also stated that plant-based food companies pay an average total of $1.1 billion in tax each year [2].

A world survey conducted by Ipsos MORI, a British market research company, concluded in 2018 that 5% of the world’s population were vegetarian, 3% were vegan and 14% were flexitarian [3]. Statistics from 2019 show that 4% of the adult American population identify as either vegetarian or vegan [4]. The United Kingdom reported in 2012 that 1.2 million people followed a plant-based diet and in 2020 this number increased to 3.1 million people [5]. If the upward trend of vegetarianism and reduced meat consumption continues, the economic benefits that come with it will also increase.

Currently, there is no official statistics on the number of vegans and vegetarians within South Africa nor the growth rate of vegetarianism, but Google search data shows that South Africa is ranked 14th in the world in terms of searches for Vegetarian and Vegan diets [6]. If large scale reduced meat consumption were to occur in South Africa, there is insufficient research available regarding how this change would impact the economy of the country.

1.1 Problem statement

Each year a greater share of the global population begins embracing a meat reduced or meat free diet. The impact of this dietary shift towards plant-based foods has extended into many industries, creating both economic opportunities and losses. This project focuses primarily on identifying the economic impact of a large-scale reduction in meat consumption on the agricultural sector, food industry, and healthcare sector, and analyses how these combined impacts will affect the South African economy.

1.2 Project objectives

The following objectives make up the structure of the project and are used to analyse the extent of the impact that reduced meat consumption will have on the South African economy.

1. Identify features within each of the analysed industries that are affected by meat consumption.
2. Analyse the impact of reduced meat consumption on each of the specified industries using a complete data set.
3. Build and test a predictive model that demonstrates the net impact of reduced meat consumption on the South African economy.
4. Provide conclusions on the impact of reduced meat consumption on the South African economy.

1.3 Research approach and methodology

1. Features within the agricultural sector, food industry, and healthcare sector are identified and relevant data collected.
2. Data exploration techniques are applied to the data collected from international trade database [2] to create a workable data set, complete with one target feature and multiple independent features that are then used in the building of the predictive model.

3. Bivariate analysis are performed to identify key relationships and trends between the features within the data set and reduced meat consumption.
4. The regression data analysis tool in Excel is used to build the predictive model by performing multiple linear regression on the data set. The output of the excel analysis is used to perform hypothesis testing to ensure that the model and its features are statistically significant.
5. Once a predictive model that best fits the data is found, it is tested using varying reduced meat consumption scenarios to observe the behaviour of the model.
6. Using the predictive model, conclusions are made on how reduced meat consumption could impact the South African economy.

1.4 Project scope and assumptions

The scope of this project has been limited to the analysis of reduced meat consumption within three key industries namely, the agricultural sector, the food industry, and the healthcare sector. The identified features being impacted within each industry is then used to predict the overall influence reduced meat consumption will have on South Africa's economy. The effects of a reduction in meat consumption are seen in many industries/fields such as power generation, ecological science etc., however these industries have not been included within this study.

The assumptions made in this project are:

- The term "animal products" used in the economic overview of South Africa's agricultural sector, refers to red meat (beef, pork, and lamb) as well as poultry. It does not include seafood products.
- The threats of global warming and increased carbon footprint awareness are a key driver amongst the younger generation to adopt an environmentally friendly behaviour and attitude.
- Perspectives regarding health and lifestyle is assumed to be another driver among young people to adopt a meat free diet.
- Feature "Population" will be significant in the calculation of GDP per capita.

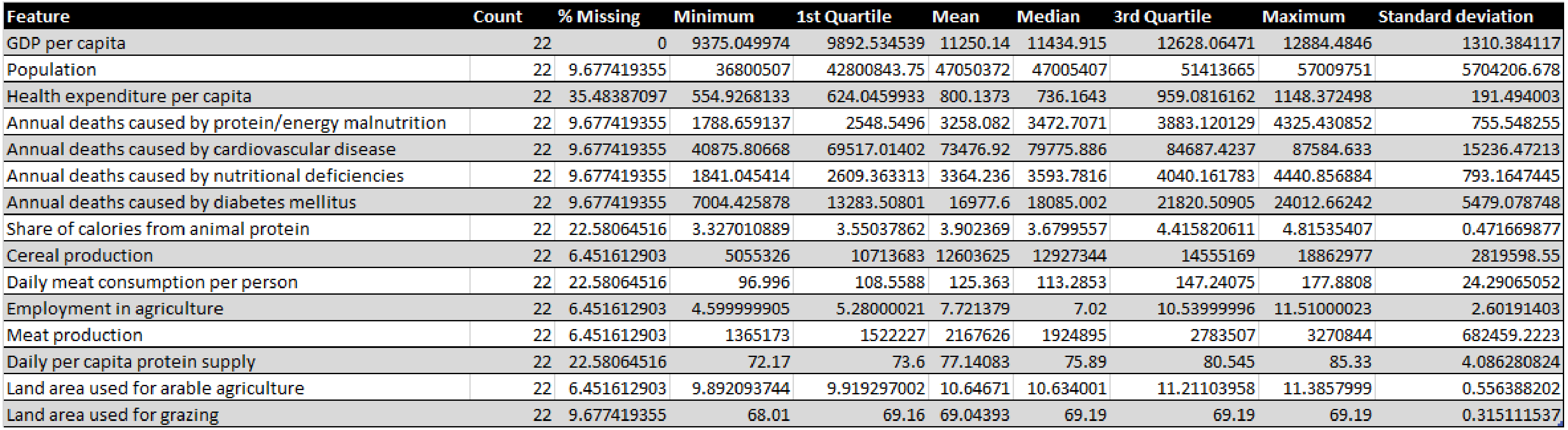
2 DATA ANALYSIS

A predictive model is created to understand the net impact that decreased meat consumption has on the South African economy. This model is built using multiple linear regression, a statistics technique commonly used in machine learning to understand the relationship between variables [7]. This is done by essentially finding the line of best fit through a dataset with the smallest prediction error [8]. The first step taken in the model building approach is to identify a target feature to become the output variable of the model. To quantitatively analyse the impact of decreased meat consumption on the economy, the target feature is set as GDP per capita, a measure of wealth and prosperity within a country [9].

Once the target feature is identified, raw data pertaining to subject variables are collected. These variables make up the remaining independent features of the model. Daily meat consumption per person is also used as a significant feature to illustrate the relationship between decreased meat consumption and other independent features. After data collection, data exploration techniques are applied. This is done to first gain an understanding of the data's characteristics and then to identify data quality issues (missing values, outliers and noise) that can affect the model [10]. The data quality issues are compiled into a report shown in Table 1, for analysis.

The report shows that four features have over 20% of instances missing. These missing values occur more regularly in instances after 2014 and for feature "health expenditure per capita" many missing instances occur over the period 1990 to 1994. Due to these occurrences, the data which initially covered a period from 1990 to 2020 is shortened to include only instances from 1995 to 2016. Missing values can negatively impact model performance by creating a bias which reduces the reliability of the data [11]. By excluding certain instances, most missing value quality issues are eliminated, however, not all missing values can be handled in this way. The instances remaining are resolved using imputation, the process of replacing missing values with a plausible estimated value based on the data set [10]. Replacing missing instances with plausible values (e.g., mean of data) allows the data set to retain its statistical distribution [12]. Outlier analysis is then done by studying feature distributions and box and whisker plots. Outliers shift the line of regression towards themselves resulting in an increase in standard error. This creates a regression line that does not best fit the data [13] which impacts the ability of the model to make accurate predictions [10]. Two outliers were found in the "Annual deaths caused by cardiovascular disease" feature and were handled using imputation. The outlier values are replaced with the data's median value of 81985.68 to ensure that the tendency of the regression line does not shift. Lastly, feature "Land area used for grazing" was removed from the data set as all instances were recorded as equal which does not accurately represent the change in land used for grazing from 1995 to 2016. The cleaned data set is then used to perform bivariate analysis. This is done by first graphically interpreting the relationships between features from scatter plots and then calculating the Pearson's corelation coefficient (R) for each pair of features.

Table 1: Data quality report



Feature	Count	% Missing	Minimum	1st Quartile	Mean	Median	3rd Quartile	Maximum	Standard deviation
GDP per capita	22	0	9375.049974	9892.534539	11250.14	11434.915	12628.06471	12884.4846	1310.384117
Population	22	9.677419355	36800507	42800843.75	47050372	47005407	51413665	57009751	5704206.678
Health expenditure per capita	22	35.48387097	554.9268133	624.0459933	800.1373	736.1643	959.0816162	1148.372498	191.494003
Annual deaths caused by protein/energy malnutrition	22	9.677419355	1788.659137	2548.5496	3258.082	3472.7071	3883.120129	4325.430852	755.548255
Annual deaths caused by cardiovascular disease	22	9.677419355	40875.80668	69517.01402	73476.92	79775.886	84687.4237	87584.633	15236.47213
Annual deaths caused by nutritional deficiencies	22	9.677419355	1841.045414	2609.363313	3364.236	3593.7816	4040.161783	4440.856884	793.1647445
Annual deaths caused by diabetes mellitus	22	9.677419355	7004.425878	13283.50801	16977.6	18085.002	21820.50905	24012.66242	5479.078748
Share of calories from animal protein	22	22.58064516	3.327010889	3.55037862	3.902369	3.6799557	4.415820611	4.81535407	0.471669877
Cereal production	22	6.451612903	5055326	10713683	12603625	12927344	14555169	18862977	2819598.55
Daily meat consumption per person	22	22.58064516	96.996	108.5588	125.363	113.2853	147.24075	177.8808	24.29065052
Employment in agriculture	22	6.451612903	4.599999905	5.28000021	7.721379	7.02	10.53999996	11.51000023	2.60191403
Meat production	22	6.451612903	1365173	1522227	2167626	1924895	2783507	3270844	682459.2223
Daily per capita protein supply	22	22.58064516	72.17	73.6	77.14083	75.89	80.545	85.33	4.086280824
Land area used for arable agriculture	22	6.451612903	9.892093744	9.919297002	10.64671	10.634001	11.21103958	11.3857999	0.556388202
Land area used for grazing	22	9.677419355	68.01	69.16	69.04393	69.19	69.19	69.19	0.315111537

2.1 Bivariate analysis

Bivariate analysis is used to identify key relationships and trends between independent features and the selected target feature. The methodology of the bivariate analysis is as follows:

1. Each independent feature is allocated to one of the main industries being focused on in this project, namely the agricultural sector, healthcare sector and food industry. This is done to create a clear analysis of each industry as set out in the project objectives.
2. Within each industry, the independent features are plotted against meat consumption and other relevant features.
3. The Pearson's correlation coefficient (R) between features are calculated using the Excel function =CORREL( ).
4. Both scatter plots and R are used to analyse the relationship between features.

2.1.1 Agricultural sector

Employment rate is a feature indicating the "efficiency and effectiveness of an economy to absorb its labour force" [14]. The scatter plot for the relationship between features "Daily meat consumption per person" and "Employment in agriculture" show that as daily meat consumption of people in South Africa increases, there is a decrease in the percentage of the population employed by the agricultural sector. The inverse would show that decreased meat consumption would lead to an increase in employment. The correlation between these features is R = 0.9 which shows a strong relationship.

Arable agriculture/farming is defined as the growing of crops and cereals, not including fruit and vegetables [15]. The scatter plot for the relationship between features "Daily meat consumption per person" and "Land area used for arable agriculture" shows a trend of increased meat consumption being inversely related to the percentage of land used for arable agriculture. This means that in the event of decreased meat consumption, the area of land allocated to the farming of crops such as wheat, rice and corn would increase. The correlation between these features is R = 0.966 which shows a strong relationship.

The last relationship analysed is between features "Daily meat consumption per person" and "Cereal production". No clear trend can be identified within the scatter plot. Irregular crop volumes could explain the lack of defined relationship between the features. The correlation between these features is R = 0.4 which shows a weak relationship.

2.1.2 Food industry

This industry is directly impacted by the diet choices of a population. To model the impact that decreased meat consumption would have on the food industry and economy, relevant variables within the industry affected by meat consumption are identified. The relationship between features "Daily meat consumption per person" and "Daily per capita protein supply" show that as meat consumption increases, the amount of protein supply in the average South Africans diet also increases. The correlation coefficient is R= 0.98 which indicates a strong relationship between the features.

The scatter plot for features "Daily meat consumption per person" and "Meat production" shows that for increased meat consumption there is an increase in the amount of meat produced in the country. This trend follows the expected relationship between production and consumption. The correlation coefficient is calculated as R= 0.99 which represents a strong relationship between the features.

2.1.3 Healthcare sector

A research paper titled *Analysis and valuation of the health and climate change co-benefits of dietary change* [16], shows that higher meat consumption increases a person's likelihood of developing certain illnesses. This in turn creates greater expense on the healthcare sector therefore increasing expenditure and impacting the economy. Data on the prevalence of protein/energy malnutrition, cardiovascular disease, nutritional deficiencies, and diabetes mellitus in South Africa are selected as features to quantitatively model this relationship.

The relationship between features "Daily meat consumption per person" and "Annual deaths caused by protein/energy malnutrition" are analysed first. The scatter plot shows that as a person's meat consumption increases, they are less likely to develop protein/energy malnutrition. The correlation between these features are R = 0.954 which shows a strong relationship. This relationship suggests that if people decrease meat in their diet without replacing it for another source of protein, an increase in annual deaths from protein/energy malnutrition can occur. The correlation coefficient is R= 0.46, this indicates a weak relationship between features "Daily meat consumption per person" and "Annual deaths caused by cardiovascular disease". The scatter plot for "Daily meat consumption per person" and "Annual deaths caused by nutritional deficiencies" shows that as meat consumption increases, the number of deaths from nutritional deficiencies also decrease. The correlation between these features is R = 0.95 which shows a strong relationship. The relationship between features "Daily meat consumption per person" and "Annual deaths caused by diabetes mellitus" shows that an increase in meat consumption would increase annual deaths from diabetes mellitus. Similarly, a decrease in meat consumption would decrease the number of deaths caused by diabetes. The correlation coefficient is calculated as R= 0.76 which represents a strong relationship between features. The initial analysis focused on the types of illnesses impacted by meat consumption. To determine how these illnesses would economically affect the healthcare sector, the relationship between the identified illnesses and healthcare expenditure is examined using the same methods. It is evident that an increased prevalence of diabetes mellitus correlates with an increase in the average healthcare expenditure per person spent by government. The opposite relationship is identified for prevalence of protein/energy malnutrition and nutritional deficiencies, as it shows a strong correlation with a decrease in healthcare expenditure per capita. No clear relationship between cardiovascular disease prevalence and healthcare expenditure is observable. To analyse the impact of reduced meat consumption on the healthcare sector, the features "Daily meat consumption per person" and "Health expenditure per capita" are plotted against each other, shown in Figure 1. It is evident that as people consume more meat, an increase in government healthcare expenditure per person occurs. The correlation coefficient is calculated as R= 0.98 which represents a strong relationship between features. In the event of reduced meat consumption, a decrease in health sector expenditure would be experienced.

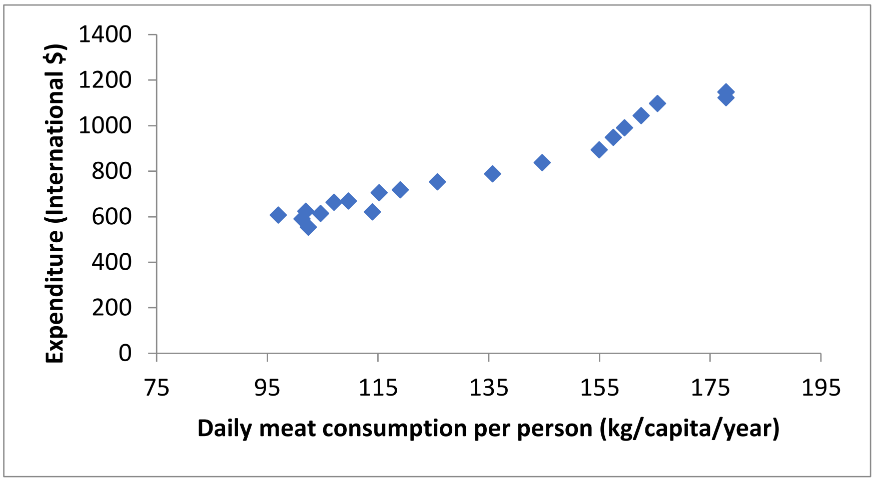


Figure 1: Daily Meat Consumption Per Person Vs Health Expenditure Per Capita

To understand the impact that this scenario will have on the economy of South Africa, the healthcare expenditure is plotted against the GDP per capita shown in Figure 2. With a correlation coefficient of R = 0.94 a strong relationship is identified where increased health expenditure leads to increased GDP per capita. The ability for government to increase healthcare expenditure per capita could show the availability of greater wealth which could be translated into a higher GDP per capita.

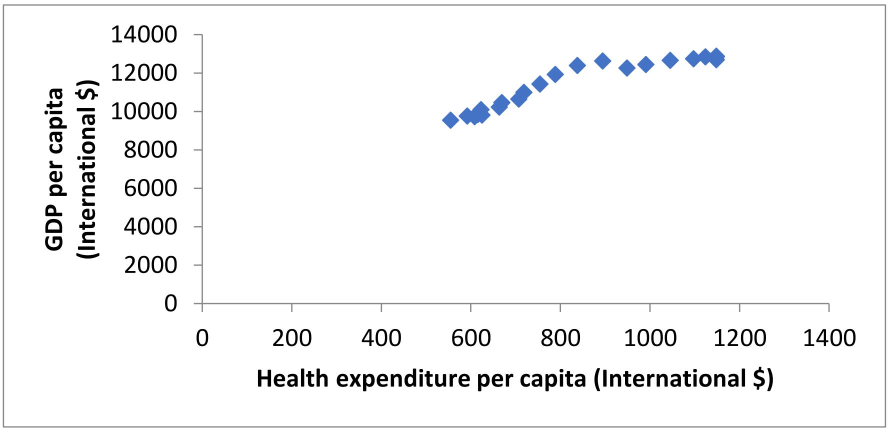


Figure 2: Health expenditure per capita vs GDP per capita

2.2 Building the Predictive Model

The purpose of the predictive model is to determine the net impact of decreased meat consumption on the South African economy. Features with a strong correlation with meat consumption are used to build the model as they represent the changes within the chosen industries as a result of reduced meat consumption. “Cereal production” and “Annual deaths caused by cardiovascular disease” are the only features that are not impacted by meat consumption and are therefore left out of the model. The trends of these features are analysed against the target feature (GDP per capita) to inspect, firstly if the set of features are a good overall predictor of GDP per capita and secondly, which specific features are significant when predicting the target feature [17].

Before the regression model can be built, it is essential to first check for multicollinearity between the chosen features. Multicollinearity occurs when the input features of the model are highly correlated to each other causing the coefficients of the line of regression to become very sensitive and less precise, therefore reducing the statistical power of the model [18]. The regression coefficients represent the change in target feature for every one-unit change in a specific independent feature while all other features remain constant [18]. When there is high correlation between these features, they are no longer independent from each other which affects the calculated regression coefficient [18]. To test for multicollinearity, a correlation matrix is created. It can be observed from the matrix that all features are highly correlated.

To reduce the impact of multicollinearity, the following steps are taken:

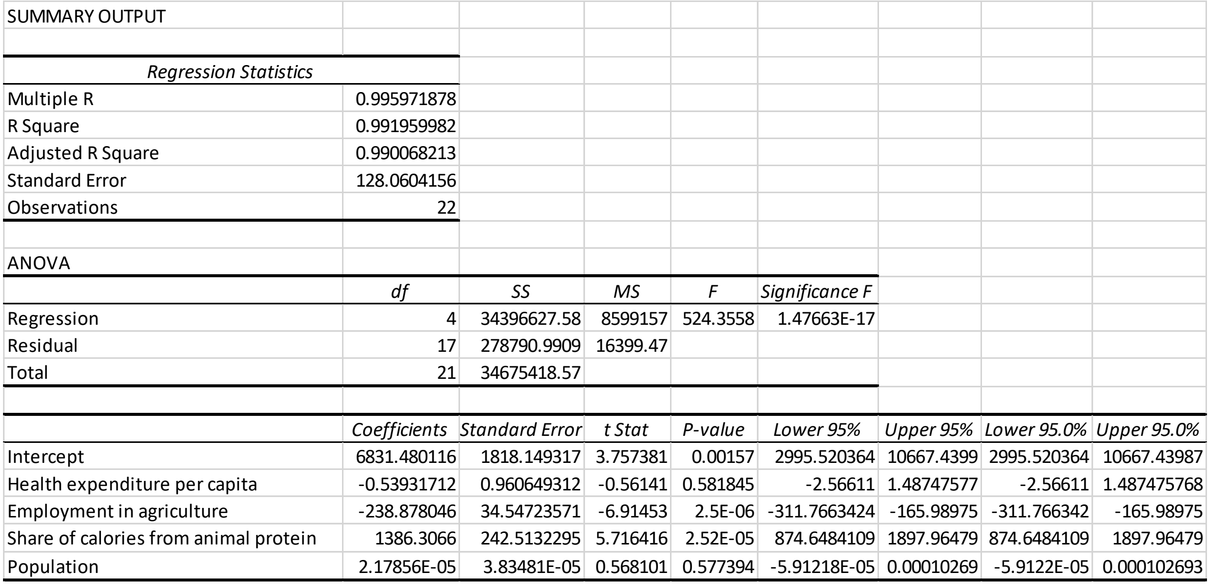
1. Features “Annual deaths caused by protein/energy malnutrition”, “Annual deaths caused by diabetes mellitus” and “Annual deaths caused by nutritional deficiencies” are combined into a singular independent variable named “Total deaths from diet related illnesses”.
2. The correlation matrix is then recreated to observe for differences in multicollinearity.
3. A feature from each industry, with the highest correlation to GDP per capita is selected to represent the impact of meat consumption for that industry. Since a high correlation exists between industry features, features are removed as they have the same impact on GDP per capita.

The final features chosen for model building are “Health expenditure per capita” to represent the healthcare sector, “Share of calories from animal protein” to represent the food industry, and “Employment in agriculture” to represent the agricultural sector. Feature “Population” is also included as it is assumed that it is significant in the calculation of GDP per capita.

The regression data analysis tool in Excel is used to perform a multiple linear regression to find the combined impact of the selected features on GDP per capita. Table 2 summarises and describes the key output data produced by Excel’s regression analysis that is utilised to build the model.

The excel output from the multiple linear regression is shown in Table 2. The regression statistics show a multiple R value of 0.99597. This means that all features have a strong correlation to GDP per capita. The value for R square shows that 99.2% of the variation in GDP per capita can be explained by the independent features of the model.

Table 2: Multiple linear regression Excel output, iteration 1



SUMMARY OUTPUT									
Regression Statistics									
Multiple R	0.995971878								
R Square	0.991959982								
Adjusted R Square	0.990068213								
Standard Error	128.0604156								
Observations	22								
ANOVA									
	df	*SS*	*MS*	*F*	*Significance F*				
Regression	4	34396627.58	8599157	524.3558	1.47663E-17				
Residual	17	278790.9909	16399.47						
Total	21	34675418.57							
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*	
Intercept	6831.480116	1818.149317	3.757381	0.00157	2995.520364	10667.4399	2995.520364	10667.43987	
Health expenditure per capita	-0.53931712	0.960649312	-0.56141	0.581845	-2.56611	1.48747577	-2.56611	1.487475768	
Employment in agriculture	-238.878046	34.54723571	-6.91453	2.5E-06	-311.7663424	-165.98975	-311.766342	-165.98975	
Share of calories from animal protein	1386.3066	242.5132295	5.716416	2.52E-05	874.6484109	1897.96479	874.6484109	1897.96479	
Population	2.17856E-05	3.83481E-05	0.568101	0.577394	-5.91218E-05	0.00010269	-5.9122E-05	0.000102693	

To test the statistical significance of the model, a hypothesis test was carried out at 95% confidence level.

$$H_0: \beta_i = \beta_{i+1} = \beta_{i+2} = 0 \tag{1}$$

$$H_1: At\ least\ one\ \beta_i \neq 0 \text{ where i= independent feature of model} \tag{2}$$

The null hypothesis states that all coefficients (β) of the independent features are equal to zero which means that the partial slopes will be zero and none of the features will produce a linear relationship with GDP per capita. H1 states that at least one of the features will have a coefficient value not equal to zero. The null hypothesis would be rejected if significance F < 0.05. Since the significance $F = 1.4766 \times 10^{-17}$, the null hypothesis is rejected, and the model is said to be statistically significant.

The next analysis done is to determine which of the features within the model are statistically significant. This is done using the hypothesis test

$$H_0: \beta_i = 0 \tag{3}$$

$$H_1: \beta_i \neq 0 \text{ where i= independent feature of model} \tag{4}$$

The null hypothesis states that the specific independent feature in question would not have a significant linear relationship with GDP per capita and H1 states the opposite. The null hypothesis would be rejected if the features P-value < 0.05. Table 3 summarises the P-values of the features.

Table 3 shows that “Health expenditure per capita” and “Population” had a P-value > 0.05, therefore the null hypothesis is not rejected, and the features are said to be statistically insignificant to the model. “Employment in agriculture” has a P-value < 0.05 therefore the null hypothesis is rejected, and the feature is statistically significant to the model. Feature “Share of calories from animal protein” also has a P-value < 0.05 and so the null hypothesis is rejected, and the feature is said to be significant.

Table 3: P-values

Feature	P-value
Health expenditure per capita	0.581845
Employment in agriculture	2.5×10^{-6}
Share of calories from animal protein	2.52×10^{-5}
Population	0.577394

The regression model is then reiterated after removing the feature “Health expenditure per capita” and “Population”. The new regression output (Table 4) shows that the model is still statistically significant with a significance F < 0.05. Changes in model behaviour are seen in the change of P-values as the remaining features become more significant within the model. The adjusted R value for the first model iteration is 0.99 and for the second iteration, 0.9909. From these values there is no evidence that the removal of the feature “Health expenditure per capita” makes any substantial difference to the goodness of fit of the model as the adjusted R values are similar.

Using the coefficients calculated in the final iteration, the equation of linear regression was written as:

$$GDP\ per\ capita = 1310.995\ x_{Share\ of\ calories\ from\ animal\ protein} - 249.492\ x_{Employment\ in\ agriculture} + 7822.9676 \quad (5)$$

The last step done in the model building process is testing the predictive model by calculating the net impact of reduced meat consumption on the South African economy. If meat consumption decreased, values for "Share of calories from animal protein" would decrease and according to the relationship identified by the bivariate analysis, decreased meat consumption would lead to an increase in "Employment in agriculture".

To create dummy data to replicate this scenario, simple linear regression is done to determine the linear equations that model the relationship between the features "Share of calories from animal meat protein" vs "Daily meat consumption per person" and "Employment in agriculture" vs "Daily meat consumption per person". Figure 3 and Figure 4 show the simple linear regression equation for each relationship.

Table 4: Multiple linear regression Excel output, iteration 2

SUMMARY OUTPUT								
Regression Statistics								
Multiple R	0.99588961							
R Square	0.991796116							
Adjusted R Square	0.990932549							
Standard Error	122.361227							
Observations	22							
ANOVA								
	df	*SS*	*MS*	*F*	*Significance F*			
Regression	2	34390945.45	17195473	1148.488	1.5247E-20			
Residual	19	284473.1274	14972.27					
Total	21	34675418.57						
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	7822.967603	651.3323808	12.01072	2.55E-10	6459.713263	9186.22194	6459.713263	9186.22194
Employment in agriculture	-249.4917731	27.99700291	-8.91137	3.26E-08	-308.0901736	-190.89337	-308.0901736	-190.893373
Share of calories from animal protein	1310.995459	113.5580314	11.54472	4.97E-10	1073.315767	1548.67515	1073.315767	1548.67515

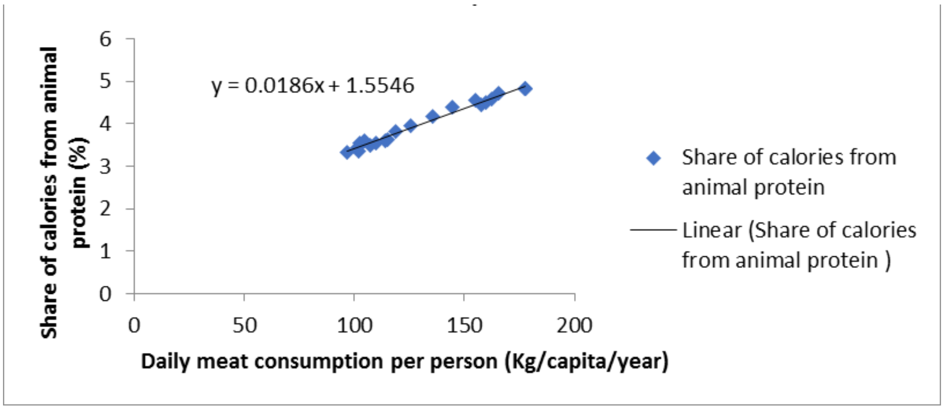


Figure 3: Linear regression equation for share of calories from animal protein

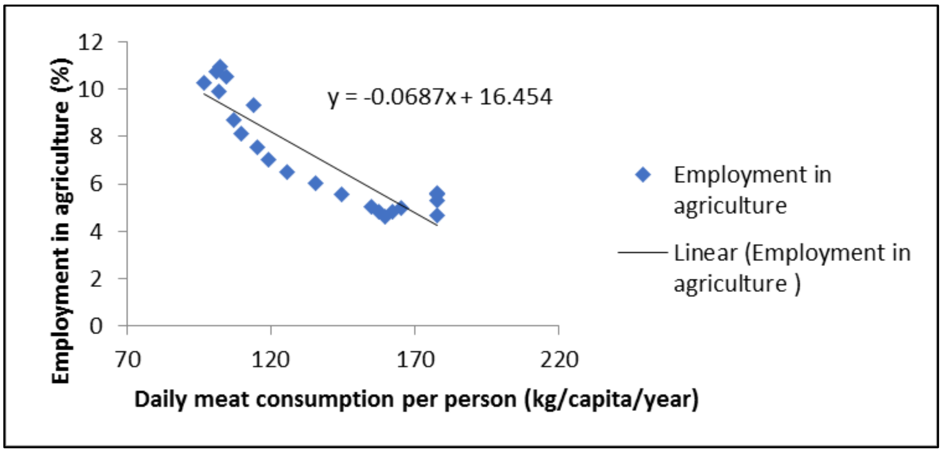


Figure 4: Linear regression equation for Employment in agriculture

The three scenarios used to test the behaviour of the predictive model is as follows:

1 Daily meat consumption per person is reduced annually by 1%.
2 Daily meat consumption per person is reduced annually by 5%.
3 Daily meat consumption per person is reduced annually by 10%.

The initial x-value for daily meat consumption was set at 177.88 kg/capita/year. For each scenario the initial x-value was reduced by the corresponding percentage over a 10-year period. Using the two simple linear regression equations where x = daily meat consumption, the values for features "Share of calories from animal protein" and "Employment in agriculture" were calculated over the same 10-year period. Once these values were calculated for the two independent features, they were substituted into the multiple regression equation to predict the values of GDP per capita.

3 FINDINGS

After all relevant data was collected and cleaned, the predictive model was built and tested. It was found that all collected data was highly correlated to both the target feature (GDP per capita) and to the other independent features, which created high multicollinearity within the data set. It was assumed that feature "Population" would have a significant relationship to GDP per capita, however due to the high multicollinearity, features were removed from the model as they had the same impact on GDP per capita and therefore could not be modelled as separate variables. By removing these features more accurate regression coefficient values could be found.

The final iteration of the model showed GDP per capita as a function of significant features "Share of calories from animal protein" and "Employment in agriculture" in the form

$$GDP\ per\ capita = 1310.995\ x_{Share\ of\ calories\ from\ animal\ protein} - 249.492\ x_{Employment\ in\ agriculture} + 7822.9676$$

The results from the test scenarios (Figure 5) show that a reduction in daily meat consumption per person will lead to a decrease in GDP per capita. The greater the rate of reduced meat consumption the greater the decline in GDP per capita. An annual meat consumption reduction of 1% over a ten-year period led to a 5.88% decrease in share of calories from animal protein, and a 24.96% increase in employment within the agricultural sector. The net impact of this was a 4.86% decrease in GDP per capita after ten years which translates to an average 0.55% annual decrease. For an annual meat consumption reduction of 5%, GDP per capita decreased by 20.78% and for 10%, GDP per capita decreased by 34.43% over a 10-year period. From the testing of the predictive model, it can be concluded that a large-scale reduction in meat consumption in South Africa would negatively impact the South African economy as a decrease in GDP per capita would be experienced.

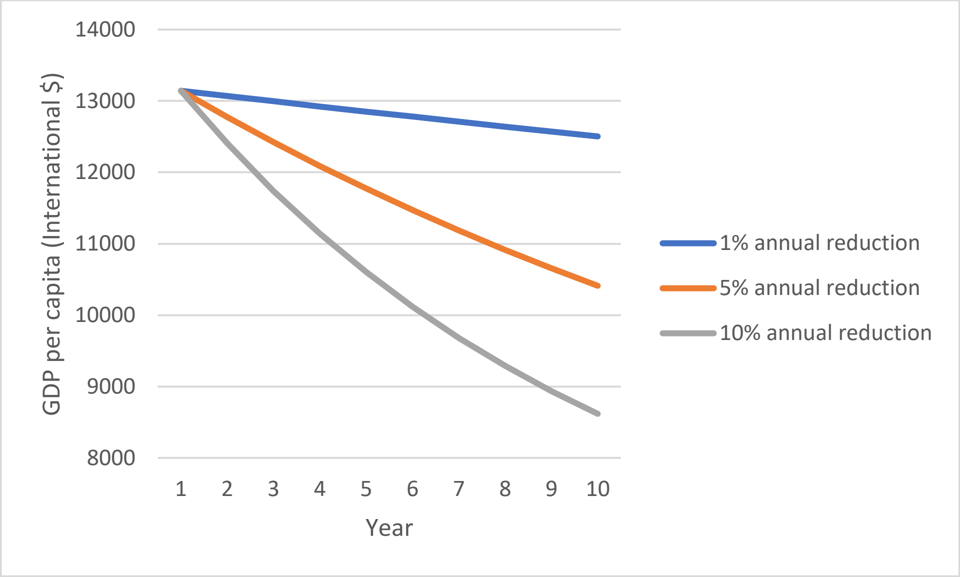


Figure 5: Impact of meat reduction on GDP per capita

4 CONCLUSION

From the analysis conducted in this project, it can be concluded that a large-scale reduction in meat consumption with the current industry structures in place, would have an overall negative impact on the South African economy. The predictive model constructed to determine the net impact of reduced meat consumption on the economy showed that increased degrees of meat consumption reduction would result to increased degrees of loss to GDP per capita. Separately, all features used in the model had a strong correlation to meat consumption and GDP per capita, however, when combined into a single model, the predictive power of features "Share of calories from animal protein" and "Employment in agriculture" were stronger than the others.

There are many ways that a decrease in meat consumption could help boost the economy. The agricultural sector would benefit from more land being dedicated to crop and horticultural production as these products generate the most trade income from agricultural exports. Greater development and investment into South Africa's plant-based food industry could increase economic growth through employment and taxation of the industry. The healthcare sector would also financially benefit from a decrease in the direct and indirect costs caused by diet related illnesses. However, this would mean a restructuring of these industries. As more research is done on this topic, more robust data will be available to remodel the impact of reduced meat consumption on the South African economy.

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IDENTIFICATION OF FACTORS THAT AFFECT THE PERFORMANCE OF VIRTUAL ENGINEERING TEAMS

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ABSTRACT

The foundation of many engineering firms and engineering companies is the engineering teams that are formed to tackle problems. These teams may have many variances in terms of size, diversity, skill-set and the problem to be solved; but what is common to all is that the performance of the team is crucial to the success of the organisation. Amidst the ongoing COVID-19 Pandemic, engineering teams have been forced to work remotely from places other than the workplace. This has set up what can be described as virtual engineering teams. The performance of these virtual engineering teams still plays the same pivotal role in the success of the organisation. The aim of this project is therefore to identify the factors that affect the performance of virtual engineering teams. This study is heuristic in nature and therefore its results cannot be interpreted as exhaustive.

Keywords: virtual engineering teams, performance, leadership,

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1 INTRODUCTION

Virtual teaming refers to a setup where members of the team are geographically distributed, requiring them to work together through electronic means with minimal face-to-face interaction [1]. Companies may have headquarters in two separate countries or may be working on a project outside the borders of the country that they reside in. This leads to members of the team being split up into various geographical regions. These teams are therefore geographically separated. Virtual teams are then set up which requires members of the team to work remotely and meet/communicate with each other using online platforms. Virtual teams have been around for a long time and have been used predominantly by large corporates who operate in many countries. In geographically separated virtual teams, there are many factors at play. Often, the members of these teams may have never met face-to-face. As such, they may not personally know their team members, but rather only a projected, virtual version of their team members. Team members may also come from vastly different backgrounds, ethical groups, cultures and religions. In managing the success of these virtual teams, it is important to navigate factors that affect the performance of virtual teams.

According to Lin, Standing, and Liu [2], these factors may be split up into 3 main categories: task dimensional factors, communication and social dimensional factors. Task dimensional factors refer to task-orientation, coordination and task-technology-structure fit. Communication refers to the lack of body language and linguistic cues. Social dimensional factors are those such as relationship building, cohesion and trust. Recently, the need for the creation of virtual teams has spiked. This is mainly due to the ongoing Coronavirus Disease of 2019 (COVID-19) Pandemic. Members of a team are unable to meet with each other at the workplace due to health and safety concerns, which has led to many companies opting for employees to work remotely. Before COVID-19, employees that worked in the virtual teaming setup were reported to be approximately 10% in developed countries and even less in developing countries, but these numbers spiked since the advent of COVID-19 [3].

COVID-19 Pandemic-induced virtual teams may differ slightly from the virtual teams formed by geographical barriers and as such may have different factors affecting their performance. These teams should have all, at some stage, met each other face-to-face and so should know each other and each other's working styles a lot better. These teams should presumably be working in the same province, within the same country and as such should have a better appreciation and understanding of each other's backgrounds, ethnical groups, cultures and religions. But most importantly, the pandemic-induced virtual teams erupted instantaneously with no opportunity for preparation. In the ever evolving and uncertain modern circumstances, it is important to understand what factors affect the performance of virtual teams in general and how these factors may be applicable in engineering virtual teams. The success of these teams and ultimately the success of the company is dependent on managing and enhancing their performance.

This study seeks to identify the factors that affect the performance of virtual engineering teams. This will allow organisations and companies to make informed decisions and management changes to optimise the performance of their virtual teams.

2 THEORETICAL BACKGROUND

Technological advancements have changed the way people, organisations and the world works. As technology continues to progress, it is becoming increasingly viable for teams to collaborate remotely to complete tasks. Even before the advent of COVID-19, there was an upward trend in the number of teams that work across geographically dispersed environment, fostering the use of virtual teams [4]. Some of the reasons cited for the upward trend in virtual teaming include reduction in real estate expenses, access to global markets, distributed expertise, improved collaboration technologies, increase in productivity and lessened overhead costs [5]-[8]. Engineering organisations are also susceptible to these global changes as virtual teams can be found across various fields of engineering including but not limited to software engineering, mechanical/aerospace engineering, industrial engineering, and construction/civil engineering [9]. Employees who work in engineering organisations have a virtual teaming adoption rate of 43.2% and this is a high value when juxtaposed with the lowest-rated occupation of sales that has only 11.4% adoption rate [3]. According to Singh, Cascini and McComb [5], there is still a lack of rigorous research that assesses the impact of virtual teaming on the engineering design process.

Virtual engineering teams (just like most type of teams) are subject to the four stages of team building described in Bruce Tuckman's classical model, namely: forming, storming, norming and performing [10]. Ayoko, konrad and Boyle [11] proposed an adaptation to this model which is of particular relevance to the development of virtual teams. Stage 1 (Forming) consists of shyness and uncertainty between group members with a large focus on group maintenance. Stage 2 (Storming) is characterised by team members jostling and struggling with each other for authority, position and influence. This stage consists of a lot of disagreement from which leadership is tested and the initial team leader may not survive this phase. Stage 3 (Norming) is when the team starts to settle into their internal structure. By now, the team will have its own process and conflict management techniques in place and the scope, and responsibilities of the team become clearer. This allows for the team to focus on the task at hand. Stage 4 (Performing) is characterised by a level of trust, cohesion and group morale. The team becomes interdependent, and they can finally solve the task at hand.

The team's performance is affected by how long the team spends in each phase. To achieve a higher performance, it is imperative that the team is able to spend more time in the performing stage and minimise the time in the storming phase [11]. Leadership plays a critical role in determining how much time is spent in each of these phases. Successful leaders can adapt to the situation and fulfil many different roles in order to best match what the team needs out of the leader. This can range from a facilitator to a producer. The leader's ability to adapt will increase the team's effectiveness towards the leader as well as improve the team's cohesiveness and ultimately performance. Leaders also play a critical role in mitigating and managing conflict [1], [12].

Conflict in a team can be split into three distinct categories: task conflict, relational conflict and process conflict [12]. There are contradictory findings on the impact of computerised communication on conflict. Certain research shows that conflict is increased by computerised communication because of ambiguity and gaps in communication, whilst other sources suggest that over time conflict is reduced as teams adapt to the virtual platforms [11], [12]. Relational conflict is the conflict that literature suggests all virtual teams struggle with and this is due to certain implications of working on a virtual platform [14].

Working on a virtual platform means that the modes and methods of communication differ from those of a face-to-face team. The most effective form of virtual communication uses video and audio media, and therefore virtual teams should avoid using text only communication [8]. The visual and audio clues such as facial expressions and tone of voice are crucial to enhance the understanding of team members as well as build an element of trust, cohesion and unity within the team. These social-dimensional factors have a significant impact on the performance of the virtual team and an increase in trust, cohesion and unity has been linked to a higher level of performance. Computerised communication also decreases the ability of team members to manage emotions. A display of emotion by a team member would usually elicit an emotion out of another team member. The lack of face-to-face communication means that often a team member's emotion is not realised. This means that a complementary emotion cannot be exchanged and for work related emotions, team members cannot create a sense of unity based on shared emotion [2].

Engineering is a high stress environment characterised by uncertainty, change and high competition. Since engineers work under pressure across the world, the link between job stress and job satisfaction among engineers has been topical among scholars and engineers

[15]. This is based on the technological advancements of recent years as well as engineers needing to fulfil numerous roles in a company, not just the pure engineering of years gone by [16]. A lower job satisfaction has also been linked to a lower level of performance [15]. Thus, companies need to find a way to minimise the stress placed on its engineers and maximise the job satisfaction, organisational environment has a significant impact on this [17]. A company with a more supportive, collaborative and motivational culture is more likely to have virtual engineering teams filled with individuals with a high job satisfaction. Companies that empower their employees, giving them more responsibility and a higher job involvement will also see a higher job satisfaction.

Virtual platforms flatten out the hierarchy of teams and thus a virtual engineering team is more likely to receive input from a range of team members, rather than just those perceived to be better qualified [13]. This is linked to an increased job involvement and a higher level of performance of the virtual engineering team. Therefore, companies who empower their individuals to be competent on a virtual platform and comfortable working with the software will experience a higher level of performance from their virtual engineering team. This is attributed to a lower level of stress felt by the individual as well as an increased efficiency, effectiveness and trust in both the organisation and in virtual team members.

As pointed out by Kilcullen et al. [7], the outbreak of COVID-19 forced organisations to adopt virtual teaming regardless of whether or not they were prepared for virtual teaming since the shift happened instantaneously, leaving no time for preparation. This shift has necessitated more research that seeks to investigate the factors that affect the performance of virtual teams [14]. Even though the performance of virtual teams has been explored in the past, evidence is starting to emerge that shows that there is a gap in what is known with regards to sustaining the optimal virtual team performance, particularly during crisis [3], [5], [7], [14].

3 SYSTEMATIC LITERATURE REVIEW

The systematic literature review methodology (SLRM) is used to collate and define the factors that affect the performance of virtual engineering teams because it is a systematic, explicit, and reproducible method for identifying, evaluating, and synthesising an existing body of completed and recorded work produced by researchers, scholars, and practitioners [18]. The results of this study are based on the SLRM to ensure replicability by using transparent steps discussed in this section.

3.1 Search Strategy

3.1.1 Review question

One of the factors that distinguishes the SLRM from the traditional literature review is that it requires the *a priori* identification of problems to be addressed by the review and this is achieved using a clearly structured question. For this study, the question for the SLRM is framed as follows:

> *What are the factors that affect the performance of virtual engineering teams?*

The review question is meant to dictate the type of work included in the review and it is the most fundamental step in the SLRM process as it ensures that the work included is relevant for addressing the main objective of the review [18], [19].

3.1.2 Search terms and possible variations

The search terms used in this SLRM are derived from the definition of virtual teaming provided by Malhotra [1] and the variations of the concept found in various studies presented in the theoretical background section.

((virtual* OR dispersed) AND team AND engineer*) ((virtual* OR (“geographically distributed”)) AND team* AND engineer*)

((virtual* OR global) AND team* AND engineer*)

3.1.3 Databases

The search used the Scopus and Web of Science databases since they were found to be more appropriate for the engineering and technology management disciplines. The results presented in table 1 below include duplicates, inaccessible work and studies that might not be relevant for the review.

Table 1: Search results returned

Search term	Scopus	Web of Science	Total per term
((virtual* OR dispersed) AND team* AND engineer*)	1008	1456	2464
((virtual* OR (“geographically distributed”)) AND team* AND engineer*)	1122	2481	3603
((virtual* OR global) AND team* AND engineer*)	1433	1297	2730

Total per database	3563	5234
Total search results returned	**8797**	

3.2 Eligibility Criteria

Practical screening eliminates articles from the search results returned by the databases based on explicitly defined criteria. During the practical screening, the returned search results are screened based on the study’s content, publication language, period, and the type of publication in which it appears [20]. The inclusion criteria are as follows:

- Content. The studies included in the review should contain information that responds to the review question. Each study should contain insights that can assist in exploring how virtual teaming affects the performance of engineering teams.
- Publication language. The researcher conducting this review is only proficient in the English language and as a result, only the studies published in English are included as part of the review.
- Publication period. The search period is specified to be from 2016 to 2022. This ensures that the review is rooted in the most recently published work.
- Publication type. Only peer-reviewed academic journals are included in the search. The search is limited to full text available online.
- Search Field. Article, abstract, keywords.

3.3 Reporting

The inclusion criteria discussed above are used to assess the literature by title, abstract and full text. The results of the SLR are reported in a systematic manner to include the steps that were followed. The results are reported using the PRISMA (preferred reporting items for systematic reviews and meta-analyses) diagram.

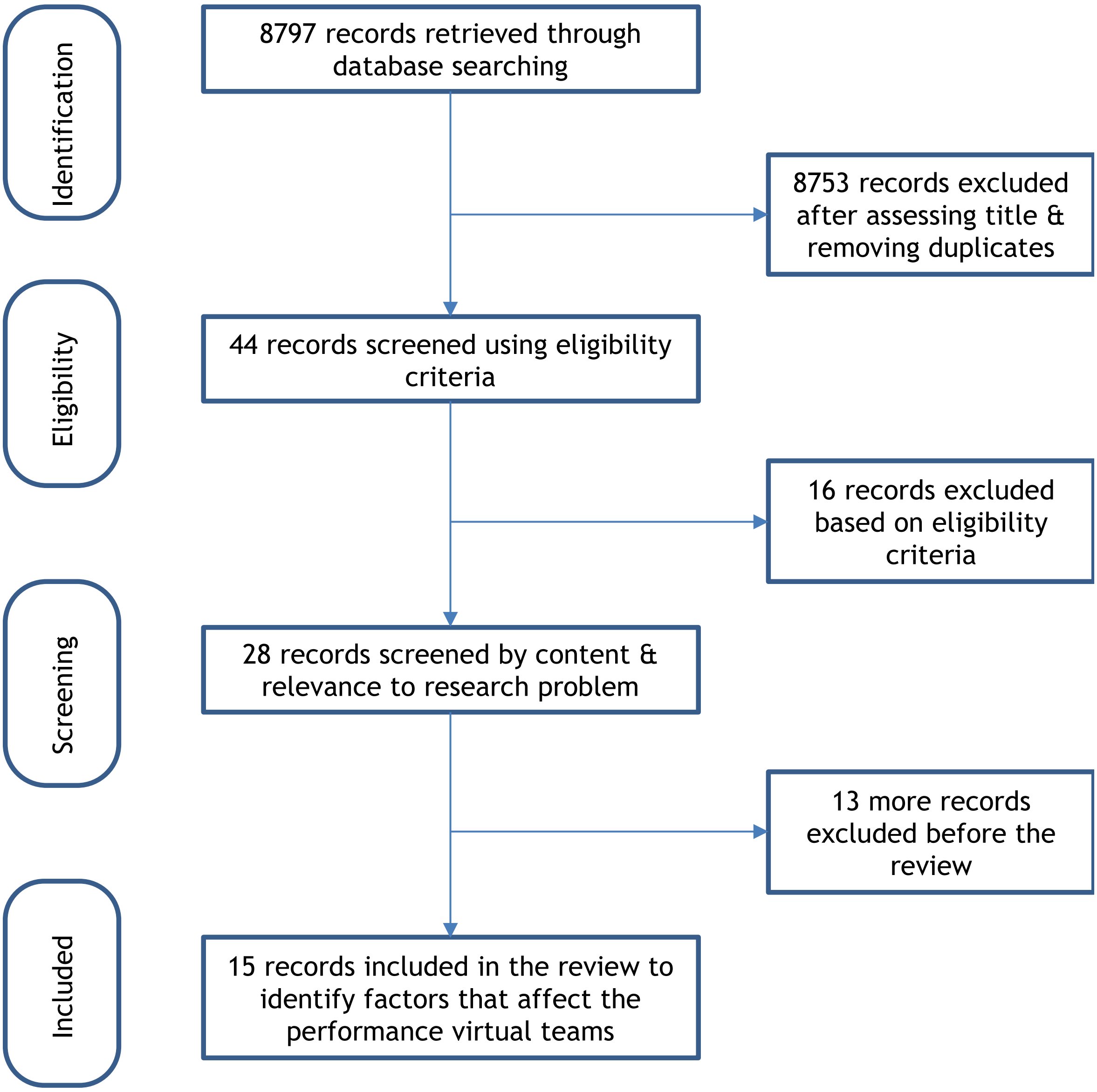

Figure 1:The flow of information through the SLRM

The included studies are presented in table 2.

Table 2: The list of studies included in the SLRM

No.	Authors	Title	Year
1	Kapeter L., Skec S., Storga M.	The effects of working from home during COVID-19 pandemic on productivity and virtuality in an engineering company	2021
2	Singh H., Cascini G., McComb C.	Comparing virtual and face-to-face team collaboration: Insights from an agent-based simulation	2021
3	Lauring J., Drogendijk R., Kubovcikova A.	The role of context in overcoming distance-related problems in global virtual teams: an organizational discontinuity theory perspective	2021
4	Kilcullen M., Feitosa J., Salas E.	Insights From the Virtual Team Science: Rapid Deployment During COVID-19	2021
5	Lumseyfai J.	A Four-Pillared Holistic Model for Improving Performance in Engineering Virtual Project Teams	2020
6	Clark D.A.G., Marnewick A.L., Marnewick C.	Virtual Team Performance Factors: A Systematic Literature Review	2019
7	Lumseyfai J., Holzer T., Blessner P., Olson B.A.	Best Practices Framework for Enabling High-Performing Virtual Engineering Teams	2019
8	Dubikovsky S., Friesel A.	Global Virtual Teams, Project Ambiguity, Trust, and Effective Communication in Senior Capstone Courses	2018
9	Hosseini M.R., Martek I., Chileshe N., Zavadskas E.K., Arashpour M.	Assessing the Influence of Virtuality on the Effectiveness of Engineering Project Networks: "big Five Theory" Perspective	2018
10	Shameem M., Kumar C., Chandra B.	Challenges of management in the operation of virtual software development teams: A systematic literature review	2017
11	Dumitrascu-Baldau I., Dumitrașcu D.D.	Occupational emerging risks affecting international virtual project Team Results	2017
12	Ferrara S.J., Mohammadi N., Taylor J.E., Javernick-Will A.N.	Generational differences in virtual teaming in the United States: Culture, time, and technology	2017
13	Chastain J.W., Nathan-Roberts D.	Recommendations for virtual teamwork based on human factors research	2016
14	Jurgens-Kowal T.	Bridging communication gaps in virtual teams	2016
15	Henrie M., D'Antonio L.	Leading from a distance: An exploratory systematic review	2016

4 FACTORS AFFECTING VIRTUAL ENGINEERING TEAMS’ PERFORMANCE

This section presents the factors affecting the performance of engineering virtual teams as extracted from the systematic literature review methodology. The factors extracted are discussed together with their interrelationships. Engineering organisations vary depending on their values, purpose and context and hence the measures for team performance may vary from organisation to organisation. However, there are well-known measures developed in literature that may be used to assess performance. The three measures for team performance conventionally known as the “iron triangle” are quality of work, quantity over time and adherence to timelines [21]. The list of factors emergent from the SLRM are presented in table 3.

Table 3: Factors affecting the performance of virtual engineering teams

Factors	Reference
Collaboration tools effectiveness	[3][14][8][22][28][24][25][7]
Knowledge sharing	[5][14][8][9][24][7]
Intra-team dynamics	[3][5][14][8]
Team member wellness	[5][24][25]
Team leadership	[8][22][9][27][28][29]

The first factor emergent from the SLRM pertains to the collaboration tools effectiveness (CTE). As pointed out by Singh et al. [5], virtual teams rely heavily on technology to communicate and collaborate on their work and hence the effectiveness of the technology medium used as the collaboration tool is an essential attribute for success in the virtual teaming setup. Due to the meteoric rise in technological advancements in the recent past, effective collaboration tools are now able to mediate the relationship between distance and communication. However, this means that any problem with the technology medium will impede communication, collaboration and knowledge sharing and this in turn negatively affects team performance. Effective collaboration tools reduce the social distance between individual virtual team members because the individual team member receives better communication from other team members and clearer understanding of their job role and this in turn leads to increased team performance [14].

To achieve effective collaboration, virtual teams should exploit a wide range of richer communication and collaborative tools from collaboration rooms to video chatting and not only rely on basic texting which is regarded as a leaner medium [8]. Utilising the richer mediums of collaboration tools enables the replication of the face-to-face interaction which leads to increased knowledge sharing [8], [22]. Knowledge sharing is the second factor that emerged from the SLRM as directly affecting the performance of virtual teams. As pointed out by Kilcullen et al. [7] and Singh et al. [5], effective collaboration tools support knowledge sharing because team members are enabled to efficiently exchange information and easily engage in problem-solving. To this end, we posit the following hypotheses:

> *H1: Collaboration tools effectiveness has a direct and positive influence on knowledge sharing.*
>
> *H2: Knowledge sharing has a direct and positive influence on virtual team performance*

The third factor emergent from the SLRM that affects the performance of engineering virtual teams is the intra-team dynamics. This factor refers to the underlying issues that give rise to a set of norms, influential actions and changes that occur within a team that characterise a specific team [23]. As a concept, intra-team dynamics is broad. However, there are three specific aspects that emerged as relevant for virtual teaming and these are organisational culture [17][8], trust [5] and diversity [14]. As an example, Lumseyfai [8] points out that an organisation that has a collaborative, motivational and supportive culture tends to increase and sustain the success of virtual teams. According to Clark et al. [22], trust within team members enhances the richness of communication which fosters knowledge sharing, and as discussed above, knowledge sharing has a direct influence on virtual team performance. The relationship between intra-team dynamics and the virtual team performance is mediated by knowledge sharing and team member wellness. To this end, we posit the following hypothesis:

> *H3: Intra-team dynamics has a direct and positive influence on knowledge sharing.*

The fourth factor emergent from the SLRM is team member wellness and has a link with intra-team dynamics. As emphasised by Chastain [24], humans are relational and the absence of face-to-face with fellow team members can inadvertently lead to negative outcomes such as mistrust, feelings of isolation, lack of belonging and reduced overall team performance. Jurgens [25] concurs with these sentiments and further notes that emotional trust emanates from shared experiences leading to team wellness and greater team cohesion. If the collaboration tools utilised are effective, a sense of belonging and identification can be fostered between team members. This supports the idea discussed earlier, that organisations should employ richer technology mediums that enable team members to support each other and develop social connections. To this end, we posit the following hypotheses:

> *H4: Intra-team dynamics has a direct and positive influence on team member wellness.*
>
> *H5: Collaboration tools effectiveness has a direct and positive influence on team member wellness.*
>
> *H6: Team member wellness has a direct and positive influence on virtual team performance.*

The fifth and last factor that emerged from the SLRM is team leadership. Over and above the fact that leading teams is complex, leading virtual teams has additional complexities related to managing tasks, communication and collaboration, and these require distinct leadership qualities for efficient governance. Engineering managers ought to be aware of the necessary leadership qualities and best practices that can enable successful outcomes of their virtual teams [8]. It behoves engineering organisations to be mindful of the personnel entrusted with the task of leading virtual teams as there is evidence that leadership styles mitigate the challenges found in virtual teams [8]. As pointed out by Clark et al. [22], negative leadership qualities such as bias and transactional leadership tendencies are vehemently antithetical to virtual teaming.

Attributes such as idealised influence (which refers to the behaviour of the leader that followers tend to imitate) inspirational motivation (which refers to the ability of the leader to set goals and motivate the team), intellectual stimulation (which refers to the leader’s ability to consider different point of views when addressing a problem and challenging employees to think about problems in new ways) and lastly, individualised consideration (which refers to the leader’s ability to acknowledge an individual’s effort and achievement of specified goals and taking into account the characteristics of each person), coalesce into a quintessential virtual team leader. These four attributes describe a transformational leader and are discussed in detail by Bass and Avolio [26]. Transformational leadership is centred on motivation, team member engagement and fostering relationships and these are all the attributes that are indispensable for virtual teaming success [9], [27]. Transformational leaders are able to directly influence intra-team dynamics because of their ability to create a safe environment wherein team members feel comfortable to open up and raise their concerns. Leaders are responsible for creating a conducive organisational culture, facilitate trust between members and manage diversity [28]. Team leadership does not only influence virtual team performance through the mediation of intra-team dynamics, but it is officially recognised as an important factor that directly influence team performance [29]. To this end, we posit the following hypotheses:

> *H7: Team leadership has a direct and positive influence on intra-team dynamics.*
>
> *H8: Team leadership has a direct and positive influence on virtual team performance.*

The structural representation of five factors that affect the performance of virtual engineering teams, and the eight interrelationships are presented below.

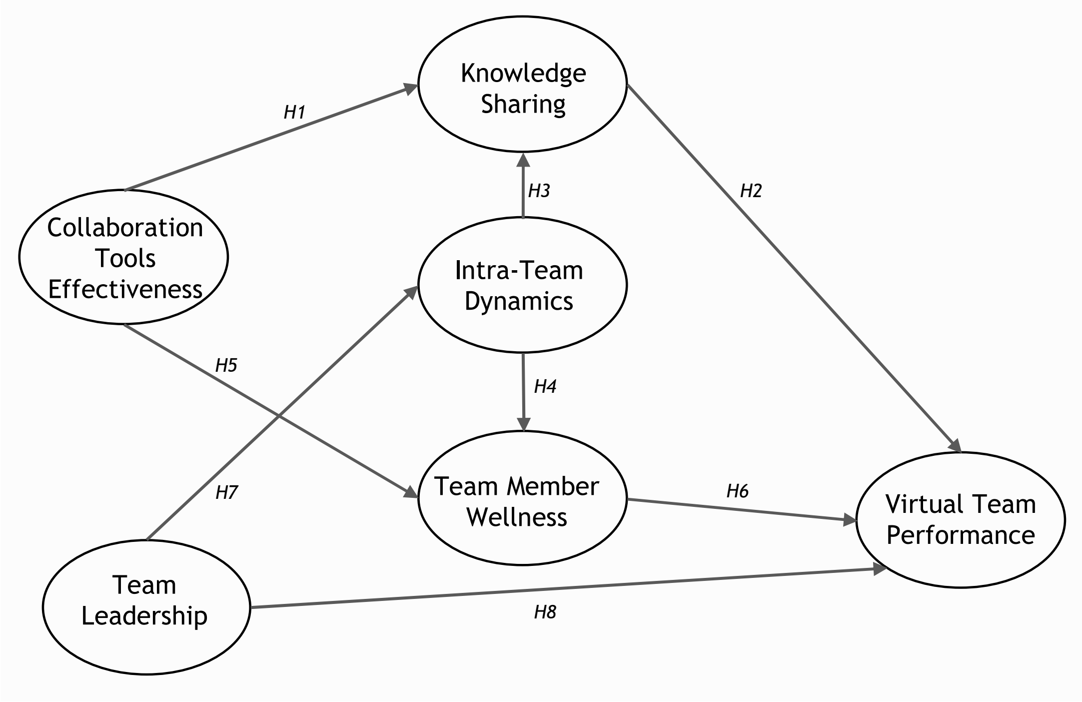

Figure 2: Structural model of engineering virtual teaming

Figure 2 depicts the structural model of engineering virtual teaming using the five factors that affect the performance of virtual engineering teams and the eight hypothesised interrelationships. The five factors presented in the model are latent variables (hypothetical constructs representing concepts that cannot be measured directly). The Collaboration Tools Effectiveness and Team Leadership latent variables are exogenous in nature and this means that they affect other variables but are not affected by other variables in the model, whereas, Knowledge Sharing, Intra-team Dynamics and Team Member Wellness are endogenous in nature and this means that they are affected by other variables whilst they also affect other variables. Understanding the nature of variables in the presented model is helpful when attempting to leverage the intervention opportunities for engineering managers working with virtual engineering teams. Further implications for engineering managers are highlighted next.

5 IMPLICATIONS FOR ENGINEERING MANAGERS

The meteoric rise in the adoption of virtual teams in the business world has led to more engineering organisations employing virtual teaming either for the purpose of taking advantage of the benefits of virtual teaming or due to the COVID-19 pandemic. Leading and managing engineering teams is notoriously difficult, the added reality of virtuality can further exacerbate this difficulty if engineering managers are not empowered to deal with virtual teaming.

This study has identified five factors that affect virtual engineering teams with two noteworthy implications for engineering managers. First, the effectiveness of collaboration tools utilised by engineering teams has a significant impact on knowledge sharing and team member wellness and this has repercussions on overall team performance. Second, the extent to which the leadership of the virtual team leader is transformational, has a direct influence on the performance of the team. Engineering managers who desire to improve the performance of their engineering virtual teams ought to ensure that the leaders of those teams possess the transformational leadership attributes. Transformational leadership is well able to improve intra-team dynamics and the wellness of team members and in turn result in improved virtual team performance.

6 LIMITATIONS AND FUTURE RESEARCH

The findings of this study emerged from a systematic literature review methodology that is limited to virtual engineering team scholarly publications. Even though the findings are potentially applicable to virtual teams in general, the findings are not generalisable since the study is limited to the engineering field. To make the findings generalisable, future research should include scholarly publications from other fields outside the engineering field.

The five factors and eight interrelationships remain hypothetical. Future research should employ multivariate modelling techniques to quantify the hypothesised interrelationships and assess their significance. Structural equation modelling techniques are capable of simultaneously testing and quantifying multiple endogenous and exogenous variables of structural models such as the one presented in this study. This study identified measures that can be used as measurement variables for three latent variables i.e. virtual team performance (quality, quantity and timelines), intra-team dynamics (organisational culture, trust and diversity) and transformational leadership (idealised influence, inspirational motivation, intellectual stimulation and individualised consideration). Future research should develop the measurement variables for the remaining latent variables in order to enable the application of structural equation modelling techniques.

7 CONCLUSION

The topic of virtual teams has been explored in several studies in the past, the need to revisit the topic has been necessitated by the COVID-19 pandemic. This study sought to identify factors that affect the performance of virtual engineering teams. Five factors are identified and the relationships between these factors are explored. The study highlighted the noteworthy implications for engineering managers before pointing out potential future lines of research.

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AN INVESTIGATION TO MEASURE PRODUCTIVITY IN A SOUTH AFRICAN IT SERVICE MANAGEMENT COMPANY

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ABSTRACT

The South African service sector is a crucial component of the industry that sustains our economy and provides societal gain. This research investigates an information technology (IT) service management organization that provides services in software and software management. This organization has an ineffective representation of its productivity which affects its ability to renew and establish new strategic visions and remain competitive. By following the DMADV method, this study develops and tests the Goal alignment model which facilitates productivity measurement and clear representation thereof. This model is inspired by the sequential methods from the Plan-Do-Check-Act (PDCA) cycle and the Hoshin Kanri theory. The study reveals that service productivity measurement is better understood when placing emphasis on the process of operations which include social cohesion, employee performance, and increasing operating income. This model can be tailored for various organizations in the service sector and made relevant to similar sectors in South Africa.

Keywords: Service productivity, Service management, Goal Alignment Model, PDCA cycle, Hoshin Kanri

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1 INTRODUCTION

1.1 Background to research

Industrial Engineers are recognized in various industries in all parts of the world [1]. The field of Industrial Engineering was originally geared toward manufacturing sectors where the values and contribution of this field were soon recognized. These roles, and to some "perceived superpowers", soon became popular in various other industries. One such example is demonstrated in the service industry.

Currently, service-providing organizations are turning to software solutions or 'softwarization' [2]. The Marketline Industry Profile [3] projects that by 2024 the South African software market will have increased by 62.2%. A suggested reason for this increase may be due to the benefits that the Information Technology service management (ITSM) industry provides. One benefit is that ITSM assists in increasing operational efficiency within organizations [4], which may be an attractive trait for organizations that seek to increase productivity within organizational operations.

Although this market is projected to increase, a particular challenge encountered is the growing need for an appropriate analysis of the productivity concept in a service context [5]. It is important to note that defining productivity in a service context is not similar to productivity in a manufacturing or production context [6, 7].

In a manufacturing context, Krugman [8] defines productivity as the ratio between volumes of inputs and outputs of a process. Whereas for service productivity, Djellal and several others [7, 9, 10] define service productivity as the method in which input is effectively transformed into value for the customer. A further and more recent challenge is the effect of the COVID-19 pandemic and companies needing to operate with a distributed workforce. This workplace transformation is believed to remain distributed for some organizations due to its operation expenditure advantages [11].

The COVID-19 pandemic may have created longstanding, detrimental effects to the business cycle of organizations, more specifically, the organizational renewal or decline phase. An important aspect of ensuring growth or renewal is providing organizational leaders with the ability to identify areas where growth is needed and to utilize resources efficiently [12]. Therefore, the described challenges that the service industry faces require attention to enable organizational renewal and sustain long-term growth.

1.2 Problem overview

This research makes use of an organization situated within the South African ITSM industry. This research found itself with limited data and productivity, and so the scope of the problem was formed during a Gemba and through consultation with management.

At this specific organization, there is an ineffective representation of productivity which affects their renewal. Therefore, the aim of this research is to develop a design that can effectively measure and account for productivity within the organization.

The following research objectives are formulated:

- Define the current state of accounting for productivity in an ITSM organization
- Conduct a root-cause analysis
- Measure and identify the effectiveness of the current process
- Conceptualize and evaluate alternative designs
- Development of final design
- Verify and validate the final design

The research scope is focused on the representation of productivity in the service productivity industry and sets out to investigate this on design level. An examination of the core research problem is further unveiled in the define, measure and analyse phases that feature in section 4.1 – 4.3.

The paper is first structured with an introduction for the purposes of contextualization. A literature review in section 2 provides an overview of crucial theory used in the conceptual designs that feature in this research, further discussed in section 4. This research is completed using the DMADV method discussed in section 3. Section 4 includes discussions on each phase of the aforementioned method used for the study. Section 5 provides conclusions and recommendations that pertain to this research.

2 LITERATURE REVIEW

The Literature review includes brief discussions on identified conceptual designs relevant to the discussed problem in Section 1.2. The discussions include a description, method, and relevance to the research.

2.1 SERVQUAL model

The SERVQUAL model is used to measure service quality and makes use of the RATER (Reliability, Assurance, Tangibles, Empathy, Responsiveness) measuring method as well as surveys [13].

Goumairi [14] identified that the SERVQUAL model could indicate the perception level of participants and provide an indication of the quality of service provided. Salvendy [15] introduces the 'Service Encounter' which is defined as "a period of time during which a consumer directly interacts with a service", where the two major components are the service processes and the service outcome. Salvendy [15] proceeds to narrow the use of the SERVQUAL model as an approach to measure the quality of the service processes involved in the service industry.

Van Looy [16] states that service productivity and quality should be measured simultaneously. This suggestion makes the SERVQUAL model relevant to the nature of this research.

2.2 Goal Alignment Model

Harris [17] states that the Goal Alignment Model (GAM) places emphasis on aligning workers behaviour and goals with the organizational goals such that it facilitates individual productivity measurement and their contribution to the success of the organization. Furthermore, Harris [17] suggests that the initial approach is identifying objectives with the purpose of identifying measurements. Figure 1 illustrates the GAM by making use of the Goal-Question-Metric (GQM) method which is used by Basili [18].

Lepmets [9] applied the GAM to improve a process but discovered that there is no clear method or guide to achieve this. Furthermore, Lepments [9] suggests that organizations will be more successful in improving their process if there is more knowledge and experience in aligning process goals with organizational goals. Two methods or guidelines have been introduced previously, namely (1) the GQM method by Basili [18] and (2) the multi-factor productivity measurement model by Sahay [5]. From these two methods, the GQM method will be considered for this research.

It is imperative to note that the GQM method was updated by Basili [19] and coined as GQM+Strategies. Furthermore, the GQM+Strategies method was used in a case study by Takai [20] since it was discovered that the method proved useful for a complex environment. This method not only connects organizational needs with metrics but also assists in the implementation of solutions on the metric level.

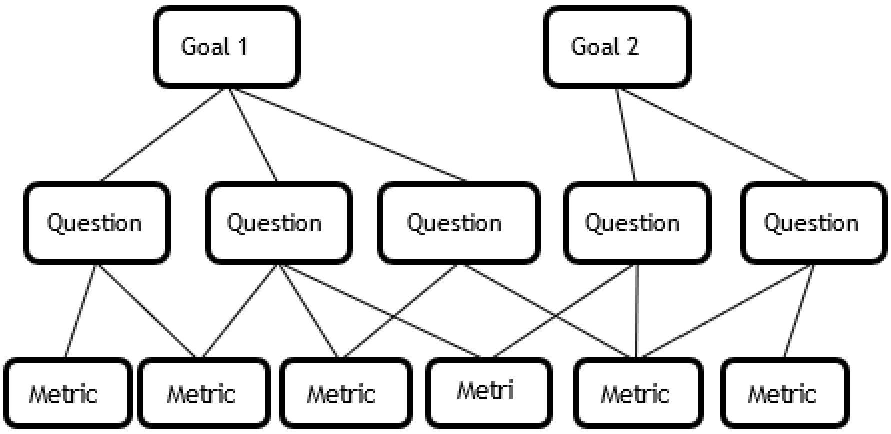


Figure 1. Goal-Question-Metric method extracted from Basili [20]

The Goal Alignment model appeals to the research as it incorporates the action of defining parameters and measurements and relating it to organizational goals. The model will assist in identifying and measuring the process of input resources, its transformation, and assessing whether a task or activity adds value for the customer.

2.3 Productivity Servosystem Model

The Productivity Servosystem Model attempts to illustrate factors that influence workers performance [17, 21]. Furthermore, Harris [17] and Khater [22] communicate that it provides a theoretical foundation for understanding and analysing worker performance. Figure 2 illustrates the use of a Conceptual Productivity Model provided by Harris [17].

Hershauer [23], developed the Servosystem model for worker productivity. After its development, Hershauer [23] mentions that the model provides a level of qualitative analysis needed to define, comprehend, and improve productivity. The model also focuses on concerns about the measurement of productivity by demonstrating desired organizational goals and concerns regarding resource consumption. A significant observation made by Hershauer [23] is that the model draws attention to the major factors which must be considered in developing productivity improvement programs.

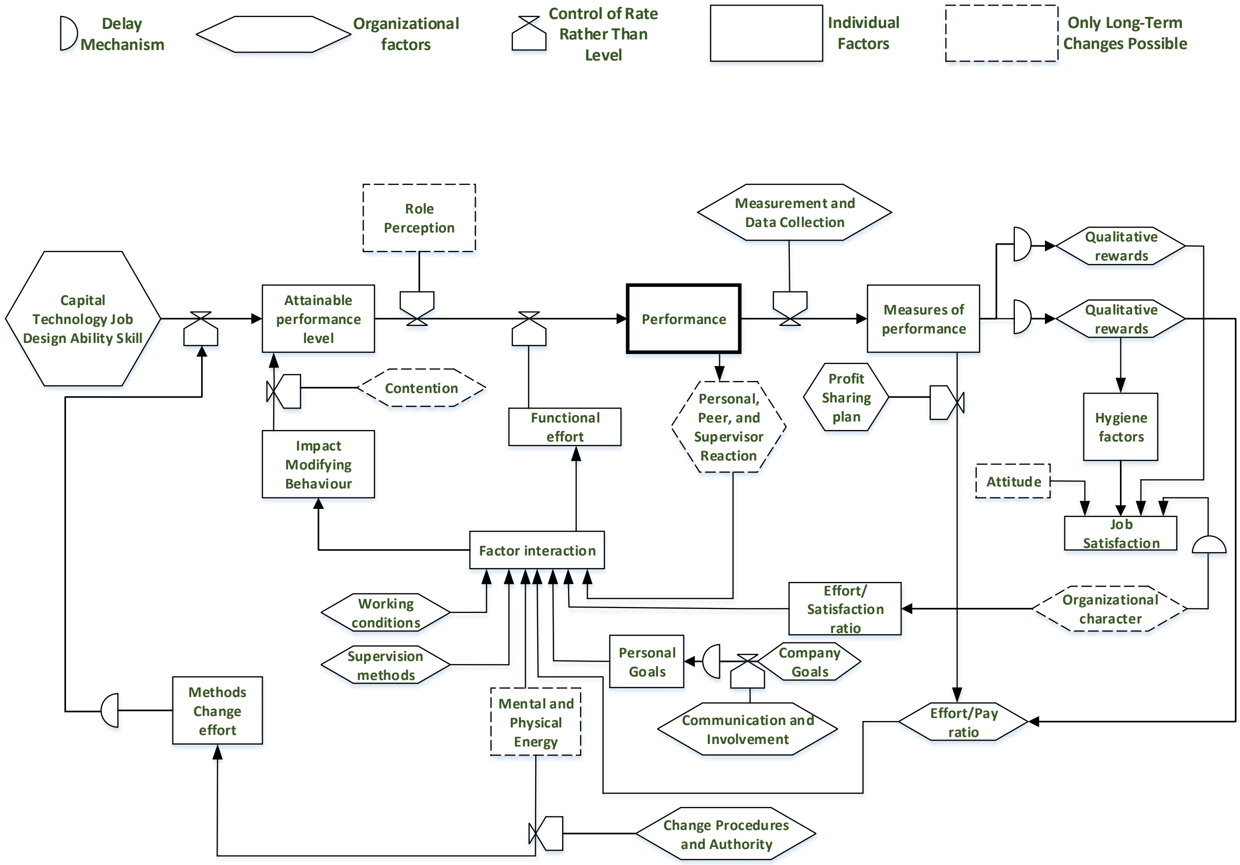


Figure 2. Productivity Servosystem model [17]

The Productivity Servosystem Model introduces and illustrates the relationships that have an effect on an employee's operation. In turn, this assists in identifying involved parameters and measurements which may have an effect on productivity.

3 RESEARCH METHODOLOGY

DMADV incorporates a design, redesign approach which is applicable to processes that vary [24], and DMADV provides a means to obtain six-sigma quality levels which play a role in obtaining high productivity [25]. Against the discussed traits DMADV has to offer, the research methodolgy is utilized in this research as illustrated in Table 1. For the purposes of this research, the last phase of DMADV method has been adapted to include validation in order to ensure more rigorous and reliable research.

Table 1. Research Methodology [26]

Research Phase	Relevant Methods	Purpose
Define	- Introduction to background of the problem. - Discussion of the current state. - Contextualise the problem using business process mapping with BPMN	- Define the current state of accounting for productivity in an IT service management organization - Accumulate relevant research on the identified problem and its context
Measure	- Collection of secondary data from the organization - Processing of the raw data for interpretation purposes using pie charts and bar charts	- Measure and identify the effectivity of the current process
Analyse	- Requirements and criteria evaluation - Case study research analysis - Pressure-State-Response model - Fishbone diagram	- Analyse and evaluate literature - Conduct a root-cause analysis
Design	- House of quality - Evaluation of concept designs using advantages and disadvantages	- Evaluate concept designs and select final concept design
	- Hoshin Kanri and one Plan-Do-Check-Act (PDCA) cycle is used for development of final design	- Development of final design
Verify & Validate	- Checklist to verify model - Application of review phase of Hoshin Kanri and Check-Act phases of PDCA cycle - Rigorous and reliability assessment	- Verify and validate final design

The Design phase of the research method in Table 1 illustrates the novelty of this study, showcasing the manner in which Hoshin Kanri and the PDCA cycle can be merged to align organizational goals with measurements involved within the process [27]. This alignment provides a means of measuring performances related to the organizational goal which would, as a result, assist in identifying areas of needed improvement in order to reach the organizational goal. Having these areas identified may support strategic resource distribution and organizational growth [28, 29].

4 FINDINGS AND DISCUSSIONS

This section provides the intepretation of data analysis and results according to the dedicated phases of the DMADV methodology.

4.1 Define Phase

The research methodology used, discussed in Section 3, includes a define phase. The define phase consists of defining the problem through examining the current process of operations.

Business process mapping (illustrated in Figure 3) [30] is used as a method to identify processes involved for measuring, communicating, and analysing information from a day's work within the organisation.

Figure 3 illustrates the daily operations at the specific organization. Furthermore, it is perceived, in Figure 3, that information is communicated over several channels and the relevant software used. Through observation, it was discovered that the current process is strenuous and tedious work due to multiple channels of communication and different software being used. Due to it being strenuous and tedious work, it is doubtful that the current process is an effective means of capturing data of operations. Therefore, for this research, a model that incorporates fewer channels and software will be considered. Further observations will be discussed in the Measurement Phase (Section 4.2).

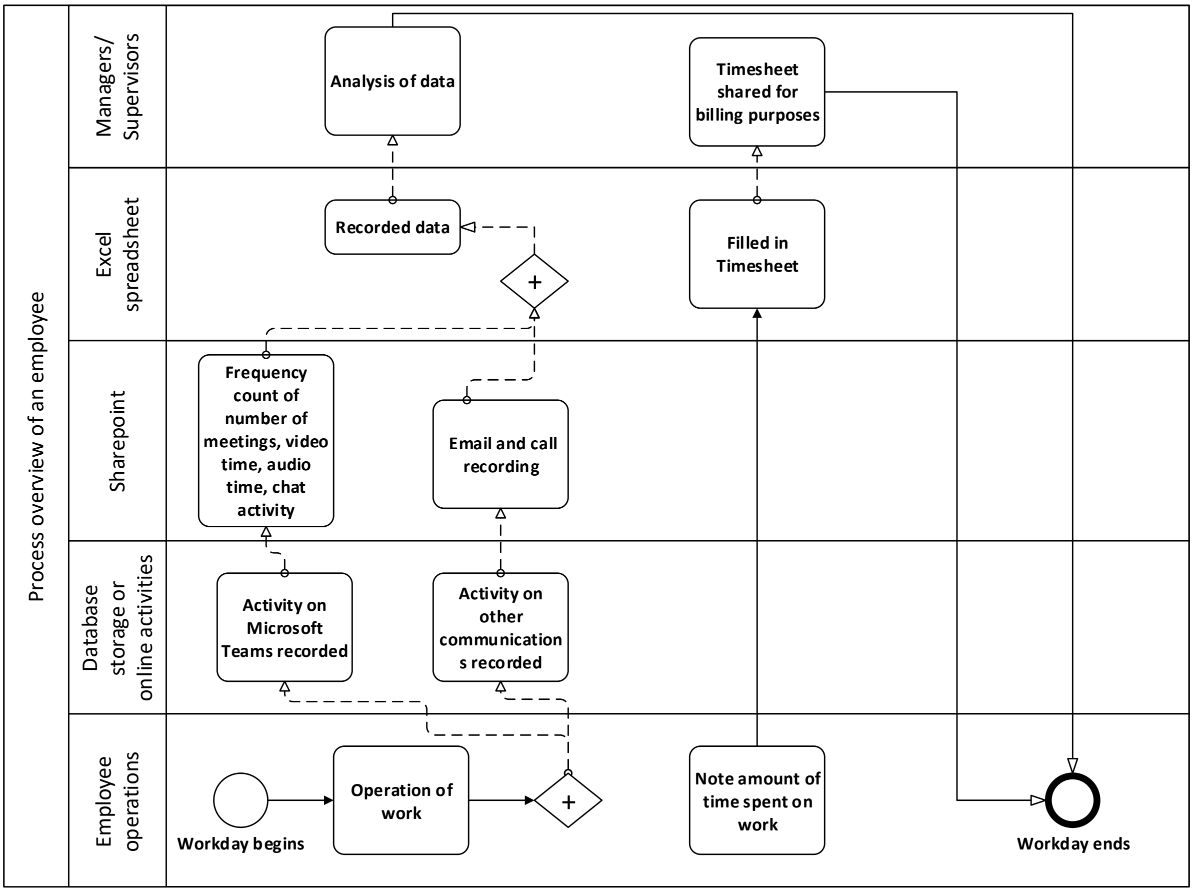


Figure 3. BPMN model of current state

4.2 Measure Phase

The research methodology includes a second phase namely the measure phase. The measure phase consists of the collection of secondary data from the organization and the processing of this data for interpretive purposes. The secondary data demonstrates the online activity of employees. The captured activity includes emails sent via Microsoft outlook, chat activity on Microsoft teams, Microsoft teams meeting statistics, and the frequency of different software usage.

The secondary data is provided in excel spreadsheets which includes lists of the employee's credentials and their record of online activity in the various divisions. The data investigated the activity of approximately 7000 employees that assist with managing and installing software. Figure 4 includes a box and whisker diagram indicating online meeting activity per employee over a 6-month period.

Figure 4 also includes round markers indicating outliers of the dataset. One can notice that a great proportion of employees lie below 100 total online meetings over the six-month period. Furthermore, there is high variability in the number of meetings per employee for each meeting category. A further observation suggests that the deviation is caused by the data being non-representative of various roles in the organisation since certain roles in the organisation dictate more or less frequent online meetings.

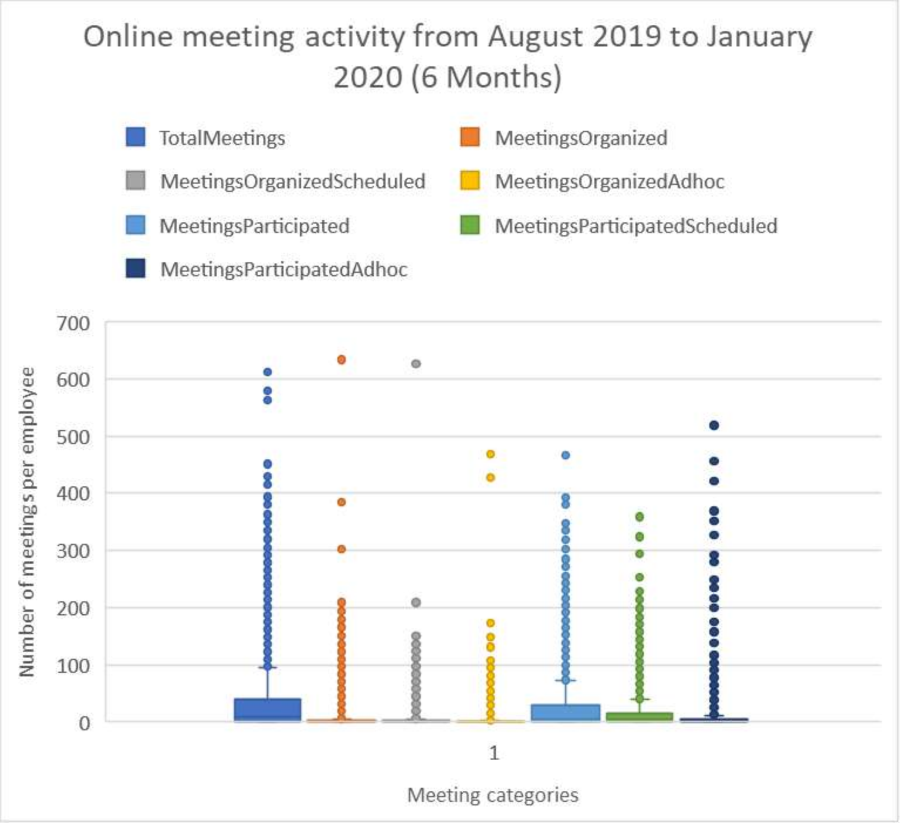


Figure 4. Employee Meeting Activity

Moreover, Figure 4 also indicates that although current employee activity is monitored, it is not clear whether the employee is productive or not. For example, the number of online meetings an employee participated in does not include a definitive number of productive outputs. Therefore, research suggests that a new form of measurement should be investigated since the current productivity measurements do not indicate where improvement is needed [28]. This leaves an organisation operating in uncertainty.

4.3 Analyse Phase

To investigate a new form of measurement, the analyse phase of the research methodology incorporates a root cause analysis for the purpose of identifying root causes of the identified problem and determining design requirements for design selection. The root cause analyses incorporated a pressure-state-response model and fishbone diagram. It should be noted that, observations discussed in Sections 4.1 - 4.2 are considered in identifying the root cause analysis.

The pressure-state-response model (illustrated in Figure 5) [31] provides a framework for the work environment and an opportunity to identify roles involved in decision-making. Observe that Figure 5 illustrates the importance of information flow and the impact it has on decision making.

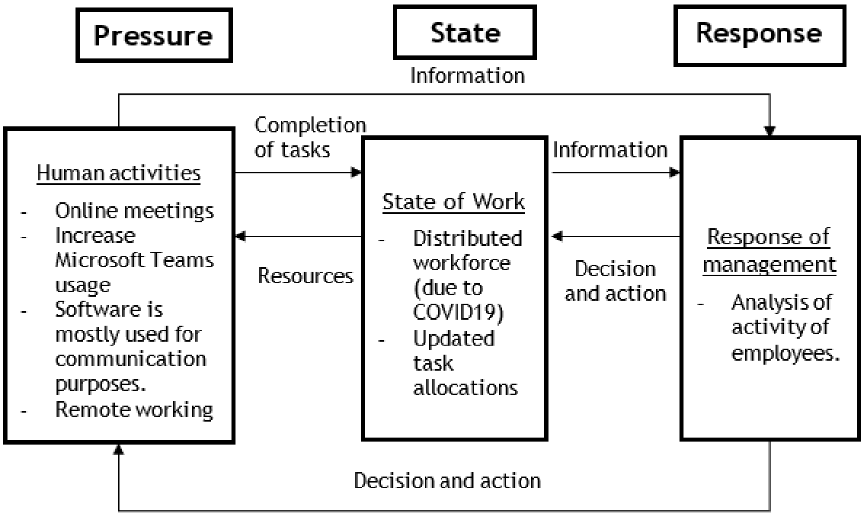


Figure 5. Pressure State Response Model

The Fishbone diagram, in Figure 6, outlines the potential causes leading to ineffective representation of productivity within the organization.

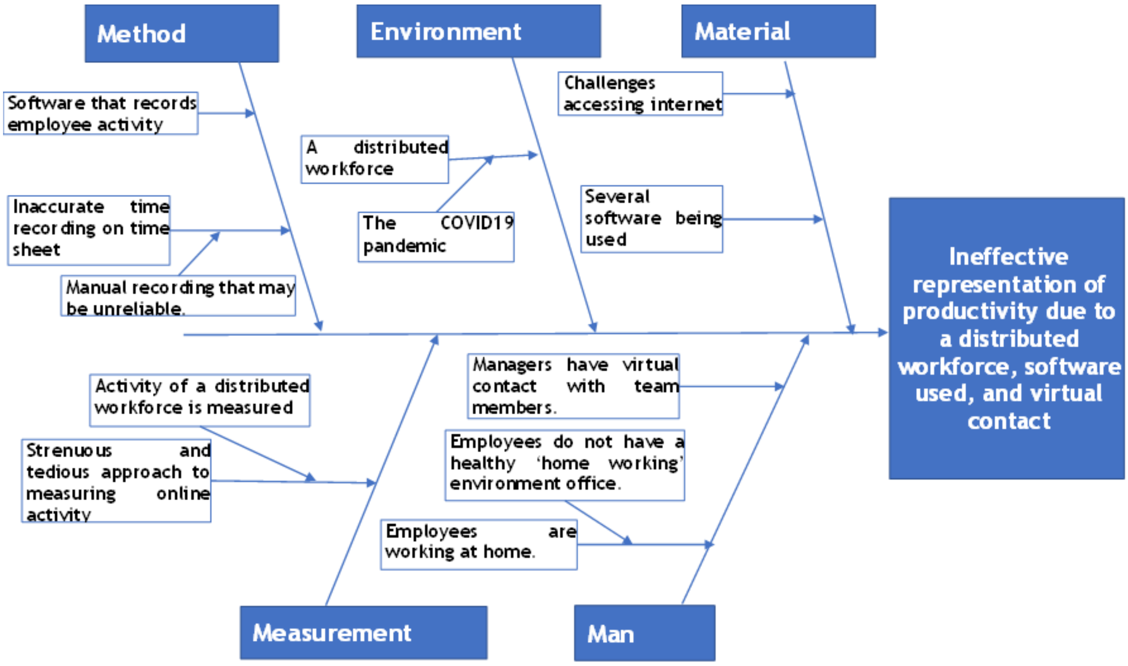


Figure 6. Fishbone Diagram

Through analysis of the current process (refer to Section 4.1), current data accumulation (refer to Section 4.2), and involved external factors the following root causes were identified:

- The measurements used to acquire information produces raw data that requires a manual approach to interpret.
- The method of communication is via emails and online meetings. For decision making purposes this may be tedious and affect the motivation to communicate.
- Measurements lack a purpose. In effect, this results in information measured that may not be used for decision making.

Stets [32] described that design requirements can be formulated after a current state analysis. Therefore, by adapting these root causes, the following design requirements are that the model:

- must partially or fully automize the process of acquiring information to making it interpretable.
- must minimize the channels of communication of information.
- must allow a user to strategically select parameters and measurements for decision making purposes.

The identified root causes were then used as a guideline to identify conceptual designs in literature. In addition to this, case studies of these conceptual designs were researched for identifying the application of identified conceptual designs and its relevance to the research. The conceptual designs are discussed in Section 2 and the mentioned approach enabled the identification of three conceptual designs which are compared and evaluated in the design phase.

4.4 Design Phase

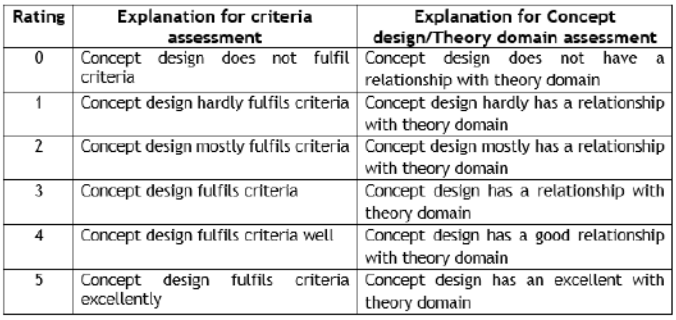
As part of the design phase of the DMADV methodology, each proposed design needs to be viable and address the problem identified in this research. Three alternative designs were identified from literature and further conceptualised. In addition to the designs, two theory domains are considered namely, Hoshin Kanri and the PDCA cycle, and Total Quality Management (TQM). These designs feature in sections 2.1 – 2.3, followed by an evaluation using the house of quality (section 4.4.1). The final design is then presented (section 4.4.2).

In order to identify the best suited design, a design selection process which combines house of quality and weighted scoring [33, 34, 35, 36, 37] was followed.

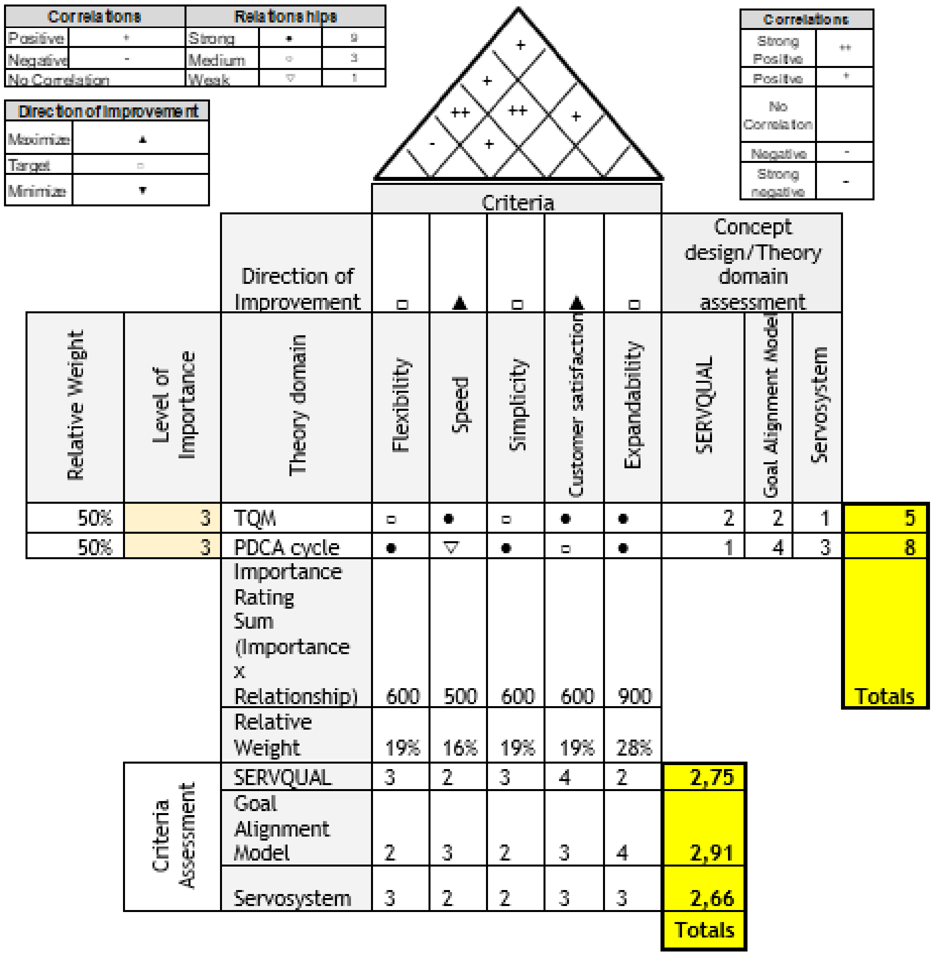
4.4.1 House of quality design selection

House of Quality (HOQ) is used for product planning [38]. For the purposes of this research, HOQ is used for the evaluation of each conceptual design proposed in the preceding subsections. Each concept is evaluated and rated against a set criterion. The compiled criteria used for evaluation is inspired by the design requirements for the identified problem. Furthermore, relationships with the considered theory domains are evaluated. The considered theory domains are used to provide a framework for development of the selected design. Lastly, weighted scoring is used to determine weighted values that are combined with the relative weight determined in the HOQ. The weighted scoring plays the role of 'customer demand' in a traditional HOQ. Table 2 includes a table of ratings used to evaluate concept designs and theory domains against a set criterion found in the HOQ. The identified criteria are traits that associate with identified design requirements found in Section 4.3. Figure 7 illustrates the HOQ and total scores are determined by multiplying determined relative weights with weighted scores.

Table 2. Table of ratings



Rating	Explanation for criteria assessment	Explanation for Concept design/Theory domain assessment
0	Concept design does not fulfil criteria	Concept design does not have a relationship with theory domain
1	Concept design hardly fulfils criteria	Concept design hardly has a relationship with theory domain
2	Concept design mostly fulfils criteria	Concept design mostly has a relationship with theory domain
3	Concept design fulfils criteria	Concept design has a relationship with theory domain
4	Concept design fulfils criteria well	Concept design has a good relationship with theory domain
5	Concept design fulfils criteria excellently	Concept design has an excellent with theory domain



Correlations		Relationships		
Positive	+	Strong	●	9
Negative	-	Medium	○	3
No Correlation		Weak	▽	1

Direction of Improvement	
Maximize	▲
Target	□
Minimize	▼

Correlations	
Strong Positive	++
Positive	+
No Correlation	
Negative	-
Strong negative	-

		Direction of Improvement	□	▲	□	▲	□	Concept design/Theory domain assessment			
Relative Weight	Level of Importance	Theory domain	Flexibility	Speed	Simplicity	Customer satisfaction	Expandability	SERVQUAL	Goal Alignment Model	Servosystem	
50%	3	TQM	□	●	□	●	●	2	2	1	5
50%	3	PDCA cycle	●	▽	●	□	●	1	4	3	8
		Importance Rating Sum (Importance x Relationship)	600	500	600	600	900				Totals
		Relative Weight	19%	16%	19%	19%	28%				
	Criteria Assessment	SERVQUAL	3	2	3	4	2	2,75			
		Goal Alignment Model	2	3	2	3	4	2,91			
		Servosystem	3	2	2	3	3	2,66			
								Totals			

Figure 7. House of Quality adapted from [44]

Figure 7 illustrates that the highest ranked concept design is the Goal Alignment Model. Furthermore, the theory domain that ranks the highest as a framework for development is the PDCA cycle. Therefore, the Goal Alignment model developed within a PDCA cycle framework is selected as the final design. This design will be coined as the Goal-Oriented Measurement Design.

4.4.2 The Goal-Oriented Measurement (GOM) Design

PDCA has been used as the structure to categorise the application of Hoshin Kanri and the Goal Alignment Model during the development of the final design. This novel approach combines the strategic benefit of Hoshin Kanri with PDCA guidance.

For the development of the GOM design, the Goal Alignment Model is used as an extension to the Hoshin Kanri matrix. The purpose of the Hoshin Kanri matrix is to determine high level goals and KPI's which provide the Goals used in the Goal Alignment Model. The Goal Alignment Model elaborates further by determining the specific metrics that should be measured.

The development of the GOM design is initiated in the plan phase of the PDCA cycle. Figure 8 illustrates the Hoshin Kanri matrix used for the development of the GOM design where relevant goals and KPI's are determined through consultation with the organization's liaisons and other research.

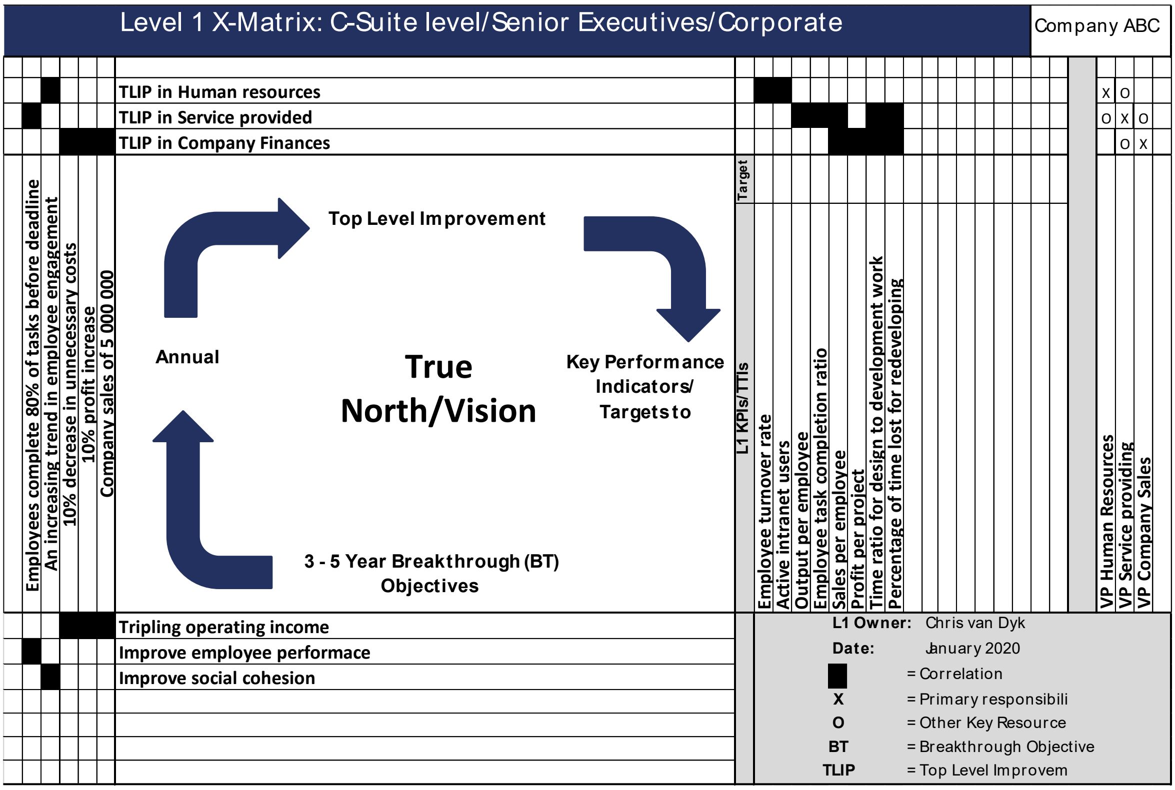


Figure 8. Hoshin Kanri Matrix

KPI's included in Figure 8 are used as Goals for the Goal Alignment Model. Table 3 includes the identified KPI's that act as Goals in the model linked to formulae which speak to set variables for KPIs and metrics.

Table 3. List of KPI's, formulas, and metrics [39]

KPI	Formula	Metrics
Employee turnover rate	$\frac{total\ number\ of\ employees\ that\ left}{total\ number\ of\ employees\ at\ the\ beginning\ of\ the\ period}\ x\ 100$	• Total number of employees that left • Total number of employees at the beginning of the period
Active intranet users	$\frac{Activity}{Number\ of\ employees}$	• Total number of employees at the end of the period • Total chat messages • Total participated meetings • Activity times
Output per employee	$\frac{Number\ of\ Objectives\ reached}{Time\ spent}$	• Number of Objectives reached • Time spent on project (hours)
Sales per employee	$\frac{company\ sales}{number\ of\ employees}$	• Company sales • Number of employees

KPI	Formula	Metrics
Profit per project	$\frac{profit}{number\ of\ projects}$	- Profit at the end of the period - Number of projects
Time ratio for design to development work	$\frac{Time\ spent\ on\ design\ phase}{Time\ spent\ on\ development\ phase}$	- Time spent on design phase - Time spent on development phase

For the Do phase of the PDCA cycle and testing purposes, the final design is a system built into a database. The GOM design incorporated a Hoshin Kanri and PDCA cyle framework for inspiration. A pilot database model with form, query, and report components was included in the development of a prototype system to test the GOM design (Refer to Figure 9). Furthermore, through checklist, reliability, and rigour assessment it was determined that the GOM design is verified and validated.

Microsoft Access is used to develop the database to demonstrate the functionality of this model, where identified metrics are configured with a form GUI. This helps identify KPI's formulated as queries from the identified Goals illustrated in Figure 8. In turn, this system also assists in generating reports. Figure 9 illustrates the flow of information within the database that represents this model.

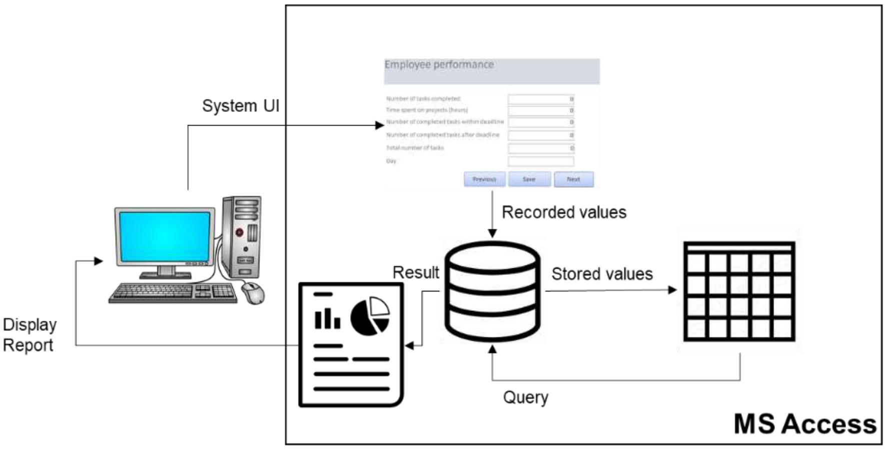
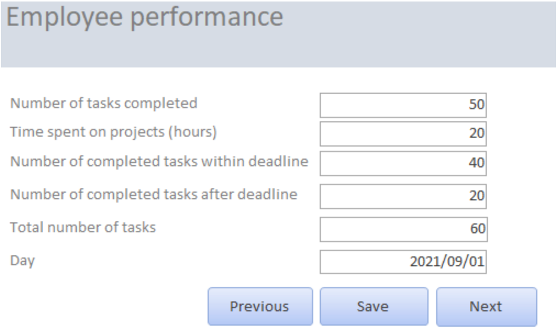


Figure 9. Database information systems model

To elaborate on Figure 9, the pilot database model allows the user to enter data in a form, which is then recorded and stored in a table. The stored values undergo a query where KPI values are calculated. The results of the calculated values are then presented on a report which is displayed.

Three 'high-level' goals are used (which are shown in Figure 8) in the database namely, (1) Tripling operating income, (2) increasing social cohesion and (3) increasing employee performance'. Table 3 includes the identified KPI's and metrics for the mentioned goals. Metrics are included in the developed forms, KPI's as the queries, and the relationship of KPI's to the 'high-level' goals are perceived in the developed reports. As an example Figure 11, Figure 10, and Figure 12 include a developed form, table, and report respectively for the 'increasing employee performance' goal.

Figure 11 illustrates identified metrics included in a form format in order to capture information relevant to KPI's and goals. The captured information is stored in a database/table. in report format.

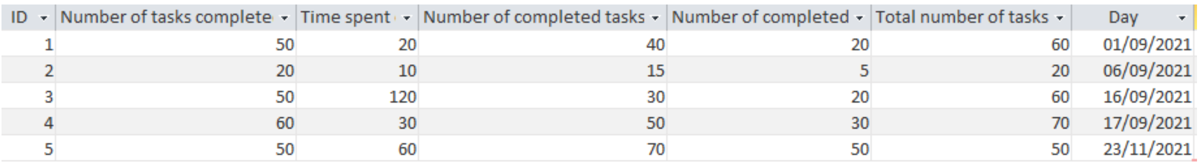


Employee performance

Number of tasks completed	50
Time spent on projects (hours)	20
Number of completed tasks within deadline	40
Number of completed tasks after deadline	20
Total number of tasks	60
Day	2021/09/01

Figure 11. Employee performance form

Figure 10 illustrates the storage of submitted information in a table which is used for further calculations. Values calculated are then presented in a report.



ID	Number of tasks complete	Time spent	Number of completed tasks	Number of completed	Total number of tasks	Day
1	50	20	40	20	60	01/09/2021
2	20	10	15	5	20	06/09/2021
3	50	120	30	20	60	16/09/2021
4	60	30	50	30	70	17/09/2021
5	50	60	70	50	50	23/11/2021

Figure 10. Table including submitted employee form data

Figure 12 illustrates the employee performance report including KPI's for the measurement of employee performance which can be used for decision making or operation monitoring purposes. Verification and validation are applied to ensure the GOM design met research objectives, and that the GOM design is rigorous and reliable.

4.5 Verification and Validation Phase

Employee performance KPI

Saturday, 09 October 2021
13:59:57

Day	Employee output (tasks per hour)	Employee task completion ratio
2021/09/01	2,50	33,33%
2021/09/06	2,00	50,00%
2021/09/16	0,42	16,67%
2021/09/17	2,00	28,57%

Figure 12. Employee performance report

For the Check phase of the PDCA cycle, the GOM design undergoes verification and validation. Table 4 includes a checklist used to verify the GOM design. This incorporated the identified root causes and design requirements for the research.

Table 4. Design Verification Checklist

No.	Checklist questions	Yes	No	Remarks
1.	**Deliverable addressing root causes (Discussed in Section 4.3.)**			
1.1	Does the deliverable require a manual approach to interpret raw data?	✓		The deliverable is not fully automated but provides a more automated approach to interpreting raw data.
1.2	Does the deliverable provide a simpler method of communicating information?	✓		This is indicated using of forms and reports.
1.3	Are measurements used purposeful?	✓		Measurements are purposeful in the sense that they align with identified 5-year goals.
2	**Design requirements (Discussed in Section 4.3)**			
2.1	**Does the design partially or fully automize the process of acquiring information to making it interpretable?**	✓		The design presents a partial automation of a process through the use of a cloud and forms. Furthermore, data is interpretable through online reports.
2.2	**Does the design minimize the channels of communication of information?**	✓		
2.3	**Does the design allow a user to strategically select parameters and measurements for decision making purposes?**	✓		The Hoshin Kanri Matrix and Goal-Question-Metric provides a method of selecting goals, KPI's, and metrics

A rigorous and reliable approach was followed in order to validate the GOM design. In order to assess the rigour of the GOM design, the four-dimension criteria by Forero [40] are used. Table 5 includes the rigour assessment of the GOM design where the purposes of the criteria are provided by QUC [41].

Table 5. Four-dimension criteria table adapted from Forero [40]

Rigour Criteria	Purpose	Criteria strategies	Criteria strategies applied to the research to achieve rigour
Credibility	To establish confidence that the results (from participants' experience) are true, credible and believable.	Reflexivity	It was believed at the start of the research that measuring service productivity is not possible, but the research presents a model that shows otherwise.
Transferability	To ensure the findings of this qualitative inquiry are repeatable.	Provide a method that future researchers can follow	A step-by-step PDCA cycle is done which is repeatable
Dependability	The decision trail used by the researcher can be followed.	A detailed description of the research method used	A research method is defined namely the DMADV method.
Confirmability	To maintain a sense of awareness and openness to the research and results	Reflection on research	This is provided in the conclusion (refer to Section 5)

To ensure the GOM design is reliable, the research followed Middleton's [42] definition of reliability. That is, to evaluate the degree to which a method consistently measures something and whether the method itself is consistent. The GOM design incorporates consistent formulae for identified goals, and consistent types of input are used for the forms. String and character types were not used, only numeric values. Furthermore, a variety of scenarios were run for three different goals with different KPI's and metrics. Due to the consistent use of formulas for different identified goals with consistent types of input in a variety of scenarios, the GOM design deems reliable.

For the act phase of the PDCA cycle, various improvements were identified and are discussed in Section 5.

5 CONCLUSIONS AND RECOMMENDATIONS

When first approaching this research, it was difficult to believe that productivity can be effectively measured in the service industry. It was understood that productivity is measured as a ratio of output to input of a process, but research shows that there are available methods to measure productivity in the service industry.

It was found that it is possible to disintegrate 5-year goals to operational measurements which provides an opportunity for employees to add value to the company on metric level for the metric associates with the 5-year organizational goal. However, Measuring operations on a metric level may incorporate micro-management which could be detrimental to the work environment [43].

The analysis assisted in identifying a model that can be used to develop a usable design. Furthermore, development of the design within Microsoft Access provided a framework of testing the usability and operation of the design itself, which enabled the design to address identified root causes. The scope of the research is on design level thus the software used does not form part of the solution of the problem, but assists in addressing identified root causes. Therefore, investigation in the implementation of the Goal-Oriented-Measurement design is recommended.

The research addresses the problem of ineffective representation of productivity which affects their renewal on design level. Table 4 illustrates how the GOM design addresses root causes, design requirements, and as a result solves the problem of ineffective representation of productivity at design level.

What makes the research appealing is the shift of focus for productivity measurement from ‘output to input’ to ‘process’ of operations. This is significant as organizational decisions do not have to rely on the result of an operation, but on strategic Key Peformance Indicators during operation. This adjustment may assist in mitigating losses, operation problems, or operation hazards before operational disaster.

Industrial engineers have a ‘superpower’ of having the ability to optimize complex systems. John Kelvin once said, “If you cannot measure it, you cannot improve it”, and if industrial engineers would want to apply their ‘superpower’ of optimization, one critical aspect of this would be measurement and, more specifically, goal oriented measurement which will assist organizations to identify problems, shape feasibile decisions, and promote organizational growth.

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AN INVESTIGATION INTO THE GAP BETWEEN BUSINESS MODELS AND SUSTAINABILITY TRANSITIONS AND THE IDENTIFICATION OF INTERMEDIARY CONCEPTS

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ABSTRACT

Working towards the achievement of long-term sustainability goals remains one of the most prevalent challenges faced by society today and it is becoming increasingly important to drive fundamental and multi-dimensional shifts toward more sustainable modes of production and consumption, namely sustainability transitions. It can be argued that businesses, despite their increased awareness of sustainability issues, could be doing more to bring about societal change. The ways that business model innovation may contribute to the acceleration of sustainability transitions has been of particular interest to researchers since the last decade. This paper, by means of a structured literature review, explores the extent to which the gap between business model innovation and transition literature has been addressed. Fifteen bridging constructs are identified and discussed that can serve to enhance practitioners' understanding of the interactions between business models and sustainability transitions.

Keywords: business models, sustainability transitions, structured literature review

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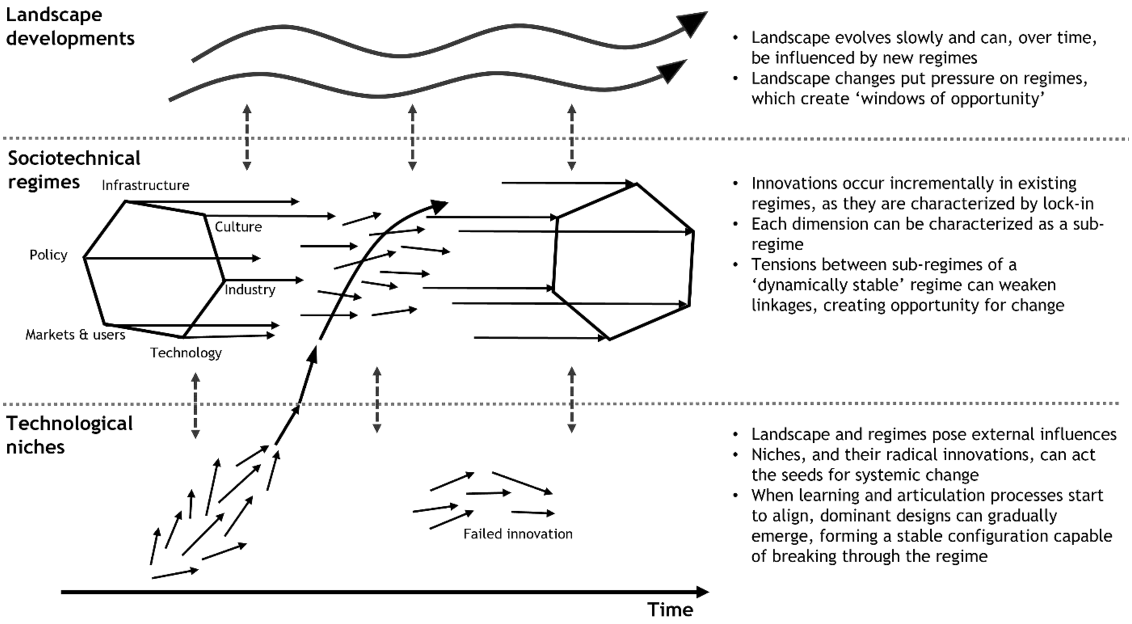
1 INTRODUCTION

In the wake of a global pandemic and its poignant social and economic consequences, it is more important than ever to work towards the fulfilment of the United Nations' Sustainable Development Goals (SDGs). The SDG Report of 2021 indicates that the pandemic has caused several streams of progress to halt or even regress [1]. Greenhouse gas emissions have continued to increase, poverty and inequality levels have worsened, and other sustainability challenges, such as waste production and environmental degradation, are no less prevalent.

The private sector is not unaware of this fact and businesses have increasingly adopted such practices as ESG (environmental, social and governance) reporting, corporate social responsibility, corporate sustainability, and the triple bottom line approach [2]–[4]. It can be argued, however, that businesses *can* and *should* be doing more --- their resources, influence, reach, and innovation capability put businesses in a position to challenge and transform the paradigms that underwrite current sociotechnical systems [5]. Given the magnitude and pervasiveness of the sustainability challenges faced, and the way they are embedded in the world's sociotechnical systems (*e.g.*, energy, transport, agriculture, water supply), it is by precisely by *rewriting* these paradigms (transitioning to more sustainable modes of operation) that we can bring about real and lasting change [6]–[8]. In other words, it is necessary to encourage businesses to help drive and govern *sustainability transitions*.

1.1 Sustainability transitions

Sustainability transitions can be defined as long-term, multi-dimensional, fundamental changes in sociotechnical systems that aim to shift these systems to more sustainable modes of production and consumption [6], [7]. Prominent frameworks in the academic realm of transition studies that have been adopted towards the governance and promotion of sustainability transitions are the multi-level perspective (MLP) (depicted in Figure 1), strategic niche management, and transition management [6].



- Landscape evolves slowly and can, over time, be influenced by new regimes
- Landscape changes put pressure on regimes, which create 'windows of opportunity'

- Innovations occur incrementally in existing regimes, as they are characterized by lock-in
- Each dimension can be characterized as a sub-regime
- Tensions between sub-regimes of a 'dynamically stable' regime can weaken linkages, creating opportunity for change

- Landscape and regimes pose external influences
- Niches, and their radical innovations, can act the seeds for systemic change
- When learning and articulation processes start to align, dominant designs can gradually emerge, forming a stable configuration capable of breaking through the regime

Figure 1: Summary of the MLP on sociotechnical transitions (adapted from [9] and [10])

Geels's multi-level perspective for sociotechnical transitions involves three levels: The *landscape* is the wider, external context made up of demographical trends, societal values, political ideologies, and macro-economic patterns [9]. The landscape contains a 'patchwork' of *regimes* [10]. Regimes are characterised by the rules and practices that stabilise existing systems and are often dominated by incumbent firms [10]. Lastly, *niches* (protected spaces for radical innovation [10][11]) exist within regimes. *Strategic niche management* entails the development of specific niches geared to trigger changes in the regime [12], while *transition management* offers a practise-oriented and more prescriptive model for advancing ongoing sustainability transitions [13].

It should be noted that sustainability transitions differ from *sociotechnical* transitions in that they are deliberate and goal-oriented, the *goal* being to accomplish sustainability for the collective good [9]. The sociotechnical systems that undergo these complex transitions, and subsequently the transitions themselves, consist of multiple actors, such as policy makers, public authorities, consumers, civil society, and businesses [8]. The role of businesses in sustainability transitions, although not entirely unaddressed [8], [14], has only started to garner increased attention from researchers in the past decade, particularly the question of how *business model innovation* can act as a catalyst for the system-wide, fundamental transformation required to address sustainability challenges [4], [15].

1.2 Business models for sustainability transitions

The term 'business model' has appeared in literature since the mid-1990s to describe or depict how firms "do business"[16]. Although many different definitions exist, a business model essentially articulates how a business proposes, creates, captures, and delivers value. Additionally, business models can provide a holistic, system-level perspective when describing the key elements required to realise a business strategy [16], [17].

A framework often used to design business models, given its intuitiveness and simplicity, is the business model canvas developed by Osterwalder and Pigneur [18]. The canvas is composed of the following 'building blocks': customer segments, value propositions, channels, customer relationships, revenue streams, key resources, key activities, key partnerships, and cost structure [18]. A second common framework for business models is Zott and Amit's activity system perspective [19]. This perspective on designing business models comprises two parts. The first entails describing the design *elements* of content (*what* activities are performed?), structure (*how* are the activities performed?), and governance (*who* performs the activities?). The second is concerned with deciding on the design *themes*, *i.e.*, the dominant value propositions, that serve as connections between the elements of content, structure, and governance [19].

While crucial to the commercialisation of technological innovation [17], and more recently noted, *sustainable* innovations [13], business models *themselves* can undergo innovation and some scholars argue that herein lies the opportunity to develop new business models that can contribute to the acceleration of sustainability transitions [4], [20]. Businesses, being the *"predominant mode of resource allocation in capitalist society, having privileged access to government, finance, and other key resources that need to be mobilised to enact societal change"* [4, p. 8], have the *potential* to exact substantial, sustainable transformation. Business models for sustainability transitions might be the key to unlocking this potential and lies at the intersection of transition studies and business model literature --- an intersection that is still relatively unexplored [4].

1.3 Aim and objectives

Aagard *et al*. [4] posits that business model innovation for sustainability and sustainability transitions may be viewed as either ends of a spectrum of intermediary concepts that 'bridge' the two extremes. These intermediary concepts will be crucial to practitioners wishing to design and implement business models capable of contributing towards transformative change. The *aim* of this paper, therefore, is to explore, by means of a structured literature review, the intersection between sustainability transition studies and business model literature in search of constructs that can assist practitioners in understanding the interactions between business models and sustainability transitions --- how sustainability transitions influence businesses (and by extension, business models) and especially how business models can help drive sustainability transitions. This aim is shown graphically in Figure 2. Specifically, two objectives are pursued, also portrayed in Figure 2.

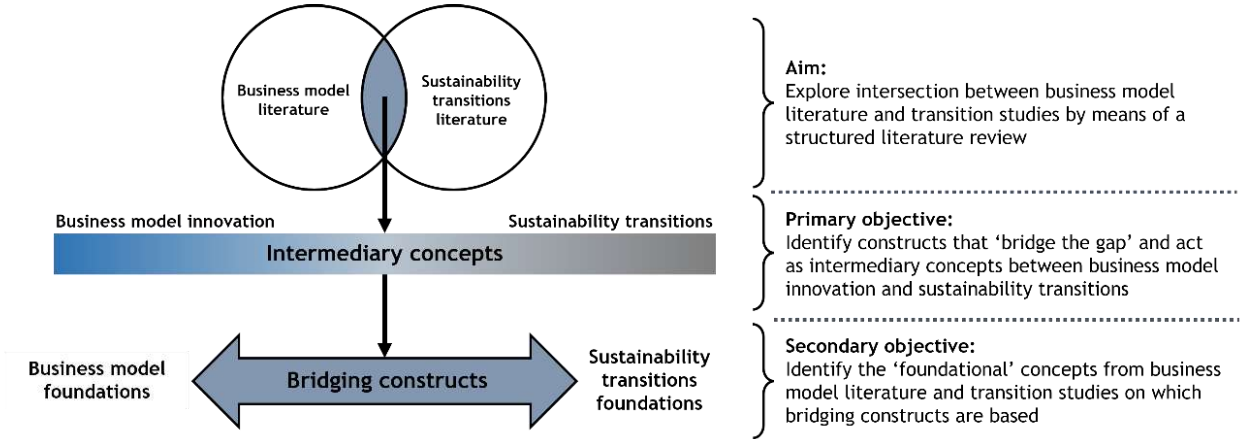


Figure 2: Visualisation of aim and objectives

The primary objective is to identify and summarise theoretical and conceptual constructs (frameworks, typologies, *etc*.) that bridge the gap between business model and sustainability transition literature. The secondary objective is to identify the concepts from both fields of literature that commonly form the 'foundations' of the bridging constructs.

2 STRUCTURED APPROACH

It is necessary to adopt a structured approach to identify and review the pertinent pieces of literature in pursuit of the two abovementioned objectives. The approach followed in this paper is guided by the preferred reporting items for systematic reviews and meta-analyses (PRISMA) methodology proffered by Moher *et al*. [21]. The PRISMA statement prescribes four phases, namely identification, screening, eligibility, and qualitative review and synthesis [21]. The adapted approach taken by this paper is depicted in Figure 3.

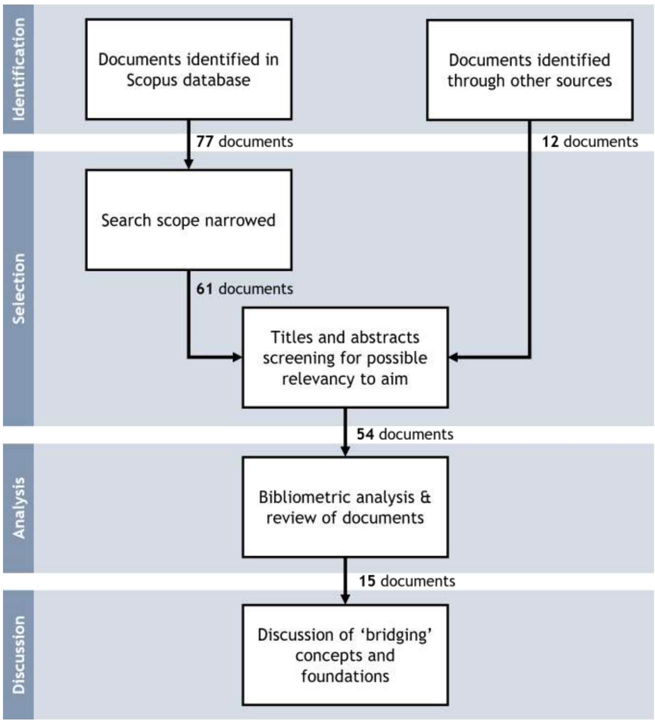


Figure 3: Structured approach to literature review

The remainder of this section pertains to the *identification* and *selection* phases. Section 3 contains a bibliometric analysis of the publications that were selected during the previous phase, followed by a content analysis in which the bridging constructs and foundational concepts are identified. Thereafter, the outcomes of the two objectives are discussed in Section 4.

2.1 Identification

The Scopus[†] database is the predominant source from which applicable literature is identified by means of different variations of search terms that appear in document titles, abstracts, or keywords. Drawing on common terms found in the fields of transitions studies and business models (Table 1), different combinations of search queries were constructed[‡]. These are shown in Table 2 alongside the number of results returned from the database.

Table 1: Search terms and variations

Transition studies	Business model literature
Sustainability transition(s)	Business model(s)
Sociotechnical/sociotechnical/socio technical transition(s)	Business model innovation
	Business models for sustainability
	Sustainable business model(s)

More specific queries were initially used, growing gradually more generic in order to get an overall idea of the scope and amount of potentially promising literature. The number of results obtained for the different queries affirm that fairly little research has been done at the intersection of the business model and transition literatures.

Table 2: Combinations of terms and number of results

ID	Search query for titles, abstracts, and keywords	#
1	"business model* for sustainability" / “sustainable business model” AND "sustainability transition"	15
2	"business model* for sustainability" / "sustainable business model*" AND "sustainability transition" / "sociotechnical transition"	16
3	"business model innovation*" AND "sustainability transition"	22
4	"business model innovation*" AND "sustainability transition" / "sociotechnical transition"	27
5	"business model*" AND "sustainability transition"	75
6	"business model*" AND "sustainability transition" / "sociotechnical transition"	102
7	"business model*" AND "sustainability transition" / "sociotechnical transition" AND “framework”	36
8	"business model*" AND "sustainability transition" / "sociotechnical transition" AND “concept*”	44
9	"business model*" AND "sustainability transition" / "sociotechnical transition" AND “tool*”	9

The final search query (a combination of queries 2, 4, 7, 8, and 9) was used to identify a collection of 77 records in the Scopus database. Additionally, twelve book chapters that are not in the database were added manually. These represent the twelve documents in Figure 3 that were “identified through other sources”. The chapters are sourced from a recently

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[†] Scopus is a platform that provides access to a vast database of abstracts and citations. The database covers 240 disciplines and more than 7,000 publishers [44].

[‡] The Scopus queries were constructed such that plurals, loose phrasing (for instance, ‘business model for sustainability’ and ‘business *modelling* for sustainability’), and spelling variations (for instance, ‘socio-technical’ *versus* ‘sociotechnical’) were also accounted for. No temporal restrictions were applied.

published book by Aagaard, Lüdeke-Freund, and Wells, titled *Business Models for Sustainability Transitions* [22] which explores the interactions between businesses and societal transitions.

2.2 Selection

Evaluating the abstracts of the 77 Scopus results revealed that several records are not specifically concerned with the role of business models in sustainability transitions, or only explicitly mentions one of the relevant search terms in the abstract, thus not fully considering the intersection between business model and transition literature. For this reason, the Scopus search query was adapted to exclude keywords and instead only search among record titles and abstracts. Doing so reduced the number of results to 61. The titles and abstracts of the remaining records, particularly the context in which terms from the search query are used, were then screened to ascertain the basis on which they were included in the results. The twelve book chapters are similarly screened on the titles and descriptions provided in the introductory chapter of the book. In this manner, sixteen Scopus records and three book chapters are excluded.

In the subsequent section, a bibliometric analysis is carried out on the remaining 45 Scopus records. Because the book chapters are not yet a part of the database, these are not included in the analysis. Thereafter, the 45 documents and nine book chapters are investigated to ascertain whether they proffer a so-called 'intermediary concept' connecting business model innovation and sustainability transitions.

3 ANALYSIS

3.1 Bibliometric analysis

In order to gain an understanding of the origins, timeline, and scope of the body of literature pertaining to the interaction between business models and sustainability transitions, the bibliometric information available in the Scopus database is analysed using Excel, Scopus's own analysis function, and VOSviewer[§].

The distribution of publications over time is shown in Figure 4. The majority of papers reviewed were published during the past four years, with the earliest publication occurring in 2014. The fact that research substantially took off only from 2018 onwards, is indicative of the novelty of this focal area. At the time of writing only five pieces of literature had been published in 2022, though it is likely that this number will rise over the course of the year.

The journals having published two or more of the reviewed documents are compared in Figure 5. True to the respective focus areas of the journals, *Environmental Innovation and Societal Transitions* alongside *Sustainability (Switzerland)* and *Journal of Cleaner Production* are responsible for most of the publications.

[§] VOSviewer is a software tool that uses citation data to construct and visualize bibliometric networks [45].

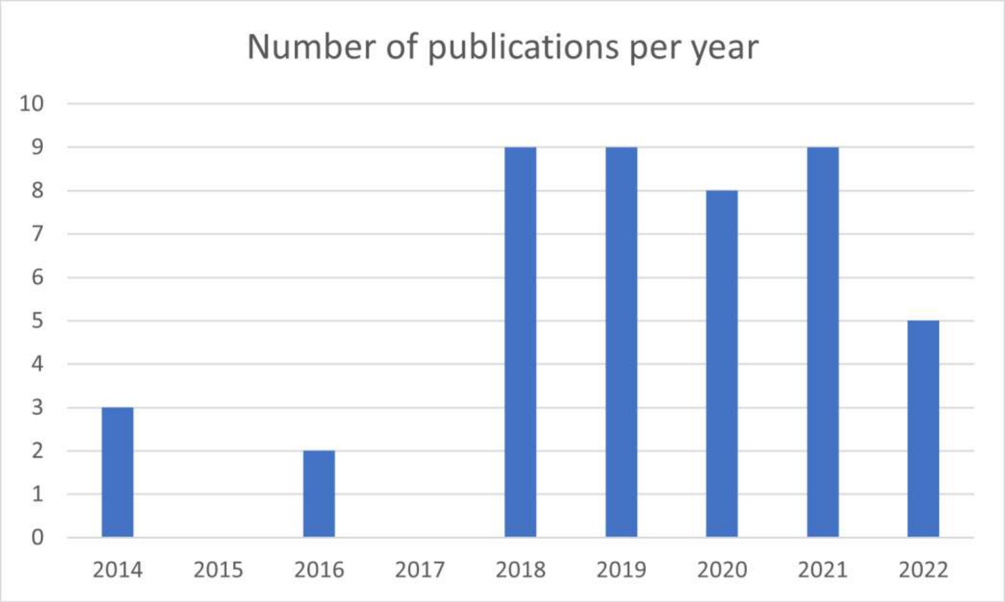

Figure 4: Publications per year

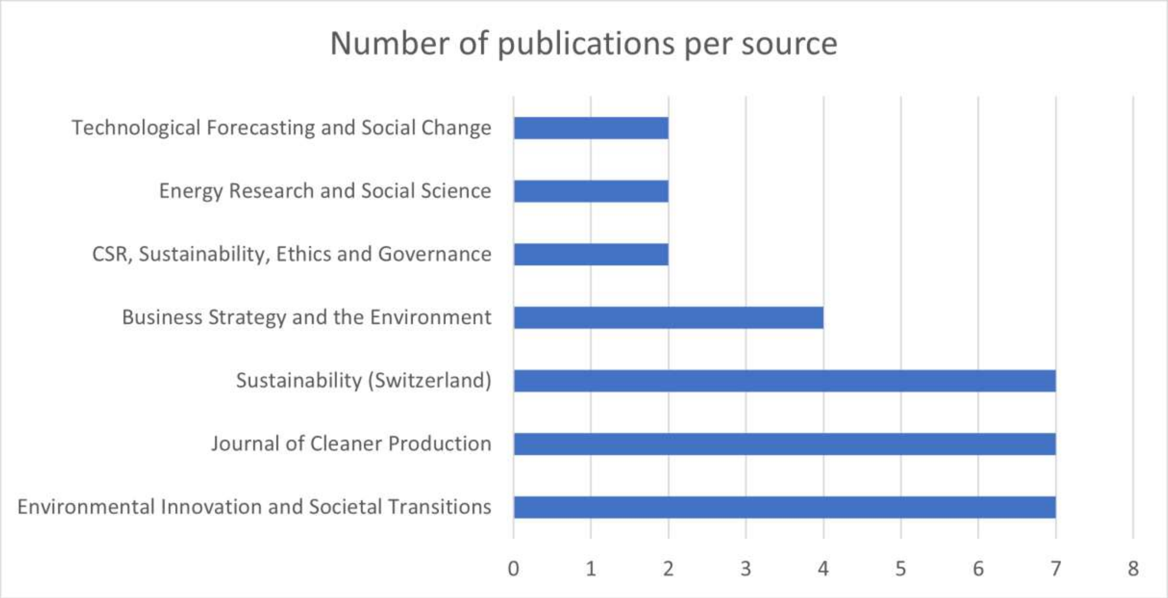

Figure 5: Publications per source

Figure 6 shows the countries from which two or more publications originate. It is interesting to note that the research so far originates mainly from west European (*i.e.*, Netherlands, Germany, Spain, Italy) and Scandinavian countries (*i.e.*, Finland, Sweden, Denmark). For transitions research, for example, the lack of representation in literature on issues such as sustainability transitions is often raised [6], [23]. It is thus not surprising therefore that the same lack of non-western representation is seen in a relatively new strand of literature such as business models for sustainability transitions.

In order to provide a starting point for addressing the second research objective, namely discovering the topics from the business model and transitions literature that commonly form foundations of the so-called "bridges" between the two fields of literature, a co-citation map is generated with VOSviewer (Figure 7).

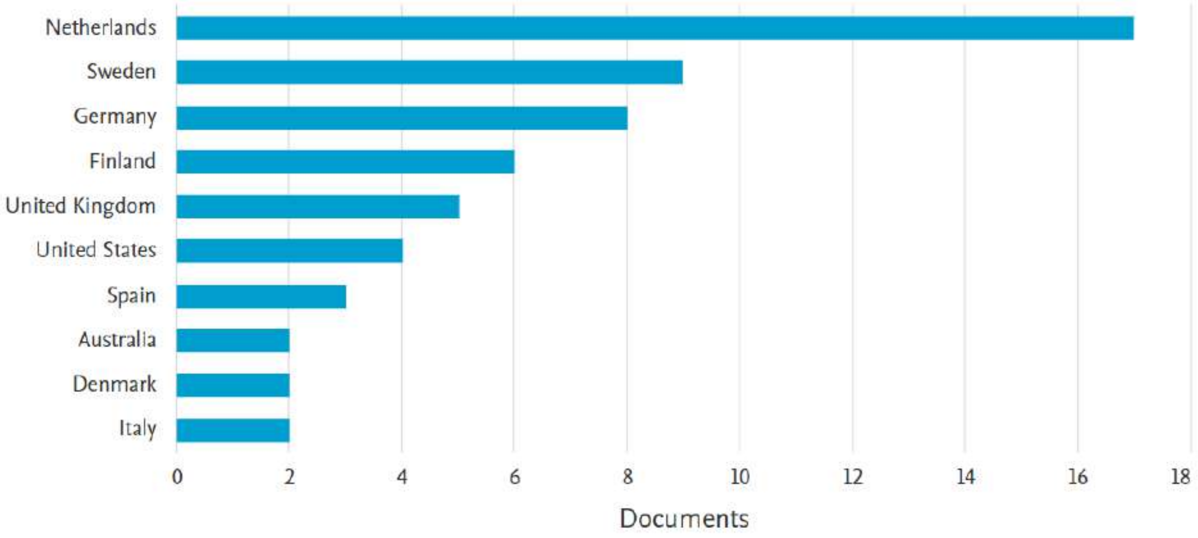

Figure 6: Publications per country (Source: Scopus)

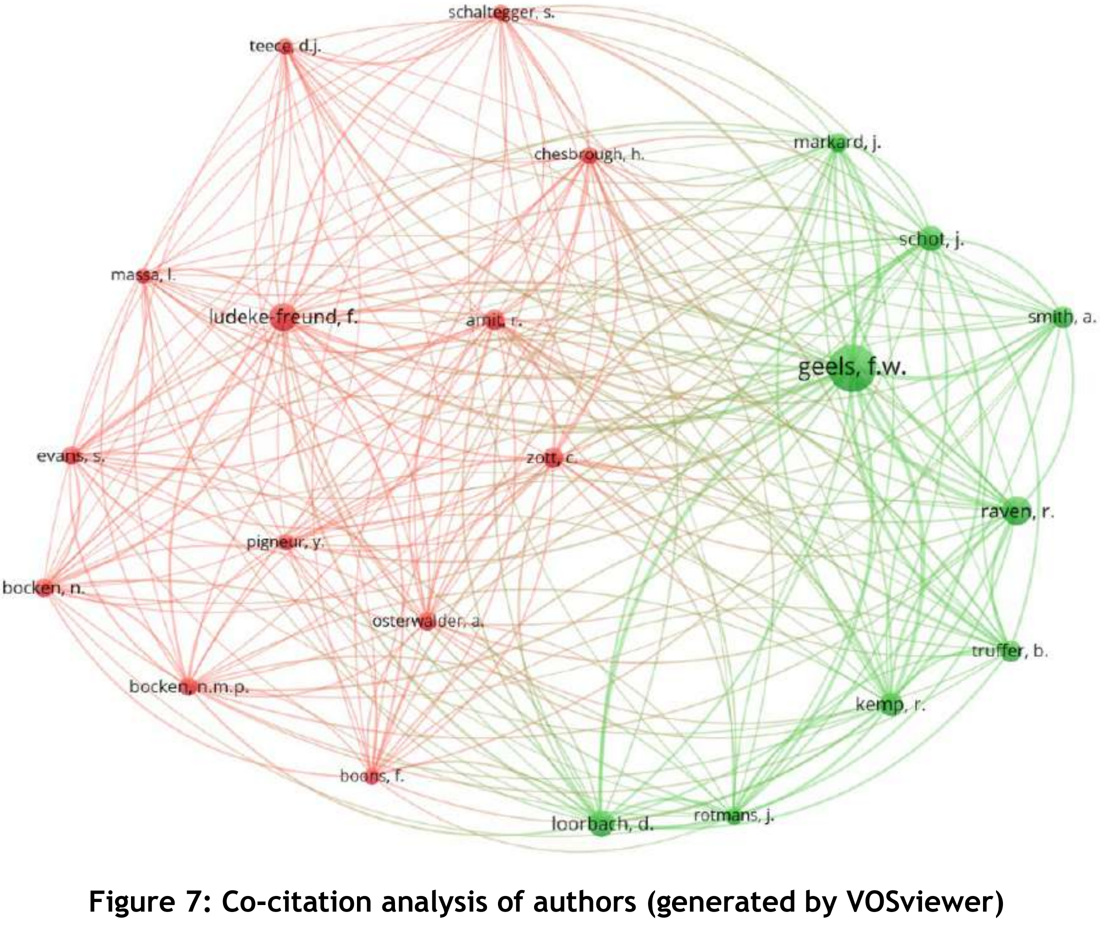

Figure 7: Co-citation analysis of authors (generated by VOSviewer)

Given the inconsistency of the citation formats in the Scopus database, the map is not a completely accurate representation of the most cited authors. Further investigation of the citations (based on the total collection of references exported from Scopus) uncovered the twenty most cited publications across all 45 publications, shown in Table 3. These already hint at some of the topics most likely to inform concepts on the continuum between business model innovation and sustainability transitions.

Comparing commonly cited publications to the clusters in Figure 7 reveal that authors in the red cluster are associated with topics associated to business models, business models for sustainability, and business model innovation. The authors in the green cluster are related to literature on sustainability transitions and sociotechnical systems.

Table 3: Summary of the twenty most cited publications

Authors	Title	Year
Osterwalder, A., Pigneur, Y.	Business Model Generation: A Handbook for Visionaries, Game Changers and Challengers	2010
Teece, D.J.	Business models, business strategy and innovation	2010
Boons, F., Lüdeke-Freund, F.	Business models for sustainable innovation: State-of-the-art and steps towards a research agenda	2013
Geels, F.W.	Technological transitions as evolutionary reconfiguration processes: A multi-level perspective and a case-study	2002
Markard, J., Raven, R., Truffer, B.	Sustainability Transitions: An Emerging Field of Research and Its Prospects	2012
Bocken, N.M.P., Short, S.W., Rana, P., Evans, S.	A literature and practice review to develop sustainable business model archetypes	2014
Geels, F.W., Schot, J.	Typology of sociotechnical transition pathways	2007
Zott, C., Amit, R., Massa, L.	The Business Model: Recent Developments and Future Research	2011
Chesbrough, H.	Business Model Innovation: Opportunities and Barriers	2010
Bolton, R., Hannon, M.	Governing sustainability transitions through business model innovation: Towards a systems understanding	2016
Geels, F.W.	The multi-level perspective on sustainability transitions: responses to seven criticisms	2011
Smith, A., Raven, R.	What is protective space? Reconsidering niches in transitions to sustainability	2012
Zott, C., Amit, R	Business model design: an activity system perspective	2010
Bidmon, C.M., Knab, S.F.	The three roles of business models in societal transitions: New linkages between business model and transition research	2018
Loorbach, D., Wijsman, K.	Business transition management: Exploring a new role for business in sustainability transitions	2013
Schaltegger, S., Hansen, E.G., Lüdeke-Freund, F.	Business Models for Sustainability: Origins, Present Research, and Future Avenues	2016
Schaltegger, S., Ludeke-Freund, F., Hansen, E.G	Business models for sustainability: A co-evolutionary analysis of sustainable entrepreneurship, innovation, and transformation	2016
Geels, F.W.	From sectoral systems of innovation to sociotechnical systems. Insights about dynamics and change from sociology and institutional theory	2004
Stubbs, W., Cocklin, C.	Conceptualizing a sustainability business model	2008

3.2 Content analysis

The remaining 45 Scopus records and nine book chapters are reviewed in search of theoretical, practical and/or conceptual contributions that may serve as a bridge or link between the respective business model and sustainability transition bodies of literatures. If such a contribution is not immediately evident from the abstract, the entire document is examined to determine whether there is a clear focus on the interactions between businesses and sustainability transitions.

In fulfilment of the primary objective, a total of sixteen constructs are identified, fifteen[**] of which form part of the content analysis. These fifteen are listed in Table 4 and a description of each construct is provided in

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[**] The sixteenth, namely *transformative business model for sustainability* [46] is not openly accessible to the public and could therefore not be included in the detailed discussion.

Appendix A.

Table 4: Theoretical, practical and/or conceptual contributions identified

Link	Construct identified
A.1	Conceptual framework combining business models with socio-technical transition theory [24]
A.2	Systems-based approach to understanding business model innovation in a socio-technical context [20]
A.3	Framework for integration of business model change and system transition [25]
A.4	Three roles of business models in societal transitions [26]
A.4	Integration of four business model themes and transition theory [27]
A.6	Framework of business model innovation in business model design space [28]
A.7	Transition model canvas [29]
A.8	Business model activity system for sustainability transitions [15]
A.9	"Spiral"-framework connecting business model to sustainability transitions [4]
A.10	Transformative business model framework & 2 ideal types [30]
A.11	Networked business model for systems change [31]
A.12	Sustainable value creation approach for advancing system-level sustainability [32]
A.13	Roles for different BoP business models in sustainability transitions [33]
A.14	Analytical framework of firm's roles in niche development [34]
A.15	Collaborative sustainable business modelling for sustainability transitions [35]

Further examination of the final fifteen publications reveals the key concepts and frameworks from business model and transitions literature that were used by authors to create *new* concepts and frameworks that aim to visualise or demonstrate the interactions between business models and sustainability transitions. Overall, the authors drew on a vast and varied pool of contributions from both literature fields, but those that were explicitly used as a basis for a new development are summarised in Table 5, in fulfilment of the secondary objective of this paper.

Table 5: Foundational concepts and frameworks identified from literature

Business model literature	Transitions literature	Complementary topics
• Business model canvas [18] • Activity system [19] • Business transformation typology [36] • Business model design space [37] • Emergent themes in business model literature [16] • Business ecosystems [38] • Sustainable business modelling (various sources)	• Multi-level perspective [9], [10] • Triple embeddedness framework [39] • Transition management for sustainability[13] • Collective system building [40]	• Dynamic capabilities [41] • Typology of corporate sustainability [42]

4 DISCUSSION AND CONCLUSION

Given the reach and resources of businesses, and in the context of continually pervasive sustainability challenges, researchers have become increasingly interested in how businesses, viewed through the lens of business models and business model innovation, can help drive and govern transitions to more sustainable modes of production and consumption [4], [15], [35]. This paper explored what contributions scholars have made in recent years towards better understanding the interactions between business models and sustainability transitions.

A structured literature review of the intersection between the academic realms of business model theory and transition studies was undertaken. The outcome of this review is the identification and evaluation of fifteen bridging constructs (see Table 4 and

Appendix A), as well as their respective theoretical and conceptual foundations (see Table 3Table 3 and Table 5).

4.1 Nature of contribution of identified constructs

The contributions that bridge the gap between business model innovation and sustainability transitions have thus far been largely theoretical --- derived from existing concepts in business model and transition literature --- and mostly validated by means of illustrative case studies, *e.g.*[15], [20], [26], [31]. Frameworks constructed from findings made during empirical studies are less common, *e.g.* [24], [30], [32].

The constructs identified during the content analysis can largely be classified into four groups, with some constructs belonging to more than one group. These are summarised in Table 6. The first group proffers contributions aimed at the better conceptualization or analysis of the interactions between business models and transitions. The second group proposes an approach towards using business model innovation as a mechanism to drive sustainability transitions. Business model frameworks designed to contribute to sustainability transitions form the third group. The fourth and final group offers frameworks of a more prescriptive nature for designing or adopting business models capable of accelerating societal change.

Table 6: Key insights

Group	Description of constructs belonging to group	Constructs
1	Conceptualisation/analysis of interactions between business models and sociotechnical transitions	[4], [15], [24]–[29], [33], [34]
2	Using business model innovation to drive sustainability transitions	[20], [32], [35]
3	Frameworks for designing business models for sustainability transitions	[30], [31], [35]
4	Prescriptive frameworks for designing/adopting business models for sustainability transitions	[15], [32], [33]

The distribution of constructs in the above table indicates that the literature linking business models and transitions primarily aim to provide a better understanding of the interface between businesses and sustainability transitions. The focus is on the interactions and dynamics between sustainability transitions and businesses and/or business model innovation. Far fewer pieces of literature offer frameworks or guidelines for the successful design and implementation of business models that positively contribute toward sustainable society-wide transformation. Whereas most of the constructs, and the publications in which they appear, show that business models *can* help drive and govern sustainability transitions, there is not yet enough emphasis on the *how* in a more practical sense.

4.2 Countries and sectors of application

Comparing the publications per country (as listed in Figure 6) with the countries' corresponding energy transition readiness score[††] show that the ten countries listed in the bibliometric analysis similarly rank very highly according to 2021's Energy Transition Index (available here). Because the volume of research is still relatively low, little value can be attributed to the fact that these two measures coincide. The measure of transition readiness, however, can serve to indicate which countries could be more receptive to business models capable of inducing transformative change.

Little research has so far been done to ascertain *which* sectors or specific sustainability transitions could most benefit from, or be most receptive to, business models for sustainability transitions. Low carbon energy solutions [15], [20], [24], [35], electric vehicles [15], [28], and

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[††] The Energy Transition Index is a benchmark used by the World Economic Forum to measure the *system performance* and *transition readiness* of countries in the context of transitioning to more sustainable energy systems [47].

agriculture [30], [32] are some of the sectors that featured in the illustrative or empirical studies that showcased the bridging concepts that formed the focus of this paper.

4.3 Limitations and further research

The true complexity of the interactions between businesses and sustainability transitions is not done justice in this paper. This paper can, however, serve as a guide to the pertinent literature at the intersection of business model theory and transition studies.

The involvement of multiple actors in any sociotechnical transition suggests a strong need for multi-level, multi-stakeholder decision making processes wherever business models for sustainability transitions are concerned. Not discussed in this paper are the implications for policy makers or the relationships between businesses and governmental structures, but these will be key for establishing an enabling environment for businesses to contribute to societal transformation. The components of such an enabling environment are hinted at in some of the literature but have not been described explicitly.

The integration of literature on business models and sustainability transitions is still a very novel strand of research, and as such, presents many avenues for future research. Much of the current research is highly theoretical and aimed at fellow researchers. The opportunity exists, therefore, to consolidate current findings into more practical and prescriptive frameworks aimed at business practitioners. A management perspective, combined with a systems approach, could yield in guidelines for the design and implementation of business models that could go a long way towards spurring transformative change for the greater good.

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APPENDIX A

This appendix provides, in order of publication, a brief discussion on each of the fifteen identified theoretical, practical and/or conceptual contributions.

A.1 Conceptual framework combining business models with socio-technical transition theory

Wainstein and Bumpus [24] were some of the earliest researchers to argue for business model innovation as a way of accelerating sustainability transitions. Drawing on popular business model theory and Geels's MLP of sociotechnical transitions [10], they developed a conceptual framework (Figure 8) highlighting specific dynamics between business models and the sociotechnical regime. The authors argue that innovative business models can provide the necessary competitive advantage for the sustainable technologies to potentially disrupt the regime's 'business-as-usual' for the better [24]. The framework was applied to three case studies in the low carbon power transition and proved useful in characterising the different dynamics of business models in the ongoing transition.

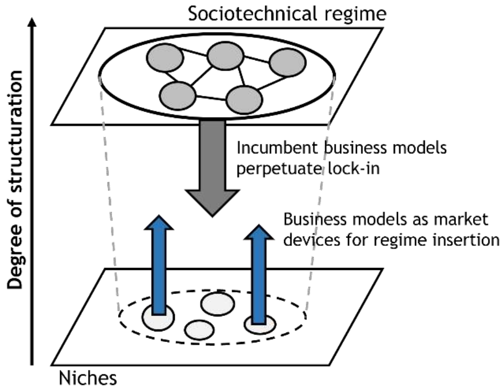


Figure 8: Conceptual framework by Wainstein and Bumpus (adapted from [24])

A.2 Systems-based approach to understanding business model innovation in a socio-technical context

Bolton and Hannon [20] suggest a systems-based approach to governing sustainability transitions through business model innovation. They employed three different systems approaches (Geels' MLP [10], business models as an activity system [19], as well as large technical systems (LTS) and the concept of system builders) to analyse the interface between business models and sociotechnical systems. The abilities of the different systems approaches to account for the relationship between business models and sustainability transitions are assessed based on two case studies of energy service companies [20].

Based on this assessment, Bolton and Hannon recommend that the alignment between the activity and sociotechnical systems can serve as a useful conceptual framework to understand the interactions between business model innovation and sociotechnical change [20]. Elements noted by Bolton and Hannon that need to be aligned are depicted in Figure 9.

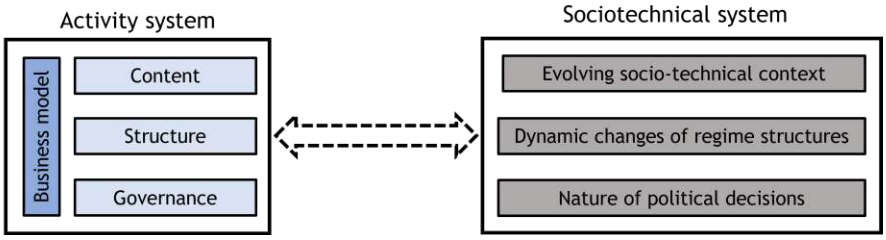


Figure 9: Activity and sociotechnical systems approach (based on [20])

A.3 Framework for integration of business model change and system transition

In an attempt to work towards the integration of the business model and sustainability transition disciplines, Koistinen *et al*. [25] developed a framework for visualising the sought-after integration. The framework, shown in Figure 10, is the product of the systematic combination of three distinct frameworks from the literature on sustainability, business model innovation, and system transitions [25]. More specifically, the foundations of this particular bridging construct are Dyllick and Muff's typology of corporate sustainability [42], Gauthier and Gilomen's typology of business model transformation [36], and Geels's triple embeddedness framework [39]. The different notions and forms of value served as the integrative concept that connected the disciplines. This integrative, theoretical framework consolidates and acts as an illustration of the myriad dynamics that can occur at company and system levels.

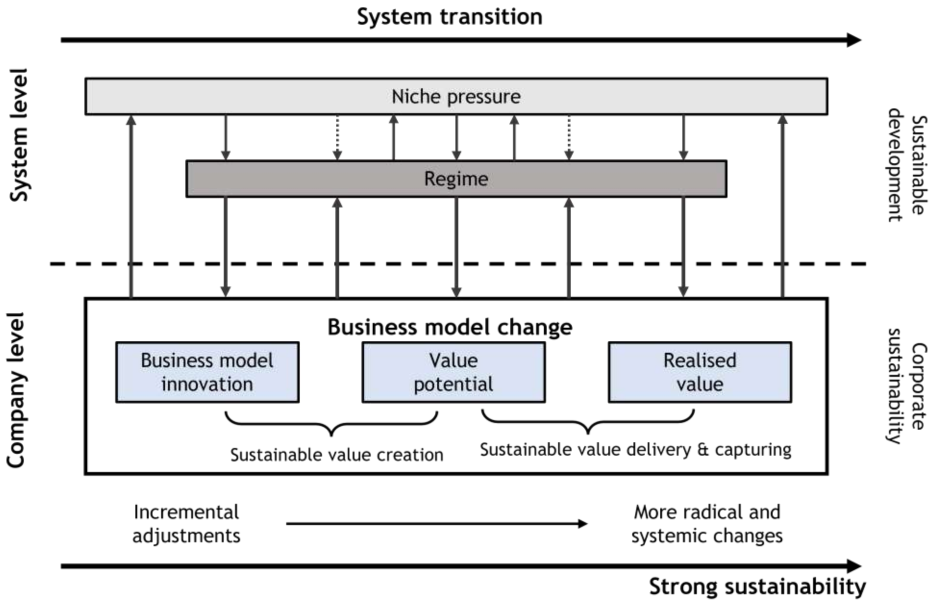


Figure 10: Integration of business model change and system transition (adapted from [25])

A.4 Integration of four business model themes and transition theory

Sarasini and Linder [27] sought to redress the perceived lack of a firm-level perspective in transition theory by integrating a business model perspective with the four types of transition management governance activities. The themes in business model literature observed by Zott *et al*. [16] form the basis of the business model perspective. The authors' synthesis of the theory lead them to four new lines of enquiry for future researchers, from which the potential interactions between business models and transition management activities depicted in Figure 11 may be derived [27].

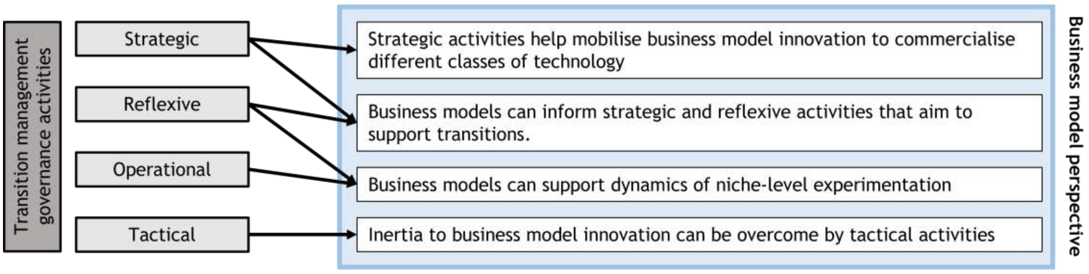


Figure 11: Business model perspective on transition management activities (based on [27])

A.5 Three roles of business models in societal transitions

Bidmon and Knabb's contribution [26] is among the most cited references discovered during the bibliometric analysis (see Table 3). By systematically integrating various core concepts from business model literature with Geels's multi-level perspective, particularly the notions of regimes and niche innovations, the authors identify three roles that business models can assume in a sociotechnical transition, thereby enhancing the understanding of business model contributions to societal change [26]. These three roles are summarised in Table 7 and visualised in Figure 12.

Table 7: Summary of business models' roles in transitions [26]

	Role	Description of role
1	Industry recipes	Existing business models (of incumbent firms) reinforce the stability of the regime and act as a barrier to sociotechnical transitions.
2	Devices to commercialise technological innovation	Business models mediate between the technological niche and regime and can drive transitions by facilitating the new technology's breakthrough to regime level.
3	Subject to innovation	Novel business models have more stability than novel technology and can contribute to building a novel regime by challenging dominant regime logic without relying on technological innovation.

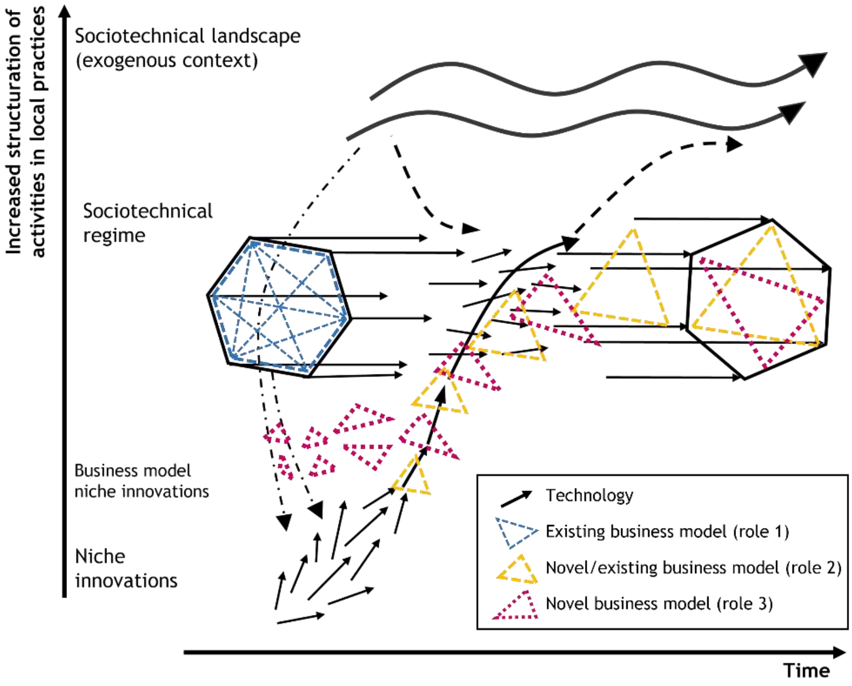
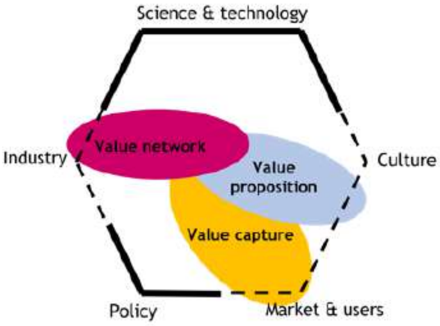


Figure 12: Three roles of business models in sociotechnical transitions (adapted from [26])

A.6 Framework of business model innovation in business model design space

Wesseling *et al.* [28] conceptualise business model innovation within the business model design space and argue that business model innovation can either conform to the regime in which the design space resides or attempt to transform it. The conceptualised framework builds on the notion of niche empowerment [11] and the following simplified business model elements: value proposition, value network, and value capture. The conceptualisation is shown in Figure 13, alongside a summary of the relationships between the dimensions and niche-related business model innovation.

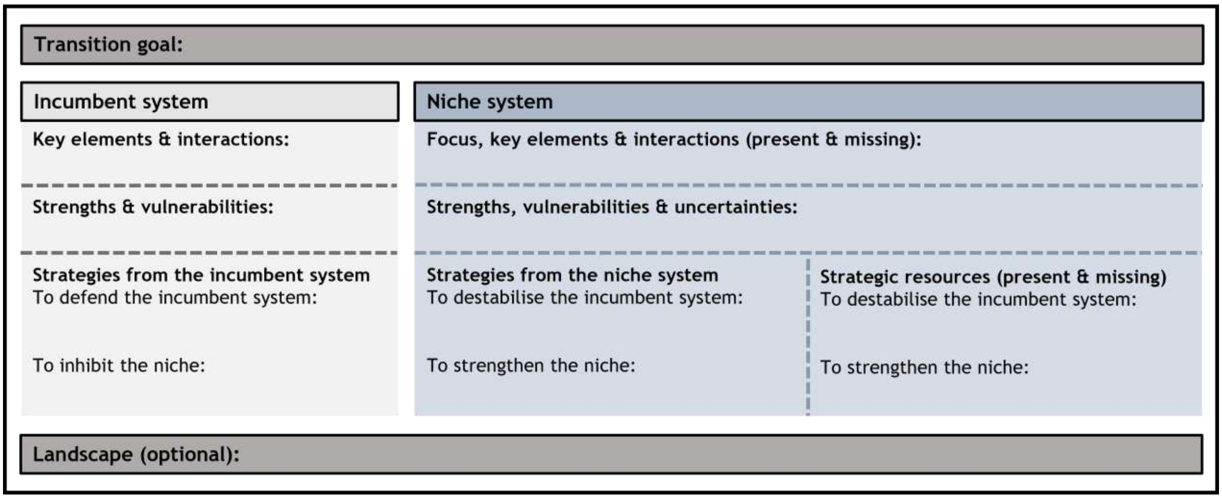


Key	Business model innovation influence on regime dimension
▬	**Hard edge**: business model innovation cannot directly influence regime dimension
- - -	**Soft edge**: regime dimension can be directly affected by business model innovation
🟥	New entry and collaborations (networks) can support industry change.
🟦	New value propositions can promote change in public values and ideas about niche technologies, thereby influencing culture change.
🟨	New value propositions and value capture mechanisms can enable faster adoption of new technologies, thus altering markets.

Figure 13: Conceptualisation of business model innovation in business model design space (adapted from [28])

A.7 Transition model canvas

The transition model canvas (TMC) developed by Van Rijnsover and Leendertse [29], while not directly contributing to the understanding of the interplay between business models and sustainability transitions, is nevertheless an interesting combination of transition and business model theory. Inspired by the business model canvas [18] and based on multi-level perspective on transitions, the TMC is a practical tool that can help practitioners understand transition studies and systematically evaluate transition processes [29]. An empty TMC template is showcased in Figure 14.



Transition goal:

Incumbent system

Key elements & interactions:

Strengths & vulnerabilities:

Strategies from the incumbent system
To defend the incumbent system:

To inhibit the niche:

Niche system

Focus, key elements & interactions (present & missing):

Strengths, vulnerabilities & uncertainties:

Strategies from the niche system
To destabilise the incumbent system:

To strengthen the niche:

Strategic resources (present & missing)
To destabilise the incumbent system:

To strengthen the niche:

Landscape (optional):

Figure 14: Transition model canvas (adapted from [29])

A.8 Business model activity system for sustainability transitions

Hernandez-Chea *et al.* [15] contributed to bridging the gap between the themes of business and sustainability by means of a conceptual framework. The authors carried out a systematic literature review at the intersection of sustainable business model and sustainability transition literature. Based on the subsequent content analysis, they devised the *business model activity system for sustainability transitions* [15], shown in Figure 15. The visual representation is accompanied by three tables that further explain the activities and challenges faced at each level. The framework is applied to two industry case studies to demonstrate its use [15].

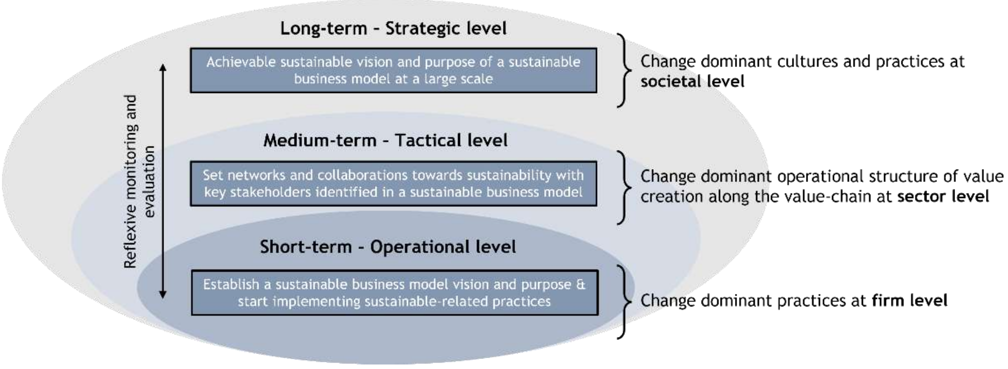


Figure 15: Business model activity system for sustainability transitions (adapted from [15])

A.9 "Spiral"-framework connecting business model to sustainability transitions

In the introductory chapter of their book *Business Models for Sustainability Transitions*, Aagaard, Lüdeke-Freund, and Wells [4] introduce the ‘spiral’ (Figure 16) --- a framework to better understand how business models connect to sustainability transitions. The framework is developed in response to the authors’ own observations and criticisms on current literature on sustainability transitions and business models for sustainability.

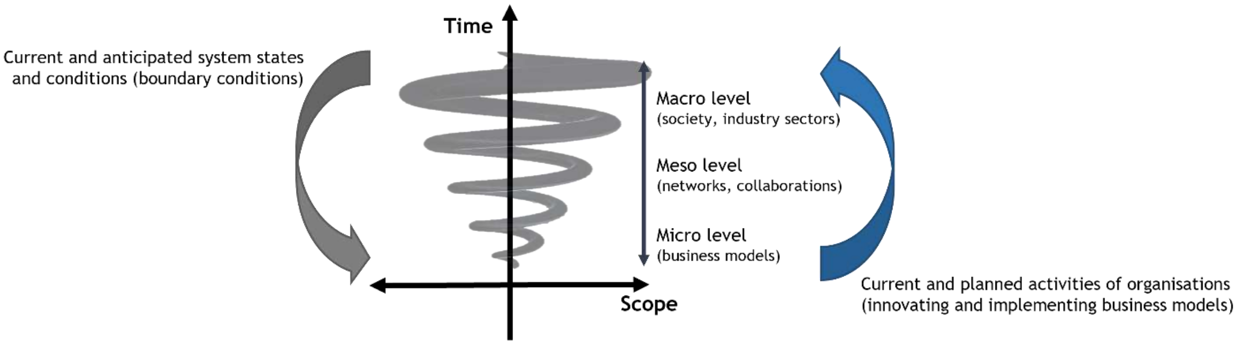


Figure 16: Spiral framework (adapted from [4])

A.10 Transformative business model framework

Beers *et al.* [30] expand on existing sustainable business model approaches by including a transition orientation. The resulting framework is depicted in Figure 17. From reviewing the pertinent literature, the authors conclude that, for a business model to be considered *transformative*, it should wield both a sustainability orientation and the potential to contribute to societal transition [30].

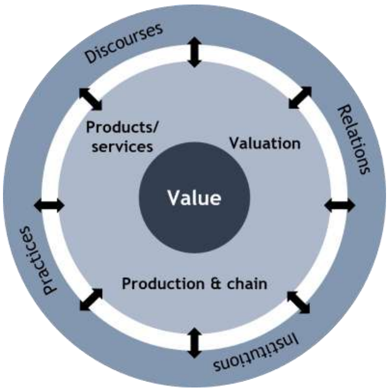


Figure 17: Transformative business model framework (adapted from [30])

A.11 Networked business model for systems change

Expanding on previous work on strategic collective system-building [40], Planko and Cramer incorporate business model theory to develop the networked business model shown in Figure 18. The authors argue that multi-actor networks, such as firms operating in a system-building network, can bring about effective change at a systems level [31]. Two illustrative cases are used to demonstrate its use and impact.

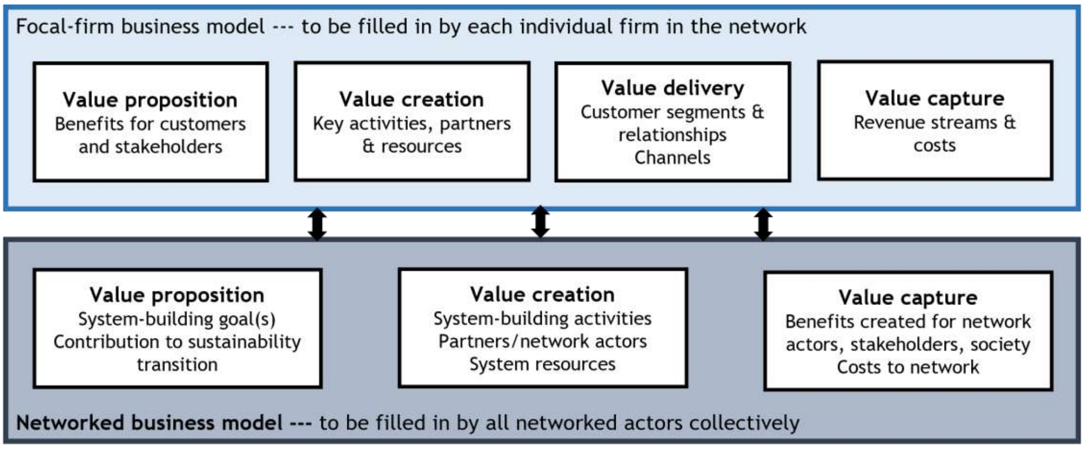


Figure 18: Networked business model and interaction with business models of individual firms (adapted from [31])

A.12 Sustainable value creation approach for advancing system-level sustainability

Laukkanen *et al.* [32] propose a sustainable value creation approach to ultimately realising system-level sustainability through sustainable business models. The approach, visualised in Figure 19, is based on sustainable business model literature, as well as empirical evidence from an in-depth case study [32]. Additionally, the authors also recommend five steps for managers wishing to adopt the sustainable value creation approach in the design, development, or implementation of sustainable business models.

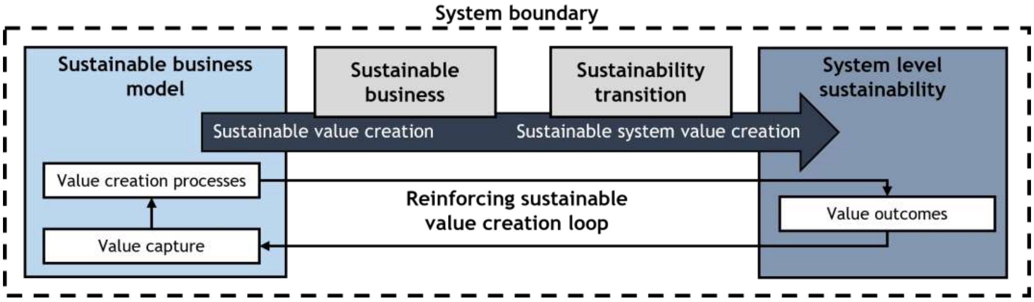


Figure 19: Sustainable value creation approach (adapted from [32])

A.13 Roles for different BoP business models in sustainability transitions

York and Dembek [33] do not offer a conceptual framework, but instead contribute insights to how businesses addressing so-called ‘bottom-of-pyramid’ (BoP) communities can better contribute to sustainability transitions. The authors analysed seventeen different BoP business models (classified as either *delivering*, *sourcing*, or *reorganising*, according to Dembek’s earlier work [43]) based on Bidmon and Knabb’s three roles for business models in sociotechnical transitions [26]. York and Dembek synthesized their findings to produce, for each role, opportunities and risks related to each BoP business model type. The authors further provide business model design principles towards avoiding ‘system traps’ and towards ensuring that BoP business models align with sustainability transitions [33].

A.14 Analytical framework of firm's roles in niche development

Stalmokaite *et al*. [34] combine transition studies with a dynamic capabilities approach to produce the analytical framework shown in Figure 20. The framework is based on the work of Teece on business models and dynamic capabilities [41], as well as Geels’s MLP, particularly his depiction of the multiple levels as a nested hierarchy [10]. Stalmokaite *et al*. devised this framework in order to study and compare the innovation processes of incumbent and newcomer firms [34].

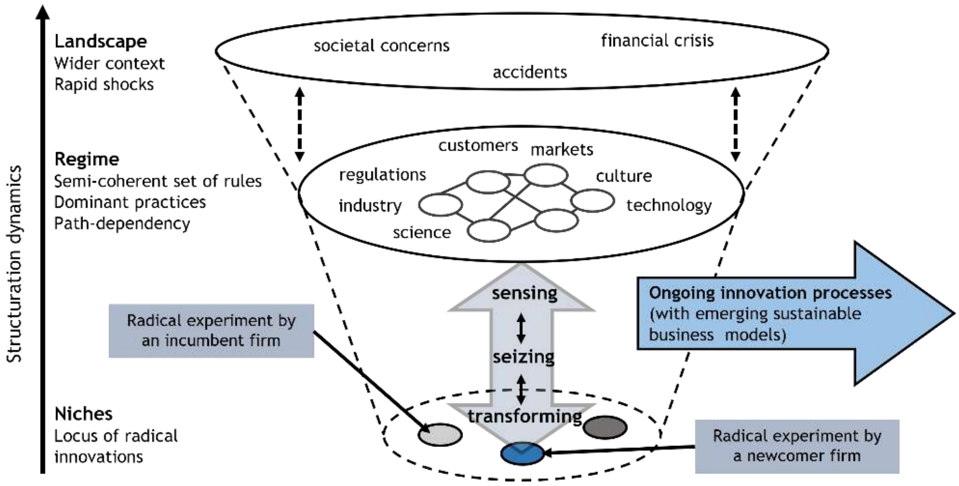


Figure 20: Analytical framework of niche-regime dynamics (adapted from [34])

A.15 Collaborative sustainable business modelling for sustainability transitions

Derks *et al*. [35] propose *collaborative sustainable business modelling* as a way to accelerate sustainability transitions. The authors do so by integrating existing theory on collaborative sustainable business models with transitions literature, specifically the MLP and transition management [13]. Sustainability transitions are likened to changes in the business ecosystem [38] and collaborative sustainable business modelling is subsequently conceptualised as the link between individual firms, organised in value networks alongside supporting actors, and transformative societal change [35]. To demonstrate the efficacy of their concept in practice, Derks *et al*. analyse two cases in the Dutch energy transition and affirm that collaborative sustainable business modelling can lead to system-level change.

MINIMISING ENGINEERING DELIVERY CYCLE TIME VARIABILITY ON SIMILAR PROJECTS: AN ESKOM CASE STUDY

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ABSTRACT

Eskom is experiencing a high level of cycle time variability for the delivery of similar engineering deliverables within similar project phases across different projects that are executed on similar plant areas. This research investigates the impact of engineering processes, intra-organisational knowledge transfer, variability of activities for similar engineering deliverables and variability of activities durations for similar engineering deliverables on cycle time variability. Both primary and secondary data were used for the research. Primary data was obtained by means of questionnaire surveys consisting of 20 different questions while the secondary data was obtained from a combination of paired sampled power stations projects schedules with similar engineering deliverables. The research revealed that intra organisational knowledge transfer, use of engineering processes, variability of activities and variability of activities durations have direct impact on similar projects cycle time variability. Knowledge transfer and utilisation of engineering processes were identified as leading variables.

Keywords: engineering deliverable, cycle time variability, intra-organisational knowledge transfer, activity duration, engineering processes.

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1 INTRODUCTION

1.1 Background

The construction of Eskom's new power stations and major refurbishment of existing power stations resulted in Eskom engineering division being put under tremendous pressure to deliver project engineering deliverables faster than ever before.

The pressure to deliver engineering deliverables was exacerbated by the concurrent execution of new power stations projects and existing power stations major refurbishment projects.

Engineering processes were not adequately designed or compiled within the project management context thus making it difficult for engineering to function optimally within the project management space. The Engineering Operating Model was only launched on the 12th of September 2012 **[1-5].** It should be appreciated that for an organisation as large as Eskom, the Engineering Operating Model was relatively young and still had a long way to maturity and to organisational cultural change.

The Eskom context of project engineering deliverables includes all engineering activities carried out during the project life cycle as per the Eskom project life cycle model **[5]**.

The project life cycle model is divided into six phases namely: Pre-Project Planning, Concept, Definition, Execution, Finalisation and Post Project phase. Each phase has at least one stage and a governance approval gate. Figure 1 below indicates major components of the Eskom project life cycle model.

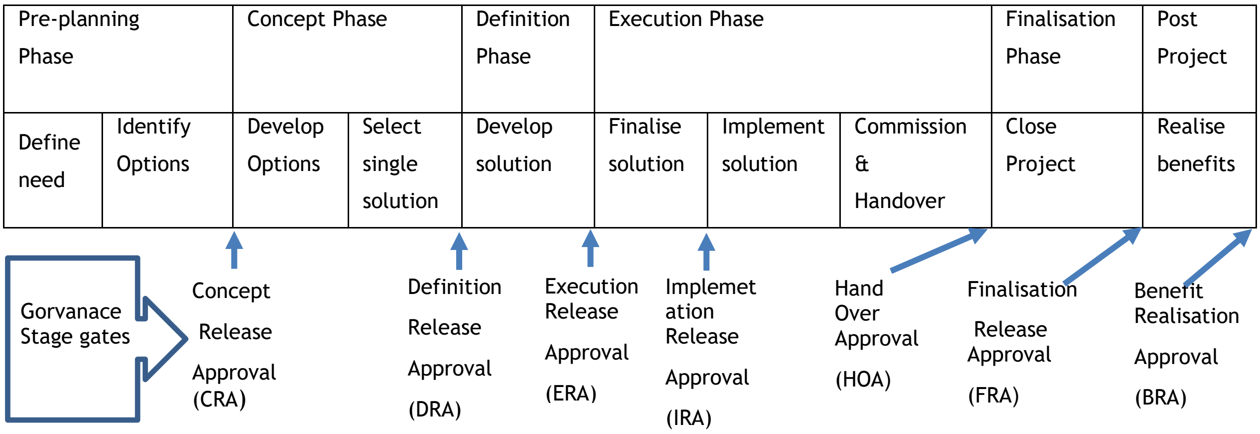

Figure 1: Eskom Project Life Cycle Model

The success or failure to deliver on engineering deliverables depends mainly on factors interacting with engineering effort deployed. These factors relate to the project context and influence the cycle time of engineering deliverables.

The article by Abbie Griffin **[6]** "The effect of Project and Process Characteristics on Product Development Cycle Time" includes product newness, product complexity, use of formal processes and use of cross-functional team as factors influencing cycle time. Griffin further associates project strategy, development process, organisational characteristics and firm characteristics with cycle time in another article **[7].**

Reda M.Lebeir and Jyoti Choudrie in their article **[8]** "A Dynamic Model of Effects of Project Complexity on Time to Complete Construction Projects" indicate that project complexity is driven by four factors namely: project uncertainty, infrastructure newness, infrastructure interconnectivity and infrastructure size.

This research focused on the **use of formal processes** and **use of cross-functional teams with the main focus on intra-organisational knowledge transfer**, as the researcher believe that these factors represent variables which can be easily accessible for optimisation of cycle time on similar projects engineering deliverables **within** similar project phases **across** different projects **that are executed on** similar plant areas**.** The influence of other factors mentioned above are inevitably implied in the **use of formal processes** and **use of cross functional team factors** as they form part of the project management context.

The general practice by Eskom project engineers is that work in progress for the delivery of engineering activities that could not be included in the project master schedules due to the **detail level** of schedule requirements, is monitored within engineering disciplines and this reduces visibility of activities executed at more detailed level.

The schedule **levels of detail** are quantified by single digit numeric values ranging from 1 to 5. The smaller the digit the more summarised the schedule is and the larger the digit the more detailed the schedule become. According to Association for the Advancement of Cost Engineering (AACE) International Recommended Practice No.37R-06 **[9]**, level 3 is a more suitable level of detail for overall project control as it is neither over summarised nor too detailed.

The reduced visibility of engineering activities inherently contributes to reduced crossfunctional influence at that level thus contributing to reduced **crossfuctional learning** by the project team members and often leads to **inconsistent application of engineering processes**.

These reduced visibility is not only limited to crossfunctional teams of the same projects but also of team members of similar projects having similar project engineering deliverables that are executed on similar plant areas as the stored detailed information is likely to be within engineering disciplines and not within the relevant projects.

High levels of variability of activities,variability of activities durations and variability of cycle times of similar engineering deliverables for similar projects are often observed.

1.2 The Research Problem

Eskom Generation is experiencing a high level of **cycle time variability** for the delivery of **similar engineering deliverables** within **similar project phases** across **different projects** that are executed on **similar plant areas.**

The research problem statement is thus defined as: *To reduce cycle time variability on similar engineering deliverables within similar project phases across different projects that are executed on similar plant areas.*

Figures 2 below provides visual illustration of the research problem.

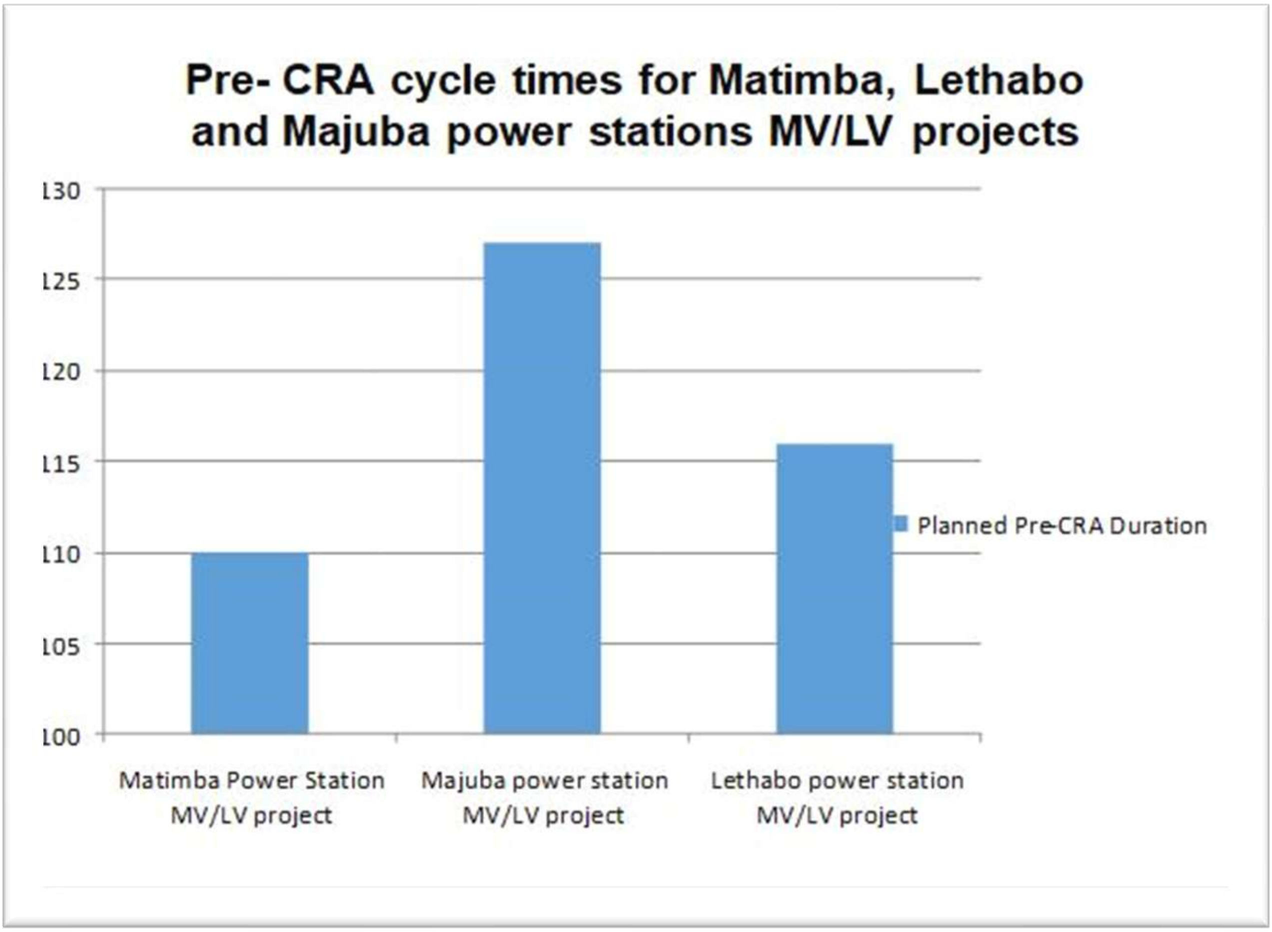

Figure 2: Cycle time Variability for Similar Engineering Deliverables within Similar Project. (Extracted from actual projects)

Figure 2 indicates variability of similar engineering deliverables cycle times for Matimba, Majuba and Lethabo Power Stations Medium and Low Voltage (MV/LV) Projects.

1.3 Formulated Hypothesises

According to Emory and Cooper **[10]**, two kinds of hypothesis are used in classical tests of significance. These tests are null hypothesis and alternative hypothesis. The null hypothesis is a statement indicating that no difference exists between the parameters while the alternative hypothesis indicates a difference. In this research H_a represent the alternative hypothesis and H_o represent the null hypothesis. Below are the formulated hypothesises for the research:

- H_{a1}: There is a direct relationship between variability of activities for similar engineering deliverables and cycle times of similar projects.
- H_{o1}:There is no direct relationship between variability of activities for similar engineering deliverables and cycle times of similar projects.
- H_{a2}:There is a direct relationship between variability of time durations for similar activities of similar engineering deliverables and cycle times of similar projects.
- H_{o2}:There is no direct relationship between variability of time durations for similar activities of similar engineering deliverables and cycle times of similar projects.

- H_{a3}:Implementation of engineering processes has a direct impact on the engineering delivery cycle time of similar projects.
- H_{o3}:Implementation of engineering processes has no direct impact on the engineering delivery cycle time of similar projects.
- H_{a4}:Intra-organisational knowledge transfer has a direct impact on engineering delivery cycle time of similar projects.
- H_{o4}:Intra-organisational knowledge transfer has no direct impact on engineering delivery cycle time of similar projects.

1.4 Purpose of Research

The purpose of this research is to:

- Study the impact of **engineering processes** and **intra-organisational knowledge transfer** on engineering delivery cycle time.
- Study the impact of Variability of **activities** for similar project engineering deliverables within similar project phases and plant areas on project engineering delivery cycle times.
- Study the impact of Variability of **time durations** for similar activities of similar project engineering deliverables within similar project phases and plant areas on project engineering delivery cycle times.
- Identify areas of focus for minimising engineering delivery cycle time variability on similar projects.

1.5 Anticipated Benefits

Anticipated benefits of the research includes the following:

- Minimsed project engineering delivery cycle time variability for similar projects.
- Increased accuracy in schedule estimates for similar projects engineering deliverables.
- Reduced project engineering delivery risk for similar projects engineering deliverables.
- Contribution towards project engineering body of knowledge.

2 THE RESEARCH METHODOLOGY

2.1 Data Collection Method

The researcher opted to collect both primary and secondary data for the research. The primary data was collected by means of questionnaire surveys consisting of 20 different questions which were based on the formulated hypothesises while the secondary data was obtained from a combination of paired sampled power stations projects schedules with similar engineering deliverables.

2.1.1 Target Population

The target population for primary data was at least 60 personnel consisting of Eskom project engineering managers, construction managers, project engineers, engineering discipline managers and project managers working on Eskom power plant new built and major refurbishment projects and the corresponding target sample was 21 personnel.

The target population for secondary data consisted of Project schedules from Eskom major refurbishment projects for the running stations and the corresponding target samples were:

- Basic design schedules from Eskom Matimba Power Station and Lethabo Power Station control and instrumentation projects.

- Eskom Matimba Power Station, Lethabo Power Station and Majuba Power Station medium voltage (MV) pre-concept designs projects schedules.
- Lethabo and Kendal power stations High frequency transformers (HFT) concept designs projects schedules.

2.2 Presentation of Primary Data

Questions 1 and 2 from the research questionnaires were used to profile candidates in terms of their roles and work experiences in the project environment. Questions 3 and 4 were used to obtain opinions on the existing systems, Question 5 for alignment with project management process and Questions 19 and 20 were used to obtain opinions on the benefits of minimising cycle time variability for similar engineering deliverables and the rest of the questions were used to obtain opinions for the formulated hypothesises.

2.2.1 Response Rate for Questionnaire Surveys

Table 1: Response rate for questionnaire surveys

Number of research surveys sent	Number of returned research surveys	Response percentage
21	14	67%

2.3 Analysis of Primary Data

The analysis of primary data is divided into the following categories:

- Candidates profiles
- Existing systems
- Alignment with project management processes
- Benefits of minimising cycle time variability for similar engineering deliverables
- Comparison with the formulated Hypothesises

2.3.1 Candidates Profiles

The majority of the candidates had 10 and more years work experience. There was only 1 engineer with 2 to 5 years work experience and 1 project manager with 5 to 10 years work experience.

2.3.2 Existing Systems

The general perception is that:

- Eskom does **not** have a well-established framework for capturing, analysing and retrieving lessons learned for similar engineering deliverables within similar project phases across different projects that are executed on similar plant areas. 10 out of 14 (71%) of candidates support this statement.
- Eskom does **not** have comprehensive tools for minimising cycle time for similar engineering deliverables within similar project phases across different projects that are executed on similar plant areas. 8 out of 14 (57%) of candidates support this statement.

2.3.3 Alignment with Project Management Processes

The general perception is that Eskom engineering processes **are aligned** with the project management processes. 13 out of 14 (93%) of candidates support this statement.

2.3.4 Benefits of Minimising the Cycle Time Variability for Similar Engineering Deliverables

The general perception is that minimising cycle time variability for similar engineering deliverables will improve schedule estimates for subsequent similar engineering deliverables and will reduce project delivery risk. 14 out of 14 (100%) of candidates support this statement.

2.3.5 Comparison with the Formulated Hypothesises

Table 2: Comparison with the Formulated Hypothesises

HYPOTHESIS	RELATED QUESTIONS	CONSOLIDATED RESPONSE
H_{a1} / H_{o1}	Question 16	100% of candidates agree that having **differing activities** for similar engineering deliverables will l**ead to variability** of cycle times for similar engineering deliverables.
H_{a2}/ $H_{o2:}$	Question 17	100% of candidates agree that having **differing time durations** for similar activities will **lead to variability** of cycle time for similar engineering deliverables.
H_{a3}/ $H_{o3:}$	Questions 6,7 and 8	(6) The results indicate that 6 out of 14 (42%) of candidates agree that **following engineering processes accounts for most project delays** within Eskom power generation project environment. (7) The results indicate that 12 out of 14 (85%) of candidates agree that **Inconsistent application of engineering processes** within similar projects **lead to cycle time variability** of similar project engineering deliverables for similar projects executed on similar plant areas. (8) The results indicate that 12 out of 14 (85%) of candidates agree that **Simplified project engineering processes will Minimise inconsistencies** in applying them.
H_{a4}/ $H_{o4:}$	Questions 10,12,14 and 15	(10)The results indicate that 9 out of 14 (64%) of candidates agree that the organisational knowledge transfer system has an impact on lessons learned for similar engineering deliverables on similar plant areas across different project in the power generation project environment. (12)The results indicate that all participants (100%) of candidates agree that Lessons learned are more effective when all relevant disciplines within the project are participating in the process. (14) The results indicate that 6 out of 14 (42%) of candidates agree that Cycle time variability of similar engineering deliverables is solely attributed to the lack of skills and competencies. (15) The results indicate that 13 out of 14 (92%) of candidates agree that **Inadequate knowledge transfer** on similar project engineering deliverables within similar projects **leads to cycle time variability** of similar engineering deliverables.

2.4 Presentation of Secondary Data

The paired schedules were represented as graphs and are plotted on the same set of axis in order to identify discrepancies. The following graphs represent typical profiles from the sampled schedules.

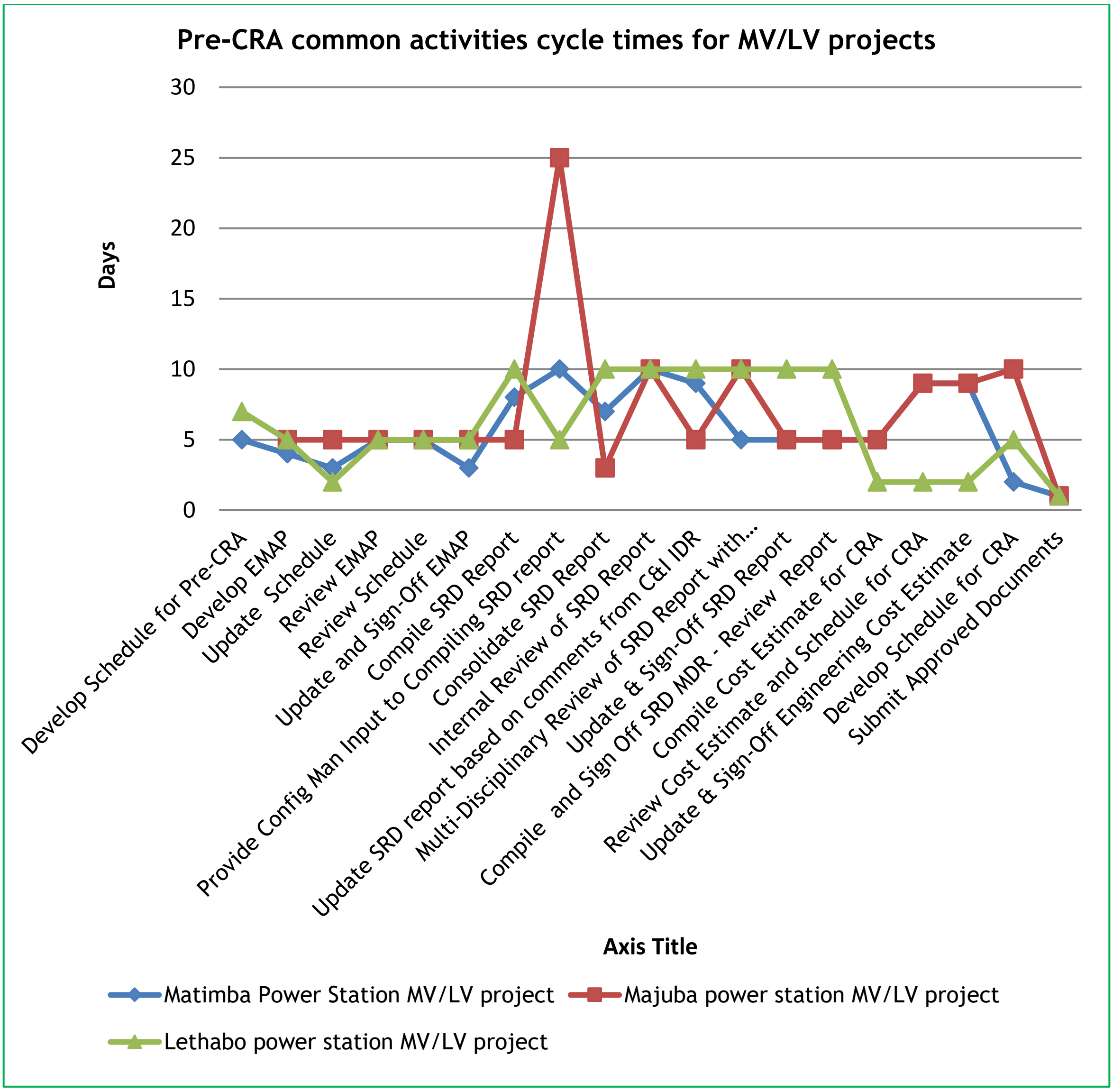

Figure 3: Eskom Matimba Power Station , Lethabo Power Station and Majuba Power Station Medium Voltage (MV) Projects Schedules.

Figure 3 indicates variability of common activities durations for Eskom Matimba,Lethabo and Majuba power stations medium voltage projects pre-concept design schedules .

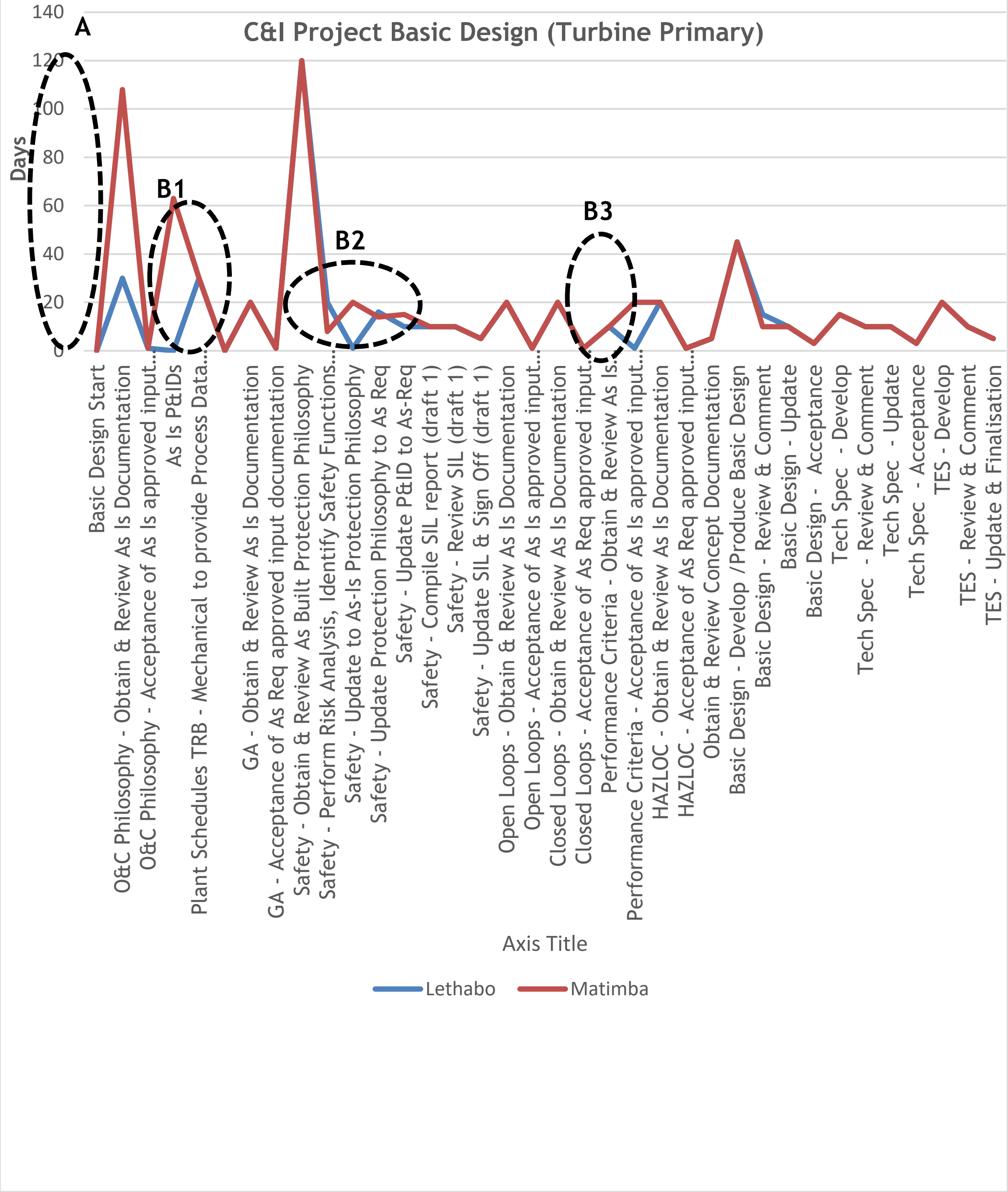

Figure 4: Eskom Matimba Power Station and Lethabo Power Station Control and Instrumentation Projects Schedules. (Turbine Primary)

Figure 4 demonstrates variability of activities and activities darations for Eskom Matimba and Lethabo power stations control and instrumentation project schedules for the Turbine Primary plants.

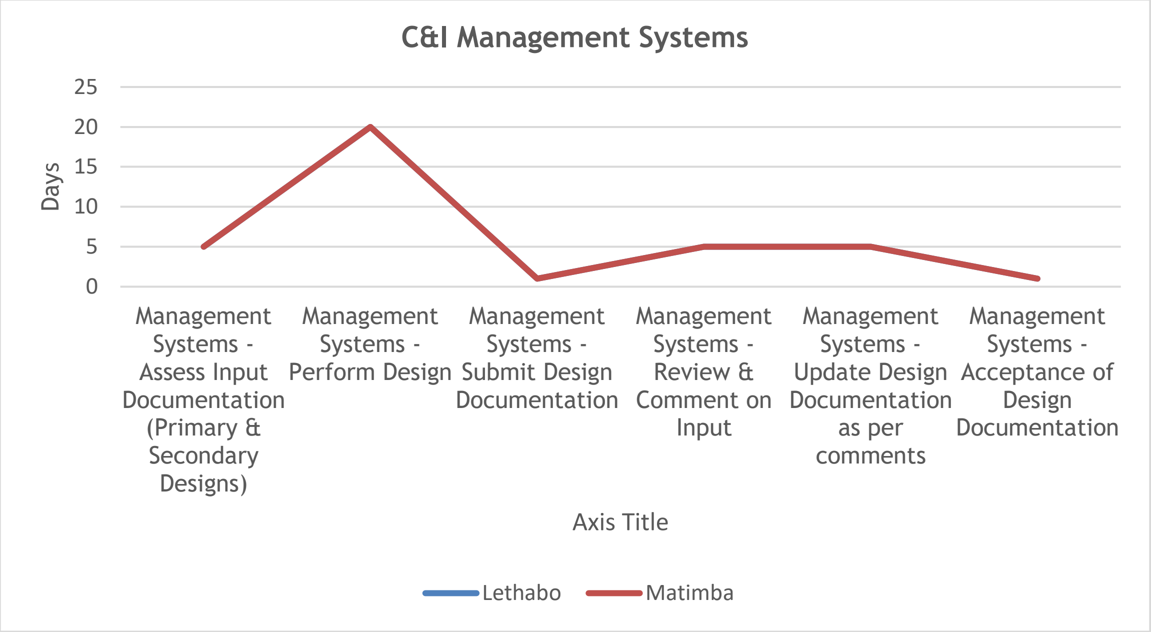

Figure 5: Eskom Matimba Power Station and Lethabo Power Station control and instrumentation projects Schedules. (Management Systems)

Figure 5 demonstrate similar (no variation) project activies and activities durations for Eskom Matimba and Lethabo power stations Management Systems project schedules.

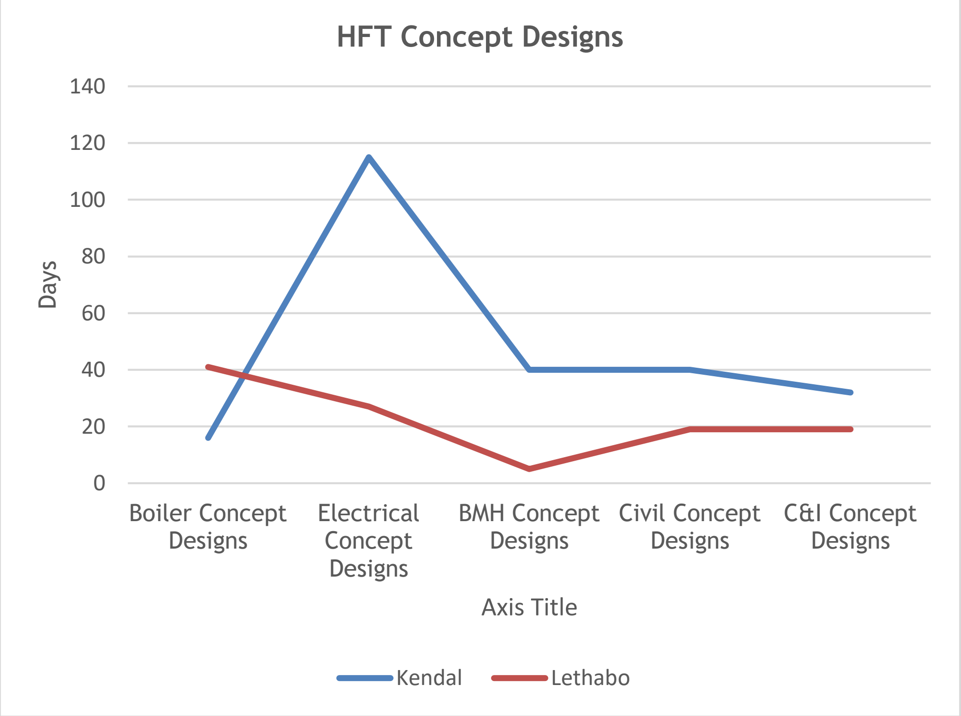

Figure 6: Eskom Lethabo and Kendal Power Stations High Frequency Transformers (HFT) Projects Schedules

Figure 6 demonstrates variability of similar projects cycle times and variability of schedules graphs profiles of similar projects.

2.5 Analysis of Secondary Data

The analysis of secondary data was achieved by analysing the profiles of the plotted graphs representing the paired schedules and comparison of the findings with the formulated hypotheses.

Below are the findings from the analysis of the graphs profiles:

- **No variability** of similar deliverables on some graphs. Figure 6 represent such graphs.
- Variability of **activities, activities durations** and engineering deliverables cycle times of similar projects. Figures 3, 4 and 6 represent such graphs.

2.5.1 No Variability of Similar Deliverables

The research revealed that if two or more similar projects deliverables have **similar activities**, **same activity durations** and are **sequenced in the same manner**, their graphs are perfectly **superimposed** as one graph. see figure 5 above. This implies that similar activities and the same activities durations result in minimised variability of similar deliverables even to a point of eliminating variability. This can be demonstrated by means of Euclidean distance measure formula which states that the distance **d** between two vectors x and y $= \sqrt{\sum_{k=1}^{n}(x_k - y_k)^2}$. where d $\geq 0 \in R$.

d = zero means that there is no variability and therefore the compared vectors are similar and as the value of **d** increases variability increases. Applying the above formula to the graph in figure 5 (i.e.) letting x and y denote Lethabo and Matimba power stations schedules respectively will yield a value of **d** equals to zero since x and y are measured on the same point k (**similar activity sequenced in the same manner**) and they are equal in magnitude (**activity duration**).

The graphs in figure 5 are similar and therefore the cycle times are **similar** or there is **no variability of cycle time** for their deliverables.

The results from primary data collected in questions 16 and 17 of the questionnaire survey, indicates that all participants (100%) of candidates agree that having differing time durations for similar activities will lead to variability of cycle times for similar engineering deliverables and differing activities for similar engineering deliverables leads to variability of cycle times for similar engineering deliverables.

F. Acebes, J. Pajares, J. M. Galán and A. López-Paredes in their paper **[11]** “Exploring the Relations between Project Duration and Activity Duration” assert that an increase in the activity duration can lead to an increase in the project duration and the decrease in the activity duration can lead to the decrease in the project duration. They also indicate that the **Criticality index** and **Cruciality index** of the project activities can both be used as a measure of the influence of the duration of each activity on the duration of the entire project.

The **Criticality index** of an activity is the probability that such activity lies on at least one critical path of the project and the **Cruciality Index** of an activity is the correlation between an activity and the duration of the entire project **[11].**

2.5.2 Variability of Activities and Activity Durations of Similar Deliverables

Figures 3 , 4 and 6 above indicate **variability** of activities and activities durations. The graphs are not superimposed as one graph as in figure 5. Cycled areas A, B1, B2 and B3 in figure 4 indicate the following:

- Variability of **activities** for similar deliverables. (B1,B2 and B3)
- Variability of **activity durations.** (A)

The research revealed that while differing activities for similar deliverables leads to variability of activities, the **unbundling** and **bundling** of similar activities for similar deliverables seem to contribute towards variability of the engineering deliverables cycle times as the combination or saparation of these activities does not match the summation of corresponding activities durations.

These variabilities can be attributed to the following in relation to the factors of focus:

- Inconsistent application of **engineering processes**
- inadequate **intra-organisational knowledge transfer**

2.5.3 Inconsistent Application of Engineering Processes

The Eskom engineering processes are captured in the process control manuals (PCM's) which are arranged to achieve specific project delivery objectives. The application of engineering processes inherently influence activities and how they are carried out.

As supported by 85 percent of the research candidates in the research surveys question 7, inconsistent application of engineering processes leads to cycle time variability. Based on above it can be deduced that if activities of similar deliverables are subjected to the same influence of engineering processes, they are likely to be similar. The other way of putting it is that If the same engineering processes are applied to similar deliverables during or before activities are scheduled, the **activities** variability will be minimised or eliminated and subsequently **activity durations** variability will be minimised.

2.5.4 The Impact of Inadequate Intra-organisational Knowledge Transfer

Considering figure 4, Inadequate intra-organisational knowledge transfer manifested in all cycled areas (A,B1,B2 and B3) for the following argument: If there was adequate knowledge transfer on similar activities for similar deliverables, the activities and activities durations variability would have been minimised as there would have been lessons learned from cross functional teams.

As indicated in the literature, the use of cross – functional teams cannot be separated from intra-organisation knowledge transfer. According to Mohamed et al, **[12]** Cross-functionality cannot be effective without sharing knowledge among team members. It can be deduced that knowledge transfer forms part of the lifeblood of cross-functionality. Literature review indicates that Knowledge can be divided into the following main categories **[12- 14]:**

- Explicit Knowledge
    - This is knowledge that is coded and stored in devises, archives, books etc. and can be retrieved mechanically or electronically without directly involving the provider of knowledge.
    - It is relatively easier to retrieve explicit knowledge.
- Tacit Knowledge
    - Knowledge that is stored in individuals or individual entities.
    - It is difficult to retrieve without directly involving the source.
    - Although it is difficult to retrieve, it is considered to be the most effective form of knowledge yet the most ignored.

Tacit knowledge in the project environment can be **embedded** in the individual personnel participating in the execution of the project while explicit knowledge can be embedded in documentations such as processes, policies, directives, regulations, reports, etc.

Mohamed, et al,**[12]** assert that the uniqueness of tacit knowledge requires the formation of **Cross functional teams** and the communities of practice for its externalisation. In order to benefit from the available knowledge in any form, it must be retrievable.

Nonaka and Takeuchi **[13-14]** based on their Socialisation, Externalisation,Combination and Internalisation Model (**SECI Model**) emphasize the need for proximity and ongoing relationships of project participants as they share tacit knowledge through engagements on project activities.

Above statement is validated by the following observations from the research:

- Considering the Eskom Matimba Power Station and Lethabo Power Station control and instrumentation (C&I) Basic designs schedules, there are several graphs that are superimposed and several areas within some graphs that are superimposed. See figures 4 and 5.
    - The main contributor to these similarities is that the two projects were developed concurrently having key resources working across the two projects.
    - These setup increased proximity and ongoing relationships of project participants as they share tacit knowledge through both dialogue and activity as asserted by Nonaka and Takeichi.
- Considering the Matimba Power Station, Lethabo Power Station and Majuba Power Station medium voltage (MV) pre-concept designs, the variability of graphs is noticeable. See figure 3.
    - Above projects were developed separately and independently by the same engineering department.
    - The prevalent form of knowledge transfer was explicit knowledge transfer in the form of engineering processes, procedures and other forms of documentations.
- Considering Lethabo and Kendal power stations High frequency transformers (HFT) concept designs schedules in figure 6 above, the graphs do not show any similarity as if the projects are completely different from each other even though they have similar deliverables.
    - This is a clear indication of inadequate to no intra-organisational knowledge transfer.

2.5.5 Comparison with Formulated Hypothesis

Table 3: Comparison with the Formulated Hypothesises

HYPOTHESIS	FIGURES	CONSOLIDATED ANALYSIS
H_{a1} / H_{o1}:	Figure 3 and 4	It was observed that variations in activities for similar engineering deliverables led to variations in cycle times. These variations includes: 1. Additional activities. 2. bundling and unbundling of activities. 3. differing activities names for the same function.
H_{a2}/ H_{o2}:	Figure 5	It was observed that in the absence of variability of similar activities durations, no additional activities and no bundling or unbundling of similar activities, there were no cycle times variability of similar deliverable cycle times.

3 CONCLUSION

Based on above analysis, it is clear that application of engineering processes and intra-organisational knowledge transfer on activities are the **leading variables** while variability of activities and variability of activity duration are the **lagging variables**.

This implies that if **consistent application of engineering processes** and **adequate intra-organisational knowledge transfer** takes place in similar projects, variability of activities and variability of activity durations will be minimised leading to minimised cycle times of similar engineering deliverables.

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A SIMULATION-BASED HORIZONTAL WATER TRANSPORT MANAGEMENT STRATEGY IN DEEP-LEVEL MINES

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ABSTRACT

Dewatering and water transfer pumping is one of the main electricity consumers in the South African mining industry. It is important to consider all possible angles to ensure maximum possible savings and efficiency when investigating industrial water reticulation systems. Horizontal pumping systems, however, was previously excluded from optimisation techniques. In this study, a scientifically derived water management strategy is developed for horizontal water pumping in deep-level mines through simulation of current and future mining activities. System simulations of the current system was based on the most recent return flows on each level. Additional simulations were done to establish maximum demand limits for installed spindle pumps. Results revealed the system is over-specified for the application. Scope exists to exchange numerous of the current 48 spindle pumps with better suited pumps based on current and future water demand requirements. Implementation will result in electrical cost saving of R 5 100 720 p.a.

Keywords: Integrated, Simulation-based, Horizontal water transport

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1 INTRODUCTION

Deep-level mines in South Africa use process water in large quantities for various applications on surface operations and underground [1]. Underground applications mainly include cooling, drilling- and mining activities, dust suppression, energy recovery, backfilling, and water jet cleaning [1] [2] [3] [4].

The large underground water demand in deep-level mines adds significant complexity to the construction and operation of the distribution systems. End users are located on different mining levels which adds to distribution challenges throughout the underground mining complex. Figure 1 is a schematic of a typical underground water reticulation network.

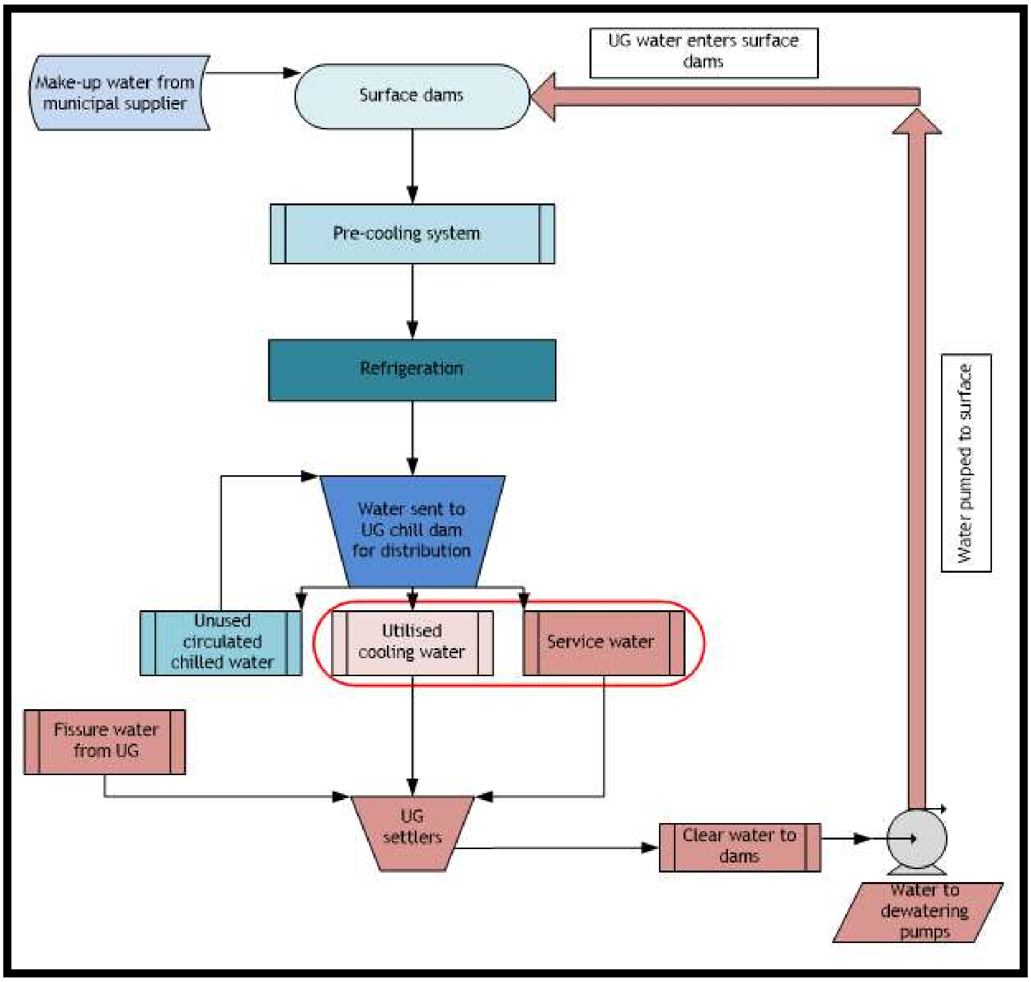

Figure 1: A typical deep-level mine water reticulation network

Water is distributed from surface after it exits the refrigeration system. For deeper mines, there are usually dams situated strategically on descending levels as water moves through the shaft column [2]. This is also done to ensure there is enough storage capacity for the water being sent underground.

As the water moves down, it usually accumulates at a central location with a large dam capacity where it is distributed to the various mining levels. Most mines feed the production levels through gravity feed and make use of booster pumps situated on the production levels to ensure the chilled water reaches end users at a sufficient pressure [2] [3].

The most common underground chilled water end users include cooling cars, Bulk Air Coolers (BACs), winders, drills, ore face cleaning and fridge plants [2] [4]. Chilled water is first used for cooling entities after which a portion of water in each cross-cut (XC) is sent to the stopes according to demand required at specific hours of the day.

To mitigate pumping cost, some mines consist of a chilled water return system. This ensures most utilised chilled water (not used for drilling) returns to a central chilled water accumulation point and correspondingly, mitigating pumping cost on the dewatering pumps [5].

A typical representation of an underground chilled water return system is shown in Figure 2.

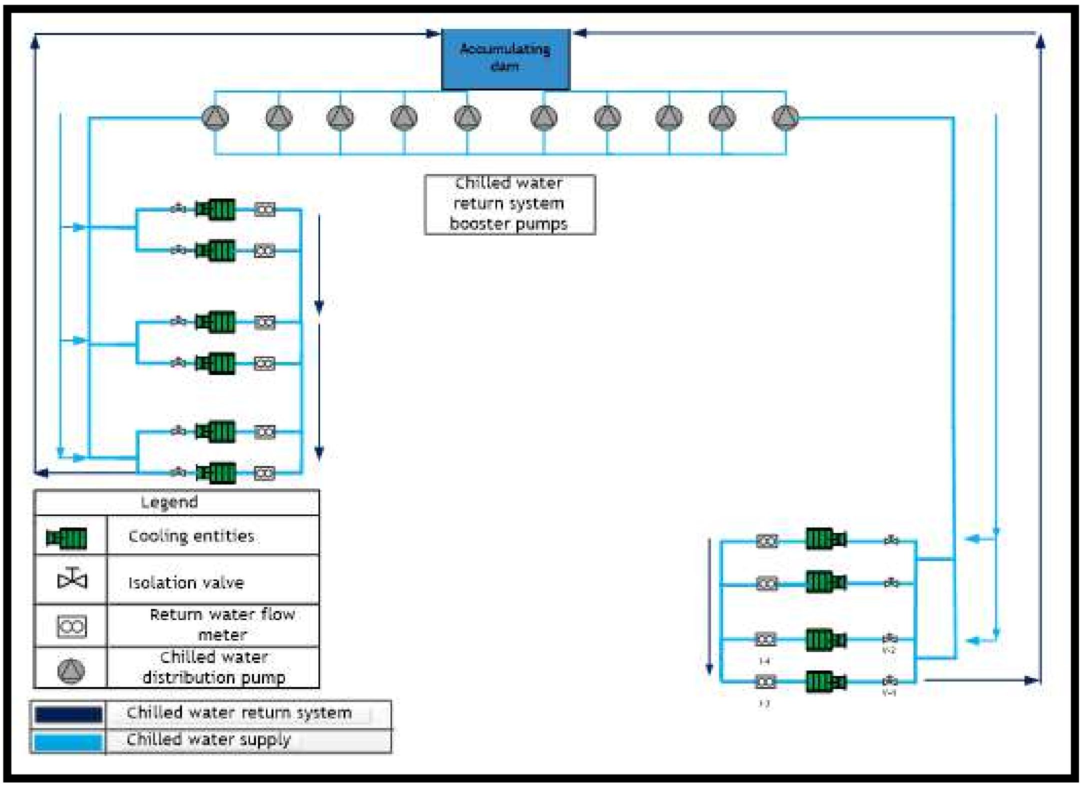

Figure 2: Typical chilled water return system

Water sent to the stopes (used for mining activities) does not remain in the chilled water system. Mining activities adds significant heat to the water and would render a large temperature gradient should it return via the chilled water system. These quantities of water are transported by the spindle pump return system (Horizontal Water Transport System, HWTS) towards annex holes/ holding dams on respective levels after which it enters the dewatering system.

Horizontal Water Transport System

Used mining water drains from the stopes by means of footwalls and service water pipes. Service water return pipes are suspended from the rock face within a XC directing the water to the front of the section. Water accumulated along the footwalls of a XC is transported through a series of submersible spindle pumps towards the front of the section where the return service water is dumped into a sump.

Each XC contains a sump at the bullnose (entrance) of the XC where the service water accumulates and is pumped into the main service water return line suspended in the main haulage of the level. Figure 3 is a visual representation of the spindle pump return water system currently in use at the active XCs.

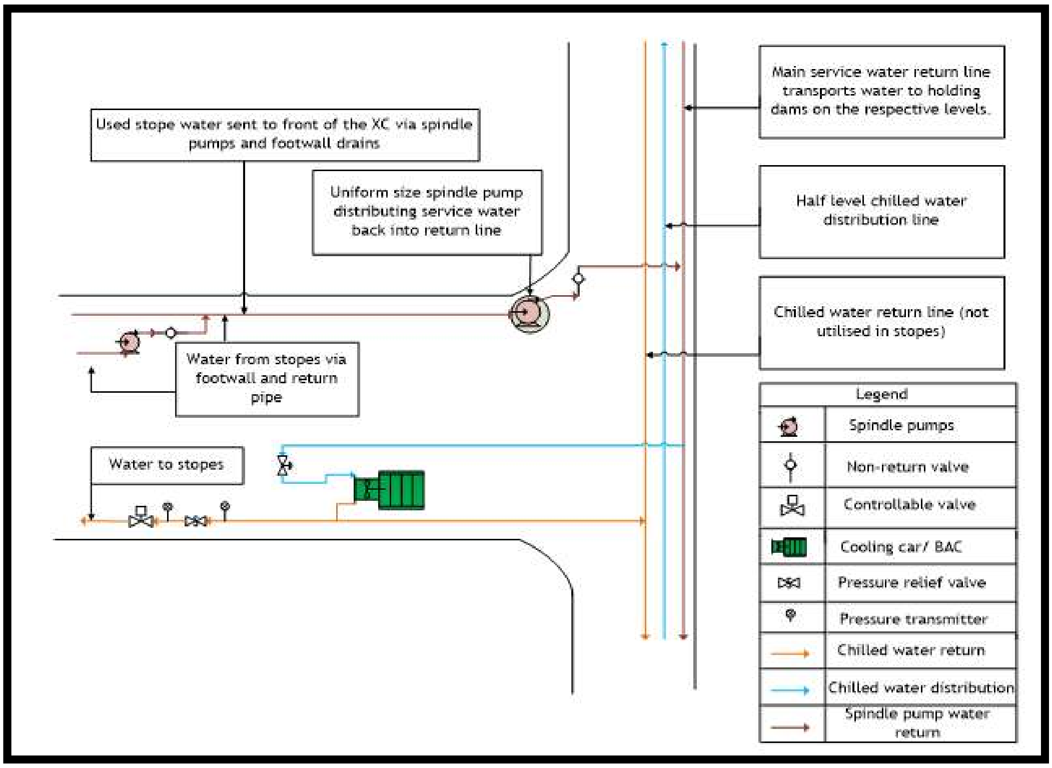

Figure 3: Bullnose spindle pump XC configuration

Research was done on the operation of the HWTS in deep-level mines. **It was found that according to mining standards and procedures set out for deep-level mining, the bullnose spindle pumps are of a uniform size for each operation regardless of the water demands present on the levels of installation** [6].

Aim and objectives

Due to the lack of engineering principle integration concerning bullnose pumps within the HWTS, **a need exists to develop, implement and validate a simulation-based water management strategy to improve operation of the HWTS in deep-level mines**. To successfully evaluate the HWTS, an objective list was constructed to establish the specific focus points of horizontal water system improvement. Objectives will aim to address the shortcomings within current literature and be used to develop a strategy to properly research, evaluate and improve existing spindle pump return systems. These **objectives** are:

1. Integration of current and future water demands through simulations to reduce OPEX costs.
2. Increase water demands forecasting accuracy for better capital allocation.
3. Test scenarios of horizontal water management improvement and the effects on water demand prior to implementation.
4. Add a system monitoring aspect to previously unmonitored and under-equipped systems

Literature review

Various water management strategies have been researched to reduce the Operational Expenditure (OPEX) cost of the larger dewatering pumps in deep-level mines. The HWTS contributes significantly less to electrical load and is therefore regarded as a lower priority energy system [7]. Literature studies were chosen to illustrate the **types** of water management strategies researched and implemented on deep-level mines.

This includes basic control strategies, electrical load shifting, pump specification improvement, reconfiguration of water systems, service delivery improvement, failure analysis and management relating to electrical cost savings. As far as can be ascertained, an extensive review of literature relating to water reticulation systems revealed that **no focus** has been placed on HWTS management. To illustrate the gap identified in literature, a state of art matrix was constructed in Table 1.

Table 1: Literature review matrix summary

			A simulation based horizontal water transport management strategy in deep-level mines							
Study	**Year**	**Ref**	**Underground horizontal water management inclusion**	**Pump specification optimisation**	**Simulation**	**Electrical cost savings**	**System monitoring tool with minimum infrastructure**	**Sustainable**	**Water demand management & forecast**	**Dynamic adaptability**
Vosloo	2008	[8]		X	X	X		X		X
Botha	2010	[9]				X			X	
Rautenbach *et.al*	2008	[10]			X	X		X		
Stephenson	1983	[1]		X						
Bridgwood *et.al*	1983	[11]		X						
Murray	2000	[2]		X	X	X		X		X
Venter	2020	[12]				X		X	X	
van Niekerk	2017	[13]			X	X	X		X	
du Plessis *et.al*	2015	[14]			X	X		X	X	X
Conradie	2018	[15]			X	X			X	
van Staden	2018	[16]				X			X	
van Rooyen	2019	[17]					X	X		
Ashmead	2019	[18]				X				X
Taljaard	2012	[19]			X	X		X		X
Zhang	2011	[20]		X		X		X		X
Cilliers	2014	[21]			X	X		X		X

Jacobs	2021	[22]					X	X		
Jerling	2019	[23]				X	X		X	
Peach *et.al*	2018	[24]				X		X	X	X
Mare'	2016	[25]			X	X		X	X	X

**The state of art matrix compares the focus of the different water management strategies and assessed whether any of the studies extended the strategy development to the HWTS.*

The literature review of water system improvement techniques reveals that a gap in literature exists through the lack of focus placed on improvement of the HWTS in deep-level mines. Although the HWTS typically contributes 6% of total pumping expenditure, the size of modern day deep-level mines more than motivates the need for improvement. This study aims to address the exclusion to ensure a strategy for horizontal water system improvement is established.

2 METHODOLOGY

The methodology was developed to establish a **dynamic and sustainable** horizontal water transport management strategy and address the objectives through use of simulation software.

2.1 Step 1 – Performing a pumping system audit

The first process step entails a preliminary pumping system audit from which certain conclusions, limitations and design specifications can be determined. Secondly, a detailed investigation regarding the pumping system should be conducted to establish usable operational parameters and more efficient operating configurations [26] [27] [28]. This is shown in Figure 4.

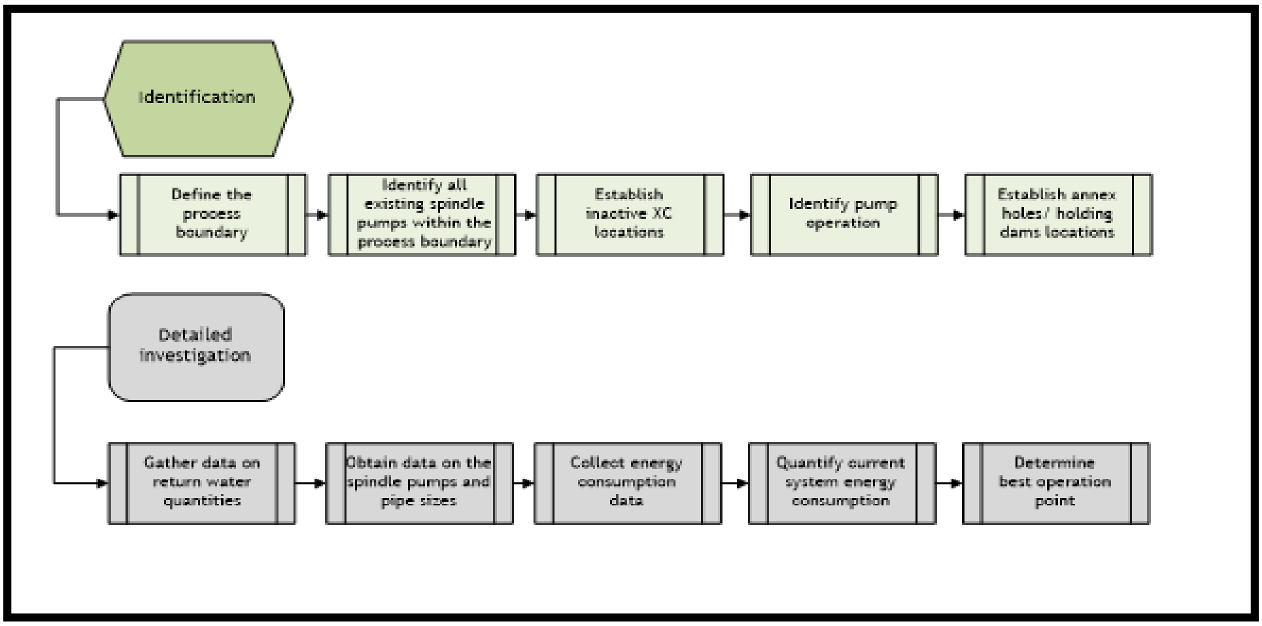

Figure 4: Pumping system audit and investigation flowchart

2.2 Step 2 – Modelling the current system configuration through simulation

Simulation software adds the benefit of validation after initial measurements and calculations have been done. Detailed simulations additionally assist in providing valuable information while considering a vast number of network constraints allowing both a localised and holistic overview of an entire modelled system [29].

Various simulation software systems have been in use in the mining industry over the past few decades. Certain mining companies prefer specific simulation software, mostly due to familiarity. It was seen upon comparison however, that there are some shortcomings to some of the most used software entities.

The construction of the horizontal water transfer pumping system will be done using Process Toolbox (PTB3D). PTB3D is a transient thermal flow solver which enables the solving of complex systems using a wide array of contributing parameters [29] [30]. The simulation will be used as an integrated verification evaluation to assist in establishing accurate parameters by using the data collected in Step 1 of the methodology.

2.3 Step 3 – Improve the system energy consumption and configuration

After proper calibration and verification of the model is completed, potential changes to the system can be considered [31]. Measured and simulated performance results of the current system should be used as a baseline for the potential changes to the system.

2.4 Step 4 – Dynamic adaptability and sustainable solutions incorporation

Dynamic adaptability and sustainable solutions are key elements to the success of any given project. Past identified projects, which delivered promising initial results, have failed miserably due to a lack of dynamic adaptability and sustainable solutions integration [32].

According to Mvudi [33], the main attributing factors to project failure are the following:

1. Project scope change,
2. Internal conflicts between project and departmental tasks,
3. Lack of resource and project performance tracking,
4. Deviation from, or lack of project management methodologies,
5. Lack of a defined software project management methodology framework,
6. Unrealistic project expectation and lack of future change planning.

All factors need to be considered to ensure a dynamically adaptable and sustainable solution.

2.5 Step 5 – Implementation tracking and results analysis

Project implementation can be a challenging task on a deep-level mine, often due to mismanagement of resources and lack of communication between departments. The key to project implementation comprises of comprehensive planning prior to actual implementation [34]. A proper plan aids to streamline the implementation process and ensures project completion within the allocated timeframe and budget if followed correctly.

After project implementation, the performance of the newly implemented system needs to be assessed to determine the benefit of the project. Analysis forms an essential part of the final project stages and can be loosely described as the benchmark for project success [35]. It is recommended, if applicable, that results analysis should be conducted as a continuous process throughout implementation and should not be left until project completion [36]. A flowchart of the project implementation and results analysis is shown in Figure 5.

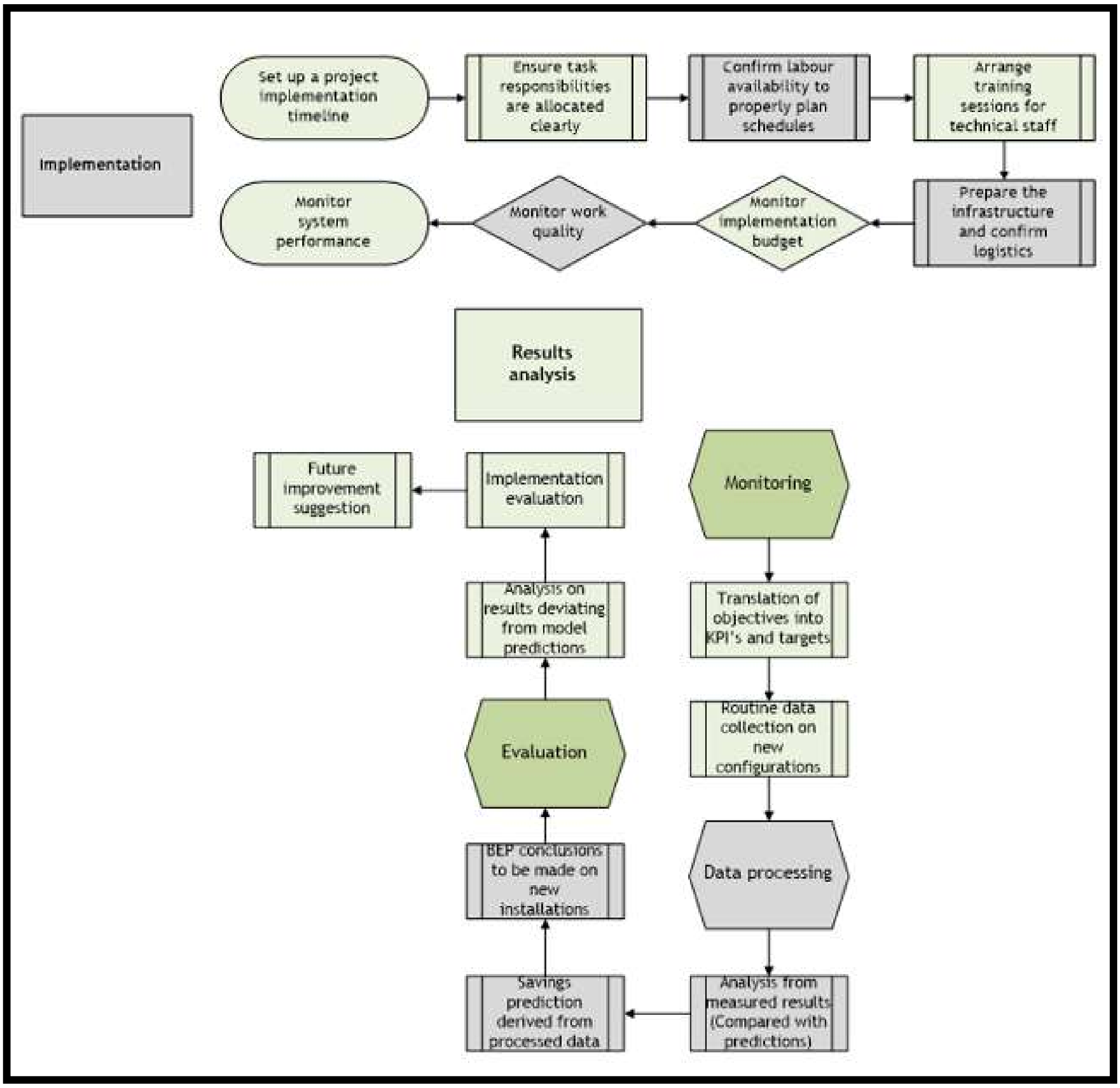

Figure 5: Implementation and results analysis flowchart

A summary of the methodology is shown in Figure 6.

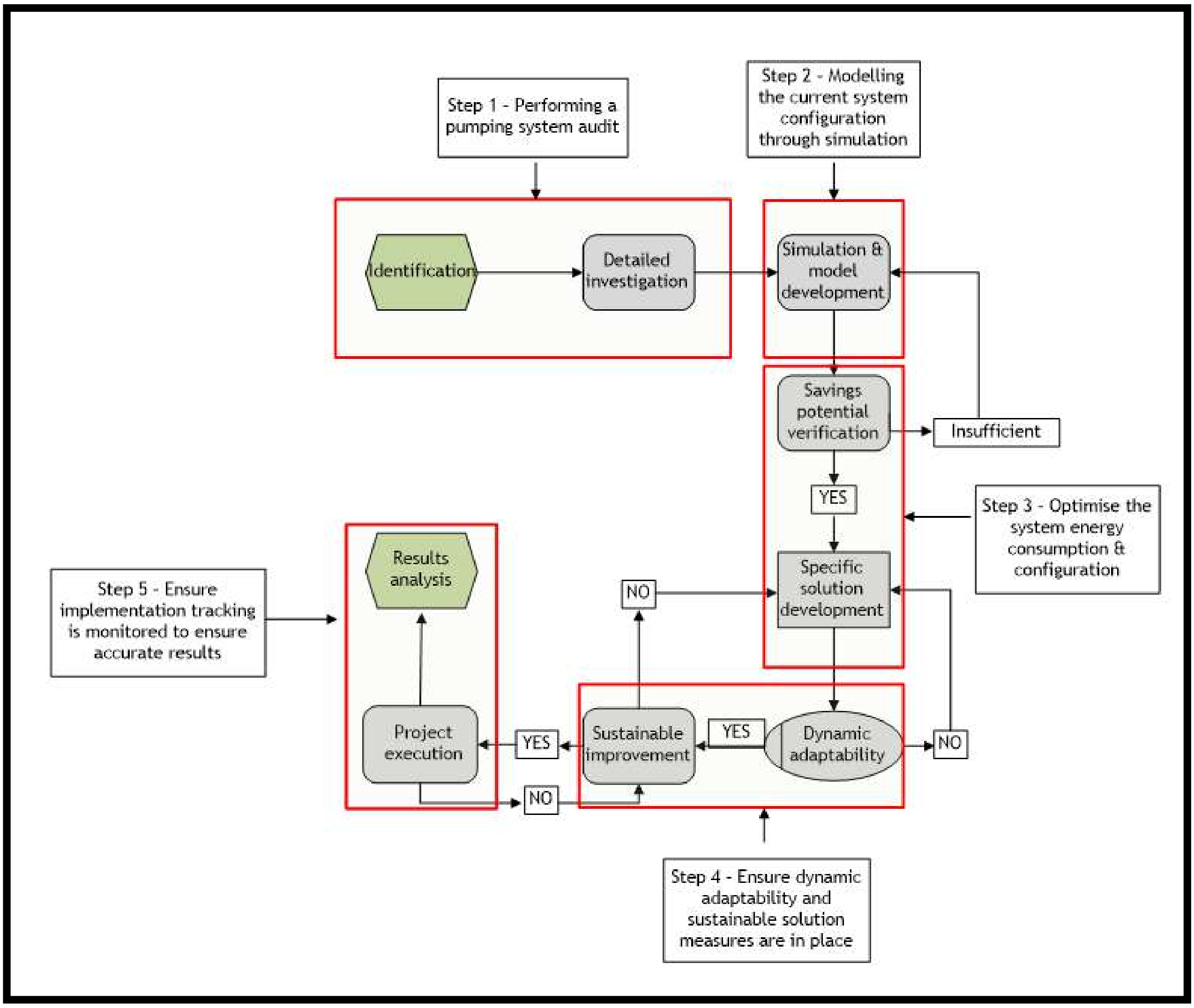

Figure 6: Methodology for horizontal water transport management strategies

3 RESULTS AND DISCUSSION

The developed methodology steps will be applied to a case study on Mine A, situated in South Africa. Mine A follows the standardized mining procedures set out for deep-level operations and use one uniform size pump at the XC entrances. The water demands will be assed through measurements and simulation afterwhich a conclusion on the pumping configuration will be made. The results of the case study will be evaluated and be presented in the same order as the five-step methodology developed in Figure 6.

3.1 Step 1 – Identification and investigation

Data was gathered through manual measurements and SCADA (Supervisory Control And Data Acquisition) historian analysis of the pumps identified within the process boundary. The process boundary on Mine A is shown in Figure 7.

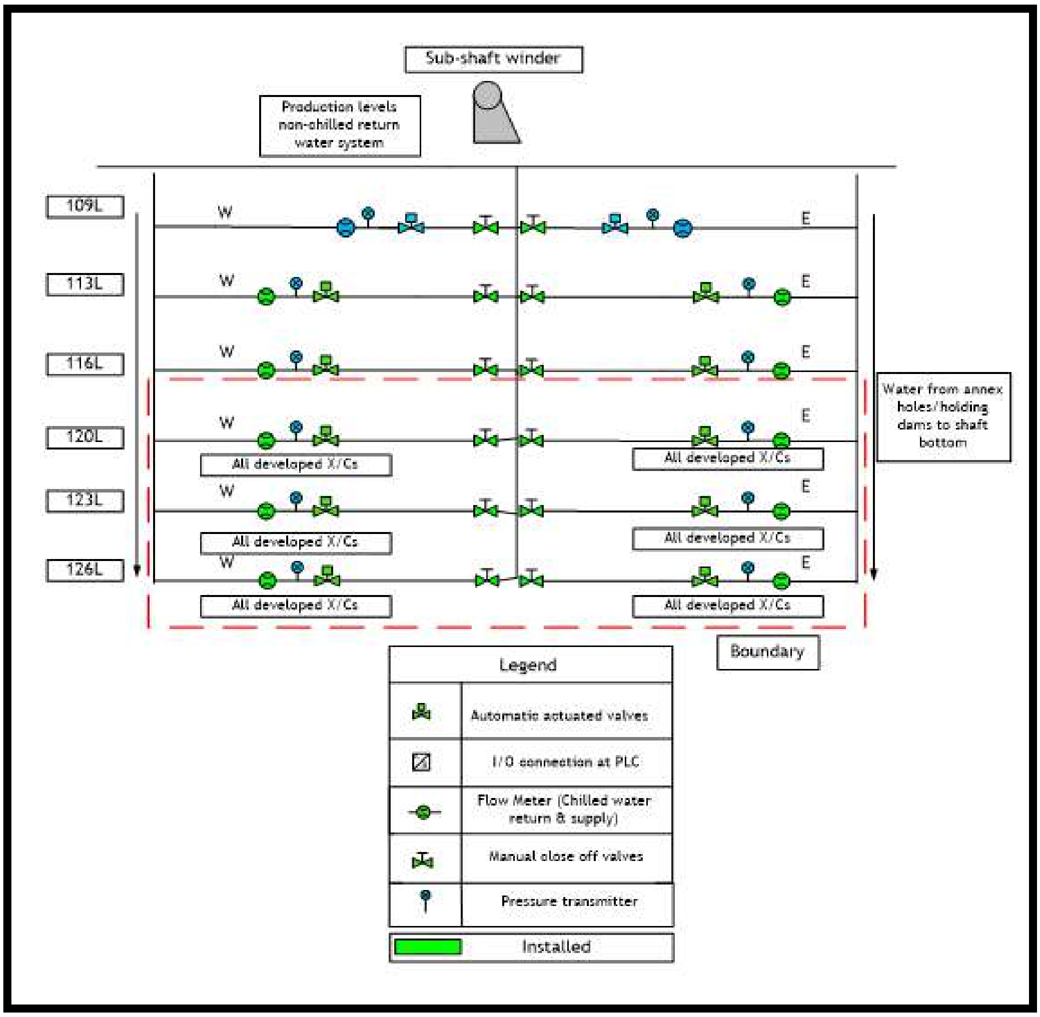

Figure 7: Mine A process boundary

Initial manual logger measurements of the installed bullnose spindle pump system (45kW spindle pumps) revealed consumption of 20.73 kW based on a weighted average calculation and operated on a permanent basis. Logger measurements comparison to performance curves are important due to the HWTS forming part of larger mining feeders which restricts proper assessment unless done through measurements.

Figure 8 shows the current pump performance of the 45kW pumps based on logger measurements and current observed water demands.

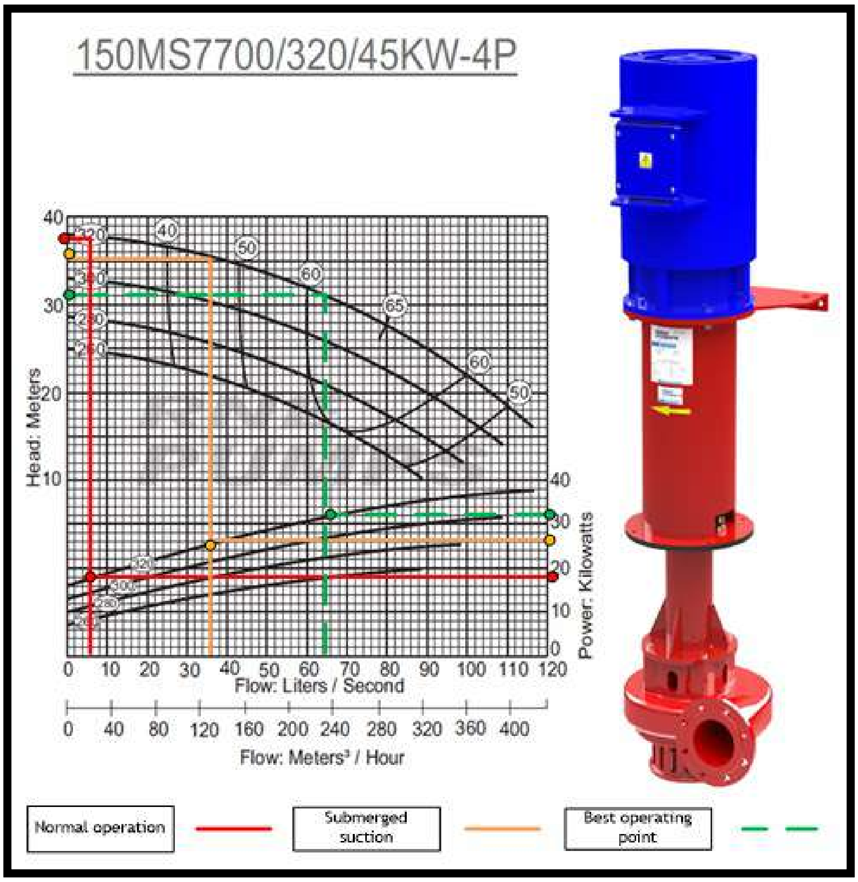

Figure 8: 45kW pump performance based on current demands

Cumulative cost of spindle pump consumption within the process boundary amounted to R 11.7 million p.a based on the measured deviation of 17.74% (head calculation) from the pumps Best Efficiency Point (BEP) during normal operation [7][37]. Operation closer to a pump's BEP would result in improved performance. Simulation development, based on the data collected from the initial audits, will be used to identify better suited pumps for improved system operation.

3.2 Step 2 – Modelling the current system configuration through simulation

The simulation models were developed by using PTB3D, which was specifically designed for large-scale applications in the mining industry. It was seen that the current system operates at 15, 28 and 20% of its available capacity on 120, 123 and 126L respectively. Results of the current, inefficient system, was used to establish the maximum operational demands each of the identified pump sizes will be able to transfer to the annex holes/ holding dams on each level. Additionally, pump performances relating to BEPs was established.

3.3 Step 3 – Improving system energy consumption and configuration

Three simulations scenarios were compared to the **current** system demand to illustrate the available water transfer capacity should demand requirements increase. This ensures limits are clearly identified to invoke action after exchange when needed. Critical evaluation of level results revealed significant scope to install better suited pump sizes on **all** the production levels. The maximum demand flows of a spindle system comprising of 45, 15 and 7.5kW pumps, compared to the current water demands are seen in Figures 9 – 11 .

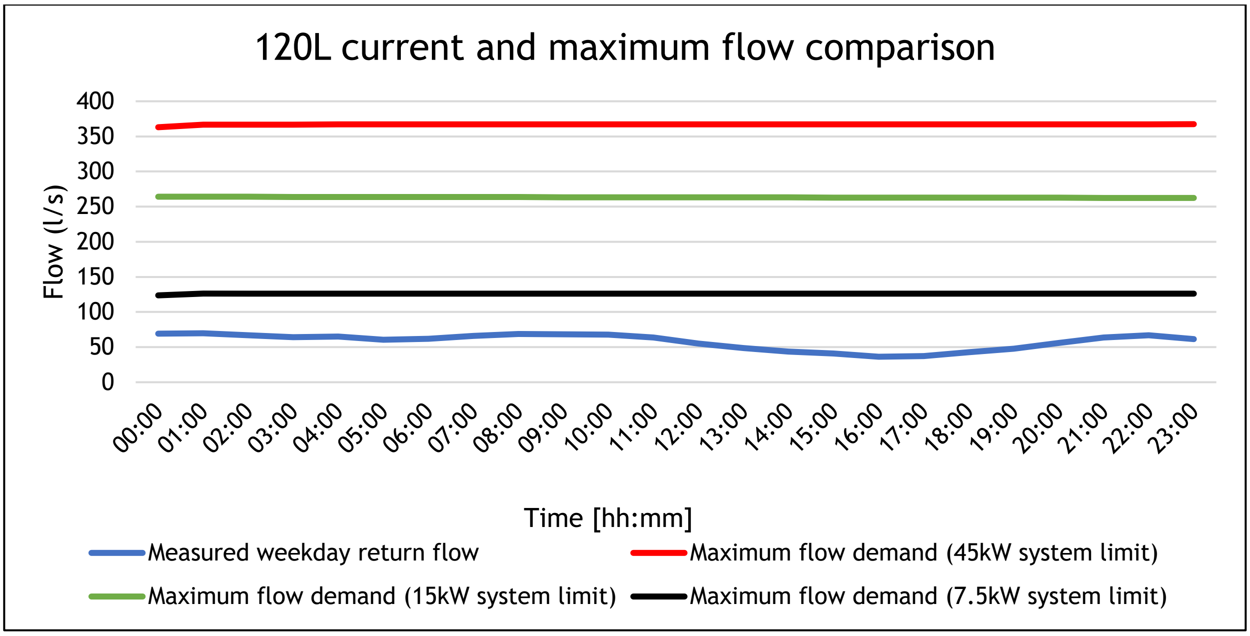

Figure 9: Maximum demand capacities on 120L

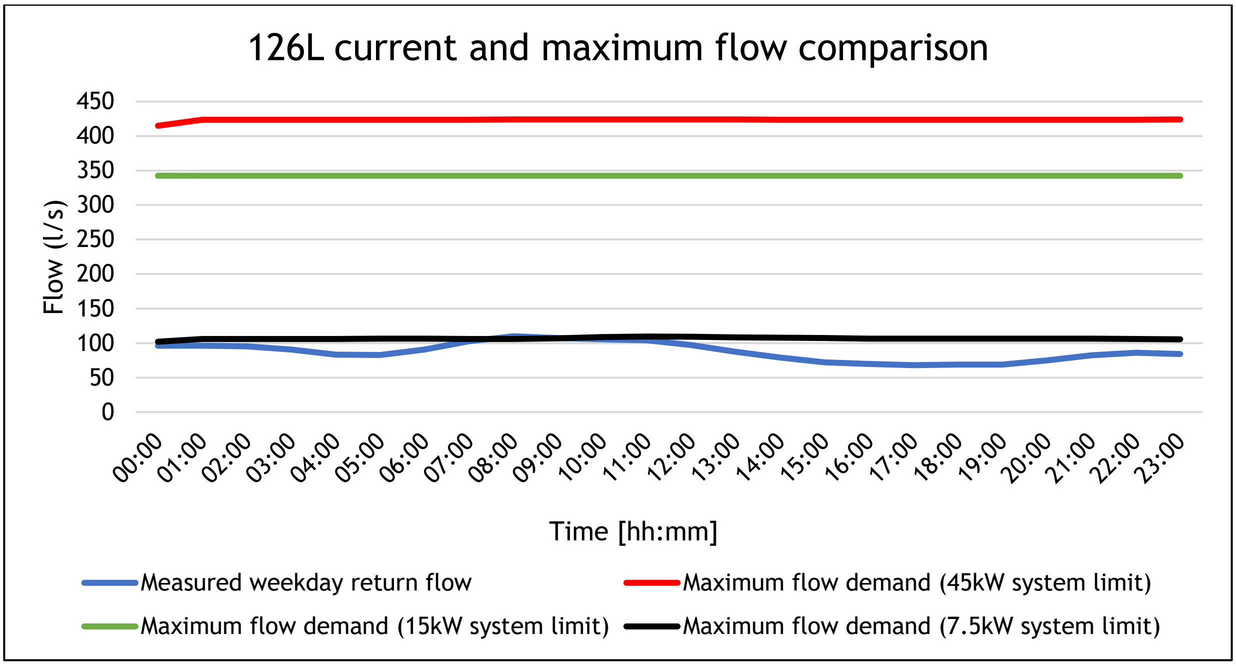

Figure 10: Maximum demand capacities on 126L

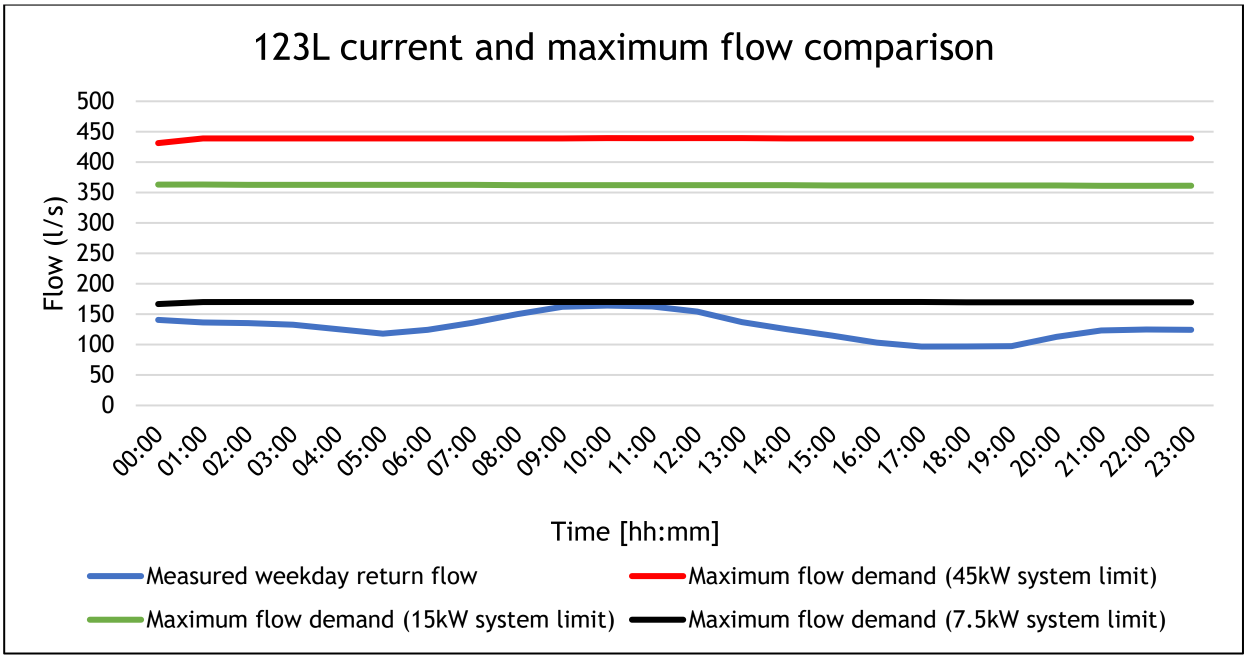

Figure 11 Figure 12: Maximum demand capacities on 123L

As seen on the figures above, the maximum water demand limits for both the 15- and 45kW systems remain well clear of the current demands on the production levels. The 7.5kW system's maximum capacity still operates above the current demand during certain times of the day, but operates close to the maximum limit during peak drilling times. Table 2 provides a summary of the operational point of each evaluated spindle pump system at current flows.

Table 2: Production levels operational point comparison

Mine A average operational horizontal water transport capacity comparisons			
Level	**45kW operating point (i.r.t. maximum capacity)**	**15kW operating point (i.r.t. maximum capacity)**	**7.5kW operating point (i.r.t. maximum capacity)**
120	15%	21%	46%
123	28%	36%	76%
126	20%	26%	82%

The results reveal the 7.5kW spindle pump system would not be sufficient to transport the current water demand out of the respective sections during peak drilling time and is therefore not a suitable replacement for the 45kW. Levels scaling down on mining activities may be considered for configuration changes with the 7.5kW pump. The 15kW system operates closer to maximum capacity than the 45kW system, but remains well within the capacity boundaries. This allows for a buffer should sudden influxes of water occur.

The 15kW pump is currently chosen as the **replacement** for the 45kW pump on all the levels **considering the water demands present**. Logger measurements were done for the 15kW pump and revealed a weighted average consumption of 11.32 kW with current water demands. Continuous analysis is recommended for areas significantly scaling down on mining activities. If **all recommended** pumps within the process boundary are replaced with 15kW pumps, the expected electrical cost savings amounts to R 5.1 million p.a.

3.4 Step 4 – Dynamic adaptability and sustainable solutions development

Real-time monitoring of the spindle pump system was established without additionally installed infrastructure through simulation integration with the operating SCADA system. System limits were established and incorporated into the software. Corresponding actions, based on the system limits (for the 15kW application), were developed to certify necessary steps are in place at various flow intervals to ensure mining personnel are prepared should changes to the system be required. Personnel will be alerted through automated communication channels should these limits be surpassed.

To ensure sustainability of the project, influence of implemented initiatives on the water demands are noted and corresponding demands for the foreseeable future are predicted. Water demand predictions are done using the mine ore planning schedule and the current mining intensity (kL/tonne) on the focused levels. The predicted water demands are used to identify sections where mining activites will scale down, and predict the installed system performance based on the new water demands. It is recommended to not extrapolate predictions too far ahead due to inevitable mining changes. Figure 12 shows the demand predictions for the Q3 of FY23.

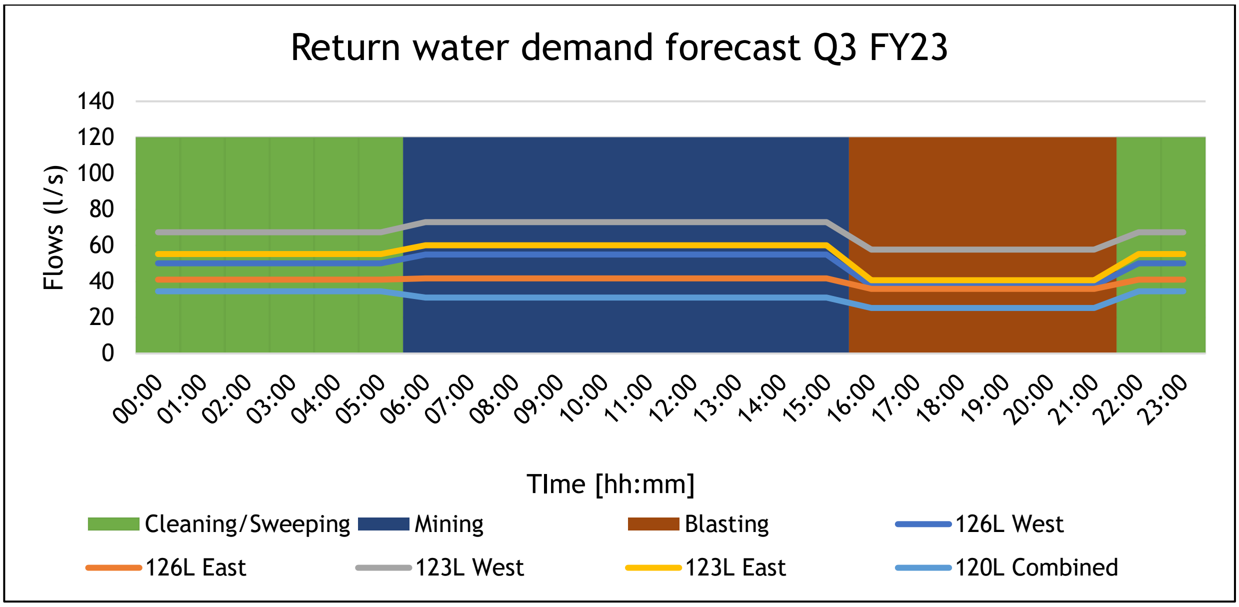

Figure 12: Water demand predictions for FY23 Q3

Each level's water demand is displayed according to the time period of each mining activity. Flow forecasts should be evaluated during each quarter to ensure forecasts remain up to date if changes occur. Flow prediction models is an effective way to ensure the most applicable pump sizes are used on levels where mining activities predomintantly take place.

3.5 Step 5 – Implementation tracking and results analysis

Project implementation revealed scope for additional pumps' removal due to inactive mining sections. The additionally conducted audits were done as part of the sequential pump exchange roll out agreed upon by Mine A.

Unrequired pumps on lower ore producing levels were identified, removed and exchanged for new 15kW pumps (at a reduced cost) to be installed on the main production levels. Audits revealed pumps running with no water demand towards to the sump in addition to faulty non-return valves. These pumps were switched off and removed. Personnel involved with pumps exchange were trained to ensure all parties are aware of the various responsibilities.

At time of writing, Mine A exchanged **seven** 45kW pumps for 15kW pumps on the lower production levels. Most reclamation pumps on the lower priority levels were not running, but

six 45kW pumps could be additionally switched off and reclaimed for exchange. Logger meaurements were conducted after pump replacement to establish pumping performance and savings potential.

Initial objectives set out for the study were addressed in the following steps:

1. Integration of current and future water demands through simulations to reduce OPEX costs – Steps 2 and 3.

2. Increase water demands forecasting accuracy for better capital allocation – Step 4

3. Test scenarios of horizontal water management improvement and the effects on water demand prior to implementation – Steps 3 and 4.

4. Add a system monitoring aspect to previously unmonitored and under-equipped systems – Step 4.

The achieved objectives substantiates the validity of the study and highlights the importance of analysing and monitoring lower energy-intensive systems to improve operations' efficiency.

Figures 13 and 14 show the comparison between the 45-and 15kW pump power consumption and the 15kW pump performance relating to new installations.

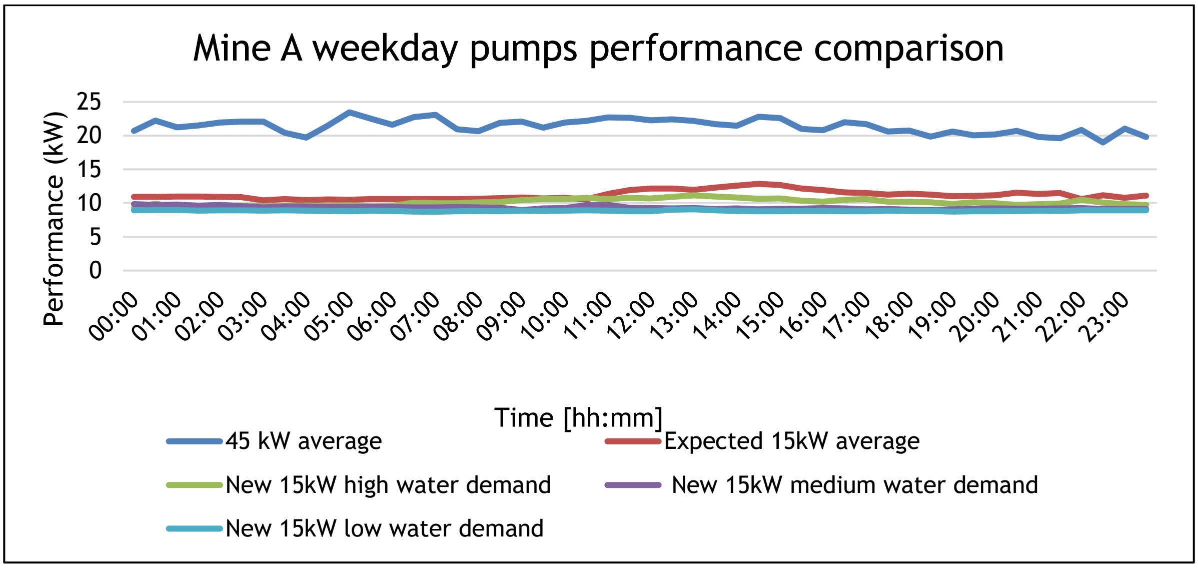

Figure 13: Spindle pump consumption comparison

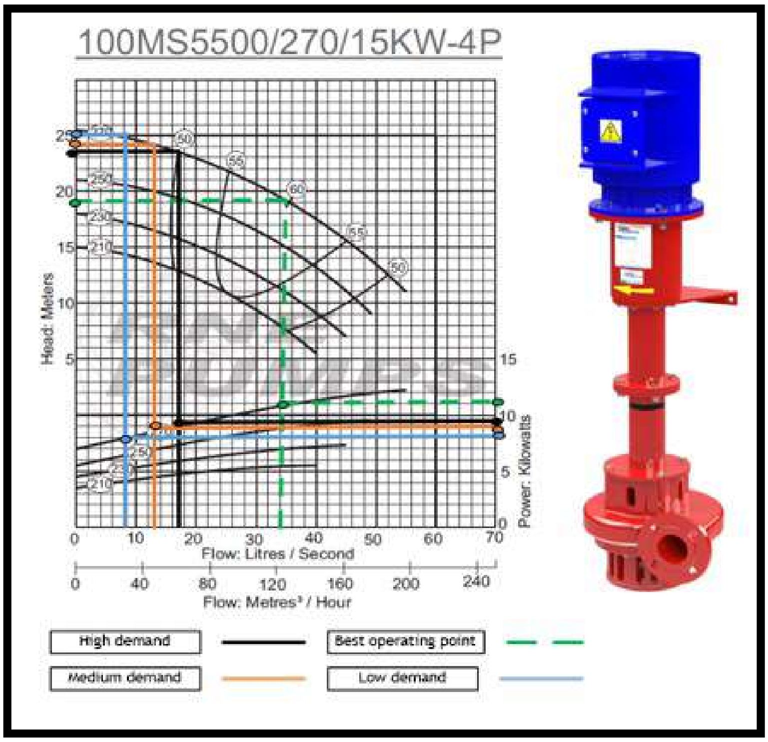

Figure 14: 15kW spindle pump performance (new installations)

Based on the **current** changes and replacements, the 15kW pump deviates 22.4%, 18.4% and 14.5% from its BEP (based on head calculations) for the low, medium and high demands, respectively. This amounts to an electrical cost saving of **R 2.28 million p.a**.

4 CONCLUSION

Water system improvement strategies developed for deep-level mines largely focused on the energy-intensive dewatering pumps used to pump water out of deep-level mines. Research indicated that past improvement has not yet focused on the horizontal water transport system used to move used service water from the production sections towards the annex holes/holding dams on the respective levels. This is primarily due to outdated mining standards and procedures being followed and failure to analyse the potential of improving lower energy-intensive sytems

This study provided a new water management strategy driven by placing focus on the system performance, energy consumption, water demands forecasting and monitoring of the less energy-intensive HWTS. **All** of the set out objectives were addressed through implementation of the methodology and discussed in the results & discussion Chapter. The strategy enabled the exchange and removal of inefficiently operated pumps resulting in an electrical cost saving of **R 2.28 million p.a.**

The developed strategy therefore provides an accurate and practical approach to improving horizontal transport systems and highlights the importance of analysing smaller energy-contributing systems to improve pumping operation and obtain potential electrical cost savings.

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USING ADVANCED M&V TO IDENTIFY UNPLANNED ENERGY INCREASES ON DEEP-LEVEL MINES

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ABSTRACT

Advanced M&V is the process of using measurement and verification (M&V) standardised baselines, along with data monitoring points, to calculate energy savings in real-time. However, varying baselines can negatively affect energy savings calculations via unplanned events. This study developed a method to forecast and identify unplanned events in advanced M&V through machine learning. Two predictions were made each month; one for a baseline, and the other for continuous updating. Discrepancies can be identified, quantified, and prioritised as the models begin to differ. In a case study, M&V-approved values are only obtained 70 days after month beginning. During this time the water pipeline was opened unexpectedly. The issue was manually identified and corrected 97 days since the month started. The developed model would have reduced the time spent on the review process by 70 days (72% improvement). The loss suffered due to water wastage could have been reduced by R1.1 million.

Keywords: Advanced measurement and verification, unplanned events, varying baselines, forecasting, deep-level mines

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1 INTRODUCTION

As South Africa's population has been growing, and consequently, so has the electricity demand, leading to capacity shortages [1,2]. To resolve the capacity issue, electricity tariffs were increased, well above inflation, to fund upgrades [3]. To assist with managing increasing electricity costs, proper finance management is required [4]. Creating budgets is a helpful method to monitor and plan the next fiscal year accordingly [4,5]. With the added pressure of the mines' performance, accurate budgets are a necessity to be financially successful [6,7].

A budget is typically calculated from historical data for the energy systems of the previous twelve months, only reflecting normal operations without any new planned actions [8,9]. The data trends can be acquired from installed meters and are summarised in monthly or quarterly periods [8]. After the budget has been compiled, it is distributed to the mine personnel for approval [8].

Similar steps for compiling budgets are used when compiling baselines, as budgets are based on baselines [10]. Baselines are created according to a set of rules and guidelines to standardise known as the measurement and verification (M&V) process [11]. Guidelines such as the International Performance Measurement and Verification Protocol (IPMVP) and the Federal Energy Management Program (FEMP) M&V assist in standardising the process [12,13,14].

The guidelines stipulate that engineering estimates and mathematical models can be used to assess the parameters chosen for the baseline model [15]. The energy saving measures (ESM), such as the budgeted savings projects, are implemented on approved baselines. These baselines represent the energy consumption of the system before the project, or ESM, has been implemented. An estimated savings impact can be calculated by comparing the baseline and the post-implemented actual energy consumption using Equation 1 [16].

$$Project\ impact = (Baseline - Actual) \pm Adjustments \tag{1}$$

Here, $Baseline$ is the energy, in kilowatt-hours (kWh), the system consumed before the implementation of a project, or ESM. $Actual$ is the energy, in kilowatt-hours (kWh), the system consumed after project implementation. $Adjustments$ is the energy impact, in kilowatt-hours (kWh), affecting the project implementation.

Projects can be affected in a multitude of ways, such as delayed timelines and operational changes [17,18]. Using Equation 1 helps to determine what would have happened if no intervention took place, highlighting the difference calculated as the project impact [14,16]. The impact used for adjustments is caused by unplanned events, such as the installation of new equipment unaccounted for in the budget [19]. These events can also cause unplanned savings or increases by causing lower or higher energy consumption respectively [20]. However, all changes to the system energy due to an event not caused by the ESM should be isolated from the ESM impact. This should be done whether the energy consumption is higher or lower [19].

Currently, unplanned events are manually detected by M&V personnel when calculating the project impact and compared to the actual consumption once finalised. This is a tedious and time-intensive process, requiring the involvement of the mine personnel for supportive information [21]. The process only becomes more difficult as multiple ESMs are implemented and planned for on the mine [19].

Deep-level mines often use a central control with a supervisory control and data acquisition (SCADA) system to monitor for any errors [22]. The SCADA displays data measured by power, pressure, and flow meters on surface as well as underground [22]. This data is continuously logged on a historian for later use [22]. Since the development of data logging in the 1970s, the practice has only become more popular, allowing companies to store and extract high volumes of data from power meters, up to every second, through advanced metering infrastructure [21,23,24].

More sophisticated techniques have been created with the larger scale of attainable data. This caused more investigations to be launched into applying them to the M&V process. Research known as advanced M&V focuses on automated data processing methods under standard M&V principles to calculate ESM impacts [25].

Baselines are the starting point for the M&V process, thus *Van Aarde* [8] investigated the accuracy of the data used to calculate these baselines in terms of the budget. Even though the study improved on the accuracy, the baseline is only one part of the formula. *Booysen* [12] analysed how the ESM impact would be determined if multiple projects were implemented on the same system. This study found that the original baseline could be used for the first project and then an adjusted one for the next project, created by using the original baseline minus the impact of the last installed project.

However, when there is no implementation time between projects, there is no data to build an adjusted baseline from. This led *Botes* [26] to use regression models to isolate the impact. The model was later used by *Granderson* [27] to not only determine the impact of ESM, but to forecast a system's energy consumption. As the robustness of these models gained more confidence for practical use, *Crowe* [28] applied them to calculate the energy savings in real-time. The model was moulded to the actual consumption and then plotting the predicted energy consumption to the baseline. Finally, this led *Gallagher* [29] to prove that regression models can be used in advanced M&V with machine learning methods.

All the above studies help to improve the M&V process, whether it is by evaluating models or by application. However, M&V is based on predetermined baselines and equations, causing problems when unplanned events come into play. These events occur when equipment or operations change without being planned for. Changes in the operation may increase or decrease the energy demand more than what was planned for during the budgeting process. Unplanned events are not just a set of equations, but require the input of experienced mining personnel to solve and identify.

Van Aarde [8] noted: "The savings obtained, when compared with the baseline, are rarely seen on the budget. This raises the question of whether the budgets are correctly developed." However, the question could also be directed at whether the baseline is still viable during the final comparison.

The M&V studies evaluated for this research, all used a constant baseline with advanced M&V techniques, assuming that the baseline was unchanged during the project period to calculate savings in real-time. *Booysen* [12] investigated how the baseline should change for multiple projects, however, these projects were planned changes to the baseline. Limited studies have been done on the process of addressing unplanned changes to the energy system, in essence changing the baseline during the performance period.

Therefore, there is a need to develop advanced M&V methods to identify unplanned changes to the baselines. The objectives of this study are as follows:

- Create a model or method to accurately forecast energy consumption for savings calculations.
- Be able to identify unplanned changes in the baseline when calculating savings with possible offenders.

With the advancements in M&V and real-time data monitoring, researchers are capable to calculate the impact of the ESM continuously. As per the M&V standards, the energy consumption during the performance period must be compared to a baseline period to verify the impact. These baselines are subject to unforeseen changes due to unplanned events. The model developed in this study will assist in identifying these events in real-time to improve the advanced M&V process.

2 METHODOLOGY

Previous studies on the topic of advanced M&V used regression models and machine learning to calculate an energy system's consumption in real-time. For this study, machine learning was not considered due to the time intensity associated with programming the model for a beginner. Regression models were also exempted as they are based on a constant formula fitted to previous actual data. Thus, the moving average formula was chosen as a base and applied to two different models.

The predictive model will consist of 24-hour profiles for each day of the week. A moving average will be used for each profile to predict the coming month's consumption for each subsystem using Equation 2. For example, the measured average hourly data logged on every Monday at 11:00 in April for the compressed air system will be inserted into Equation 2 to provide the predicted consumption for every Monday at 11:00 in May for the compressor system. This calculation will have to be completed for each hour in a seven-day week.

$$Predicted\ consumption = \frac{A_1 + A_2 + \cdots + A_n}{n} \tag{2}$$

Here, A is the average value, in this case energy consumption, in period n and n is the number of time periods. The time periods for this study were taken as days.

The model will be used in two different ways. The first will be to predict the consumption of the coming month, used as a baseline. The second will be to continuously predict the month's consumption, used as a comparison. Theoretically, if the actual consumption is constant, the error, calculated using Equation 3, between the baseline and performance models will be negligible. As the actual data start to differ, the error will increase, resulting in larger discrepancies.

$$Error\ consumption = Predicted\ actual - Predicted\ baseline \tag{3}$$

Here, $Predicted\, actual$ is the energy in kilowatt-hour (kWh) the system is predicted to consume for the month (continuously calculated) and $Predicted\, baseline$ is the energy in kilowatt-hour (kWh) the system is predicted to consume for the month (calculated at the start of the month).

With the models summarised in 24-hour profiles, Megaflex tariffs can be applied to calculate the costs of any discrepancies. The electricity tariffs used to bill mines differ throughout the day. The least demanding hours in the day receives a lower tariff than high-demand hours. This motivates the mine to consume less energy by saving on cost based on when the electricity grid is under more stress. The hours of the day are divided into peak, standard and off-peak tariffs, all in cent per kilowatt-hour (c/kWh), as seen in Figure 1 [1].

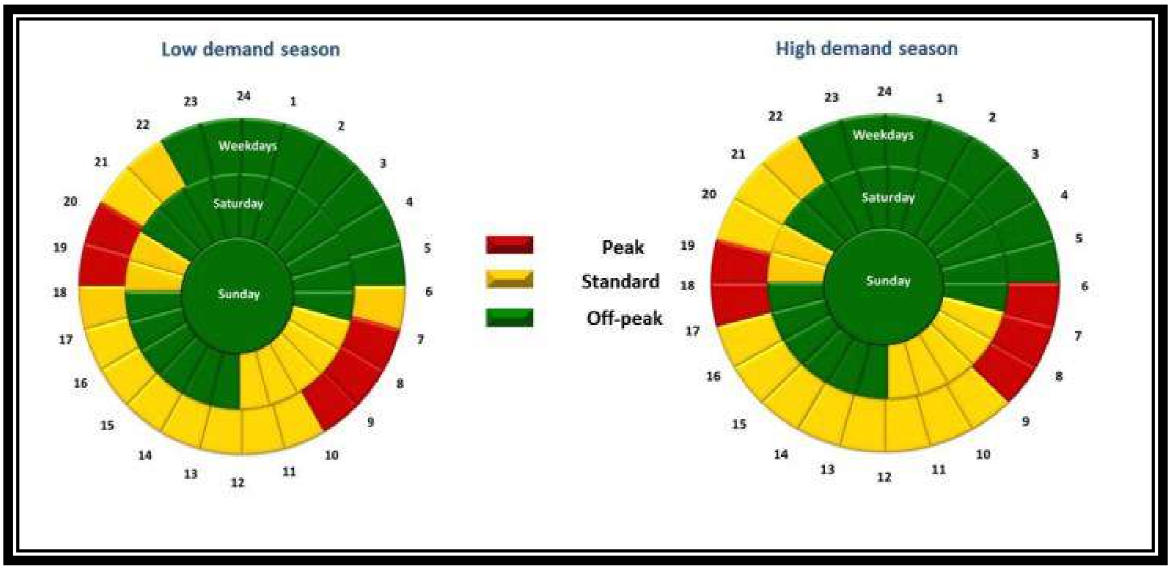

Figure 1: Eskom's Megaflex TOU tariff periods [1]

With the error consumption determined, Equation 4 can be used to calculate the financial impact of each discrepancy on a high level, and can be sorted from most to least significant, prioritising the system changes. These values can then be used to identify out of the ordinary issues or verify newly implemented projects' energy savings.

$$Electricity\ cost = Error\ consumption\ x\ Tariff \tag{4}$$

Here, $Error\ consumption$ is the energy difference, in kilowatt-hour (kWh), between the baseline and performance model (determined in Equation 3), and $Tariff$ is the cent per kilowatt-hour (c/kWh) electricity cost allocation for each hour of the day.

To this point, the model will be able to identify high level discrepancies found on the energy system. However, the energy system may consist of subsystems, each affected by multiple factors. For deep-level mines, the energy consumption is affected by changes in demand. Thus, all meters on demand related resources, such as flow and pressure transmitters, should be monitored.

The prediction model and identification process described above should be applied to the relevant flow and pressure meters in the interested system. Using these tools, one will be able to flag all discrepancies similar to how energy savings are calculated and compare the current value to the expected.

Before the errors can be sorted, all the values have to be relayed to the same measuring unit for consistency and simplicity. The energy consumption of providing water and compressed air can be quantified by calculating the specific energy impact of a single resource unit on their respective system by using Equation 5. This equation will be able to quantify the energy consumed by the fridge plants to refrigerate each litre of water supplied to the underground areas as well as the energy consumed by the dewatering pumps to remove that water from underground.

$$Specific\ energy = \frac{Energy\ consumption}{Demand\ flow} \tag{5}$$

Here, $Energy\ consumption$ is the kilowatt-hour (kWh) the system consumed in total for a set period and $Demand\ flow$ is the number of litres (L) the system consumed for the same period.

Knowing the error associated with each resource, the error calculated previously can be used to estimate the total energy required and sort the discrepancies by using Equation 6.

$$Error\ consumption = Specific\ energy \times Error\ demand\ flow \tag{6}$$

Here, $Specific\ energy$ is the energy in kilowatt-hour (kWh) the system consumes to process one unit of a resource and $Error\ demand\ flow$ in litres (L) is the difference between the baseline and performance model.

A need for an accurate prediction model was identified. By applying the moving average formula, a prediction model, able to forecast the energy consumption of a system, was created. Using the prediction model as the basis for the baseline and performance models, enabled the models to detect and prioritise deviations possibly caused by unplanned events.

3 RESULTS AND DISCUSSION

The above-formulated model was applied to a case study with an unplanned event identified through traditional M&V and investigations. This was done to test the model's ability to detect deviations in real-time.

The case study focuses on a deep-level gold mine using chilled water for its cooling operations. A simplified diagram of the operations can be found in Figure 2. Used mine water is chilled by the fridge plants on surface, supplying water to the chilled water dam on the surface and 20 Level (L). The 20L chilled water dam delivers water to all the production levels and cooling equipment on 37L, 39L and 40L. This equipment is supplied via four chilled water pipelines indicated in blue: the 37L production pipeline, the 39L spray chamber pipeline, the 39L production line and the 40L production pipeline.

Chilled water is circulated through the seven cooling cars and five spray chambers, making up the mine's cooling equipment. Most of the equipment dumps the used chilled water into the drainage system, which then flows to the 41L dam via gravity and spindle pumps. The water from 41L is pumped out via a series of pumping chambers found on 41L, 31L 20L and Intermediate Pump Chamber (IPC) level as indicated in green.

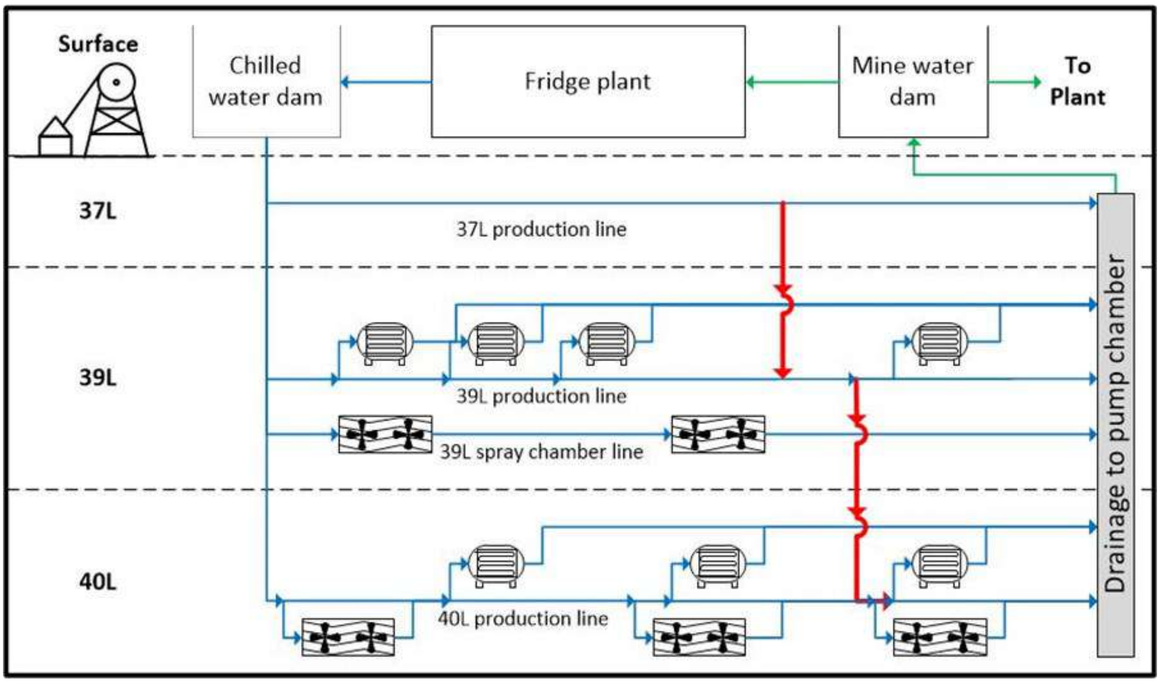

Figure 2: Case study's water reticulation system

The mine personnel chose to change the pipe configuration on 37L and add a supply line to 39L as indicated in red. Some working places on 39L were struggling with low water pressures as the developed incline was too steep, already reaching the 37L haulage. The plan was to close the feed to the 39L working areas from 37L and close the original pipeline.

However, this was not the case. The working area was connected to 37L with 39L still open, leading to an unexpected and unplanned increase in water demand. This increase can be seen in Figure 3, where the daily average water flow to 37L is plotted from December 2020 until March 2021. A sudden increase can be seen from 15 January 2021, indicating that the water line was opened to 37L. As this change was not planned for and not communicated with the M&V team, the change was only realised when the savings calculations were conducted at the start of February. The team found that the pumping and refrigeration energy consumption increased unexpectedly.

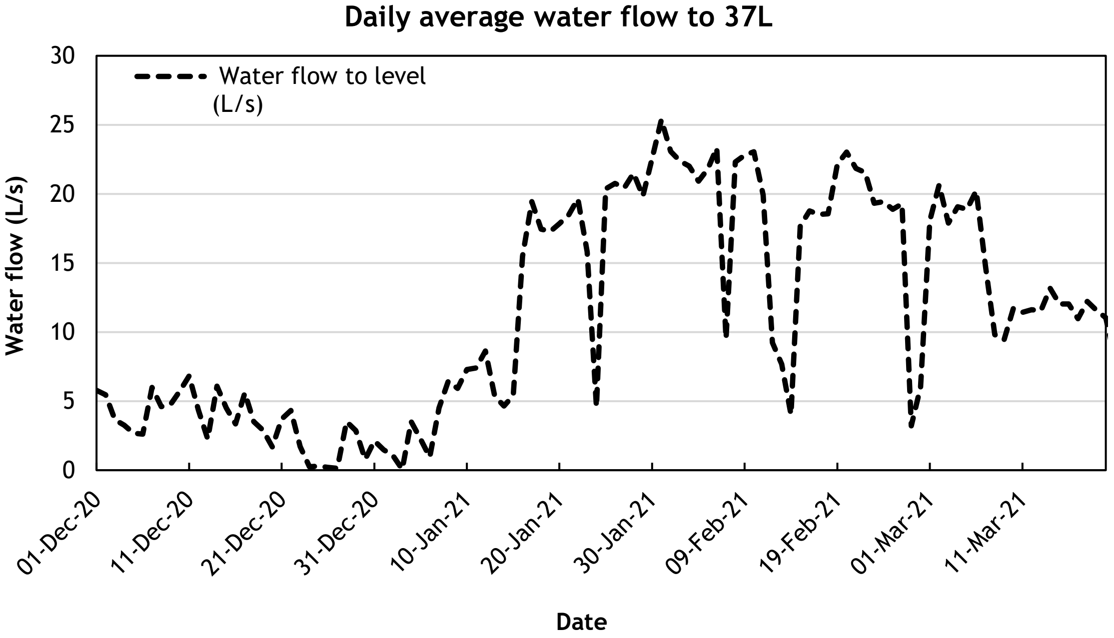

Figure 3: Daily average water flow to 37L from December to March

An investigation was launched into the mine's water flow, and an increase in water volume supplied to the underground sections was found, verifying the notion of a demand increase. More in-depth studies were done on each level's water flow consumption until 37L was identified as the most significant water consumption increase. The increased demand's impact was calculated according to Equation 5 and Equation 6. The issue was then raised and discussed with the mining engineer, who provided the reasoning for this increase. The water pipeline was throttled from 9 March 2021 for the first time, resulting in the first step to amend the unplanned change.

Figure 4 provides a Gantt chart of each step in the M&V process on a high level to explain why identifying these unplanned events takes time. Each step of the process, shown by coloured blocks, is plotted against the calculated impact of the increased demand, shown by the dotted black line. The Gantt chart timeline is set from December 2020 to March 2021. December was included to display the typical power usage of the level before the change occurred in January.

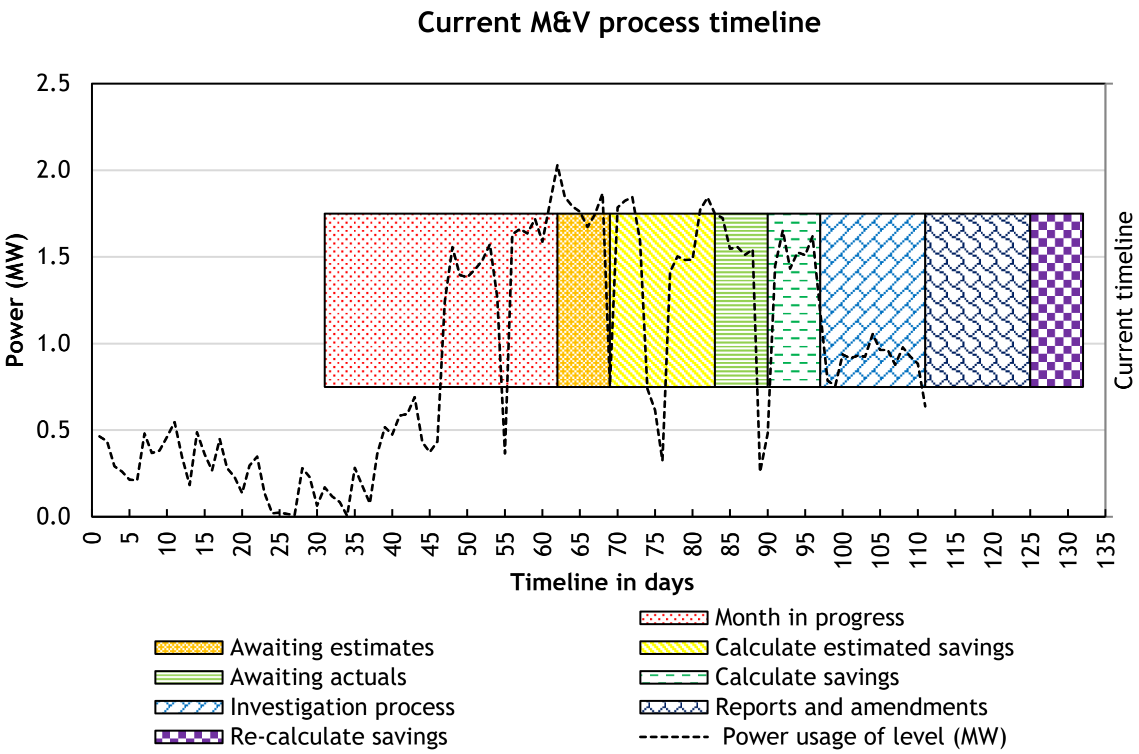

Figure 4: Timeline of the current M&V process at deep-level mines

The main reason for the delay is waiting for January to conclude, as indicated by the first block in the Gantt chart, so the estimated energy consumption data can be acquired. This particular mine compares its total energy consumption to the Eskom bill for verification. Firstly, an estimated consumption for the month is calculated via power meters and later compared to the Eskom bill for the actual consumption. Once the estimated energy consumption for January was received on day 70, at the beginning of February, the first calculations of the estimated savings could start. In this situation, the water flow started to reduce at the same time as the investigations started on day 97, i.e., 67 days after the event took place. In this scenario, the opening of the pipeline took 23 days for the investigation to start since the event began.

By investigating previous studies on M&V principles and methods to calculate energy savings in real-time, a model could be devised to reduce this time. Equation 2 was used to predict a baseline for November based on October's actual data. The predicted November consumption was compared to actual November consumption to verify the accuracy of such method. By applying the moving average formula to a previous month's data to predict the following month, an accuracy of 98.1% was achieved.

With an error of 1.9%, the baseline for January could be calculated from December data, as indicated in the previous section. Normal operations were simulated for this test. As the month continued, the data for each day was added to the performance model to identify any discrepancies. Figure 5 depicts the results of this process calculated on each day of the month, stacking the energy subsystems to provide the total consumption. Each day the consumption for the end of the month was calculated, adding the previous days' actual data, and was compared to the baseline (B in the figure) to identify any discrepancies. As the month continues, the predicted consumption for the month-end increases daily, indicating that the demand has increased and will, most probably, continue to do so.

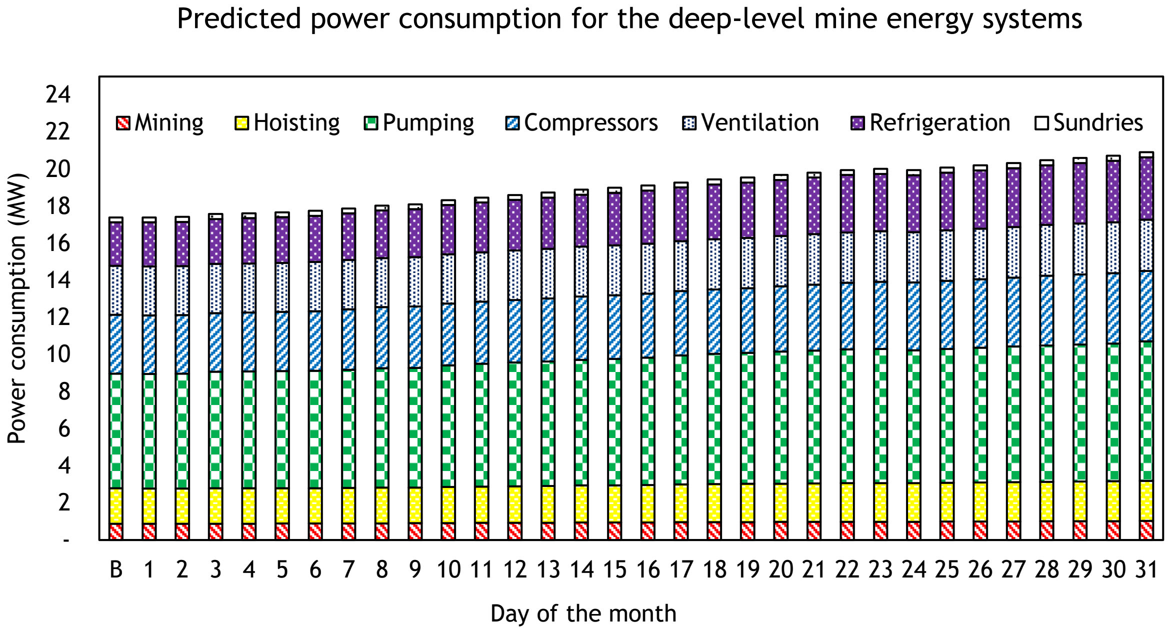

Figure 5: Baseline and predicted power usage comparison for the energy subsystems

Each subsystem was prioritised and found that the pumping system contributed most significantly to the power increase. Thus, according to the prediction methods being compared, the water flows to each level were predicted similarly and quantified with Equation 5 and Equation 6 to produce Figure 6. Power usage was chosen instead of percentage increase to normalise the data as a percentage is subjective based on the system size. Figure 6 displays the quantified power usage for each level on the deep-level mine due to the chilled water supply, calculated daily.

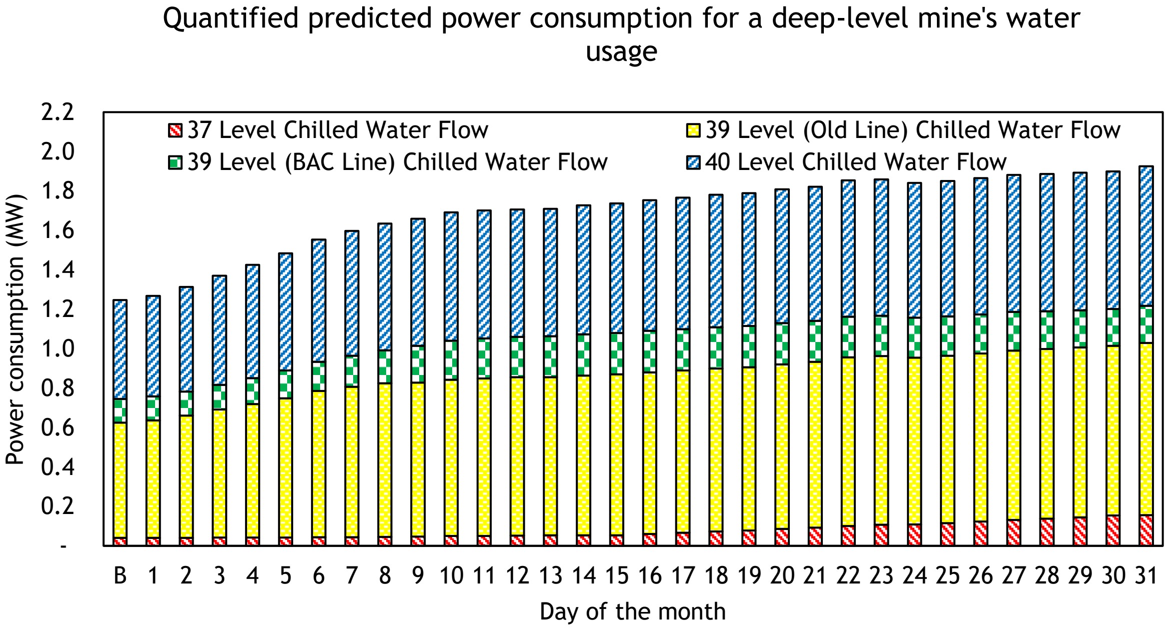

Figure 6: Baseline and predicted power usage comparison for the pumping system

From Figure 6, the most notable increase was on 39L (old line) and 40L. These pipelines supplied the working areas as part of the ring feed system between 37L, 39L and 40L. The early increase between day 4 and day 8 indicated that the 39L and 40L water demand increased. The curve flatted from there for the month, possibly due to countermeasures from the mine to control the demand. However, looking further into the month, this could just have been that these two levels reached their maximum supply. This was an indication that the 37L water flow will likely increase shortly after. As was the case from the seventeenth day. Indications such as these can be better utilised with the necessary practical knowledge.

With the prediction and baseline model comparison, the change in flow was identified in quick succession to the event. Eliminating the time spent waiting for the month to end and the estimated values, tallying 37 days. Reducing the process by another 25 days by eliminating the waiting time for the actual energy consumption as well as improving the manual labour needed when calculating the energy savings. Along with guidelines to identify the reasons behind these changes more rapidly, the process could be reduced by a further 7 days. Totalling 74 days, i.e., a 73% improvement on the current process.

The above-mentioned information is depicted in Figure 7. Figure 7 provides two Gantt charts for comparison: one the current timeline (top) and the other the possible timeline, using the prediction model applied to this scenario (bottom). These are plotted against the cost impact of the increased demand to visualise the importance of the two processes.

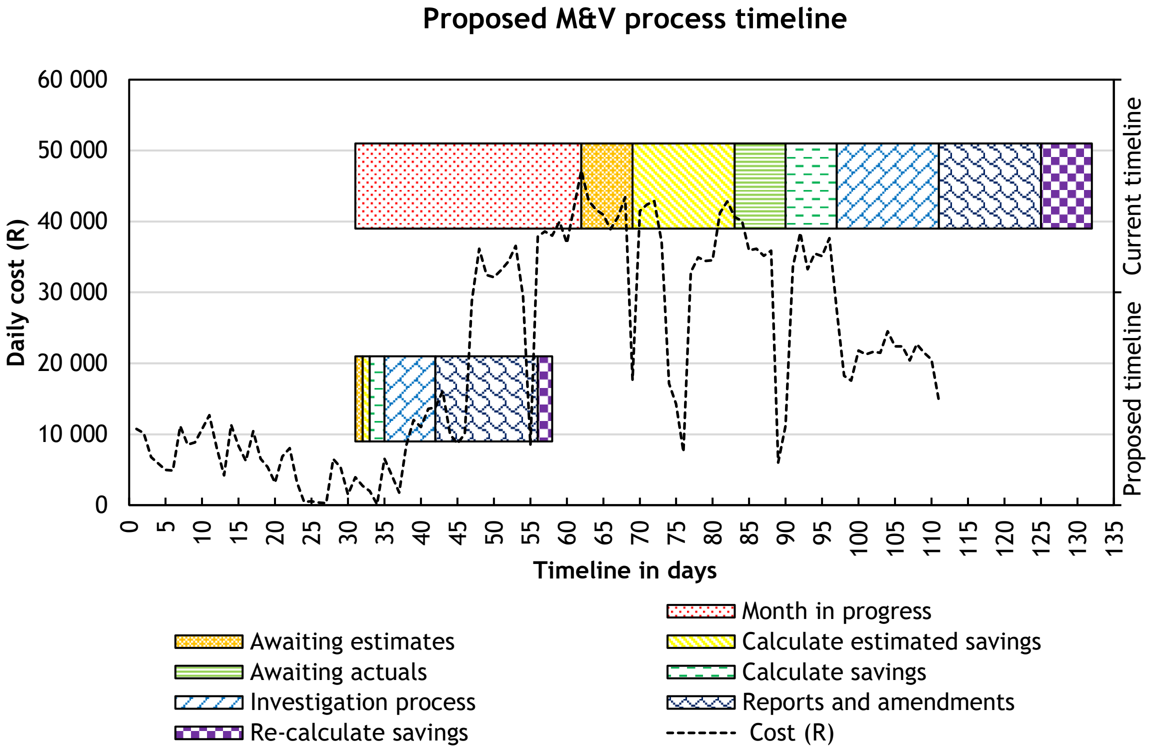

Figure 7: Timeline of the current and proposed M&V process at deep-level mines

During the current process, the opening of this pipeline cost the mine R1.6 million in electricity fees, quantified using Equation 4, until it was resolved due to water wastage. With the proposed model and method, this loss could be reduced to R450 000, essentially saving the mine R1.2 million. The baseline prediction model was applied to multiple deep-level mine systems over two years and was able to identify four similar issues, over three different mines. This case study only represents one of the unplanned events.

4 CONCLUSION

Accurately forecasting energy consumption assists with finance management during increasing tariffs on deep-level mines. With unplanned consumption increases negatively affecting the future of a mine, predicting and monitoring power usage is becoming more essential. With improvements in constant data monitoring, these energy savings can be calculated in real-time through what is known as *advanced M&V*.

To incorporate shifting baselines into advanced M&V, the moving average formula was applied to develop a model which could accurately predict the energy consumption for a deep-level mine. Two predictions were made each month, one for a baseline and the other for continuous updating. As the models start to differ, discrepancies can be identified.

The objective of this study was to develop a method to forecast and identify such events in advanced M&V to help prevent unforeseen financial losses due to wastage. This objective was met using the designed method and applying it to the case study.

In a case study, M&V-approved values are only received 70 days after the beginning of the month. During this time, the water pipeline was unexpectedly opened. The issue was identified manually and corrected 97 days since the month started. The developed model would have reduced the time spent on the review process by 70 days (72% improvement). The financial loss suffered due to water wastage could have been reduced by R1.2 million. The model was able to identify four similar issues, two of which were on different deep-level mines when applied.

Future studies could focus on automating this process through programming and machine learning. However, the time taken to implement such a feature should be brought into consideration as the method is designed to save time. The method could be applied to systems with limited data to predict the consumption as the data is received even if it be on a daily or weekly basis. The integration with digital twin simulation could also be investigated as a training ground to learn the system through visual aids and guidelines.

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INTEGRATIVE ENGINEERING FRAMEWORK FOR A RESEARCH AND DEVELOPMENT ENTERPRISE

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ABSTRACT

This paper proposes an Integrative Engineering Framework for performing enterprise architecture, enterprise, systems, and software engineering in a research, development, and innovation enterprise. A constructivist approach is used in developing this framework, without showing the logical predicate formalisms from philosophy of science. The framework is based on a Design Science Research process that incorporates the idea of Zachman Framework reification transformations that can integrate approaches from enterprise architecture and various engineering disciplines. The framework is also generalizable to integrate various engineering disciplines.

Keywords: Integrative Engineering Framework, Design Science Research, research, development, innovation

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1 INTRODUCTION

The global requirement for digital transformation also has an impact on the research, development, and innovation enterprise. A changing global economic landscape forces organisations to innovate new products and services faster to keep up with global competition. This requires significant effort to focus on research, development, and innovation (RDI) of new products and services for the market.

In the South African context, the need to reindustrialise domestically is seen as one of the main drivers of job creation in a country with a high unemployment rate and a low-skilled workforce. The RDI enterprise must strike a balance between RDI and supporting the industrialisation by finding alternative ways to advance for a better tomorrow for Africa by taking advantage of the opportunities that the continent has to offer [1]. This can be achieved in research grounded in science and innovation, as well as considering the needs of industry and society [1].

A framework is needed to provide innovative technologies and solutions that practically contribute to a competitive continent and sustainable economic growth [1]. The value of these technologies and solutions should be measured by determining the improvement in industry competitiveness and improving the quality of life of the people of Africa [1]. The framework should make the most of the diversity, ingenuity, and energy of African people in a collaborative and agile way to realise the potential of the continent [1].

The problem is how to strike a sensible balance between scientific and industrial research and the industrialisation of innovations, especially in an engineering organisation? The engineering organisation is understood as the Technology Development support or secondary activity, or at least part of it, in the Porter Value Chain [2].

In a discussion amongst principal engineers at a research institution in South Africa, the following outcomes, among others, have been identified for an engineering enterprise:

- Establishment and strengthening of an engineering practice based on multiple disciplines.
- Establishment and sustainment of the knowledge reference.
- Transferring of relevant knowledge to stakeholders.
- Elevated quality in activities.

For the purposes of this paper, the following disciplines are considered for integration in an engineering organisation:

- Enterprise Engineering/Architecture,
- Systems Engineering, and
- Software Engineering.

To achieve the above outcomes, the following were identified:

- Establish a generic ontology for the above engineering enterprise that can accommodate discipline-specific ontologies.
- Instil the following concepts into the culture of the above engineering organisation:
    - Enterprise Architecture / Enterprise Engineering / Enterprise Modelling.
    - Systems Engineering.
    - Software Engineering.
- Conducting scientific and industrial research as part of the engineering organisation's work every day.

- Identify and plan the research portion of the work.
- Conduct research within ethical guidelines.
- Publish research results in peer-reviewed forums; this includes formal design reviews, colloquia, patents, conferences, scientific journals, etc.

The research question answered in this paper is as follows:

> Can a framework for Enterprise Engineering/Architecture, Systems Engineering, and Software Engineering disciplines be derived to create products and services in an integrative manner in a research, development, and innovation (RDI) environment?

The derived question is:

> Can Design Science Research (DSR) be used to support an integrative approach?

The rest of this paper uses a constructivist philosophy of science approach to answer this question. The underpinning mathematical formalism for the constructs is not shown; only the interpretation of the mathematics in the context of this paper is shown. The basis for the construct, based on the research question, is discussed in the next section.

2 BACKGROUND

2.1 Architecture of the Engineering Organization

The architecture of an engineering organisation [3] is shown in Figure 1. The created system is the same as the system under development in [4]. The creating system is called the designing system in [4]. The Engineering Organisation has the main objective to develop innovative technologies and services (created system) [3] that can improve the primary activities in the Porter Value Chain so that the margin between the price of the goods and services delivered by the primary activities and the cost of delivery of these goods and services can increase [2]. This can create profits for an enterprise and, if there is competition in the market, lower prices for goods and services to the consumer [5].

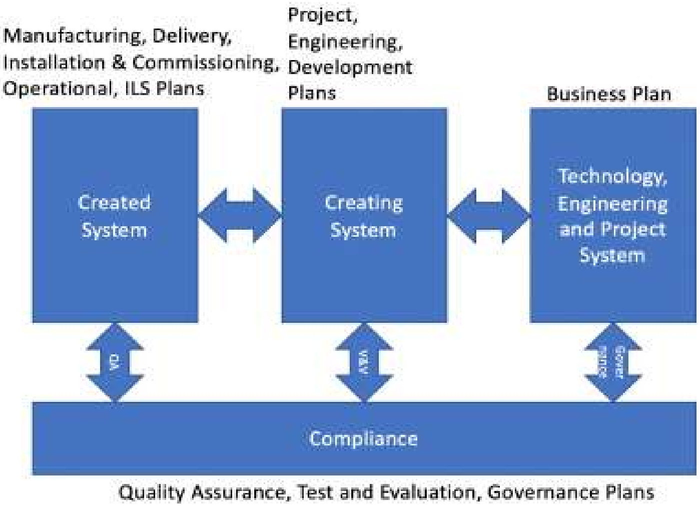

Figure 1: The Engineering Organisation [3]

The technology and services (created system) delivered by the Engineering Organisation [3] should not be confused with the goods and services delivered by the primary activities of the Porter Value Chain [2]. The created system is integrated into the larger business operations of an enterprise to support the creation of value for the stakeholders. The created system can address operational issues in the primary activities: Incoming logistics, operations, outgoing logistics, marketing and sales, and services, with the aim of increasing the margin in the value chain.

The focus of this paper is the creating system, created system and the parts of compliance that cover quality assurance (QA) of the created system as well as the verification and validation activities (V&V) of the creating system.

2.2 Design Science Research

A candidate to implement the creating system to deliver the created system with the required quality focus in an engineering organisation is to use a Design Science Research (DSR) approach [6, 7]. It has been used successfully in information systems research [7]. The experience of the authors is that DSR is implicitly performed in most engineering research work at South African universities. Engineering is the manipulation of information representing the material world (matter, energy, signals, and data [8]) to solve problems and the results are validated in the physical world [8, 9].

An expanded and revised summary of DSR in [6] is shown in Figure 2. The main activity is the creation of the artefact for an application domain, but it is based on a knowledge base. The application domain provides the requirements for the design effort (technology pull or demand pull), and the knowledge base provides the scientific grounding of the design (knowledge pull). The evaluation of the design (V&V and QA) can be done through several ways, including laboratory evaluation, field evaluation, simulation, etc. using quantitative, qualitative, or mixed-method research methods. The final testing of the solution is done in the application domain. The new knowledge gained from DSR is captured in the knowledge base (knowledge push); this includes the publication of research papers in peer reviewed forums, e.g., conference, journals, etc.

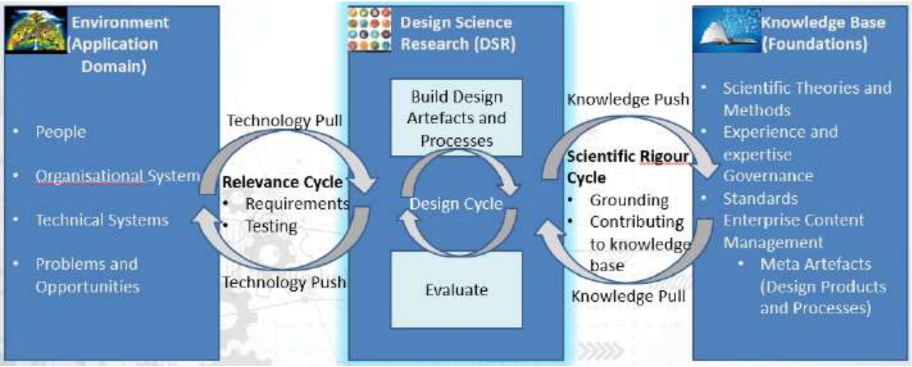

Figure 2: Summary of Design Science Research, based on [6].

The depiction in Figure 2 also includes a Technology Push, where an innovative technology is developed without requirements originating from the application domain. This is typical of technology developments following a technology readiness approach that comes from a pure theoretical basis, developed into an applicable technology to solve general problems, and later developed by technology demonstrators to mature the technology and transition it into an operational environment until it has been adopted by the market and sold commercially [10].

SAIIE The phases and detailed activities of the DSR based on [7] are:

- Phase 1: Problem identification with the following activities: Identify problem, stakeholder and expert interviews, literature research - part I, pre-evaluate relevance.
- Phase 2: Solution design with activities: Design artefact, literature research - part II
- Phase 3: Evaluation with activities: Refine hypothesis, expert survey, laboratory experiment, case study/action research, stakeholder survey.
- Phase 4: Summarise results with activities: Publish research report, publish peer reviewed article, present conference paper/poster, publish engineering report, deliver engineering design, publish technical article, present design to stakeholders.

DSR provides a way in handling various technology development approaches in a research environment by keeping a balance between the problem and opportunities to be solved from the application domain and delivering a practical solution based on a foundation of peer reviewed information, i.e., scientific theories and methods, experience and expertise, corporate governance, standards, enterprise content management system, etc.

2.3 Brief overview of the Zachman Framework

This section is not an extensive overview of the Zachman Framework. Only the parts that are used in this paper are highlighted. Zachman [11] proposed a framework to deal with the increasing size and complexity of information systems implementations. It is based on a logical construct (or architecture) for defining and controlling interfaces and the integration of system components. This is done by creating a neutral descriptive framework based on various disciplines independent of information systems. The basic construct of the Zachman framework is the set product between communication interrogatives and the millennia-old reification process steps [11, 12].

The communication interrogatives are: Why, what, who, when, where and how [11, 12].

A dictionary definition of reification is “the act of changing something abstract (= existing as a thought or idea) into something real” [13]. Zachman [11, 12] identifies the steps for reification as follows:

- identification,
- definition,
- representation,
- specification,
- configuration, and
- instantiation.

In this paper, the interest is in the steps for reification.

3 CONSTRUCTING THE FRAMEWORK

3.1 Reification

For the purposes of this paper, the above reification steps above are mapped to the steps shown in Figure 3, by renaming Identification to General identification, Definition to Engineering Discipline, Representation to Meta Models, Specification to Rules and Processes, Configuration to Design, and Instantiation to Design Implementation.

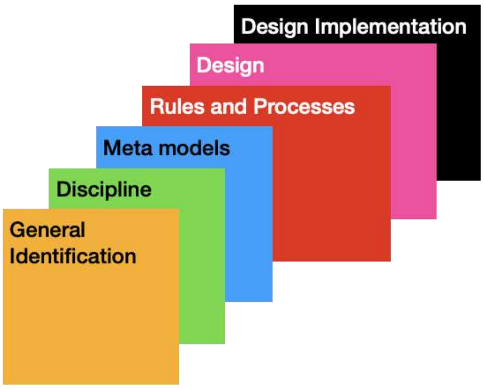

Figure 3: Reification for integrating engineering disciplines

3.1.1 *General Identification*

When examining the various ways in which engineering is performed in the different disciplines [14], a general engineering approach can be identified, which is shown in Figure 4. The authors also use this approach in their daily practice of engineering.

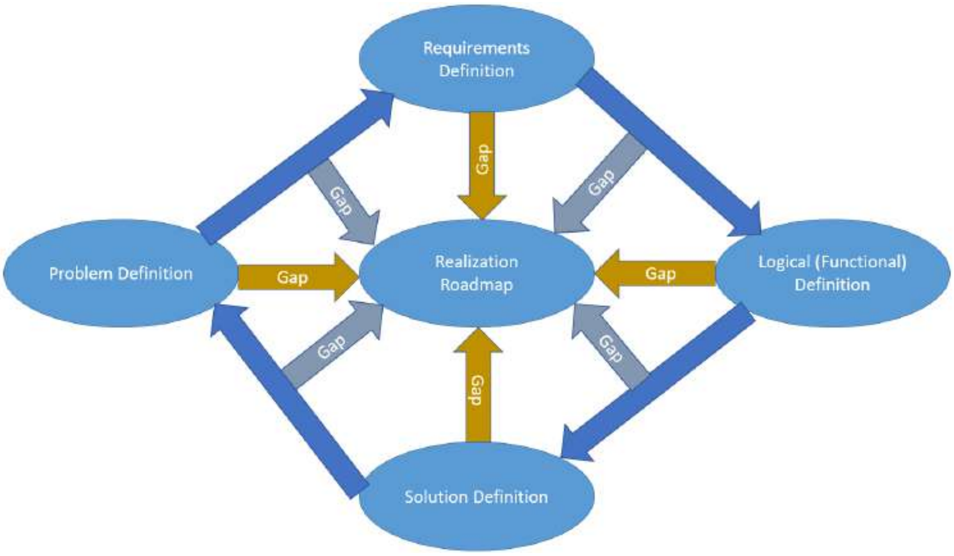

Figure 4: General Engineering Approach

This approach is widely discussed in various forms in systems engineering, software engineering, and enterprise engineering and is encoded in international standards for systems engineering and software engineering [15,16].

The General Engineering Approach in Figure 4 is the basis for relating the engineering work at a more detailed level to the DSR shown in Figure 2.

Problem definition is the starting point for any research and engineering effort. This is related to the activities in the Problem Identification Phase of the DSR.

Requirements Definition in Figure 4 is part of the cycles of relevance and scientific rigour in Figure 2. This is related to the results obtained by the activities of the Problem Identification Phase of DSR. The resulting problem definition or hypothesis is the relevant requirements evaluated through scientific rigour.

The logical/function definition in Figure 4 is part of the design and scientific rigour cycles in Figure 2. This is related to the activities of the DSR Solution Design Phase. The results are the basis for further development of the solution.

The Solution Definition in Figure 4 is part of the design and scientific rigour cycles in Figure 2. This is related to the activities of the Solution Design, Evaluation, and Summarise results phases of DSR.

The gaps indicated in Figure 4, are the information gaps that exist in an engineering approach. These gaps are the information that needs to be created to obtain a traceable design with integrity. The gaps are organised in a roadmap that is used to plan the work to be done to achieve the result. The plan is executed by the creating system and is managed by the Project Management System in Figure 1.

3.1.2 Discipline

In this transformation step, the relevant engineering disciplines that are part of the integrated development effort are identified. For the purposes of this paper, it is Enterprise Architecture, Systems Engineering, and Software Engineering. The General Engineering approach identified in the previous section allows any engineering discipline to be considered. Each discipline has its own defined set of principles and assumptions to focus on aspects of the real world.

3.1.3 Meta-Model

The information models used per engineering discipline are identified and defined to capture the information that underpins the ontology for a specific discipline. These are the models that practitioners of a specific engineering discipline use to capture their information about the materialistic world. These information models are representations of the materialistic world in which engineers solve problems.

3.1.4 Standards, Procedures, Rules, and Processes

In this transformation step, all discipline-specific rules and processes are identified to perform engineering work to solve problems. This encodes the world view of a specific discipline and how to deal with real-world problems. It is a specification of how a specific engineering discipline interprets and manipulates information representing the real world. An example is the different approaches that mechanical and chemical engineers have in solving heat transfer problems. It is the same real-world phenomenon, but each discipline uses a different approach to solving the problem.

3.1.5 Design

In this transformation step, the design information resulting from the application of rules and processes in a specific discipline is recorded. This is information on the configuration of materialistic elements (matter, energy, signals, and data) using scientific principles, and if the information is used, it will successfully instantiate machines, structures, other equipment, and systems in the real world.

3.1.6 Design Implementation

In this transformation step the instantiation of an engineering design in the real world is happening. This instantiation is based on the configuration of materialistic elements specified during the design. The real value of engineering work is only unlocked for the value chain and society after the implementation of the design.

3.2 Integrating different disciplines through cocreation and emergence

The reification process steps described above for integration can be represented as shown in Figure 5. In the forward construction process using the objects identified in each step of reification, the orange level is the General Engineering approach discussed in 3.1.1 above. For the purposes of this paper, the three green blocks in Figure 5 represent Enterprise Engineering/Architecture, Systems Engineering, and Software Engineering. The blue blocks in Figure 5 represent the metamodels for the disciplines. Each discipline can have more than one metamodel to represent information from their point of view of the real world. Each meta-model supports its own set of standard, procedures, processes, and rules.

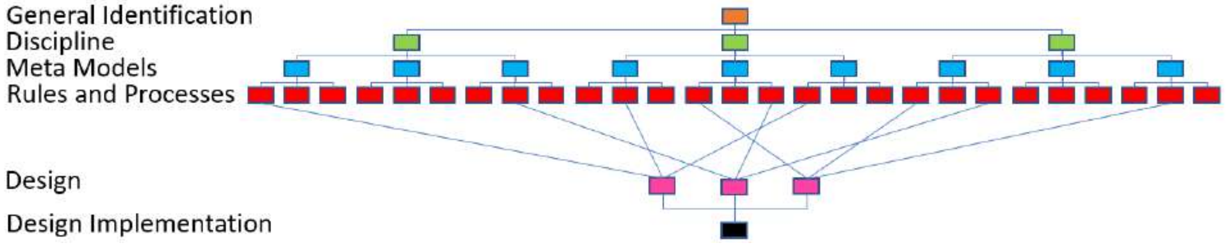

Figure 5: Illustration of the framework co-creation and emergences in design

The pink blocks in Figure 5 represent the different designs or configurations of materialistic elements according to the rules and objects that are processed. Note that a specific configuration can be influenced by more than one set of rules and processes. This represents a co-created design influenced by the applicable rules and processes sets. The implementation of this step with DSR is shown in Figure 6, with the applicable rules and processes as constraints on the process, the need (problem or opportunity of a client) as input to the process, and the design artefacts (configuration of materialistic elements) as output to the process.

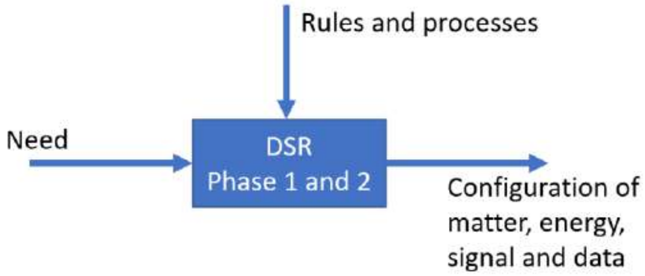

Figure 6: Realising the Design step with DSR Phases 1 and 2

The Design Implementation in Figure 7 is the instantiation of the designs in the physical world. The instantiation or realisation of designs as products or services in the real world is done by physically configuring matter, energy, signals, and data according to the design artefacts created during the design step.

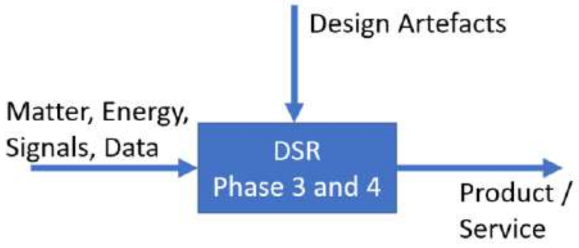

Figure 7: Realising the Design Implementation step with DSR Phases 3 and 4

The instantiation of the design in the context of DSR can be as follows:

- The minds of people, evaluated through expert and stakeholder surveys.
- A laboratory evaluated through experimentation.
- An operational environment, evaluated through case studies/action research.

The DSR phases depicted in Figures 6 and 7 are a detailed implementation of the creating system that delivers the created system in Figure 1. An important part of DSR is the publication of the results.

In the evaluation of the elements/objects from the reification transformations, a co-creation between disciplines can starting to happen when elements/objects of metamodels, rules and processes, and designs are the same. The top-down discovery of these sameness of elements leads to co-creation between disciplines on a design. When the discovery of the sameness is bottom-up, it is the emergence of the sameness of elements.

Integration between disciplines can start to happen through co-creation or emergence already during the definition of a meta-model. The primitives to describe integration and commonality are captured in the meta-model.

The rules and processes are the perspectives and interpretations of the primitives in a meta-model according to a specific discipline. For example, the primitive of a requirement and a specification exists in all engineering disciplines. The perspective and interpretation of a requirement from the perspective of Enterprise Architecture is only a need statement from the perspective of systems engineering and a motherhood statement with little meaning for implementing anything from the perspective of software engineering. These differences in perspective give rise to the observation that the specification developed by systems engineering becomes the requirements for development by discipline engineering.

3.3 Validation of the framework

The framework is validated daily in the work of the authors. It has been used in the proposals and execution of projects that require multidisciplinary integration. The first successful implementation of a tailored version of the framework was done in 2021 on a project to demonstrate augmented reality training for rock drill operators at the stope face in hard rock mines. Integration between several disciplines was planned, coordinated, implemented, and demonstrated successfully to the client by one of the authors.

The framework was also used in two proposals for research work in the research group of the authors. The one project proposal is for an underground sensor integration for advance orebody knowledge. An integrated approach between enterprise architecture, systems engineering, and software engineering could be defined with the necessary scientific rigour and practical relevance for underground hard rock mining. The other project proposal was for a system to securely facilitate online assessments of students using advanced technologies, which also required an integrated approach between enterprise engineering, systems engineering, and software engineering.

The framework provides guidance for the planning of integrated research projects to ensure scientific rigour and practical relevance while developing the artefacts for the solution. So far, only one project has been successfully delivered.

4 CONCLUSION

The construct in Section 3 is a framework that uses DSR that supports an integrative approach between different engineering disciplines using a reification process. A general engineering approach unifies the different engineering disciplines. The different engineering disciplines are supported by metamodels that contain primitives with commonality between the different disciplines and describe integration. Each discipline has a set of rules and procedures codified in standards, processes, and guidelines that are perspectives on the primitives in the meta-models. The rules and procedures control the design process for each discipline to deliver in a co-created manner design artefacts that describe the configuration of matter, energy, signals, and information. Design Implementation instantiates design artefacts in three ways: in the minds of people, in a laboratory, or in an operational environment. Also, an important part of the design implementation is publishing the results in the appropriate forums.

The framework proposed in this paper can be used to create products and services in an integrative manner in a research, development, and innovation environment facilitating the collaboration between Enterprise Engineering/Architecture, Systems Engineering, and Software Engineering disciplines.

It can be concluded that Design Science Research (DSR) can be used to support an integrative approach.

Further work following from this paper may include the full-scale development of an enterprise model using the Zachman Framework.

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NOVEL USE OF SIMULATIONS TO RECONFIGURE CENTRIFUGAL PUMPING SYSTEMS IN REVERSE OPERATION TO GENERATE ELECTRICITY

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ABSTRACT

Energy is a major expense for industrial consumers such as deep-level mines. Energy costs are increasing and there exists a resistance towards renewable energy sources especially in the mining sector. Gravitational potential energy can be recovered in various ways on mines. Integrated simulation software offers unique solutions for energy-intensive systems. One common energy-intensive component in mines is dewatering pumps. This study will focus on reconfiguring pumps in reverse operation to generate electricity by recovering energy. With the aid of simulations, the overall pump control strategy is optimized for optimal benefit and lower maintenance costs. This case study presents an integrated simulation for a reconfigured mine pump. It is shown that the reconfigured system (hydropower) produced approximately 1.007 MW of power, saving the mine an equivalent of R10.5 million p.a. Capital expenditure of R4.9 million is required to realize the project which will incur a payback of 5.6 months.

Keywords: hydropower, pump in reverse operation, energy generation, renewable energy, energy recovery, pump as turbine

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1 INTRODUCTION

1.1 South Africa's current energy status

South Africa's energy system has been exceptionally dependent on mineral resources which has also contributed significantly to the country's economic development [1]. South Africa is a coal abundant country due to the rich and bountiful deposits, which allows for inexpensive electricity generation [1]. Despite this, there is an evident absence in the generation infrastructure to ensure consumers have electricity [1]. As a result of the infrastructure inefficiency, South Africa has been experiencing load shedding. A total of 22.9 days has been lost to power outages during the year 2022 to date (9th May 2022) [2].

The South African energy system is extensively carbon-intensive and has been overwhelmed by unreliable power generation as well as theft and end users non-remittance [3]. To further complicate the situation, Eskom has a hesitancy towards signing power agreements with renewable energy generators therefore maintaining the monopoly in the sector [3]. Figure 1 demonstrates the comparison between the main energy sources of South Africa.

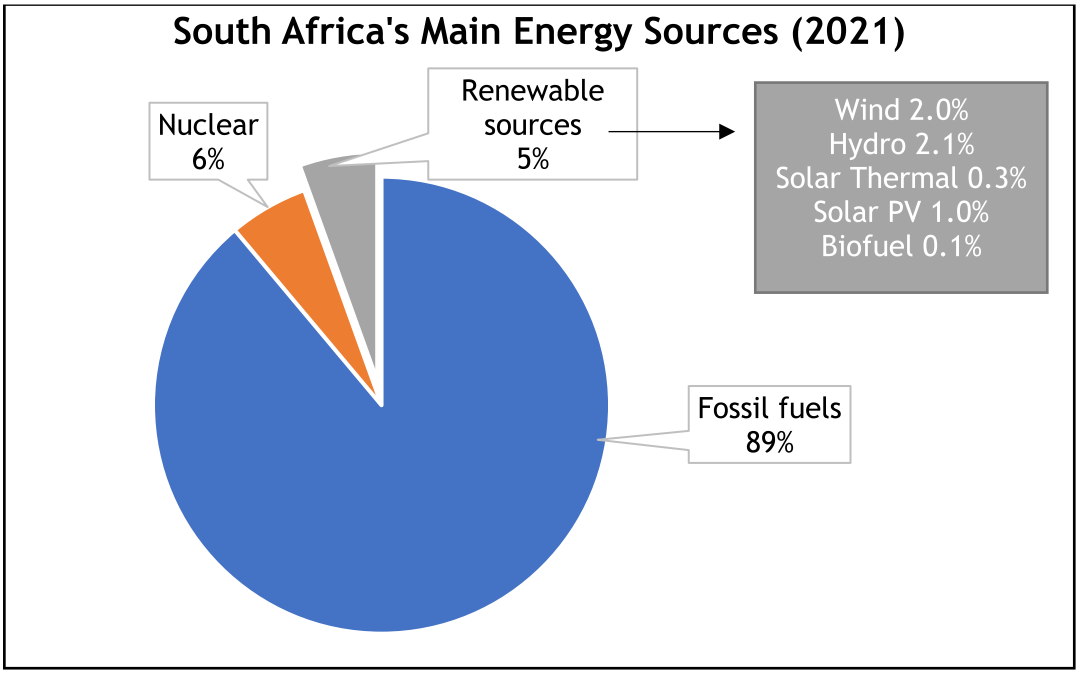

Figure 1: The energy distribution within South Africa in 2021 [4]

Eskom's tariffs have increased drastically from 2004/2005 to 2020/2021. Tariffs have increased from year to year an average of 13% and a total of 957c/kWh over the above-mentioned period. Figure 2 depicts the tariff increases over the entire period.

There is a growing need for alternative energy sources within the energy sector to complement the current energy supplier and possibly in the future, convert completely to a sustainable energy source with minimal greenhouse effects and maximum energy potential [5, 6].

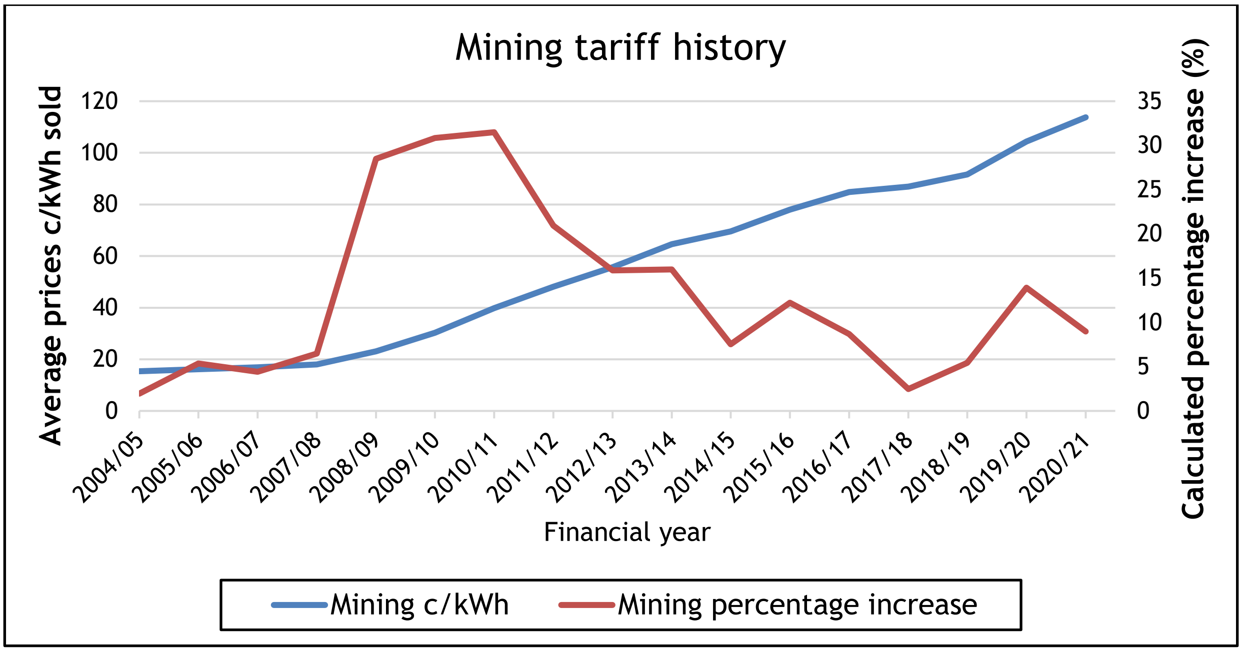

Figure 2: Eskom average tariff vs. inflation (CPI) [7]

Hydropower is considered one of the most popular renewable energy sources as it is convenient and reliable [8], and is growing swiftly across the globe [9]. Hydropower is responsible for 17% of the world's total power generation and is the least expensive source of energy [8].

Rising energy demand has started to engulf the coal generative plants in South Africa [4] and Eskom has resisted the ideology of sustainable energy sources, which has led to the further demise of the current energy situation [3]. South African deep-level mines have been suffering as a result of the load shedding and load curtailment schedules, but possesses generative capacities ranging from 0.5 – 1.5 GW, because of the abundance of water underground [10].

Excluding Eskom's installed hydropower systems, it is projected that 60 hydropower systems, installed by private and communal societies, have been installed in the underground mining sector which is currently being overlooked [11].

1.2 Hydropower

Hydropower is a versatile system and can be implemented in various configurations. Three types of configuration exist that can be implemented [12], namely Impoundment, Diversion and Pumped storage.

Impoundment is the most common form of hydropower and typically is used to store water obtained from a river or water source, at a certain height (Head (m)), which is then discharged to flow through a turbine. The turbine in turn, initiates a generator where electricity is generated [12].

Diversion also known as "run-of-river", diverts a percentage of flow of the running source down a natural terrain decline to generate electricity [12].

Pumped storage systems primarily functions as an energy storage system, utilising another power source (renewable energy) to pump water to an elevated reservoir during low electricity demand periods [12]. The gravitational potential energy of the pumped storage is then converted to useful work via a turbine to generate electricity during high electricity demand periods [12].

1.3 Generative calculation

A turbine converts water pressure accumulated typically by possessing potential energy (Head) into mechanical energy through the turbine shaft [13]. The turbine shaft rotates as a result and is attached to a generator [13]. The turbine shaft rotates the generator shaft and electricity is then generated [13]. The electricity generated via the hydropower system can be calculated through Equation (1) [13, 14]:

$$P_{Gen} = \rho * g * H_n * Q * \eta_t * \eta_p \tag{1}$$

Here:

P_{Gen} = Power generated (W)

ρ = Water density (1 000 kg/m^3)

H_n = Net head (m)

Q = Water flow rate (m^3/s)

g = Gravity (9.81 m/s^2)

η_t = Turbine efficiency

η_p = Pump efficiency

Water pressure can be calculated with the following equation [15]:

$$P_W = \rho * g * H_n \tag{2}$$

Here:

P_w = Water pressure (Pa)

Thus, the final equation can be deduced to:

$$P_{Gen} = P_W * Q * \eta_t * \eta_p \tag{3}$$

1.4 Turbine applications and cases

Literature has shown many efforts to improve the operational efficiencies of the pump-as-turbine (PAT) as well as numerous testing methods via numerical, experimental, and computational trials. PAT's offer many benefits which include [16]:

- Availability for various head and flow
- Various standard sizes
- Inexpensive
- Availability of parts
- Easy installation

Researchers have also focussed on PAT selection and various forms of PAT in different applications as shown in **Error! Reference source not found.**.

1.5 Need and objectives of study

There is extensive literature for PAT's and hydropower in complex water networks, however, there exists a lack in the use of a thermo-hydraulic simulation software. This shortage encompasses the entire water complex, its key performance indicators (KPIs) and developed control strategies designed to sustain production and maintain water supply at identified KPIs.

There exists a need for the use of thermo-hydraulic simulation software to develop an optimal control strategy to reconfigure or specify a PAT for an application to generate electricity and leave the current operations unaffected. The high-level simulation will be able to determine the feasibility of the PAT in the identified system.

The objectives of the study are to generate electricity using hydropower principles, optimise control and test the feasibility with a thermos-hydraulic simulation software as well as predict the output performance of the PAT in large mining and energy intensive systems. The PAT performance will also be evaluated in various applications and configurations exploited for optimum benefit.

Table 1: Applications of turbines in literature

No.	**Author(s)**	**Cit.**	**Computational simulation**	**Description**	**Reconfiguration analysis**
1	Van Antwerpen and Greyvenstein	[17]	No	Variable and constant turbine speed systems can be used to recovery energy and pressure regulation in deep mines	No
2	Liu *et al.*	[18]	Yes	Vertical axis water turbines are analysed under single-phase water and two-phase open channel flow to analyse performance	No
3	Edirisinghe *et al.*	[19]	Yes	Experimental analysis of gravitational water vortex turbines and performance improvement using Computational Fluid Dynamic analysis for different blade configurations	No
4	Velasquez *et al.*	[20]	Yes	Analysis of the basin and inlet channel of a gravitational water vortex hydraulic turbine using the surface response methodology	No
5	Kumar and Saini	[21]	Yes	Analysis of the flow field and performance of a small scale Savonius turbine at a low water velocity	No
6	Badrul Salleh *et el.*	[22]	No	Evaluation of power performance of a conventional Savonius turbine augmented with various configurations using a water channel and wind tunnel with identical flow dynamics	No
7	Khan and Sasikumar	[23]	Yes	Analysis of a water droplet erosion-induced fatigue crack propagation and failure in turbines at low pressure	No
8	Derakhshan and Nourbakhsh	[24]	Yes	Various forms of analysis were utilised to determine the best efficiency point of a centrifugal pump in reverse operation	No
9	Kandi *et al.*	[25]	Yes	The criteria of pump selection for a pump as turbine are modified and performance improved	No
10	Nejadali	[26]	Yes	The performance of a pump as turbine was analysed in a Pico-hydropower plant and revealed an acceptable prediction (excluding very low flows)	No
11	Qin *et al.*	[27]	Yes	A runner optimisation strategy was used to increase efficiency on the high-pressure side in both pump and turbine mode especially focussing on the blades	No
12	Mao *et al.*	[2	Yes	An analysis of internal fluid stability of a pump turbine by reducing the change rate of pressure and improving the flow regime	No

No.	Author(s)	Cit.	Computational simulation	Description	Reconfiguration analysis
		8]			
13	Le Marre	[29]	No	The hydraulic regulation and hydraulic electric regulation were studied in economic and energy terms where a decision-based support algorithm was utilised to conduct the study	No

2 METHODOLOGY

Implementing a hydropower system can be complex and requires adequate financial, logistical, economical, and practical preparation. A solution development procedure has been developed which focusses on achieving the main objectives and ensuring the optimal and suitable solution has been created and chosen for each case.

The “case study methodology” is comprised of four main stages which are depicted the flow diagram, Figure 3 [30].

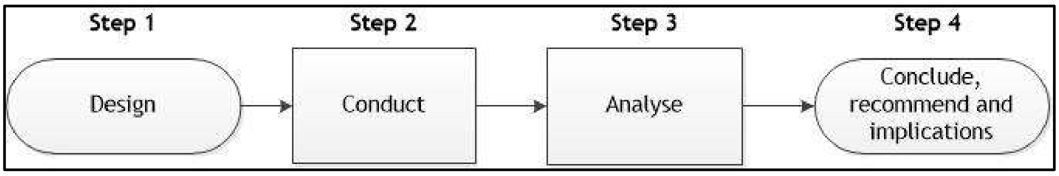

Figure 3: Case study methodology flow diagram [30]

The design step entails determining what is required and developing a procedure which is then reviewed [30]. Thereafter, the case study is conducted and data is collected [30]. The data is then analysed and from the analysis, recommendations and implications are developed [30].

Based upon the original “case study methodology” and adapted for this specific application, the solution methodology includes feasibility studies [31] as well as a simulation section due to numerical and computational benefits for engineering problems [32]. It is also critical to ensure the business aspect is included due to CAPEX (capital expenditure) requirements and approvals for establishments.

The procedure is continuously evaluated throughout with iterative processes, ensuring the optimal solution is selected for the identified problem. Figure 4 exemplifies the adapted method.

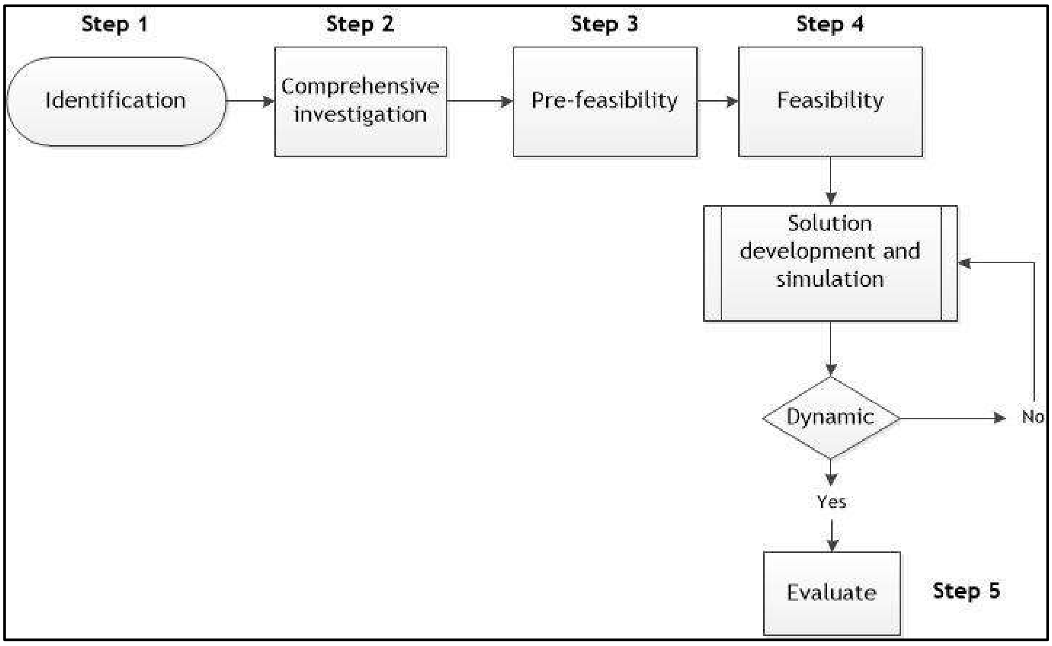

Figure 4: Solution development procedure

Entailing the main components of the engineering design and problem solving process, the procedure was adapted to a computational approach for a more detailed and comprehensive study [33, 34]. The solution procedure identifies the problem with a comprehensive investigation, a solution is developed with the aid of computational power (based on numerical methods favoured by engineering [32]) and verified for important decision making. This process is explained in further detail below.

2.1 Step 1: Identification

Identifying the initial problem and needs is crucial when developing an efficient and successful solution [34]. Identifying the root cause will allow for the correct solution to be designed and selected. Within "Identification", the following topics will be investigated:

- Problem statement (e.g., High energy consumption and tariffs)
- Objective of the project (Possibility to recovery energy)

2.2 Step 2: Comprehensive investigation

Once the problem and needs of the study have been defined, a comprehensive investigation should be completed where all the necessary information relating to the study is assembled. This information will typically include.

- Collect existing information available (maps, layouts, experiments, actual data etc.)
- Perform comprehensive audits on the hydro-system (water source, flow rate, system type and energy recovery type)

2.3 Step 3: Pre-feasibility

To develop a comprehensive solution both a pre-feasibility and feasibility analysis is required to be conducted. This allows and ensures that the solution developed is addressing the problem statement and objectives are met.

The pre-feasibility study primarily screens possible solutions and identifies the most auspicious solutions. It entails:

- Theoretical calculations

- Estimated CAPEX
- Preliminary (Concept) design

The pre-feasibility study will be able to highlight the KPIs and form the basis of the solution method. The return on investment (ROI) will play the vital role in determining whether the hydropower project is viable. Ideally, capital intensive projects are subsequently avoided with an ROI of more than a year [35].

2.4 Step 4: Feasibility

The feasibility study analyses the solution more extensively and permits for a suitable solution to be selected for implementation. It entails:

- Source machinery and equipment with specifications
- Compile CAPEX list for scenarios and obtain pre-approval
- Build detailed simulation with design specifications for various scenarios
- Obtain approval from committee members for capital and project implementation

Once the feasibility study is completed, it will contain a list of possible solutions detailing the process and KPIs of models. From this list, the most suitable is chosen for the application. The ideal solution will also be optimised and improved to obtain the maximum benefit.

Solution development and simulations:

When constructing the detailed model, it is beneficial to follow a structured process. A thorough process that should be followed is shown in Figure 5:

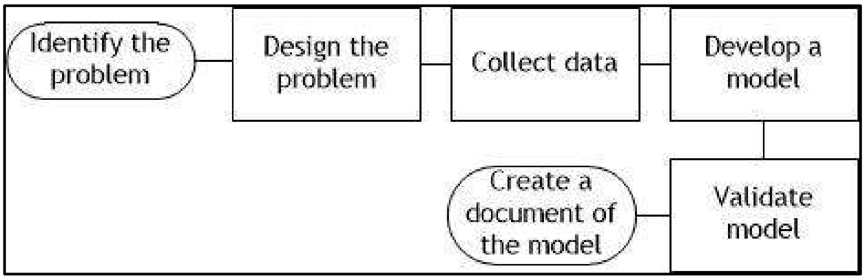

Figure 5: Flow diagram of detailed simulation process [36]

This process allows an initial problem statement to be formed, the problem is then designed with all the factors and data is then collected surrounding the problem [36]. Prior to the model being developed, it is also important consider which simulation software is to be used, as different software's achieve different outcomes [37]. The software must be tailored for the specific purpose.

A model is then developed based on the information collected and validated by modelling various actual scenarios under different conditions and then documented for future use [36]. Minor adjustments can be made to the control strategy to optimise control and obtain the maximum benefit from the energy recovery system. To ensure the optimal solution is modelled, the solution should be dynamic before progressing to the next step of the methodology, thereby ensuring an iterative process.

2.5 Step 5: Evaluate

Evaluating the solution development during the process performed to ensure the quality of stages prior and that the ideal solution has been selected to be implemented. The ideal solution will also be optimised and improved to obtain the maximum benefit.

The updated models are then compared with the theoretical models to distinguish the better option prior to implementation. This step in the process allows for the more suited solution to be selected with a higher quality data set. “Evaluate” performs as a method of quality control. The process of evaluation will determine whether the developed solution is optimal and can further be enhanced. If the process is optimal, further enhancement is void and the solution developed is suitable.

3 RESULTS AND DISCUSSION

Mine X will be used in this paper as the case study to demonstrate how the above-mentioned solution development has been used to identify inefficiencies and effectively develop an adequate solution proposal as well implementation.

3.1 Step 1: Identification

Mine X operates in South Africa and uses approximately 47.14 GWh monthly which equates to R61.4 million. The objective of the study is to implement a developed solution on Mine X where energy can be recovered by means of renewable measures, assisting with the ever-increasing electricity costs.

3.2 Step 2: Comprehensive investigation

Mine X has a total depth of approximately 3 900 m with 3 sets of turbines operating at various levels recovering potential energy and converting it to electricity. The electricity is then rerouted within the grid to the dewatering system, reducing the overall load.

Comprehensively investigating Mine X led to the retrieval of:

- Underground level layouts
- Current underground infrastructure (Dewatering)
- Dewatering supply, demand, and re-circulation
- Current underground energy recovery system
    - Flows to turbines
    - Power generated by turbines
    - Turbine specifications (Pelton turbine)
    - Turbine inefficiencies

Figure 6 illustrates the current underground chilled water supply where it undergoes various stages of energy recovery due to the large depth of Mine X. As discussed in the literature, this type of hydropower system can be concluded to a pumped-storage plant due to the high head and reservoirs that supply further underground.

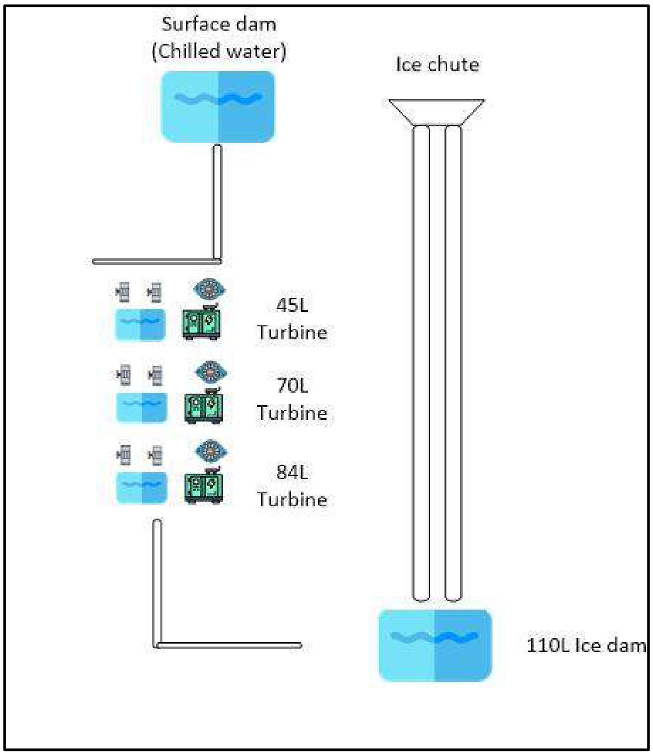

Figure 6: Mine X Chilled water supply

The turbines performance in terms of average flow and power generated are illustrated in Table 2.

Table 2: Turbine performance †

Level (L)	Head (m)	Flow (l/s)	Energy generated (kWh)
45L	1 371.6	240.5	77 135.7
70L	762.0	246.4	46 913.7
84L	426.7	242.3	14 882.4

Due to the high head difference and efficiency of the turbines and generators, the power generated varies significantly. Flow between the turbines remains consistent, however the high head difference allows for more power to be generated as more pressure is then sustained as depicted in Equation (2).

Identified from the extensive investigations, Mine X possesses an impoundment system where a turbine may be installed between the 84L and 110L ice dam. Figure 7 depicts the turbine location.

[†] Table 2 displays the actual and current generative capacity on Mine X depicted in Figure 6.

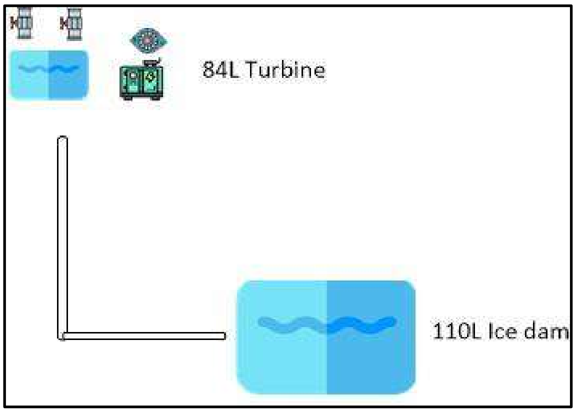

Figure 7: Turbine placement on Mine X

As illustrated above, a head of 792.48 m exists as well as an average flow of 222 l/s. Potential exists to move the equipment to mine X and install as suggested in Figure 7.

Upon the investigation, the following machinery and equipment was located at Mine Y (Within Mine X complex), which was used for an abandoned turbine project:

- Sulzer HPH-54-27/7SIG in reverse operation
- 1.6 MW Generator (11 kV)
- Dissipater valve
- Mechanical isolation valve

3.3 Step 3: Pre-feasibility

Theoretical calculations were competed based on the data collected within the investigation stage and using Equation (1). An approximated value obtained from suppliers was used for the pump and generator efficiencies. Respectively a pump efficiency of 81.4% and generator efficiency of 99% was used to calculate the theoretical generation capacity. The results of the calculations are reported in Table 3.

Table 3: Generative capacity (Theoretical)

Flow (l/s)	Total daily energy generated (kWh)	Average daily power generated (kW)
171.0	25 711	1 071
193.0	29 019	1 209
219.7	33 034	1 376

As a result of reduced average flow rate and lower head, the calculated power generated is considerably lower than the current turbines at Mine X, however, there exists a potential of 1.376MW of energy to be recovered which equates to R14.9 million p.a. based on the Eskom Non-local Authority MegaFlex 2022/2023 tariffs [38] and theoretical calculations.

A preliminary design with the aid of the design office and team of engineers was modelled according to the identified location. The following equipment will be required for a complete pump in reverse operation setup:

- Pump in reverse operation
- Generator (11 kV)
- Dissipater valve
- Mechanical isolation valve

- Flow control valve
- Piping (High-pressure and low-pressure piping)
- High pressure pipe supports, installation pipe installation
- Instrumentation (Pressure probes, flow meters, PLC etc.)

3.4 Step 4: Feasibility

Adhering to the simulation processes explained in the methodology, the following process was followed to achieve an integrated and accurate model.

Identify

The identified problem is to implement a pump as turbine on 110L without affecting the production or the KPIs. The identified KPIs are:

- 110L dam level
- 110L dam temperature
- Flow to 110L
- Power generated from turbine

Design

Figure 8 defines the problem and possible solution that can be implemented. A concept or initial design is required as a blueprint for the detailed model.

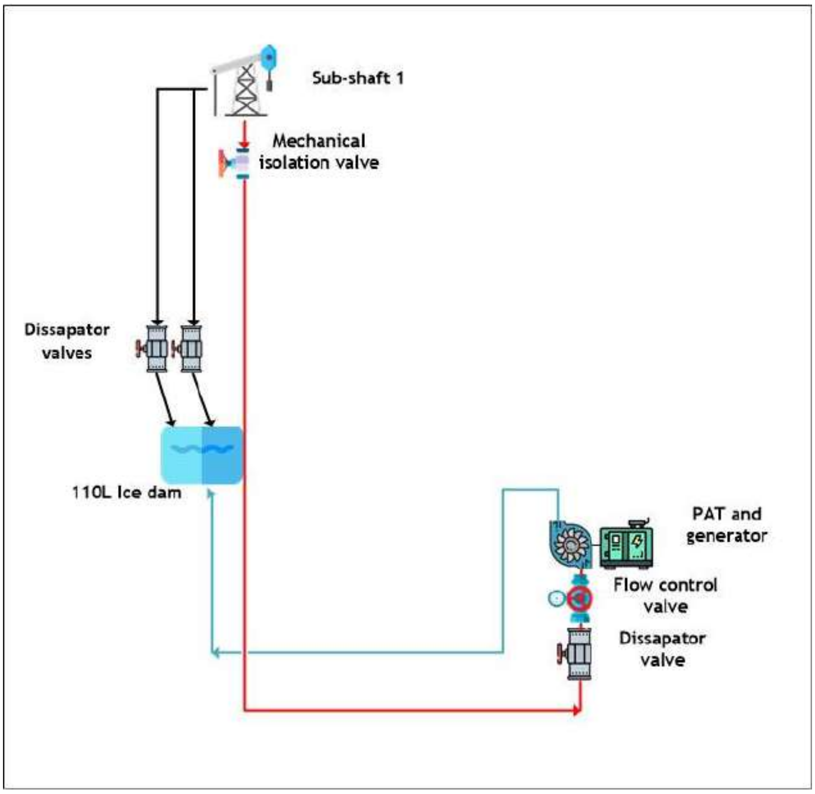

Figure 8: Initial solution design on 110L

Bypassing the 110L ice dam to the pump station, a new high-pressure pipeline (red) has been designed to the existing pump station and newly designed PAT. The low-pressure or discharge (blue) is then fed to the 110L ice dam. Required equipment for the design is a mechanical isolation valve, flow control valve, dissipater valve, PAT, and generator.

Collect data

Majority of required information has been collected in the comprehensive investigation. Figure 9 represents the average flow profile to all the turbines including the flow to 110L ice dam.

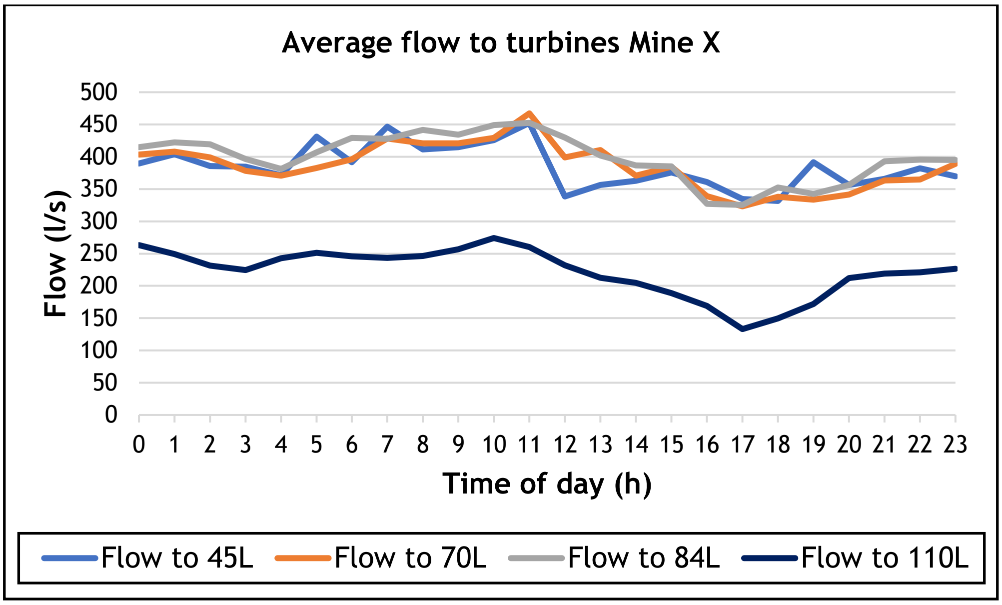

Figure 9: Average flow profiles to underground turbines

With the average flow profile in Figure 9, the pre-feasibility and feasibility studies can be completed. The flow profile can be used to determine an estimate power generation and will be used within the thermo-hydraulic simulation to determine optimal control for the entire turbine system.

Develop model

The model's aim is to confirm the application of the turbine on 110L. A detailed and complex model was developed to simulate the performance of the turbine as well as the 110L dam to ensure there is no negative effect on production (chilled water supply and temperature).

For this specific application as stated by Maré [37], Process Toolbox (PTB) is able to simulate the control of integrated systems and energy management specifically relating to mining refrigeration and dewatering systems. With the aid of thermo-hydraulic simulation software, and the turbine performance curve, a model was developed with the specifications from scenario two, which were obtained from suppliers. The developed model was compared with actual operational data from Mine X and calibrated within a 5% difference.

Table 4 compares the thermo-hydraulic simulation results with the theoretical results. A few instances were calculated for the theoretical section, as single and average profile was used to determine generative potential.

Table 4: Results comparison

	Energy generated (kWh)		
Flow constant (l/s)	Single flow	Flow profile & pressure differential (Simulation)	Simulated
171.0	25 711	25 630	13 390
193.0	29 019	27 315	19 578
219.7	33 034	28 048	23 036

There exists a significant different between the three sets of results mainly because of the simulation which makes use of pressure drops over the system, which the theoretical version does not accommodate. Another set of calculations were performed using the flow profile and pressure differential over the turbine to determine the generative capacity.

Figure 10 depicts the detailed model used for the solution. From the simulation results, it is estimated that an approximate of 1.007MW can be generated which equates to R 10.5 million p.a. based on the Eskom Non-local Authority MegaFlex 2022/2023 tariffs [38].

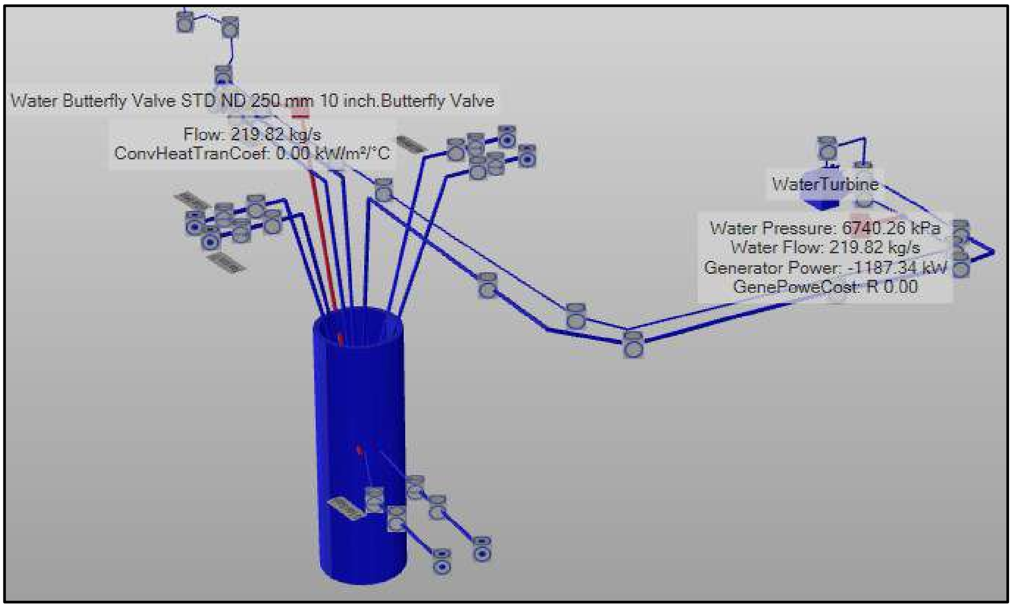

Figure 10: Detailed model in simulation software

The significant difference between the theoretical and simulation results is because of the pipe losses, pressure drop and differential over the turbine which is not considered within the theoretical calculations. As mentioned above.

Figure 11 displays the power generated at a flow of 219 l/s with the aid of the thermo-hydraulic simulation.

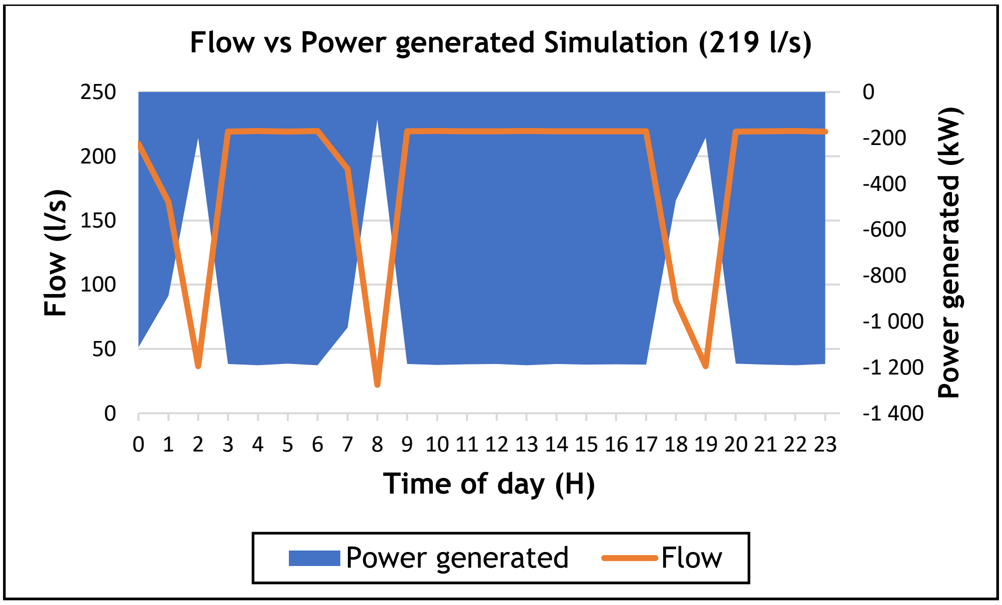

Figure 11: Turbine performance comparison (Simulation)

Although, the generative capacity is an important KPI, the 110L ice dam has significant importance and its performance needs to be modelled in conjunction with the turbine. Figure 12 displays the dam level against the temperature over a 24-hour period at a supply of 219 l/s.

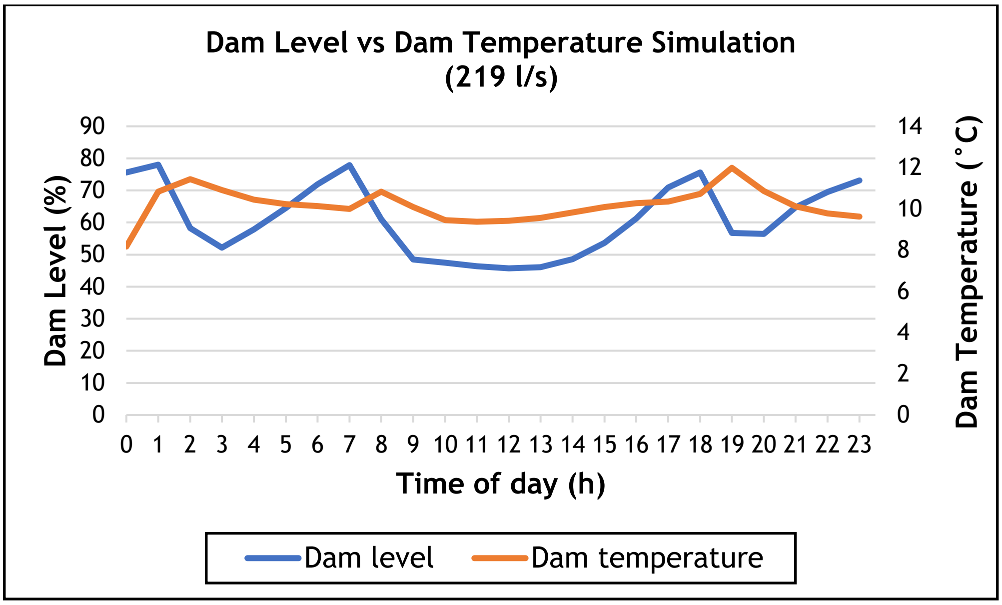

Figure 12: 110L Level and temperature comparison (Simulation)

A requirement of Mine X is to maintain 60% dam level to ensure supply at an average temperature of 11°C to ensure that mining production (ore tonnes) is not affected. The simulation was able to model an average dam level of 60.9% at an average dam temperature of 10.2°C.

Validate

The generated results have been validated in several ways as well as the main KPIs. The generated results have been validated with the turbine supplier as well numerical calculations. The model also corresponded with current conditions on 110L prior to making any adjustments and initiating the turbine.

Create a document

A comprehensive business case was completed and submitted to Mine X's management as well as a detailed report on findings, CAPEX requirements and optimum control.

Equipment sourcing

Equipment was sourced from various companies to complete the CAPEX requirements. This required to apply for capital within the next budget cycle once approved from all the committee members.

CAPEX analysis

The capital requirements were completed for two scenarios for the solution. The first solution is procuring new equipment for the project, while the second scenario, focuses on reclaiming the equipment from Mine Y, refurbishing the equipment to a perfect working order, and re-configuring some equipment to suit the application. Scenario one has a CAPEX requirement of R 9.5 million which would produce a payback period of 11 months at the calculated generated power capacity.

Table 5 tabulates the CAPEX required to execute the second scenario.

Table 5: Scenario two: Reclaiming equipment from Mine Y

Description	Cost
Generator rewind (6.6 kV to 11 kV)	R 570 000.00
Pump refurbishment and derate to a 5 stage (2 Dummy stages)	R 750 000.00
High-pressure pipes (10 inch)	R 991 000.00
0High-pressure pipe installation	R 240 700.00
Pipe supports manufacturing and installation	R 345 000.00
Low-pressure pipes and installation (10 inch)	R 228 000.00
Instrumentation	R 505 000.00
Valve refurbishment	R 354 000.00
Actuator retrofit	R 920 000.00
Total	**R 4 903 700.00**

Based on the theoretical calculations, if scenario two is to be implemented, a payback period of 5.6 months can be expected based on the simulation results. From the above-mentioned CAPEX details, it is recommended to recover the equipment from Mine Y as there is significant reduction in the amount of CAPEX required for the project and the machinery requires minimal re-configuring to achieve the same output as scenario one would. By doing so, the feasibility of the project improves significantly, and a larger return is promised.

3.5 Step 5: Evaluation and discussion of results

Optimal control has been established and the flow maximised to ensure maximal benefit from the turbine while not overloading the system and still adhering to production requirements. The optimal control is displayed in Figure 11 and Figure 12.

A suitable location was identified to recover gravitational potential energy by means of implementing a turbine and generator between two levels with an ideal water flow. A series of numerical and thermo-hydraulic computational simulations were calculated at various water flows. Table 6 illustrates the results comparison.

Table 6: Results comparison

Flow (l/s)	Power generated theoretical (kWh) - Single flow	Power generated simulated (kWh)	Percentage difference (%)
171	25 711	13 390	47.92
193	29 019	19 578	32.54
219.7	33 034	23 036	30.27

Ideally, a constant flow is typically used to calculate potential generation, however it is insufficient and inaccurate as displayed in Table 6. As the flow increases, the difference between the theoretical and simulated generated power decreases. The thermo-hydraulic simulation presents a low generated value as optimal control has been established encompassing the entire chilled water supply system. The thermohydraulic simulation is required for such cases due to the complex nature of the mine and water requirements.

The solution proposed has a generative capacity of approximately 23 036 kWh with considerably less CAPEX by reclaiming and re-purposing abandoned machinery. It equates to R 10.5 million p.a. using the MegaFlex 2022/2023 tariffs. The required CAPEX for the project is approximately R 4.9 million which will incur a payback period of 5.6 months.

4 CONCLUSION

South Africa has experienced severe increases in the cost of electricity over the past two decades, whilst Eskom who owns the monopoly within the country has resisted the idea of renewable energy sources. Within South Africa various renewable energy sources exist, however, hydropower remains the most prominent and viable, especially within the struggling mining sector. Hydropower is the most reliable and cost-effective form of renewable energy to be implemented and should be explored more intensively.

Mine X was used a case within this study to show the viability and possibility of gravitational potential energy recovery. After detailed investigations and various feasibility studies, two proposed solutions were identified. The first scenario requires the procurement of all required equipment, thus a high capital input. Approximately R 9.5 million CAPEX is required to realise the first scenario. Alternatively, the second scenario, requires R4.9 million CAPEX, which is significantly less than the first scenario. It entails reclaiming abandoned equipment from a sister mine (Mine Y) and re-purposing as well as refurbishing the equipment to a suitable operational state.

Numerical calculations were conducted showing a possible generative capacity of 33 034kWh (1.376 MW). A thermo-hydraulic simulation model was built to imitate the actual underground conditions and ensure KPIs were achieved whilst generating energy. Various flows were modelled according to the average flow of 222l/s showing the different generative potential and at different forms of control. The most optimal control and maximum output achieved was at a flow of 219.6 l/s, generating an average of 23 036kWh. The KPIs identified was to ensure the 110L dam maintained an average level of 60% at an average dam temperature of 11°C. The simulation proved an average dam level of 60.9% was achieved at an average dam temperature of 10.2°C.

Concluding, a total of R 4.9 million is required to completely fulfil the solution developed and return a payback of 5.6 months as a possible 23 036 kWh (1.007 MW) can be generated at optimum control within a 24-hour period. This equates to an approximate return of R 10.5 million p.a. The proposed solution promises to resolve a minor problem for Mine X but applied across a variety of mines may ease the cost of the electricity burden and Eskom's overall load.

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INVESTIGATE AND IMPROVE HOW GRADUATE ATTRIBUTES ARE ASSESSED AT THE UNIVERSITY OF JOHANNESBURG – BENCHMARK AGAINST GLOBAL PRACTICES

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ABSTRACT

Graduate attributes (GA) in engineering qualifications are being monitored by Engineering Council of South Africa to ensure that higher institutions of learning are producing graduates that meet international standards. The purpose of the paper is to evaluate how graduate attributes are assessed in the Engineering Faculty at University of Johannesburg (UJ) and compare them to the best assessment methods of GA's that are used globally. Learner guides were used to investigate assessments methods and assessment tools to benchmark with international standards of assessing GAs. The study seeks to determine whether the assessments of GA's at University of Johannesburg can be optimized. Based on literature, GA assessment methods could be improved by using faculty committees, focus groups, softwares and students participation.

Keywords: graduate attributes, assessments, engineering education, modules, continuous improvement.

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1 INTRODUCTION

Engineering education scholars describe the term "graduate attributes" (GAs) as the qualities, skills and understandings that a university agrees its students should develop during their study period with the institution. Higher education institutions (HEIs) around the world are increasingly using GAs to inform curriculum design and to engage with teaching and learning experiences [1]. The mandate for HEIs is to produce graduates that possess disciplinary knowledge and skills which will enable them to cope with the dynamic employment opportunities, and contribute positively to the country's economy [1].

Bitzer and Withering, [2] highlighted that there has been an increased pressure for students to succeed and for higher education institutions to prove their worth in the age of supper complexities. To prove their worth, HEIs across the world are increasingly using GAs as a measure of success when marketing their graduates to industries [3]. It is important for higher education institutions to ensure that graduates' disciplinary knowledge and skills are relevant for industries and in this era of technological and super complexities.

Anghel et al.,[4] highlighted that it is important for students to understand key concepts in learning; they further emphasize that it is very important to know how to use the skills they have acquired to solve real-life problems. The central part of the learning process is the assessment. [4]. The quality of assessment has an impact on the level of understanding of the key concepts and the skills or knowledge acquired by students, including GAs.

2 LITERATURE REVIEW

2.1 Global assessments of graduate attributes

The Canadian Engineering Accreditation Board (CEAB) requires undergraduate engineering programs, as a part of the accreditation process, to demonstrate how effective their programs are in training students GAs [5]. The CEAB adopted the following 12 graduate attributes: Knowledge base, Use of engineering tools, Individual and teamwork, Communication skills, Professionalism, Impact on society and the environment, Ethics and equity, Economics and project management, Lifelong learning, Design, Problem analysis and Investigation [6].

Higher educational institutions in Canada are expected to establish a process that will measure these CEAB graduate attributes throughout the undergraduate engineering programs [5]. The requirement from CEAB is that each attribute must be assessed by at least one direct method but assessments are more meaningful when both direct and indirect methods are used [8]. Essa [14] further highlights that direct assessment methods (tests, exams, rubrics) allow the examination of student knowledge or skills that is associated with the GAs indicators while, indirect assessments (surveys and interviews) focus on assessing students' opinions or self-reflection.

The CEAB criteria for assessing GAs includes having documented assessment tools that are suitable to each attribute and using these assessment tools to gather data on student learning [9]. Rubrics are assessment tools that can be used to gather data on student learning. According to Parker et al., [7] rubrics are the most appropriate tool for authentic assessment since they distinguish proficiency and provide more detailed feedback to students.

The University of Guelph designed rubrics to assess their capstone design courses (modules) within their accredited engineering programs [10]. By using rubrics as assessment tools, the university intended to provide consistency on grading and to improve student feedback [10].

The University of Toronto created rubrics to assess graduate attributes which are design, communication, teamwork, problem solving and investigation [7]. Lecturers designed their rubrics to suit their individual course requirements [7]. The university used focus groups with students and lecturers to ensure clarity in rubric terminologies, develop proficiency levels and to provide direction for course development and improvement.

For the assessment of GAs, the University of Ottawa implemented an approach that gives freedom to lecturers that are involved in assessing GAs for a particular module to identify the most appropriate GAs and use it for their module evaluation [5].

The assessment criteria for capstone projects at The University of Turku, in Finland, focused on developing design thinking which considers analyzing the problem, concept evaluation, prototyping, communication and innovative solution [4]. Peer assessment was included as part of the realistic assessments that was developed [4].

In the United States of America (USA), the accreditation requirements from the Accreditation Board for Engineering and Technology (ABET) is that engineering faculties must have a vision, and must collectively articulate and prioritize knowledge and skills that students should gain from their programs [11]. Cicek [12] found that graduate attributes such as teamwork, communication, data analysis and problem solving are ranked as the top used graduate attributes in engineering programs in the USA. The graduate attributes that were ranked the lowest are: design of experiments, contemporary issues and understanding the impact of one’s work [12].

In the USA and Canada, the accreditation of GAs was introduced through their accrediting bodies which are ABET and the CEAB [12]. Passow [13] confirms that graduate competencies that are assessed in ABET are similar to the 12 graduate attributes that are assessed in CEAB. Universities in the USA adopted different softwares to assess student competencies. Some engineering programs adopted a courseware database system to facilitate assessment processes [14]. The database maps assignments to module outcomes, and it is effective for organizing information that is required for an assessment report [14].

The University of Georgia adopted an open course management software called Moodle, which is used to store student portfolios for their projects, as the basis for the assessment process [14]. Essa [14] further highlights that this software also manages and stores data that is required to save and document students’ achievement records of module outcomes.

The University of Nevada designed and developed an ABET course assessment tool (ACAT) system which assists faculties to produce course assessment reports for ABET accreditation however, the system only assesses the assessment at the course level and leaves out the course assessment results to student outcomes [15].

Internationally, graduate attributes are assessed using direct and indirect methods. Rubrics are used as tools to provide more detailed feedback to students for assessments. Focus groups consisting of lecturers and students are also utilized to ensure clarity on terminologies that are used on rubrics.

2.2 Improving graduate assessment methods

The graduate attributes and continuous improvement processes (GACIP) was introduced to help faculties of engineering across Canada to identify and implement program improvements that are meaningful [16]. In Canada, engineering faculties have since been re-assessing and reshaping the traditional approaches to curriculum design and assessment to integrate all 12 graduate attributes into their engineering programs [7].

In Canada, engineering programs and GAs that needed improvement were identified in order to brainstorm different strategies and solutions that can be implemented. The CEAB identified the following as GAs that are difficult to teach and assess, and need to be improved: Impact on society and the environment, Ethics and equity ,Economics and project management, and Lifelong learning [16].

For capstone courses, CEAB advocated for communication education to be included throughout the engineering program [7]. The inclusion of communication education in capstone courses is anticipated to improve capstone courses and help students gain more knowledge and experience and be better prepared for employment.

Academic staff in Australia reports that assessing GAs has been challenging for the past decades and believe that the solution to the challenge is more engagement with staff to share understanding on the teaching process and GA assessment [5]. Parker et al.,[7] cited in George et al.,[5] suggest that empowering instructors to identify GAs that are most integrated into their modules is far better than adopting the mandatory GAs that have already been prescribed by the board.

The University of Alberta detailed the continuous improvement approach that they implemented was the post-course assessment system (PCAS); this approach mainly pushes for curriculum changes [7]. The PCAS approach also prompts lecturers to reflect and report on the successes and challenges [17]. Reflecting and reporting on successes and challenges help lecturers to identify areas that need improvement.

At the University of Manitoba, “committees involved” strategy was implemented at faculty-level and it was used to evaluate information, identify and prioritize areas that need revision. Through the strategy, they would then make recommendations and advise the department-level committees for implementation in their programs [7].

Parker et al.,[7] further highlighted that McGill University had an opposite flow of the “committee involvement” approach. They mentioned that relevant changes were made by department-level committees, and put to vote after being submitted in an annual report to faculty-level committees [7].

To measure program performance for continuous improvement against GAs , the University of Ottawa established a continual program evaluation and improvement cycle that is shown in Figure 1. Assessing program performance against program expectations for all GAs requires a review program procedure leading to actions needed for program improvement [5]. Figure 1 shows that program performance is a cycle, it needs to be continuously evaluated in order to continuously identify problems and improvements.

Several important features of continuous improvement processes were mentioned by authors from Queen’s University. The features are clear goals and planning, good leadership, supportive software and the generation of useful information [18]. Having these features in place could help to successfully implement a continuous improvement program in engineering faculties.

In ABET accreditation, continuous improvement is a two-phase process: attainment of student outcomes per cycle and continuous syllabus improvement per semester [19]. They further report that this process uses direct and indirect assessments to collect data. Academic Accreditation Committee is responsible for evaluating and analyzing the data and developing methods to improve the attainment in the next cycle [19]. This improvement approach is similar to the approach that is adopted in the University of Ottawa, in Canada.

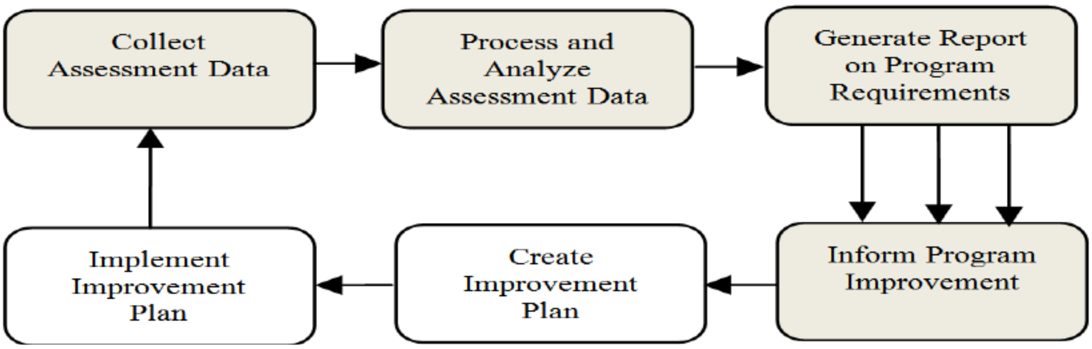

Figure 1: Program Evaluation and Improvement Cycle [5]

It can be seen that, in the investigated universirties, curriculum design and reshaping of traditional methods of assessment is used in order to improve the ways in which GAs are assessed. Post course assessment system is another approach used to report on challenges and success of GAs assessment. Many universities have adopted committee at the faculty or

2.3 Graduate assessment in South Africa

The Engineering Council of South Africa (ECSA) is a member of the International Engineering Alliance (IEA) and a signatory of Washington, Dublin and the Sydney Accords [20]. If an engineering education program is accredited by one signatory in a member state, it is then recognized by other signatories as being equivalent to their own accredited degrees [20]. Just like the ABET and CEAB, ECSA has developed GAs for engineering programs in South Africa (SA).

ECSA prescribes that engineering programs in South African universities must assess the following graduate attributes: Problem solving~~;~~, Application of scientific knowledge, Engineering design, Investigation, Experiments and data analysis, Engineering methods, skills and tools, including information technology, Professional and technical communication, Sustainability and impact of engineering activity, Individual, team and multidisciplinary working, Independent learning, Engineering professionalism and Engineering management [20]. These graduate attributes correlate with the 12 graduate attributes adopted by the International Engineering Alliance (IEA) [21].

The aim of this study is to investigate the assessment of GAs in the Faculty of Engineering and the Built Environment (FEBE) at the University of Johannesburg (UJ) and compare with international standards. The study will also explore various improvement methods for GA assessments in the engineering education curriculum. FEBE is offering three-year Bachelor of Engineering Technology (BEngTech) programs that are ECSA accredited. This paper is not investigating compliance or non-compliance of the departments for accreditation process

3 METHODOLOGY

The research paper followed a qualitative research method which is defined by Strauss and Cobin [22] as a type of research that produces findings not arrived at by a statistical method. It is a kind of research that can be used when investigating lived experiences, behaviours, emotions, and feelings with regard to people's lives. Qualitative research is also applicable when organisational functioning, social movements, cultural phenomena, and interactions between nations are researched. Qualitative research approach produces the thick description of participants' lived experiences [23]. This method was useful in gathering data on how graduate attributes are assessed across the faculty. One approach that is used in qualitative research methods is document analysis. According to Bowen [24], document analysis is a process where printed and/or electronic documents are evaluated and analysed in a systematic way. Fot the purpose of this research document analysis data was conducted where learner guides were examined and interpreted so as to gain meaning, understanding and knowledge of how graduate attributes are assessed at UJ. A systematic document analysis was conducted to investigate how graduate attributes are assessed in three engineering technology departments. Convenient sampling was used where the researchers chose three departments which are Mechanical, Industrial, and Chemical Engineering Technology. It was convenient for the researchers to collect data from Mechanical and Industrial Engineering Technology departments because they are lecturing in these departments. Final year modules that are assessing GAs were selected and analyzed.

The learner guides were interrogated for the final year modules in the respective qualifications. From the learner guides, the researchers were looking for which GA is assessed and how it was assessed.

4 FINDINGS

Data shows that GAs at UJ are assessed in final year modules using assignments, research manuscropts, projects, lab reports and tests. Assignments and projects dominate as assessment methods in the three engineering technology departments (Mechanical, Industrial, and Chemical). Rubrics and peer evaluations are used for grading students' performance. Data reveals that the assessment of GAs' is designed by module lecturers. Data analysis is presented in figure 1.

5 DISCUSSION

The aim of the study was to investigate how GAs are assessed at UJ and compare with international practices. Furthermore, the authors argue on approaches that can be used to improve GA assessment. Data shows that assignments, projects, labs and tests are used. There is insufficient data from literature to support UJ's approach to GA assessment. This is by no means an indication that elsewhere these assessment methods are not used. However, there is common approach at USA, ABET; in Canada, CEAB, in SA, ECSA. Some institutions are using Faculty based frameworks such as committees, while others are using softwares (data bases) to consolidate results. There seems to be no evidence of such a structured approach at UJ, as they seem to rely on individual module lecturers.

At the University of Guelph and the University of Toronto, rubrics are designed by students and lecturers, which is a collective approach that is used for direct assessments. The benefits of this approach could be a subject of discussion in another study. UJ's approach of using rubrics as assessment tools is also supported in Canada. Confidently lecturers have differentiated between GA rubrics and mark allocation sheet. This approach is commendable, as it ensures that students are part of the assessment process. The approach of using rubrics is also commendable because it distinguishes the levels of student proficiencies~~,~~ and provides detailed feedback to students and a clear direction for improvement [7].

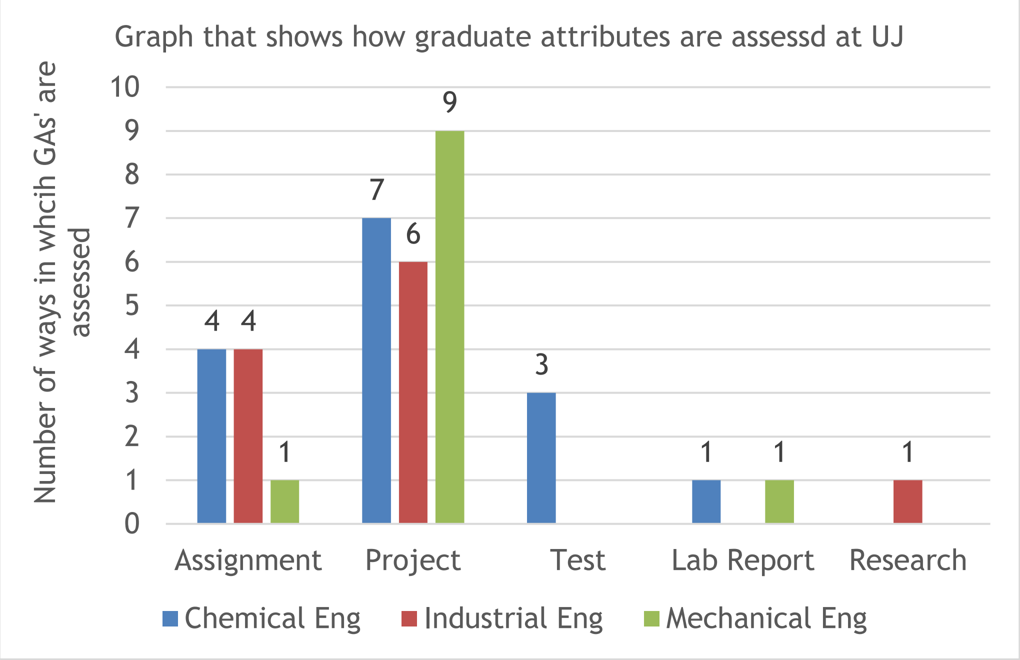

Figure 2: Assessment methods used to assess GAs

For indirect assessments, Universities in Canada use the student survey approach; this approach focuses on student perceptions of the GA development in their programs [7]. Focus groups between Faculties and industry representatives are also prevalent in Canada. There is no evidence of a continuous improvement process from the data, like student survey and, focus groups composed of lecturers, students and industry to look into detail of the assessments methods used to assess graduate attributes.

At the University of Manitoba, Faculty-based and departmental-based committees are used to evaluate information that is collected from surveys and make recommendations on areas that need improvement [7]. Engineering technology departments at UJ could also adopt a similar approach in order to identify areas of improvement in their programs.

To measure program continuous improvement, the University of Ottawa and ABET have tools for that purpose. The tools include~~:~~ courseware database system which facilitates all assessment processes and produce assessment reports [13], ACAT system which also assist Faculties with creating course assessment reports [14], and the PCSA system which focuses on post-course reflections and reporting on the course challenges and successes [16]. Engineering technology departments could develop continuous improvement tools as well. An approach to monitoring and continuous improvement of GAs assessment, adopted at departmental level, is recommended to be implemented in all FEBE departments at UJ.

6 CONCLUSION

There is evidence that UJ is assessing GAs as required by ECSA, aligned with the IEA partners. In engineering faculty at UJ, assignments, projects, tests, and lab report are used by individual lecturers to assess graduate attributes. These direct methods may be complemented by indirect methods of assessment as is the practice in other universities. Global practices also uses faculty and departmental committees and softwares to monitor and moderate the GA assessments. GA assessment methods at UJ could be improved by using faculty and departmental committees that monitor and design tools for improvement. Some of the suggested tools, as found to be used in other universities, are the focus groups that include industry partners and students, or student surveys. Furthermore, well-designed data softwares could be incorporated into design thinking process.

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EXPLORING DIFFERENT APPROACHES TO ASSESSING GRADUATE ATTRIBUTES THAT ARE PERCEIVED TO BE CHALLENGING

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ABSTRACT

The required competencies of an engineering graduate are regulated by ECSA (Engineering Council of South Africa). These are clearly defined Graduate Attributes (GAs). The study explored and presented the methods used to evaluate those GAs that are perceived as hard to assess. A qualitative research method based on data analysis was used. Data were collected from the Learner guides of the modules assessing GAs. The aim was to provide an overview of the assessment practices for GAs like communication, teamwork, sustainability and impact of engineering activity, professionalism and lifelong learning. This investigation would establish whether these GAs were appropriately understood and evaluated and whether possible improvements should be considered.

Keywords: graduate attributes, competencies, assessment, hard to assess

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1 INTRODUCTION

In higher education, outcome-based assessment is described as a planned process of eliciting evidence from students to judge their level of competency. These graduate attributes (GAs) are based on the requirements of the Engineering Council of South Africa (ECSA). It has emerged in engineering education that 'professional skills are now considered equally or more important for young engineers to develop than the finite scientific and technical content knowledge of traditional input education models [1]. In response to the widespread industry call for universities to produce graduates that are ready for employment, the professional accreditation bodies have raised the bar. Many universities have revised and updated their qualifications to have emergent graduate attributes embedded in their curriculum. The assessment of engineering graduate attributes is a complex and challenging task and may be perceived differently by the various stakeholders [2].

The International Engineering Alliance (IEA) is a not-for-profit organisation, consisting of 41 institutions from 29 countries. They are charged with the responsibility of establishing and enforcing 'internationally benchmarked standards for engineering education and practice' [3]. The organisation drives quality improvement and global mobility in engineering by developing, through educational accords, a set of graduate attributes (expected competence) that technicians, technologists, and engineers should have for professional practice [3]. The Engineering Council of South Africa (ECSA), a signatory of the Washington, Sydney and Dublin accords, developed the graduate attributes required for South Africa based on the IEA regulations [3]-[5].

Difficulty in assessing certain GAs has been expressed by academics and assessors [6]. Some GAs are explicit and straightforward to assess, while others are subjective, belonging to the non-cognitive invisible domains (collaborative skills, communication, teamwork, work-life readiness skills: resilience and time management). These GAs involve soft skills which are beyond the boundaries of discipline content [7], and therefore hard to assess. It is important to nurture students who are actively reflecting on their role, and experience in their identity development as professionals and value-adding members of society. However, a challenge stems from the question of how best can one elicit authentic evidence of the development of these desired attributes in the graduate qualifications using the assessment rubrics?

For assessments to be fair and serve the objective of knowledge judgement, the assessor needs to understand the depth and dimension of the outcome to be assessed and communicate such to the students. The assessor needs to know how best to facilitate the skills of articulation and, most importantly, obtain the required evidence to make an objective and informed judgment from the students' submissions. When these complementary factors are not in congruence, the aim of authentic evaluation of students' knowledge and acquired experience is undermined. It can be argued that when the capability and understanding required of the assessor to effectively implement these roles is lacking, it exacerbates the difficulty to develop the best approach for assessing certain long-life learning outcomes. This dysfunction may underrate the qualification of graduates produced and underscore the outcomes promised in the university graduates' profile.

A perusal of recent literature shows a dearth of research on these grey areas of graduate attributes assessments in engineering, referred to as "hard to assess". The current study aims to demystify this concept and identify steps to improve the assessment process. Hence, it sets out to answer the following research questions:

- What are the GAs that are perceived as hard to assess?
- What methods of assessment are used in the Faculty of Engineering and Built environment (FEBE) at the University of Johannesburg (UJ)?

- Are these GAs appropriately understood and evaluated?
- How can the assessment process be improved?

2 LITERATURE REVIEW

It is important to ensure that all Graduate attributes are embedded into the curriculum and to use them to continuously improve teaching, learning and assessment [8]. Some of the graduate attributes can be embedded into the curriculum naturally [9]. However, some of the graduate attributes may require additional teaching and learning. The graduate attributes that integrate into the engineering curriculum easily are GA 1 – Problem-solving, GA 2 – Application of scientific and engineering knowledge, GA 3 – Engineering design, GA 4 - Investigations, experiments and data analysis and GA 5 - Engineering methods, skills and tools, including information technology. The GA 6 - Professional and technical communication is naturally embedded in technical drawings and the writing of reports. Often students are required to do presentations as they would in the industry [10]. GA 7 - Sustainability and impact of engineering activity, is a crucial topic that was not always taught in the curriculum however, most universities currently include this as part of their curriculum. GA 11 – Engineering management is also embedded into the curriculum naturally.

The graduate attributes that are not naturally embedded in the curriculum are sometimes seen as even more difficult to assess [11]. The development of non-technical skills in a technical qualification can be complex [12]. The graduate attributes that are not embedded as naturally are GA 8, GA 9 and GA 10. Often these GAs are also described generically which leads to variability between institutions [13]. GA 8 - Individual, team and multidisciplinary working is also an important aspect of being an engineer and although there have often been group projects in the curriculum in the past, teamwork was not necessarily assessed. Ensuring students are exposed to multidisciplinary work is sometimes a challenge. GA 9 - Independent learning, is a skill required to become an engineer it is, however, not something assessed specifically within the curriculum. GA 10 - Engineering professionalism is another skill that is important but not naturally assessed in the curriculum.

It is hypothesised that in the Mechanical and Industrial Engineering Technology (MIET) department, GA 7, 8, 9 and 10 will be perceived as hard to assess. Although GA 7 is taught within the curriculum it is often not taught at the final year level where all GAs are assessed. This would then require an assessment in a subject that does not necessarily teach sustainability and the impact of engineering activity. In this literature, we, therefore, focused on GA 7, 8, 9 and 10.

The assessment of graduate attributes can be done directly or indirectly. These assessments can be done through laboratories, assignments, projects and case studies. It is also possible to assess as part of tests or exams [14]. The University of Johannesburg's department of Mechanical and Industrial Engineering decided not to use exams or test to evaluate graduate attributes [15]. The Engineering Council of South Africa (ECSA) prescribes which graduate attributes are required and provides range statements for each of those graduate attributes [16]. ECSA does not prescribe how graduate attributes should be assessed and an agreement was reached that graduate attributes should be achieved or not achieved rather than assigning a mark to the graduate attribute. Competency levels are hard to assess and it is complicated to link competency to a numerical mark to grade it [17].

A previous study at UJ concluded that the academic expertise and the ECSA range statement describing each graduate attribute may not be sufficient. A shift toward a student-centred learning-oriented approach that focused on the development of knowledge and skills was advocated [8]. It was also advocated that indirect assessment of graduate attributes at the institutional level would be beneficial to ensure continuous improvement. All exit level graduate attributes had to be moderated, there is value in registered professional engineers moderating these GAs.

The Conceive Design Implement and Operate (CDIO) education approach promotes for engineering fundamentals to be taught in the context of conceiving, designing, implementing and operating real-world systems and products. The CDIO syllabus suggests verbs to use to assess all the skills required according to this syllabus [18]. These verbs are in line with Bloom's taxonomy [19], [18]. These statements, together with the range statements of the graduate attributes as defined by ECSA, can help to guide the assessment of the graduate attributes that are more difficult to assess.

2.1 Sustainability and impact of engineering activity - GA 7

Sustainability is not only a part of a graduate attribute for engineers but it is also the goal of most higher education institutions to teach [20]. It is argued that it should also be embedded in engineering education. In Europe, the competencies required in line with European Higher Education Area (EHEA) descriptors for the sustainability, of three European Universities were compared and discussed to determine whether all important aspects were covered [21]. Many initiatives for Education for Sustained Development (ESD) originated after the Rio Earth summit declared the Decade of Education for Sustained Development (DESD) (2005- 2014). Learning for sustainable development requires skills in understanding norms and values and developing a deeper sense of ethics, systems thinking and working in multidisciplinary teams. Curriculum redesign may be required to teach sustainability effectively [22].

2.2 Individual, team and multidisciplinary working – GA 8

Evaluating individual work happened naturally within the normal assessment process. Teamwork is a key skill to teach in engineering however for educators to improve student performance they need to be able to identify the student’s strengths and weaknesses. A checklist to evaluate teamwork was developed in Spain [23]. This is potentially a valuable tool to use when assessing GA 8. In Canada, teamwork training modules were designed to be completed in each semester of the student's curriculum. These modules had to integrate with existing course activities to ensure long-term use [24]. At the Central University of Technology in South Africa, the graduate attribute of teamwork was embedded into activities educators specified for their students [9]. A literature review done in the US identified attributes of effective teamwork in engineering [25]. The attributes identified were:

- Shared Goal and Value,
- Commitment to Team Success,
- Motivation,
- Interpersonal skills,
- Open/Effective Communication,
- Constructive Feedback,
- Ideal Team Composition,
- Leadership,
- Accountability,
- Interdependence and Adherence to Team Process and
- Performance [25]

Multidisciplinary teamwork is often important to solve complex real-world problems. Engineering students need to learn how to identify the limitations and strengths of different disciplines. Communication and socialisation become even more important in multidisciplinary teams [26]. Sustainable engineering specifically requires multidisciplinary work. Some universities include multidisciplinary teamwork as part of their capstone project [27].

2.3 Independent learning – GA 9

Engineering fields change continuously and as such, engineers need to remain in touch with current developments which is why it is so important for students to learn independently throughout their careers. If a student can learn how to learn then anything is possible [28]. To have mastered lifelong learning it is important to recognise the need for lifelong learning and to engage in lifelong learning. Several actions were identified to measure recognition of the need for lifelong learning. These actions are:

- Willingness to learn new material on their own.
- Reflecting on their learning process.
- Participation in professional societies' activities.
- Reading engineering articles/books outside of class.
- Attending extracurricular training or planning to attend graduate school [29].

Nine skills to engage in lifelong learning were also identified they were:

- Observe engineering artefacts carefully and critically, to reach an understanding of the reasons behind their design.
- Access information effectively and efficiently from a variety of sources.
- Read critically and assess the quality of information available (ex. question the validity of information, including that from textbooks or teachers).
- Categorise and classify information.
- Analyse new content by breaking it down, asking key questions, comparing and contrasting, recognising patterns, and interpreting information.
- Synthesise new concepts by making connections, transferring prior knowledge, and generalising.
- Model by estimating, simplifying, and making assumptions and approximations.
- Visualise.
- Reason by predicting, inferring, using inductions, questioning assumptions, and using lateral thinking [26].

2.4 Professionalism and ethical behaviour – GA 10

Engineering education is about more than just keeping students at the cutting edge of technology but also understanding the soft skills that are required in the world around engineering activities. Ethics instruction has been superficially effective. The specific objectives when teaching professional and ethical responsibility can be divided into three sections: 1-emotional engagement, 2-intellectual engagement and 3-particular knowledge [30]. It is argued that the first is the most important which concerns the development of a student's desire to recognise, care about and resolve ethical issues. The second was concerned with the development of the student's understanding on an intellectual level and the third is about the knowledge of ethical codes, issues and precedent [30]. It has been found that case studies are an effective tool for teaching ethics and professionalism [31]. It can also be applied in projects [30]. Professionalism and ethics teaching can proceed in line with the CDIO syllabus. The main aim should be to teach ethical, economic and technical value judgement as well as ethical willpower. It was suggested that an ethics course in the curriculum would be more effective than making it part of an already existing module [32].

Literature does therefore provide us with some guidance as to how these attributes can be approached. It is, however, not conclusive and further research would be beneficial.

3 METHODOLOGY

In this paper, a qualitative research method-based on document analysis was used. The initial step was to conduct an exploratory study to determine the assessors' view of GAs because the literature does not adequately guide the assessment of challenging GAs. A google form survey link was created and distributed among the lecturers in the MIET department at UJ. The form asked directly "*Which GAs do you perceive are difficult to asses?*". In addition to this, academic staff in the department were approached in person to increase the number of responses. The survey indicated that the participation is voluntary and the participant gave their consent to use the findings by completing it.

The MIET department is one of the largest in the engineering faculty, offering two Bachelor of engineering technology (BEngTech) programmes, which are not closely related. The lecturers in the department are involved in the assessment of GAs. The findings were summarised and results were used to determine the GAs that form the scope of the study.

To present the methods of assessment of the GAs under study, data is collected from the Learner guides that provides rubrics of modules assessing the specific GAs. Five engineering technology programmes are reviewed in the field of: chemical, civil, electrical, mechanical and industrial engineering technology. A document data analysis will provide a perspective on the assessment practices and the possible improvements that should be considered. In the Learner guides we only focused on the information relevant to GAs.

In this methodology we were looking specifically for the GAs assessed, how the GAs were assessed, the type of assessment and the rubric in terms of the achievement criteria. A rubric should provide assessment indicators that are addressing the GA's range statement and also the levels of competency. An excellent rubric will cover all range statements in detail while a good rubric addresses range statements but not comprehensively. A poor rubric does not address the range statements, it is not easily understood and/or does not provide levels of competency.

4 FINDINGS

The results of the survey show that both GA 7 and GA 8 have been selected as being hard to assess, followed by GA 10 and GA 9. These are GA 7 - Sustainability and impact of engineering activity, GA 8 - Individual, team and multidisciplinary working, GA 9 - Independent learning, and GA 10 - Engineering professionalism. The types and methods of assessments for these GAs are presented below.

4.1 Sustainability and impact of engineering activity - GA 7

Graduate Attribute 7, requires the learner to "demonstrate critical awareness of the sustainability and impact of engineering activity on the social, industrial and physical environment" (E-02-PT, 2020).

Chemical Engineering Technology assesses GA 7 in one module through projects and tests for which an online rubric was created. It is unclear how the rubric assesses GA 7 and what constitutes an achieved competency. The other module called Environmental Engineering is used a test and an assignment with selected questions that allow students to show their understanding and knowledge of the impact of engineering activities. These assessments combined GA 7 and GA 9, and a common rubric showing the specific questions is provided. Although the rubric exhibits five levels of competency, there is no clear indication for an external observer as to which question assesses which GA and what constitutes the achievement of competency.

A group project is used in Civil Engineering Technology specifically to measure competency in principles of sustainability. The provided rubric has three major criteria; economic, environmental and social sustainability with detailed sub-criteria and five levels of competency and it is a clear indication of what represents the achievement of competency.

Electrical Engineering Technology is asking students to complete an assignment or to do a case study on any engineering work within standard codes that involves two stakeholders with conflicting needs. A "compliance rubric" is provided with four relevant criteria and six levels of competencies. Although the assessment is designed in such a way that addresses GA 7, 9 and 10 each GA has a well-defined rubric.

Industrial Engineering Technology is assessing GA 7 through a specifically designed assignment that comprehensively addresses the given range statement in terms of the following:

- impact of technology on society,
- occupational and public health and safety,
- impact on the physical environment,
- personal, social, and cultural values of those affected by engineering activity and includes risk assessment, management and sustainability issues.

A rubric for evaluating the task is provided together with an additional rubric for the GA achieved/not achieved fulfilment.

Table 1: Summary of GA 7 assessment

Programme	Type of assessment	Rubric for GA assessment
Chemical	1. Project and test 2.Test and assignment	On-line, very summarised Not specific
Civil	Group project	Detailed rubric with three major indicators and five levels of competency
Electrical	Case study/assignment	Detailed rubric with four relevant indicators and six levels of competency
Industrial	Assignment	The assessment rubric covers four indicators related to the GA. Additional rubric for the achieving/not achieving of GA is provided.
Mechanical	Final year project	Detailed rubric, four indicators and four levels of competency

A component of the final year design project is used in Mechanical Engineering Technology whereby the student must show a clear understanding of sustainability and the impact of engineering activity on both the people and the environment. The requirement is that the elements of sustainability based on the product life cycle and from a systems engineering perspective must be clearly articulated, and communicated. The rubric is assessing four indicators which consider diverse perspectives, considers the impact of engineering interventions, personal and collective responsibility and lastly, health and safety issues, on four levels of competency.

There are a variety of direct methods of assessment used to measure the awareness of a student regarding sustainability and the impact of engineering activity as shown in Table 1. This includes individual or group project, case study, test or an assignment that targets the related outcomes. The assessment rubrics, in most cases, are fairly detailed and, in some cases, are assessing the same outcomes. However, the assessment indicators are articulated differently, according to the assessor's understanding of the GA. Of the investigated engineering programmes, only one offers a specific module on sustainability and the impact of engineering activity. Thus, to raise awareness about the implications of any engineering activity an independent learning task may be given such that, one assessment will often combine GA 7 and GA 9 and in some cases GA 10 as well.

4.2 Individual, team and multidisciplinary working - GA 8

This GA requires to "demonstrate competence to work effectively as an individual, in teams and multidisciplinary environments" (E-02-PT, 2020).

The approach to assessing this GA used by chemical engineering technology in a process design project is through a group report and group questionnaire. It is expected that each student contributes a portion to the group design and his/her contribution is evaluated by a questionnaire. The module assesses other GAs and although there is a rubric for the evaluation of the project report there is no specific rubric for the evaluation of GA 8. There is a common rubric listing all the GAs assessed by the project whereby a yes/no is required. Chemical Engineering Technology is assessing GA 8 in another module through peer evaluation forms and oral presentations, as stated in the learner guide. There is a competency rating rubric that presents satisfactory compliance of GA 8 based on peer evaluation, group report, individual delivery, content and questions. The presentation is expected to reflect that the student was involved in group meetings and his/her section was linked to other's sections.

In Civil Engineering Technology, GA 8 will be assessed in a project group report. A general rubric is provided for the evaluation of the task with two parts, one for the group evaluation and the other for individual evaluation. However, there are no levels of competency and no relation to the GA is provided.

The information regarding the assessment of GA 8 was not found for the Electrical Engineering Technology programme. Industrial Engineering Technology mentions the assessment of GA 8 in an assignment and a generic rubric is provided with achieved/not achieved levels of competency.

Mechanical Engineering Technology examines GA 8 through peer review, on-site spot checks in a laboratory, assignment feedback and interpersonal relationship of the lecturer/laboratory support staff with the student. The assignment is a mini-project. A rubric for GA 8 assessment with separate indicators for individual and teamwork is provided, with four levels of competency.

Table 2: Summary of GA8 assessment

Programme	Type of assessment	Rubric for GA assessment
Chemical	1.Design project-group report and questionnaire 2. Peer evaluation and oral presentations	1. A rubric is used for the task however, no specific GA rubric is provided. 2. Competency rubric is provided.
Civil	Project group report	A rubric for the task is provided however, no GA-specific rubric.
Electrical	Missing information	Missing information
Industrial	Assignment	Generic rubric with two levels of competency
Mechanical	Peer review, on-site laboratory checks, mini-project assignment and interpersonal relationship between staff and student	Specific rubric with separate individual and team work on four levels of competency.

The type of assessment given for the evaluation of GA 8 is usually a project, mini-project or an assignment as summarised in Table 2. The method of evaluation is through one or a combination of a report, oral presentation, peer-review site spot checks and interaction between students and staff.

Some assessments are designed to combine the individual contribution of the team members into a final report thus, minimising the opportunities for collaboration. In many instances, the assessment specifies the task for each student, reducing the chance for the team members to interact and decide for themselves how to approach the problem and divide the task. The specific rubrics whenever presented evaluate GA8 on different indicators or sets of competencies with no commonality.

It seems that the assessment of team, individual and multidisciplinary work is rather complex as it has to capture the competency in three various aspects of engineering work. Although it is easy to measure one's individual effort in a given task, it is difficult to measure one's involvement in a team joint effort. This GA involves many aspects that require careful consideration especially in formulating the assessment indicators. Multidisciplinary work is not reflected in the assessment task nor the rubrics provided.

4.3. Independent learning ability – GA 9

For Graduate attribute 9, the learner must "demonstrate competence to engage in independent learning through well-developed learning skills" (E-02-PT, 2020).

As seen in Table 3, the common approach for assessing GA 9 is through a final year project whereby the student is expected to do an investigative research study on their research topic. A final year design or research project is considered suitable to provide a varying and unfamiliar learning context in line with the range statement provided by ECSA. Moreover, the information resource from the field's technical literature exposes the student to knowledge outside their formal knowledge-based. It is expected that the student learns to manage own learning needs/preferences according to their learning requirements. Evidence of the student's capability for independent learning is given in the literature review section of the written technical report. The project for Electrical Engineering Technology also considers the conclusion chapter of the report whereby the student, through new thinking, proposes future research challenges. The rubric for assessment of this GA, in some instances, is carefully drafted with five indicators of independent learning and four levels of competency. In other instances, the rubric is summarised and presents only the achieved/not achieved options.

Although most of the investigated programmes are assessing this GA in the final year project, Chemical Engineering Technology has adopted a different approach to the assessment of independent learning. In one module, they use selected questions that are designed in a way that allows students to show independent learning. It is stated that the questions are delivered via a test and an assignment. The assessment is based on a common rubric designed for GA 7 and GA 9, whereby the 7 questions are listed and 5 levels of competency are provided. However, the rubric does not indicate which GA is assessed by each question nor what constitutes a satisfactory performance.

In another module from Chemical Engineering Technology, students are given a topic and guidelines regarding the important aspects to be investigated in advance. The GA is then explicitly assessed through a class discussion forum and class tutorial session. The student should demonstrate satisfactory knowledge of the topic's important aspects in both the discussion forum and tutorial. The assessment rubric is provided seven indicators on four levels of competency.

Few factors are related to the ability to engage in independent learning. Some of these factors are related to the acquired skills, like the ability to use basic study skills and problem-solving skills. Other factors are related to personal attributes such as openness to learning opportunities, initiative and independence in learning, and interest and curiosity in the pursuit of knowledge. The assessment of these personal attributes makes this GA hard to assess. The rubric may address all the factors however, the authors believe that a written report (or part of it) would not properly reflect one's interest, curiosity or openness to learning opportunities.

It is interesting to investigate if the class discussion forum and class tutorial are providing better means to evaluate those factors.

Table 3: Summary of GA 9 assessment

Programme	Type of assessment	Rubric for GA assessment
Chemical	1.Test and assignment-specific questions for combined GAs 2. Class discussion forum and class tutorial	1. Common rubric for the task. No indication which question addresses which GA and what constitutes achievement of a specific GA. 2. The rubric has seven indicators on four levels of competency
Civil	Final year project-introduction and literature review section	No specific GA rubric
Electrical	Final year project-literature review and conclusion section	Well-designed rubric with five indicators and six levels of competency
Industrial	Final year project-literature review section	Well-designed rubric with seven indicators and four levels of competency
Mechanical	Final year project – literature review section	Well-designed rubric with seven indicators and four levels of competency

4.3 Engineering professionalism – GA 10

Graduate attribute 10 refers to engineering professionalism, whereby the student has to "demonstrate critical awareness of the need to act professionally and ethically and to exercise judgement and take responsibility within own limits of competence" (E-02-PT, 2020).

Chemical Engineering Technology is assessing this GA in the final year project. The learner guide relates this GA with the acknowledgement of the reported information source, or the lack of it, which is considered plagiarism. There is no specific rubric provided for the assessment of GA 10. The programme has another module that assesses engineering professionalism through an individual and group report. The requirement is that "student should be able to apply ethical principles and commit to professional ethics, responsibilities and norms of engineering in delivery of individual and group design report", emphasising the issues associated with plagiarism. There is no specific rubric for the assessment of this GA thus no clear criteria of competency are provided.

Civil Engineering Technology uses a typical engineering practice case study to evaluate GA 10. Students are expected to demonstrate acquired ethical and basic science knowledge in engineering practice. The module, called Ethics and community studies, provides a rubric for assessment of the task with three outcomes and four levels of competency. The outcomes refer to the role of engineering in society, the responsibility of the engineer in protecting the public and one's knowledge of the engineering code of ethics, laws and regulations. Although the outcomes align with some criteria specified by GA 10, the rubric does indicate what constitutes this GA's achievement.

Electrical Engineering Technology is assessing the professionalism in a case study that requires criteria for ethical reasoning in decision making, professional development and up-to-date tools, and responsibility. The assessment rubric is detailed, presenting five criteria on six competency levels.

Industrial Engineering Technology measures GA 10 in an article while the Mechanical engineering technology approach is to incorporate the assessment of GA 10 in the final year design project. Both departments' assessment of professionalism, ethics and equity is through a similar rubric exhibiting six indicators on four levels of competency.

GA 10 is assessed directly either through a case study, an article, or as part of the final year project as seen in Table 4. The range statement indicates that “evidence includes case studies typical of engineering practice situations in which the graduate is likely to participate”. Therefore a well-formulated case study type of assessment should constitute an appropriate method. The rubrics for assessment of the GA, whenever presented, have three or more assessment criteria or indicators. A specific assignment or case study may cover more outcomes that align with the competency requirements of the GA however, a portion of a project report may not be enough to provide evidence of competency in the specified indicators. Although specific rubrics are provided in some cases, each rubric has its interpretation of the outcomes of professionalism with only two common themes: responsibility for own actions and ability to recognise and act on ethical issues. This comes from a different understanding of the range statement of this GA which refers to conceptual knowledge specified in the range statement of GA 7. For a complex GA, like professionalism, it is debatable if a final year project represents an adequate mode of assessment and how best to formulate the assessment indicators that align with the GAs provided range statement.

Table 4: Summary of GA 10 assessment

Programme	Type of assessment	Rubric for GA assessment
Chemical	1.Final year project 2.Individual and group report	No specific rubric for the GA
Civil	Case study	A rubric for the assessment of the task is provided, no specific rubric for the GA
Electrical	Case study	Detailed assessment rubric, presenting five criteria on six competency levels.
Industrial	Article	Detailed assessment rubric with six criteria on four levels of competency
Mechanical	Final year design project	Detailed assessment rubric with six criteria on four levels of competency

5 CONCLUSION

The graduate attributes discussed in this paper are considered hard to assess as they are complex, requiring evaluation of competencies that are beyond the discipline content and close to life-work skills. ECSA provides guidelines for each competency requirement in alignment with international practices. The graduate attributes are interpreted differently by different engineering disciplines and this is reflected in the variety of assessment indicators provided in the rubrics. Nonetheless, it can be seen that the assessments used are appropriate although there is room for improvement. Specifically with transparency and clarity of rubrics, as all rubrics are not clear to individuals outside the department. Some of the graduate attribute assessments tend to be at a superficial level and, to ensure that these attributes are embedded well, some curriculum change may be required. The practice across the programmes is to combine, whenever possible, a few GAs in one assessment as it was observed that, giving one assessment for each GA, will overload the student. This is a good practice as long as the task is well designed to address all the GAs and a rubric is provided for each GA. As there are some instances when one type of assessment may not cover the full competencies of a GA, more than one type of assessment should be employed.

6 RECOMMENDATION

The ideal solution to provide a uniform and comprehensive assessment of the hard to assess GAs is to create an online faculty platform that engages students from all disciplines in assignments and projects related to sustainability, ethics, professionalism, independent learning, team and multidisciplinary working. The GA 7, 8, 9 and 10 could then potentially be measured more effectively and consistently. Sustainability is an area where additional attention should be given to ensure that students do not just understand superficially.

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IDENTIFYING WATER WASTAGE IN DEEP-LEVEL MINES USING A SIMULATION-BASED ZERO-WASTE BASELINE

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ABSTRACT

Deep-level mine chilled water reticulation systems are energy-intensive and prone to wastage. Current baselines used to identify this wastage cannot capture the wastage’s true extent. An alternative baselining method, namely zero-waste baselining, determines the expected water usage from the consumer demands. This study develops a new method that utilises simulation-based zero-waste baselining to identify and quantify water wastage in deep-level mines. The developed method achieves this by using the consumer specifications in a thermohydraulic simulation to simulate a theoretical zero-waste baseline. This zero-waste baseline is compared with the actual water usage profile. The difference between these profiles indicates the wastage found in the current system. This methodology is applied to a case study mine, and a water wastage of 46 L/s (or 26.7%) is identified. The study is thus successful, with the developed method satisfying all objectives. Further studies could utilise the method to eliminate the identified wastage more efficiently.

Keywords: Deep-level mine, mining water, simulation, zero-waste baseline, optimisation.

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1 INTRODUCTION

South African mines are expanding progressively deeper as they follow the gold reefs deep underground [1]. As the mine depths increase, the virgin rock temperature also increases [2]. This compromises the mine's ability to achieve the regulated underground temperatures for mine workers [2 – 3]. To counteract the increasing temperatures, deep-level mines install complex chilled water networks integrated with the ventilation system [3 – 8].

The chilled water network is comprised of cooling, supply, and return (dewatering) [3 – 8]. This complete water system is referred to as the water reticulation system and is highly prone to wastage [8 – 10]. Underground water wastage can be in the form of poorly optimised energy systems or physical water misuse [9 – 10].

The water reticulation system also accounts for a large portion of underground energy usage [11 – 12]. Approximately 28% of a mine's total energy usage can be attributed to service water pumping [11 – 12]. Up to 42% of the total energy usage is assigned to the complete water reticulation system [13 – 14].

Identifying wastage in such a large, integrated, and complex network can be time- and resource-intensive [7, 15]. An alternative solution is to consider a *usage baseline* [5]. Typically, water usage baselines are based on historic usage or previously-measured baselines [8, 14, 16 – 17]. Initiatives used to reduce water usage are then based on reducing the current water usage to match past usage [13]. Using digital twinning simulations could also allow for more accurate modelling of both the water reticulation system and the usage baseline [13 – 14].

An alternative method of developing a usage baseline is to consider only the requirements of underground water users [10, 18 – 19]. A *zero-waste baseline* is one such alternative demand-based method. By considering the total water demand of all underground users, a zero-waste baseline can be established to determine the minimum water usage for current underground operations [10, 18 – 19].

The shortcomings of a historic usage baseline is that it fails to account for the wastage present at the time of the baselining, whereas a zero-waste baseline always accounts for the minimum water usage [10]. Although zero-waste baselines exist and have been utilised to determine energy savings in the mining environment [10], they are not used to identify water wastage [10].

A need thus exists for a zero-waste baseline methodology that can be applied to any underground water reticulation system to identify the true extent of service water wastage. The aim of this study is to develop a method that identifies water wastage in deep-level mines using a simulation-based zero-waste baseline. The specific objective of this study is to develop a method that will:

- utilise a zero-waste baseline,
- developed with a digital simulation,
- to identify and quantify service water wastage,
- in deep-level mines.

The developed method will be applied to a South African deep-level mine case study. This will provide a platform for the discussion of the application of the developed method and for validation that the method meets the outlined study objectives. The case study mine will remain confidential.

2 METHODOLOGY

As discussed in Section 1, the envisioned method is applied to a case study mine. As such the method is developed by following the case study design methodology [20 – 21]. This methodology is applicable when:

1. The aim of the research is to find answers to "why" and "how" types of questions.
2. It is not possible to control behavioural events.
3. Focus is on contemporary/dynamic events.

The mining environment complies with all of these criteria. Thus, the case study design methodology can be followed for this study. The research methodology is shown visually in Figure 1.

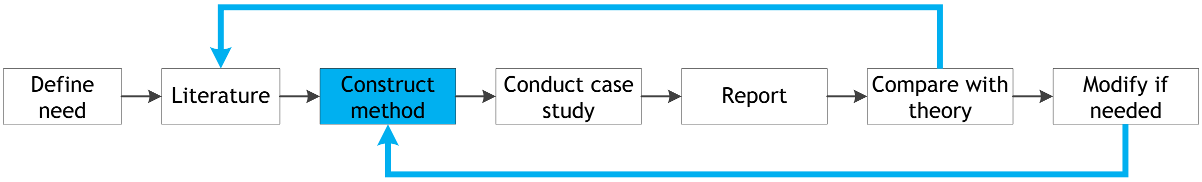

Figure 1: Case study methodology applied to the mining environment.

Figure 1 shows how the case study research methodology is applied to the mining environment. This will be used to further to evaluate the required methodology for the objectives outlined in Section 1. Per the case study design methodology and its application to the mining environment, the required method must be constructed (highlighted in Figure 1). The method construction is described in Section 2.1.

2.1 Method Construction

The method construction is shown in Figure 2. The method structure is based on other water reticulation simulation methodologies [22 – 23]. This method is broken into two portions. The first the focus of each process. The second discusses the inputs and process within each focus aspect.

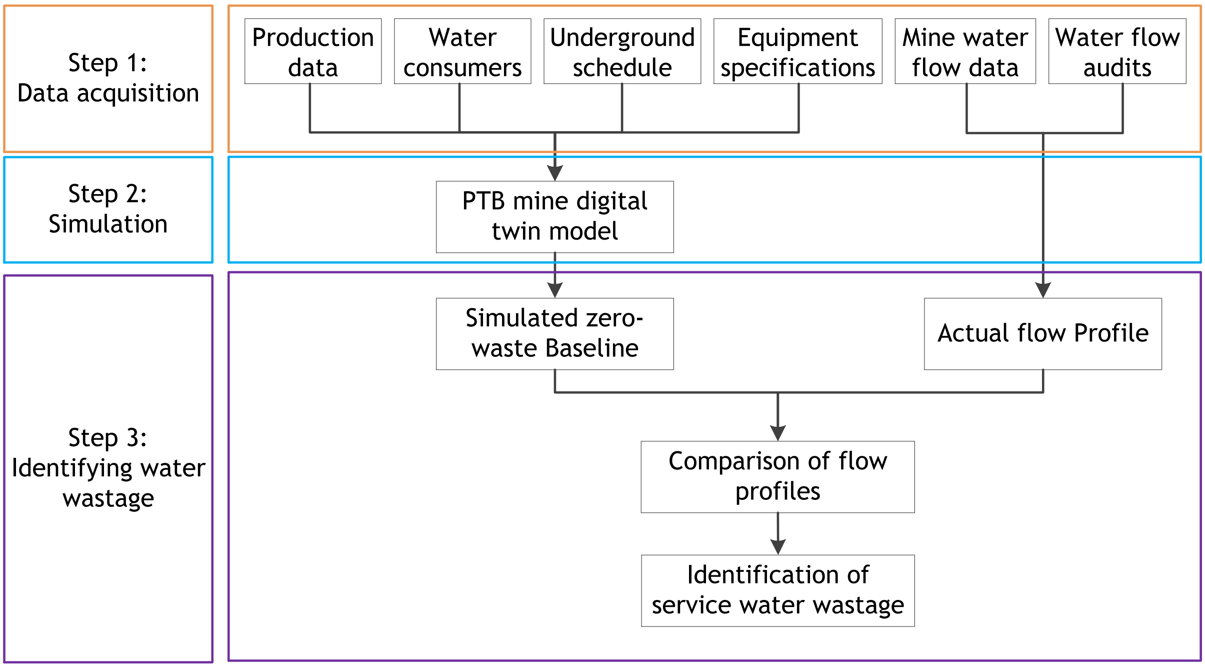

Figure 2: Proposed method for the identification of service water wastage using a zero-waste baseline.

From Figure 2 the method consists of three main steps. Step 1 encompasses the acquisition of data. This is required for the construction of the zero-waste baseline and the actual flow profile for comparison.

Step 2 encompasses the development and calibration of the simulation model using the data acquired in Step 1. This step allows for a simulation-based zero-waste baseline to be developed, with faster and more accurate results.

Finally, in Step 3, the simulated zero-waste baseline is developed using the simulation model from Step 2. Data acquired during Step 1 is used to determine the actual flow profile. These two flow profiles can then be compared to determine the service water wastage present in the current system.

2.2 Zero-wastage baseline

To develop a zero-waste baseline, the entire mine water system, the key water consumers, and their respective water usage, must be understood. From this a potential configuration for the development of the zero-waste baseline is constructed and shown in Figure 3.

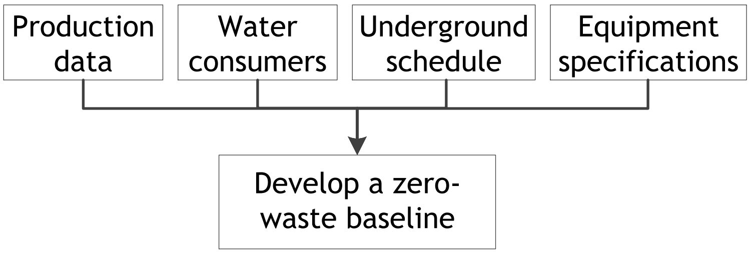

Figure 3: Configuration for the development of a zero-waste baseline.

This baseline must encompass a 24-hour profile, representing a typical weekday, and highlight periods of higher- and lower water usage. The periods of higher water usage are due to the use of drills and water-based cleaning tools [23] whereas the periods of lower water usage are a result of consistent water consumers such as cooling systems [8].

2.3 Step 1: Data acquisition

The four inputs from Figure 3 required for the development of the zero-waste baseline can be incorporated into a single data acquisition step. Alongside these inputs will be the audit and historic data required for the actual flow profile. This data acquisition step is key as missing data would invalidate the ability to utilise the zero-waste baseline to identify water-wastage [24]. Any other data requirements throughout the methodology would also fall into this step.

2.4 Step 2: Simulation

To facilitate faster development and evaluation of the zero-waste baseline, simulation software is used to create a simulation of the mine's water reticulation system [6]. Simulation software allows for quicker and more accurate modelling of complex underground systems [25]. In this study, Process Toolbox (PTB) simulation software is used to develop the zero-waste baseline. PTB is a component-based transient thermo-hydraulic system simulation solver [26]. PTB is selected as it is ideal for modelling mine water reticulation systems [26 – 27] and achieving accuracies within 5% [28].

The PTB component that allows for a zero-waste baseline simulation requires the drilling- and cleaning schedules as an input. The component determines the water consumption based on the tonnes of rock produced/removed. The tonnes produced are used to scale the water usage for both the drilling- and cleaning tools.

The PTB simulation will require the schedules, water consumer details, as well as the production information to simulate the zero-waste baseline. These additional inputs will be accounted for in the data acquisition step.

2.5 Step 3: Identifying water wastage

To identify service water wastage using any baseline a comparison must be drawn [17]. The actual water usage must be compared to the zero-waste baseline to determine any discrepancies in the flow profiles (similar to a past-usage baseline) [17]. The actual water usage would come either from available data from the mine systems or from specific water flow audits [14].

Per the case study design methodology [20 – 21] this method (Figure 2) will be applied to a case study mine to determine the validity of the developed method. This will also serve as a practical demonstration of the application of the method. Section 3 details this process.

3 RESULTS AND DISCUSSION

3.1 Case study background

The case study mine is a conventional deep-level gold mine. The mine utilises service water for cooling through cooling cars (mobile cooling units), drilling and for cleaning of blasted ore. The mine is suited to the application of the methodology as the mine has experienced an unexpected increase in water usage. Figure 4 shows an increasing trend in the average weekday water usage for 2020 through April 2022.

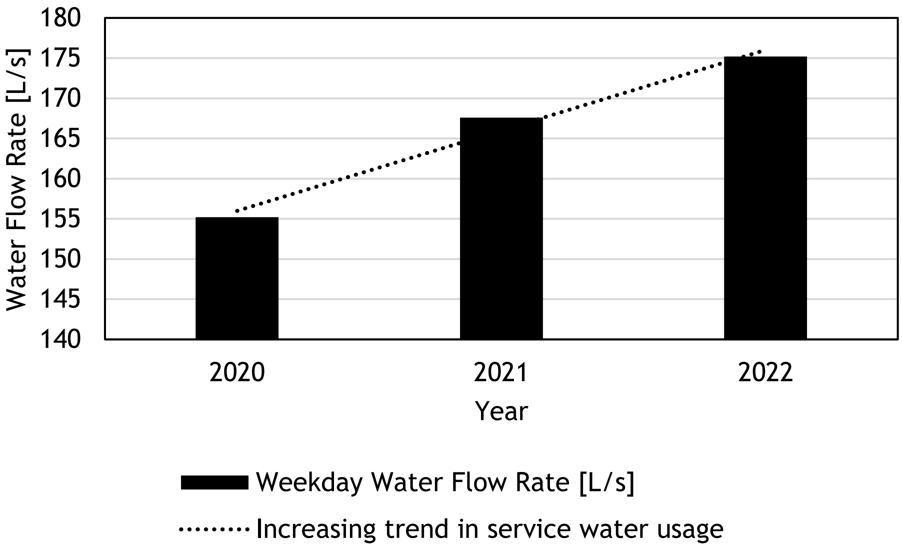

Figure 4: Average weekday service water usage per year.

Typically, an increase in production yields an increase in water usage [23]. This would be due to the addition of more water consumers (drills and water cleaning tools [23]), which would in turn result in a greater production yield.

To verify whether the increased water usage correlates to an increase in production, the water intensity is used. This shows the tonnes water used per tonne rock produced [29]. Figure 5 shows the yearly service water intensity for 2020 through April 2022 for the case study mine.

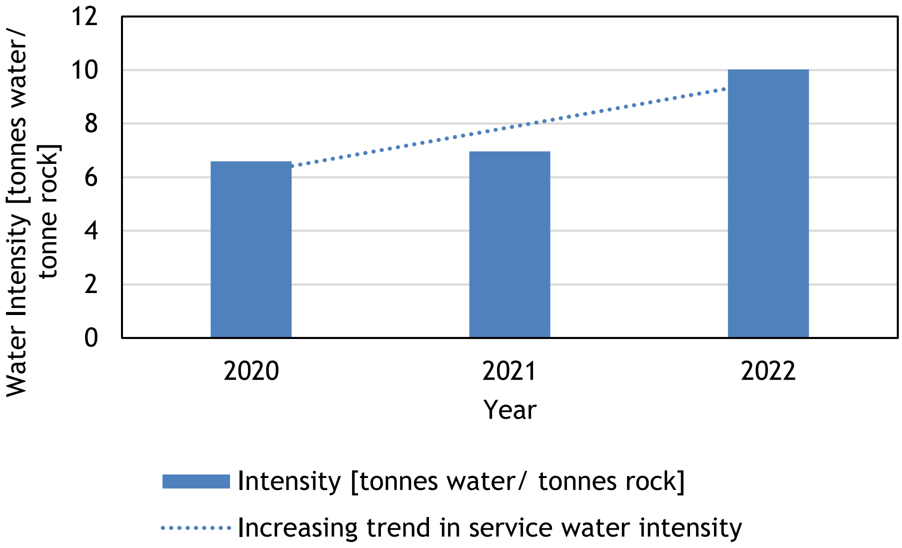

Figure 5: Yearly service water intensity.

In Figure 5 the water intensity has increased from 2020 onwards, specifically emphasised in 2022. Since the water usage and water intensity trends are both increasing, it is noted that the case study mine has been using more water for a similar amount of production. This implies that the increase in water usage noted in Figure 4 is likely due to an increase in water wastage.

3.2 Step 1: Data acquisition

Applying the methodology to the case study mine begins with data acquisition. For this case study the month of October 2021 is being used for all data for the zero-waste baseline and actual flow profile.

The specific water consumers and underground schedules are obtained from the mining personnel at the case study mine. To establish the zero-waste baseline, the specifications for the consumers must be obtained. Some of the information can be obtained from the suppliers of the equipment (such as the drills [30] and spot-coolers [31]).

The cooling car flows have been optimised in a past study [23] and will be used in this study. The last consumers are the water bazookas. These are self-manufactured by the case study mine and have never been tested.

A water bazooka is a water-based cleaning tool that uses compressed air and water to clean the face after blasting. The compressed air is used to provide a high-pressure force to the water to increase the cleaning potential of the water. The water bazooka flow results are included in Table 1 which is a summary of the water consumers and their respective water usages.

Table 1: Water consumer flow rate summary.

Tool type	Tool	Number of units	Water flow rate [L/s]
Drills	S25 rock drill	57	0.2
	S215 rock drill	30	0.2
Cleaning tools	Water bazookas	28	5.5
Cooling tools	Cross-cut cooling cars	10	4.0
	Haulage cooling cars	6	7.0
	Spot coolers	6	2.5

Additionally, the actual average weekday flow profile for October 2021 is obtained from the mine Supervisory Control and Data Acquisition (SCADA) system. Figure 6 shows the average profile extracted from the SCADA for October 2021.

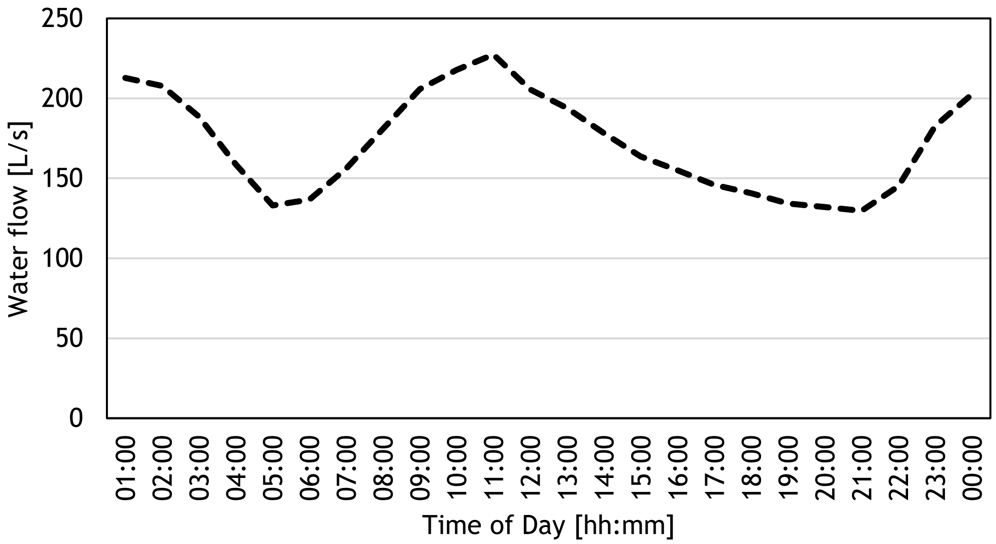

Figure 6: Actual average weekday flow profile for October 2021.

3.3 Step 2: Simulation

Using the information from the data acquisition step a zero-waste baseline model can be set up. Per the methodology (Figure 2) the developed zero-waste baseline requires a simulation model of the case study mine. The model uses the consumer breakdown to create a skeleton framework of the mine (illustrated in Figure 7).

Following the development of the simulation model, the zero-waste baseline can be simulated and compared to the actual water usage flow profile for October 2021 (Figure 6). The acquired data is included in the simulation, which also acts as the calibration for the model [28].

Following this calibration, the error between real-life and simulation is < 5%, and as such, the model is considered accurate. This mean that the difference between the zero-waste baseline and actual flow profiles can be ascribed as wastage rather than modelling error. This low error is achievable due to the low stochasticity of and finite number of components within the simulation.

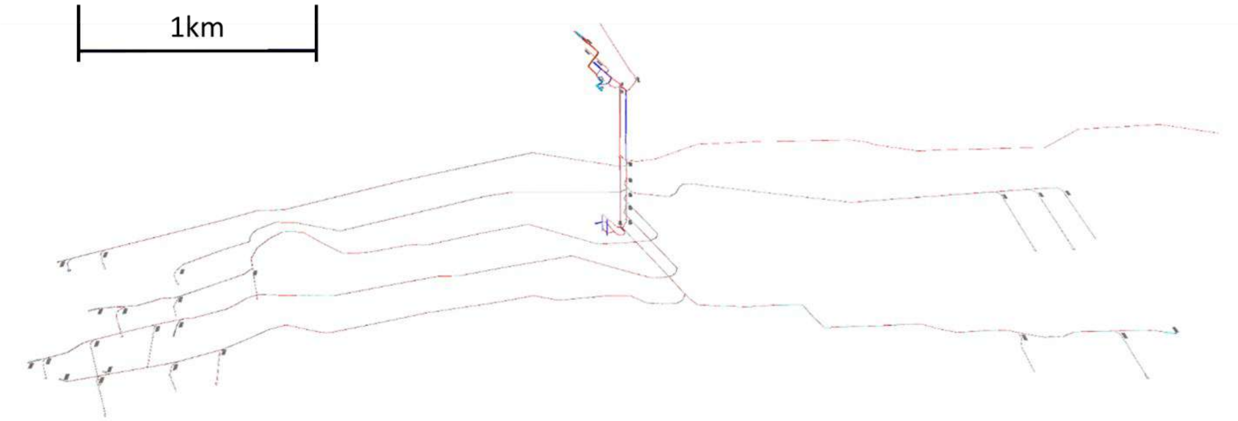

Figure 7: Zero-waste baseline simulation network of the case study mine.

3.4 Step 3: Identify water wastage

The result of this simulation is a zero-waste baseline flow profile, displayed in Figure 8. Figure 8 compares the results of the zero-waste baseline with the average weekday actual flow profile for October 2021.

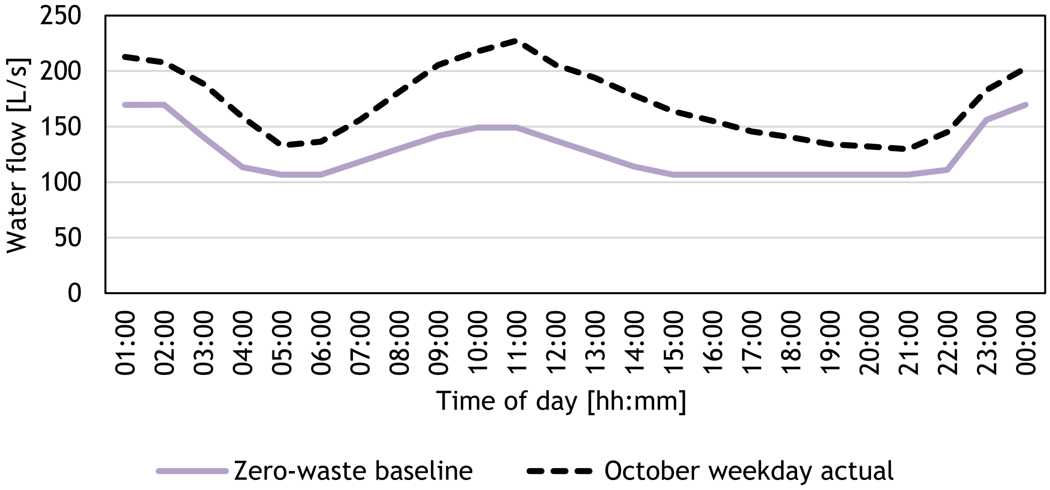

Figure 8: Zero-waste baseline flow profile compared with October actual weekday flow profile.

From Figure 8 the two profile shapes and the general trend of the two profiles fit well, although the difference between the actual profile and the zero-waste profile during the drilling shift is noticeably larger than the rest of the time period.

After further investigation the cause of the increased peak is the use of cleaning tools during non-drilling days. This can be accounted for by adding cleaning tools on a schedule for the non-drilling days. This adjusted zero-waste baseline is shown in Figure 9.

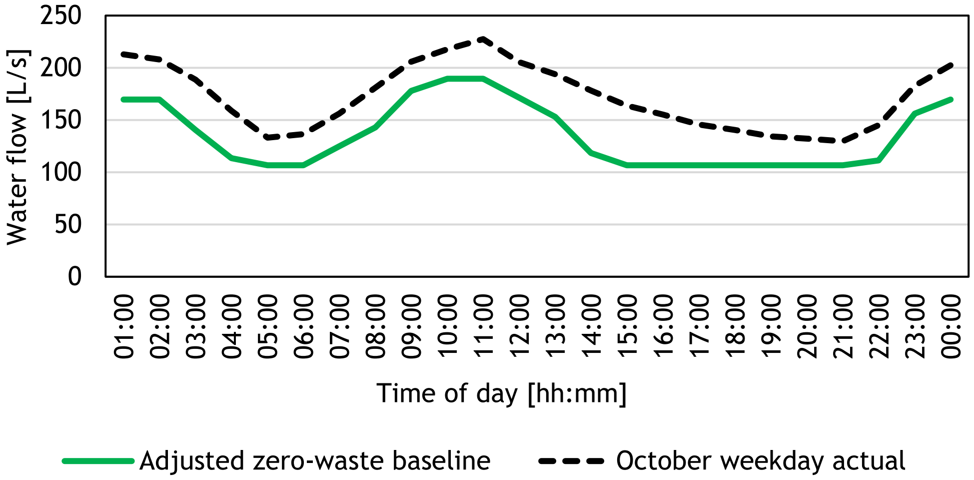

Figure 9: Adjusted zero-waste baseline compared to October actual weekday flow.

From Figure 9 it is noted that the profile shapes now match almost exactly. This means that the current operations at the case study mine include cleaning during the drilling shift, which is not planned.

From Figure 9 the average daily flow for the true zero-waste baseline is 118 L/s, adjusted zero-waste baseline is 126 L/s, and the actual average daily weekday flow for October 2021 is 172 L/s. The difference between the adjusted zero-waste baseline and October actual flows is 46 L/s, which can be added to the simulation as a consistent wastage to shift the zero-waste baseline to the actual.

Adding this calculated wastage to each time period should result in the adjusted zero-waste baseline matching the actual flow profile for October 2021 weekdays. The results from the introduction of the wastage component are shown in Figure 10 which compares the adjusted zero-wastage baseline to the actual flow profile. Additionally, Figure 10 also shows the measured baseline (the actual weekday average flow profile for October 2020).

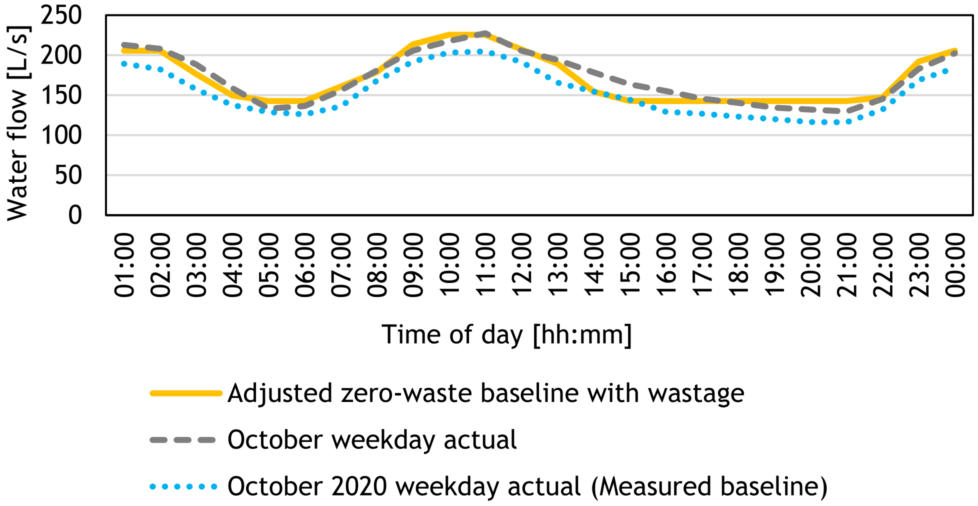

Figure 10: Adjusted zero-waste baseline with wastage compared to October weekday actual flow.

Comparing the adjusted zero-waste baseline with wastage to the October weekday reveals that the profiles match closely. The differences in the flow profiles between 13:00 and 18:00 are due to the zero-waste baseline not accounting for a slower tailing off of production at the end of the drilling shift. From 19:00 to 22:00 the mine personnel throttle the pressures to the mine, thus reducing the flow below that predicted by the zero-waste baseline with wastage.

As these differences are minor the zero-waste baseline identifies that there is a consistent water wastage present, with a flow value of 46 L/s. Assuming that some of this wastage is as a result of leaks in the water system, water system audits or other leak detection methods [17] can be used to identify the leaks and reduce the wastage.

3.5 Discussion

The case study shows that the developed methodology can be applied to a conventional deep-level gold mine and identify water wastage. In this case study water wastage of 46 L/s is identified. Additionally, the zero-waste baseline highlighted incorrect water usage in the form of cleaning during the non-blasting drilling shifts.

This demonstrates that the developed methodology meets the outlined objectives from Section 1. This is as service water wastage is identified in a deep-level gold mine through comparison between a simulation-based zero-waste baseline and the actual flow profile.

Assuming that the wastage can be reduced by 50% following leak identification and discipline improvement (which would also lead to a reduction in the incorrect water usage) the wastage would be reduced by 23 L/s (or 13.37%) of the total average daily flow. This would yield a pumping cost savings of more than R 2.5 million per annum at the 2021 Eskom power tariffs [32].

It is recommended that in future studies this methodology be applied to mining systems using a hierarchical system. Although this study identifies the true wastage present in the system it does not aid in the location of the wastage.

Applying a hierarchical structure along with this method can allow for a narrowing down of the exact area of wastage and its extent. This would allow for a ranking of the wastage areas within a mine and for more efficient reduction in present wastage.

Additionally, combining Line-of-Sight systems with this methodology can allow for a consistent evaluation of wastage in localised work areas. Furthermore, connecting this with control valves can allow for basic wastage reduction in off-peak periods [13].

Comparison to historic baseline

Using the main alternative baselining method, namely historic baselining, shows an expected flow of 154 L/s. This only identifies 18 L/s of the total wastage component identified with the zero-waste baseline. One key issue with a historic baseline is that the water consumers in a deep-level mine do not remain consistent. This means that a historic baseline will either under- or over-represent the wastage based on whether the mine is expanding or declining, respectively.

As noted in Section 1, the main benefit of the zero-waste baseline is that it shows a true reflection of the wastage present in the system. This is emphasised in this case study with the historic baseline failing to identify ~60% of the present wastage. In addition to not accounting for the changing usage from consumer, this discrepancy is due to the historic baseline not accounting for any wastage present at the time of the baseline.

4 CONCLUSION

South African mines are progressing ever deeper resulting in a greater need for integrated chilled water cooling- and ventilation systems. These chilled water systems are major energy consumers and are prone to wastage. Baselining is a common method for the identification of this wastage, although the present baselining methods fail to capture the true extent of the wastage.

An alternative method of baselining, namely zero-waste baselining, utilises the water consumer flow demands to determine the required flow. A need was therefore identified for a methodology to develop and utilise the zero-waste baseline for the identification of service water wastage in deep-level mines.

Such a method was developed based on other water reticulation simulation methodologies. This method developed a simulation-based zero-waste baseline and compared it to the actual water usage to determine the wastage.

The methodology was applied to a case study mine which presented an increasing trend in both its water usage and intensity. Through the application of the methodology, water-wastage of 46 L/s was identified, which is 28 L/s more than the traditionally measured baselining method. If 50% of this wastage can be reduced, a pumping cost savings of over R 2.5 million per annum can be realised. The developed methodology thus successfully met the outlined study objectives.

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AN ANALYSIS OF THE APPLICATION OF LEAN LIVE GAME AT A SOUTH AFRICAN HARNESS-MAKING COMPANY

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ABSTRACT

This research aimed to analyze the use of a lean live game to; create a lean thinking environment, and get the buy-in from illiterate and semi-illiterate workers who worked in a harness-making company in South Africa. The lean live game orients the workers on the lean implementation approach. The lean system was designed to reduce costs incurred due to overtime, scrap, low efficiency, and downtimes. Data was collected from historical records of the company. Research findings showed that the lean live game helps illiterate and semi-literate workers understand the different types of waste and the lean tools that can be used to identify and solve problems. The game also teaches the participants teamwork, conflict resolution, and continuous improvement programs. The lessons learned from playing the game make it easier to work in a real-life lean environment.

Keywords: Lean live game, implementation, harness-making company, South Africa

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1 INTRODUCTION

Company X is a manufacturing company that was founded in Germany in 1905. Since then, it has expanded globally and has over 40,000 workers around the world. The company has 30 manufacturing plants and service offices around the world. It supplies harnesses to Bavarian Motor Works (BMW), Daimler, Ford, and Opel automotive assembly plants. The company introduced several continuous improvement programs that follow the Plan, Do, Check, and Act (PDCA) approach. One typical program that the company introduced to improve the quality of its products and services is lean manufacturing.

1.1 Lean Development and Implementation Programs

In 2008 Company X implemented the first lean program that was called Process Optimization Worldwide Resources (POWER). However, the company recognized that its workers could not cope with the demands of the POWER lean thinking system. Sixty percent (60%) of the workers were semi-literate, and they found it difficult to implement it.

In 2016 the company introduced the operational excellence lean system. With this system, Company X sought to increase the motivation and satisfaction of its employees. The operational excellence lean system provided the workers with a platform to share ideas on eliminating waste in the organization. The system facilitated the introduction of 5s, line balancing, multi-moment recording (Downtime Analysis), spaghetti diagrams, cause and effect diagrams, 5-WHY'S, poka-yoke, and continuous improvement programs.

In 2020 Company X introduced a production system that complemented the operational excellence lean system. The production system focused more on 5S, lean principles, and other activities that helped trace the key performance indicators such as scrap, efficiency, and quality performance.

1.1.1 Lean Thinking Implementation Method

The lean programs introduced during the 2008-2020 period developed a transparent culture that helped all the stakeholders detect waste, solve problems, and optimize resource utilization. The approach also created an environment that enabled the employees, customers, and other stakeholders to understand and avoid the different types of waste.

In addition, Company X introduced a daily direction setting (DDS) dashboard to help employees know the key performance indicators and targets set for each working day. The board made the stakeholders know the performance of the different departments at any given time.

Company X also used visual management and Gemba walks to create opportunities for value creation in the factory.

1.2 Problem Statement

Company X's operations are labor-intensive, and 80% of the work done in the company is in the manufacturing department. Management identified wasteful activities in the manufacturing department through Gemba walks. These walks were conducted by following individual product families, product designs, and customer-facing processes from start to finish. They found out that housekeeping in production lines was not properly done. Operators left tapes and clips all over the floor. The company had problems with; 1) processes and standards, 2) leadership and management, 3) skills shortage, and 4) methods, tools, and systems.

Company X also experienced a lot of problems in starting production and this affected throughput and delivery lead times. Table 1 shows key performance indicators and metrics during the 2011 – 2021 period when Company X developed its lean system. Though the company sought to have 95% of the products that met or exceeded customer satisfaction, it operated at just above 91%. Another indicator that the company was not happy with was overtime. This entity averaged 92.7 hours above the planned time.

With regards to efficiency, downtime, scrap, and rework, the company did fairly well. Efficiency improved from 79% in 2011 to 94% in 2021, and this exceeded a target of 90% efficiency set for 2021. Ideally, the company wants to have zero unplanned downtime. However, there was a gradual decrease in downtime from 651 minutes (10.85 hours) in 2011 to 162 minutes (2.7 hours) in 2021. This change points to the effects of continuous improvement employed by the company. As for scrap generation, the company performed within target from 2011 to 2017. Thereafter the scrap levels were above the set targets. With regards to the reworks indicator, the company performed to the expectations of the management.

Table 1: Lean system key performance metrics in Company X during the 2011-2021 period

Year	Target Quality (%)	Actual Quality (%)	Target Efficiency (%)	Actual Efficiency (%)	Target Production time (hr.)	Time worked (hr.)	Over time (hr.)	Target scrap rate (%)	Actual scrap rate (%)	Target rework (%)	Actual rework (%)
Power system -Project E90 and F30											
2011	95	90	75	79	538	571	-113	3	2.5	5	3.5
2012	95	85	75	68	307	319	-430	3	2.7	5	2.5
2013	95	94	68	85	531	426	-61	2.5	2.1	5	4.8
2014	95	95	85	92	403	404	-314	2.2	1.8	5	5
2015	95	90	95	95	457	476	-39	2	1.9	5	3.6
Operational Excellence -Project F30 and G01											
2016	95	94.7	91	94	450	500	-50	2	1.9	5	4.7
2017	95	93.6	94	93	377	371	6	1.8	1.8	5	3.9
2018	95	90.2	90	64	391	445	-54	1.8	2	5	4.2
2019	95	91	91	81	657	627	30	1.8	2	5	4
Production system -Project G01											
2020	95	92	92	91	532	475	57	1.3	1.3	5	3.8
2021	95	90	90	94	506	558	-52	1.2	1.8	5	2.3

Another challenge that Company X had with lean implementation is the level of literacy in the company. Sixty percent (60%) of the employees in the factory were either illiterate or semi-illiterate. This possessed a serious challenge. The workers found it difficult to cope with the demands of implementing lean. The company also found it difficult to reduce waste whilst at the same time effecting continuous improvement.

However, in 2019 Company X introduced the lean live game. The game was designed in a way that simulated Company X's manufacturing environment. As one played it, one got to understand the impact of the different forms of waste. A culture of teamwork was developed. Moreover, skills in identifying opportunities for continuous improvement are developed. After playing the game the players found it a lot easier to relate the game to real manufacturing experiences.

1.3 The Aim of the Study

The study aimed to analyze the way Company X used the lean live game to; create a lean thinking environment, and get the buy-in from its illiterate and semi-illiterate workers when lean was implemented in its factory. The study was conducted in 2019, 2020, and 2021 in all Company X manufacturing departments. The performance metrics that were analyzed were efficiency, scrap rate, downtimes, and rework data. These metrics showed the improvements that lean live game made to the company. The game was also a basis for continuous improvement.

2 LITERATURE REVIEW

The concept of lean was established by the Japanese automotive company, Toyota, during the 1950s [1]. Lean cuts costs and recovers productivity by eliminating waste or non-value-adding activities [1]. Lean implementation has spread across the world, and this is due to the universally positive impact that it has on; cost, quality, flexibility, and responsiveness to customer demand [1].

2.1. Lean Implementation

Netland [2] states that the crucial factors in the successful implementation of lean are management commitment and involvement, training and education, employee participation, and correct application of lean tools and methods. Moreover, the size and type of the organization, the organizational culture, and the stage of lean implementation determine the difficulty experienced in implementing lean [2].

Lean is about generating and delivering value to the customer while minimizing waste [3]. On one hand, lean manufacturing increases a company's productivity and product quality. On the other hand, it reduces waste and production costs [4]. This is achieved by implementing lean tools and techniques such as 5S, Kanban, standard work, single-minute exchange of dies (SMED), and Kaizen [4].

A lean system requires management that creates an environment that empowers employees to solve problems and come up with regular improvements [5]. This is only possible with effective communication processes and employee engagement on the company goals, targets, and vision.

Ukey [6] mentioned that the process of lean implementation classifies and eliminates waste through continuous improvement. Continuous improvement is affected through the use of lean tools [7].

2.2. Lean Tools Implementation

Wilson [8] defined "lean" tools and methods as those that aim to decrease or eradicate waste. Some of the lean tools in use are 5S, value stream mapping, PDCA, six sigma, Kanban, DMAIC, Gemba walks, Ishikawa diagrams, and business process mapping. The application of lean tools depends on knowledge, creativity, the transformation of the environment, and the mindsets that need to change around the company [7].

Kumar [9] argued that a good decision-making structure that relies on bottom-up creativity transformational management and quality reports ensures the reliability of merchants. Kumar [9] also noted that during the implementation of lean; effective lean culture, effective leadership behavior, and a lean toolbox are necessary to achieve success. Their absence will lead to the failure of the lean implementation project.

2.2.1. 5s Principle

Ukey [6] states that 5S is part of a comprehensive production control concept that is aimed at removing waste from the work area and attaining efficient and effective fulfillment of corporate responsibility. 5S is an acronym that stands for seiri (sort), seiton (set in order), seiso (shine), seiketsu (standardize), and shitsuke (sustain).

- *Seiri* - is essential to sort all items, materials, and tools in a workplace into a collection of necessary and unnecessary items [10]. Those that are unnecessary are eliminated [11].
- *Seiton* – is essential to find a storage location for every necessary item [10].
- *Seiso* – is about maintaining cleanliness in workplaces. It minimizes wastefulness, inaccuracies, and accident occurrences [10].
- *Seiketsu* – is about establishing precise procedures to protect the product and the employees by applying the fundamentals of visual management [11].

- *Shitsuke* - is about the integration of the preceding steps and the application of the activities performed in the company [12]. This step is the most challenging and requires management and employees that use audits and control cards to attain the integration.

2.2.2 Kaizen

Kaizen is a Japanese term meaning change for the better or continuous improvement [6]. It improves processes, productivity, and profitability by eliminating waste. It can be applied to any process. In a production environment, Kaizen increases efficiency, reduces production cycles, reduces production areas, reduces work in progress, improves quality, brings flexibility to the production line, and meets the requirements of customers. With Kaizen, companies win the battle to reduce non-value-adding activities and increase productivity in stages [13].

2.2.3 Single Minute Exchange of Die

SMED is a system that reduces the time it takes to complete equipment changeover. This is achieved by performing as many changeover steps as possible while the equipment is running. It also streamlines the remaining steps. The implementation of SMED is defensible by the benefits that it offers to companies. It eliminates unnecessary movement, improves machine efficiency and capacity, and improves setup time [14].

Haddad [15] states that SMED needs to be combined with other lean tools such as 5S, line balancing, kaizen, overall device efficiency, poka-yoke, and value stream mapping. Combining these tools creates a lean production environment [14].

2.3 Lean Barriers

There are several studies on the variables contributing to the obstruction of adopting Lean [12]. Some of the barriers to implementing a lean system include; lack of lean understanding, lack of motivation from management, employees not being involved, and employees' attitude. Appropriate training and communication on the concept, and basic principles of the lean system help overcome the barriers.

Lorgaard [16] argues that lean implementation is hampered by a lack of appropriate education, and failure to have proper tools and methods. Moreover, the size and organizational culture influence the process of lean implementation [16].

2.4 The Benefits of Lean Implementation

Alkhoraif [17] explains that lean methods increase the company's efficiency and effectiveness in operations. The benefits are manifold. It reduces work-in-process, increases product quality, increases capacity, increases inventory turns, reduces cycle-time, cuts cost, increases competitive advantage, improves employee morale, and improves customer satisfaction [18]. It also frees up employees and other resources that would have been wasted doing non-value-adding activities.

3 RESEARCH METHODOLOGY

This is a case study that was conducted at Company X, and it is qualitative. The study analyzed the way Company X uses the lean live game to; create a lean thinking environment, and get the buy-in from its illiterate and semi-illiterate workers when lean is implemented in its factory.

To gain access to the information required in the study, the researchers sought written permission from the company to conduct the research.

Primary data was collected during playing the game through observations. Saturation was reached after making five observations. The observation was also done on the players in their actual working environment. The purpose of this observation was to see the changes in the performance of the workers, the quality of the product, and the efficiency. Moreover, an assessment was done on the improvements that the workers effected in their working environment after playing the game.

The sampling technique used to identify secondary sources of data was purposive sampling. Secondary data on the rules of the game, the number of players, the roles of the players, and evaluations are done during and after playing the game were collected.

4 FINDINGS

Company X used a *lean live game* to teach employees; 1) how lean works and 2) the basics of the lean application. The game teaches lean thinking basics and tools in production, warehouse, and office space. Some of the lean tools and techniques used during playing the game are 5S, line balancing, Gemba walks, and spaghetti diagrams. Before the game is played, the moderator explains the; history and theory of lean manufacturing, eight types of wastes, and the objectives of learning and playing the game. The moderator also explains the instructions and the role of each character in the game.

The lean live game is played by a maximum of 10 players and the players assume the roles of the; managers, production personnel, industrial engineer, quality inspectors, and logistics personnel (Table 2). To play the game one goes through four runs. Firstly, resources are set up based on the plant layout requirements for a specific product.

Table 2: Lean Live Participants

Plant Management			
Production	**Industrial Engineer**	**Quality Inspection**	**Logistics**
Assembles the product (car) at workstations 1, 2, and 3. Each workstation is manned by one operator.	Conducts time study Tracks the movement of workers by using a spaghetti diagram. Conducts line balancing	The quality inspector checks the quality of products at workstations 1, 2, and 3. The quality inspector inspects a work instruction	The logistics personnel provide material to workstations 1, 2, and 3.

Secondly, 5S is done on the production workstations. Each participant does the 5S on his/her workstation. At this stage, the moderator motivates the players, helps them solve their problems, and asks questions on how the participants benefited from 5S.

Thirdly, the participants simulate the manufacturing process following the Kanban system. The Kanban rules are displayed in the warehouse and at all the workstations. During the fourth and last run, the players apply line balancing methods and workflow on their workstations. The participant who plays the role of an Industrial Engineer records the time, performs time studies, and tracks the movement of the material using a spaghetti diagram.

The participants change their work content as soon as the work is balanced. The team leader continuously checks on the performance of the participants and discusses the next steps for improving the efficiency of the processes. The participants define their targets and key performance indicators on the evaluation poster after every run (Table 2). Lastly, the participants articulate the benefits derived from playing the game.

Figure 1: The legos that are used in the game

The game is set to be played over 4 hours and the simulation is done on any of the cars products in Figure 1.

The assembly line has three workstations that build each of the three cars in Figure 1 to completion. The players should be familiar with the rules before they start playing the game.

- *Workstations one, two, and three* - the three workstations assemble each of the cars given in Figure 1 to completion. During the assembly process, all the employees are required to complete their tasks within the prescribed time, follow work instructions, and provide feedback at the end of the shift on areas that need some improvements. During the game, the participants are allowed to discuss with the team leader any problems that they encounter. The participants at all three workstations call for raw material replenishment from the warehouse whenever they run out of material. When the car is assembled, it is transferred to the quality inspection station.
- *Quality inspector* - checks the finished product for quality compliance to quality standards and customer requirements. The quality inspector works according to work instructions, rules, and standards governing the assembly of the cars. The quality controller either gives the product a thumbs up, requests reworking, or quarantines it. Quarantined products are escalated to the team leader for advice.
- *Industrial Engineer* - optimizes the plant layout. He/she also conducts time studies to eliminate bottlenecks and synchronize the flow of material.
- *Logistics 1 and 2 (material provider)* – ‘logistics 1’ delivers the raw material to the assembly lines and ‘Logistics 2’ transports semi-finished goods within the production line. Delays are avoided when every member works within the prescribed time.

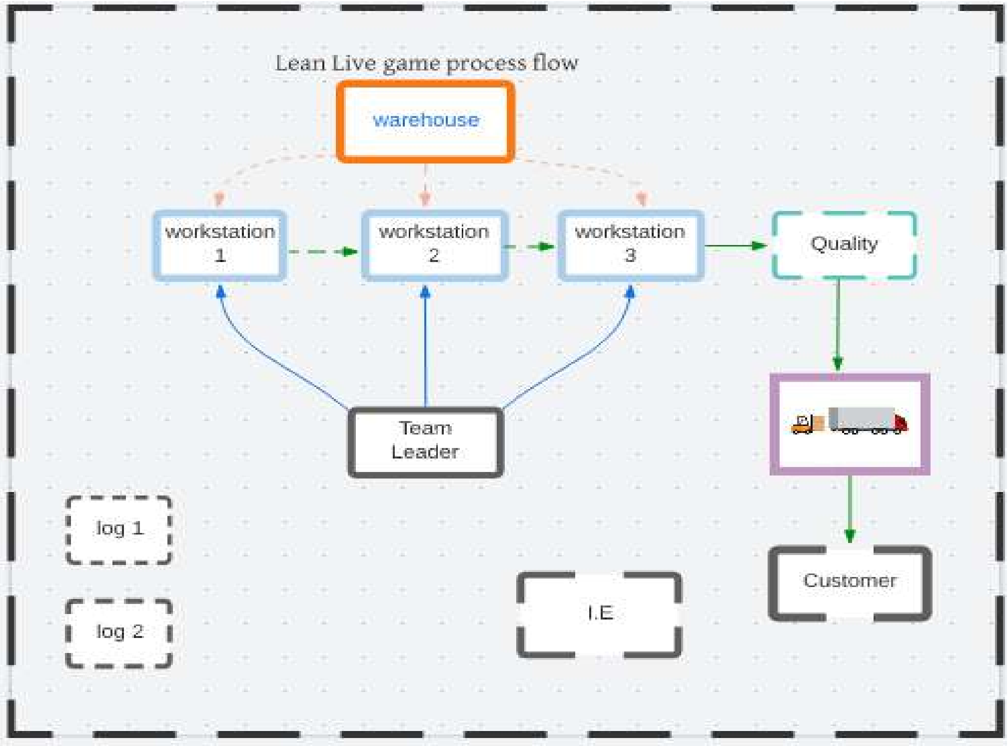


Figure 2: The flow of the materials in the assembly

- *The team leader* - is the key member on the shop floor in this game. He/she checks attendance, briefs the team members on the targets for the shift, coordinates the operations on the shop floor, and gives support to those who need it. During the game, the team leader compiles reports and controls the line speed. He/she also communicates the performance metrics for the overall lines and the different workstations.

4.1 Process flow of the game

Figure 2 shows the flow of material at the workstations. The lean live game should be played based on the layout to help the participants relate to the real events in the organization.

4.2 The Rules of the game

Every run specified in the lean live game simulates a shift, and each shift has a duration of 8 minutes. The product that is produced is either a pick-up, SUV, or Limousine (Figure 1). The cars are produced in sequence based on the customer orders and the work instructions that are provided. The players are required to follow the rules stated during the game. Figure 3 shows a typical lean live environment.

Lean Live
EVALUATION OF IMPROVEMENT RUN

	Limousine	SUV	Pickup
Material Costs	12.000 EUR	12.000 EUR	11.000 EUR
Sales Price	[illegible] EUR	40.000 EUR	[illegible] EUR

Rules of the Game for Evaluation each Run

- A car counts as a sold car once it is placed in the shipping area in sequence
- The material costs contain of all WIP bricks – material in finished goods will be counted separately
- ~~[illegible]~~

	[Unity]	RUN 1	RUN 2	RUN 3	RUN 4	RUN 5
Limousine	# cars	0	2	2	10	12
SUV	# cars	0	3	4	9	13
Pick up	# cars	0	3	4	8 11	14
Rework	# cars	3	4	5	1	1
Personnel	# FTE	[illegible] = 11	[illegible] = 11	3+5= 11	3+6=9	3+6=9
WIP	# PCS	165	128	196	78	109

Lean Live
EVALUATION OF IMPROVEMENT RUN

	[Unity]	RUN 1	RUN 2	RUN 3	RUN 4	RUN 5
Turnover	EUR	0	[illegible]	420.000	1210.000	1580.000
Material Costs (add cars)	EUR	0	83.000	176.000	349.000	454.000
Rework Costs	EUR	60.000	30.000	10.000	20.000	20.000
Personnel Costs	EUR	110.000	110.000	110.000	90.000	90.000
WIP	EUR	165.000	128.000	196.000	78.000	109.000
TOTAL PROFIT	EUR	-335.000	-8[illegible].000	-102.000	+673.000	+907.000
Total Order Time	SEC	~~[illegible]~~ 0	8×48=384 s	480 s	1440	1872
Total Operating Time	SEC	1440	1440 s	1440 s	1440	1440
EFFICIENCY	%	—	26,6 %	33,3 %	100%	130%

Line Efficiency = $\frac{\text{order time}}{\text{operating time}} \cdot 100 = \frac{\text{sum of seconds per single car}}{\text{sum of employees}^* \cdot \text{duration of shift}^*} \cdot 100$

* 8min · 60sec = 480sec

Figure 3: Lean live game environment

Whenever the material drops off the table, the line stops for 30 seconds. Takt time is calculated based on a production rate of 30 cars per 480 seconds. Hence 480 seconds are required for every 30 cars produced, and this translates to 16 seconds per every car produced. After the first run, the participants have to evaluate their performance. The participants have to write down all the defects, downtimes, and outcomes that will help to improve the performance in the second run. After playing the game, the players experience an improvement in cycle time, efficiency, and yearly sales.

4.3 The Effect of the Lean Live Game

The lean live game teaches the workers the implementation of lean in a practical way. The participants visualize the causes of waste in production processes.

The game also allows the participants to identify wastes and their occurrences during the game. It turns the shop floor into a lean working environment. The workers acquire continuous improvement skills and can solve the problems that hinder lean implementation. The game is handy for both illiterate and semi-illiterate workers. Both experience the benefits and challenges of implementing lean in a work environment.

Finally, the game teaches the workers to; work as a team, identify impediments to smooth flow of material in a production environment, make appropriate decisions, and solve production-related problems. Moreover, it teaches conflict resolution among team members.

4.3.1 Spaghetti Diagram Analysis

In the lean live game, participants learn where, when, and how to use a spaghetti diagram to determine the paths that the material and people follow during the manufacturing process. The spaghetti diagram also shows the process and the layout of the workstations. In drawing a spaghetti diagram the following steps were followed:

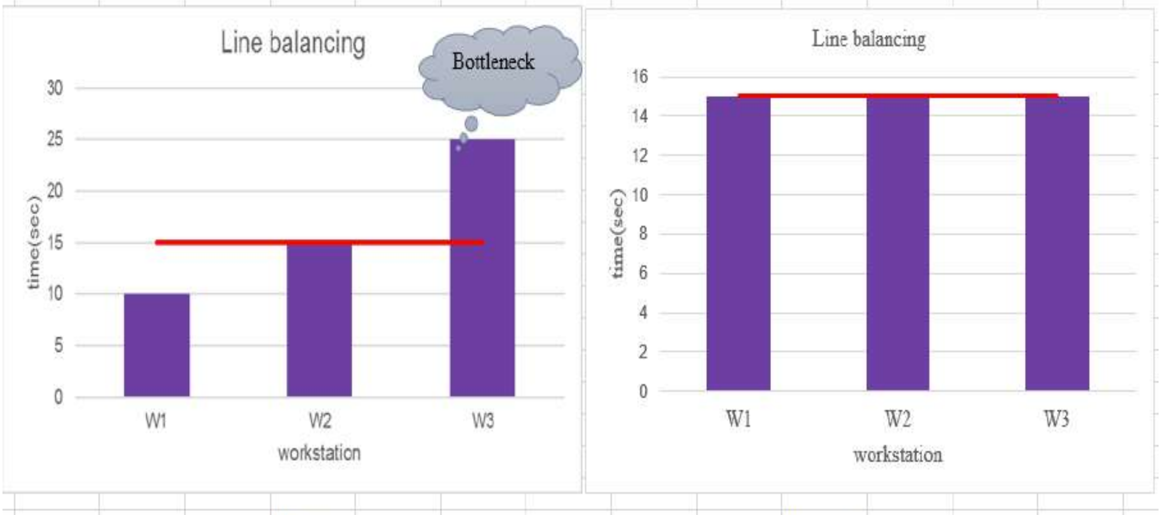
- Draw a sketch.
- Define the recording period.
- Follow the paths of workers or products and enter each with lines in the worksheet.
- Calculate the total distance traveled during the recording time.

The results or movements are analyzed to improve the process flow in that workstation. In this case, the participants are encouraged to place the materials nearby and remove non-value-adding activities.

The results of the observation done to create a spaghetti diagram are evaluated during the game. All the processes are tracked and analyzed to; visualize the process flow, identify and illustrate paths, understand material flows, and identify the value-adding activities and non-value-adding activities.

4.4 Line Balancing Analysis

The industrial engineer character in the game balances the line to level the workload across all the workstations. Figure 5 is a typical representation of the unbalanced and balanced workloads of workstations 1, 2, and 3 in the game.



Before **Improved**

Figure 4: Unbalanced vs balanced workload

Line balancing conducted in the game helps the workers visualize how idle times are reduced at the workstations. It also eliminates bottlenecks and smoothens flow in the production line. Moreover, line balancing raises the morale of the workers by equalizing the tasks and workloads among them.

4.5 Gemba walk

The appointed management team in the game performs Gemba walks in spontaneous and informal ways. These walks are done to identify waste (Muda), irregularities (mura), and excess material (muri) (Table 2).

Table 3: Waste that the Gemba walks seek to identify and eliminate in the plant

Item	8 Types of Waste	Description
1	Defects	The loss of value in the form of rework, scrap, repair
2	Waiting	The idle time during production runs
3	Transportation	The material movement required during production runs
4	Motion	Movement of employees that do not add value to the product
5	Overproduction	Producing more than what is required
6	Non-utilized talent	Underutilizing employees
7	Inventory	Products and materials that are not being processed
8	Extra processing	The effort that does not add value

After interacting with the game managers, the participants get to understand that Gemba walks support their efforts to identify non-value-adding activities. They; identify opportunities for improvement, motivate employees to work in a safe environment, identify opportunities for improving the quality of products and services, and identify opportunities to standardize work. Another benefit derived from the Gemba walks is the establishment of a continuous improvement program that involves problem-solving methods.

4.6 5S Analysis Method

Figure 5: 5S conducted on the shop floor

5S is one of the lean tools that are part of the lean live game. Once done, it becomes easy to; locate materials and files, and keep resources in order. Moreover, it saves time to locate and move material on the shop floor. A huge benefit derived from the game is that the lessons learned whilst playing the game are easily transferable to the real workshop. Figure 5 shows the transitioning of workers from 5S in the game to 5S in the real workshop. This transitioning translates into; creating a safe workplace, improving product quality, lessening breakdowns, keeping necessary items, storing each item in its rightful place, and a clean environment.

4.7 Lessons learned by the people who played the game

There are several benefits derived by the players of the game. The players learn; conflict resolution, communication skills, problem-solving, and keeping a tidy working environment.

The players also learn the effects of waste in a working environment. Moreover, through 5S, they learn that a clean environment reduces accidents, saves time to access materials and information, and improves productivity.

4.8 General Benefits of the lean Live Game

The lean live game has many benefits to Company X. Some of these benefits are also as follows:

- It is effective in imparting lean manufacturing knowledge to illiterate and semi-illiterate employees.
- Employees can afford to make mistakes without costing the company anything.
- The game is used to refresh the memory of workers.
- It is used as an induction tool for lean manufacturing for new workers.
- It creates an environment for shop floor workers to discuss lean concepts.
- It develops team spirit among the workers.
- It makes the workers understand their roles in a lean manufacturing company.
- It creates an environment for conducting problem-solving.
- Employees can distinguish the difference between value-adding and non-value-adding activities.

5 CONCLUSION

The lean live game at Company X provides a cheap way to train the worker on lean implementation. Mistakes made during the game do not result in financial losses to the company. Rather they present an opportunity to effect an improvement. The lean manufacturing performance indicators that are brought to the attention of the workers are; material costs (WIP), personnel costs, rework costs, turnover, total cycle time, profit, and line efficiency. The revelation that the workers get on the metrics during the game makes them understand the significance of implementing lean in a manufacturing environment.

The game also allows the participants to embark on continuous improvement in their work environments. Moreover, the lean live game also builds up skills and capabilities to locate and solve problems within their organization.

The participants get to know the lean tools that they can enlist to identify waste and eliminate the root causes. Moreover, the participants get accustomed to continuous improvement initiatives.

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Table 4: Response to reviewers' comments

Comments from Reviewer 1	Response
1. The transitions between themes and topics are jarring and for some confusion	This problem has been addressed in all the areas highlighted.
1. Grammatical errors in the papers	All the errors were addressed.
2. Make the target of the game clearer	It has been made clear to the game audience that the target group of the game is the illiterate and semi-illiterate shop floor workers. Playing it enhances understanding of the importance of lean manufacturing.
Comments from Reviewer 2	**Response**
The role and place of the lean game are not discussed in the introduction	The role of the lean live game was adequately discussed in the last paragraph of section 1.2
The actual benefits of the lean game are not discussed	As discussed in section 4.8
The purpose and aim of the paper need to be clearer and narrower in scope	The aim of the study was given in section 1.3
Keep the aim aligned to the game	The alignment was addressed in the topic, aim and findings, and conclusion.
Discuss what the actual people learned from playing the game	As addressed in section 4.7
The method needs to align with the purpose, analysis, and conclusions of the study	Addressed

A BUSINESS MODEL INNOVATION FRAMEWORK FOR SEIZING PRODUCT-SERVICE SYSTEMS

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ABSTRACT

Innovation is imperative for any business to obtain a sustainable competitive advantage. Business Model Innovation (BMI), where value is created by making simultaneous changes to an organization's value proposition and underlying operating model, is a good way to remain competitive. However, attempts to apply this often fail. Product-Service Systems (PSS) are business models (BM) that provide cohesive delivery of products and services. It seems that BMI literature does not currently focus on the adoption and innovation of a PSS from a BMI perspective. This paper includes a literature review of the reputable business model frameworks, BMI frameworks, and innovation frameworks. The fundamental business model constitutional elements, design principles, and paramount process stages, described within the literature were extracted and used to design a comprehensive BMI framework for PSS. This generic framework will help innovators navigate through a BMI process to adopt a PSS business model for business sustainability.

Keywords: Business Model, Innovation, Business Model Innovation, Competitive Advantage, Business Sustainability, Product-Service System, Innovation Management, Innovation Framework

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1 INTRODUCTION

In the business world, there exist the well-known terms, namely product and service. A product can be defined as any tangible item a business can put onto the market which can then be purchased or consumed [1]. Services, on the other hand, are the creation of value through intangible elements like expertise, skills, and time [1]. Certain companies such as high-tech firms, IT companies, medical technology, aerospace firms, and the automotive industry obtain an extensive amount of their income and profits through the integrated services they provide [2]. More and more companies transform their product or service business models (BM) into a hybrid product-service business model.

In the 1990s and 2000s, the rise of the internet hit the world significantly which created a lot of new markets. Several companies like Apple capitalized on this new digital market where music was distributed online for cheaper prices than the traditional record stores [3]. With the introduction of the iPod, Apple was clever and did not only put fine technology into an exceptional business model, but they combined software, hardware, and service in one model that changed the whole experience for consumers [4].

When the markets of product firms become saturated, companies need to find new innovative ways to grow and generate other revenue streams to maintain their competitive advantage. One way to do this is by offering an integrated solution of products and services [5]. Changing from selling products to selling a service provide many new profitable possibilities for traditional product-only and service-only companies [6]. When services and products are merged, a *Product-Service System* (PSS) is formed [7]. According to Storbacka [8], the process where a company adopts a PSS can be described as a business model innovation (BMI).

The development of new technology, the increase in competition, and the search for more lucrative markets are just a few drivers that form the need for business model innovation. These drivers enable the creation of new business. A PSS business model is characterised by an emphasis on the partial change from products to service, from production to use, from transaction to relationship, and from supply chains to value networks, with the main focus falling on delivering value that satisfies a customer's need [9].

2 RESEARCH PROBLEM AND OBJECTIVES

There is very little research that addresses the adoption of a PSS from a BMI point of view [6]. This was confirmed by the author through searches on scientific engines such as Scopus, EBSCOhost, Web of Science, and ScienceDirect. In the past four years (2019-2022) no relevant literature was found with regard to the stated research problem and keywords such as 'PSS BMI' and 'business model innovation for product-service systems'. A lot of research was done on the process of adopting a PSS business model [10]. There is also literature to be found that studies the attributes of a BM that is needed to successfully adopt a PSS BM [11], [12]. Other studies again examine the effect servitization has on a company's performance [13]. There is no scarcity of methods and methodologies for designing and representing business models, however, most of them suggest other representations rather than the updating or evolving of existing models [9]. There is still a lack of research done on frameworks or methods that aids the BMI of PSSs [6]. A few studies also ask for contributions that are much more practical-orientated [7], [14] and studies that conceptually examine PSSs and the BMI thereof [15], [16].

The problem is that research lacks the merging of PSS and BMI streams [16]. It was identified by Weking [6] that there are almost no empirically established frameworks with a focus on an integrated perspective of PSSs and BMI. Thus, the main research objective is to: Develop a detailed, well-defined, and comprehensive BMI framework - which will reliably navigate managers through the blurry process of innovating their business model and which consists of the suitable tools, fundamental design guidelines, and techniques to analytically and systematically design, adopt and seize a sustainable PSS business model.

3 RESEARCH METHODOLOGY

Soft Systems Methodology (SSM) can be seen as a multidisciplinary take on problem-solving with an action-orientated method to investigate complex situations, where the user examines the circumstances and gives relevant activities to enhance the situation [17]. SSM is significantly well suited to problems and situations which is management-related in an organizational context [18]. The complex and broad nature of this research project fits a SSM approach since complex situations must be resolved through soft human actions, rather than hard engineered systems. See below in Figure 1 the SSM steps illustrated. The study follows a non-empirical approach. It takes a theoretical route to gather data for the design of the framework.

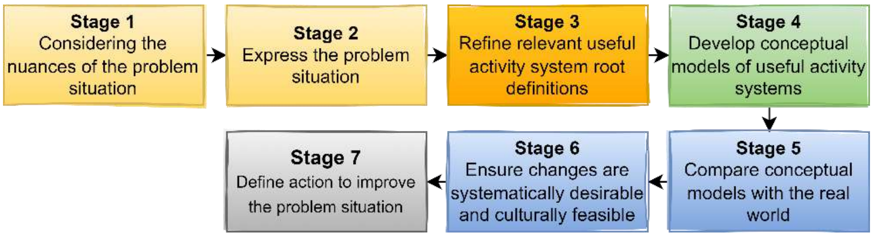


Figure 1: SSM Methodology, adapted from [19]

The business domains were selected based on their relevancy towards the research problem. The core of the research problem addresses the research domains of *business models* and *product-service systems*, where business model innovation and innovation management were seen as more overarching research domains, but sill essential. The papers studied for the literature review was solely selected based on those who have the greatest number of citations on scientific search engines such as Scopus, EBSCOhost, Web of Science, and ScienceDirect, as this guarantees credibility.

4 LITERATURE

A comprehensive literature study was done on business modelling and BMI methods to see how this literature enhances the design and adoption of PSS business models. This section gives a brief overview of the literature covered. The literature study was done in an explorative way, covering the literature of the chosen research domains.

4.1 Business Models

4.1.1 Definition

Even though the numerous different existing definitions for Business Models in literature [20], [21], [22], [4], there are a few shared and prominent themes standing out. An attempt was made to synthesize the broadest definition possible even though critique can be expected. For this purpose, a business model is defined as *"A firm's architecture and the rationale of how an organisation creates and delivers value for one or several segments of customers, and how to capture some of this value. This is to generate profitable and sustainable revenue streams and to create a sustainable competitive advantage in defined markets."*

4.1.2 The Business Model Canvas

In their book "Business model generation: a handbook for visionaries, game-changers, and challengers", Alex Osterwalder and Yves Pigneur [20] present a generic concept that allows the readers to describe and walk through the business model of their enterprise, any competitor, or any other organization. A business model is described by them based on nine building blocks to show the rationale of how the business aims to make profits. The Business Model Canvas with its nine building blocks is illustrated below in Figure 2 and briefly discussed thereafter. The business model canvas presented by Osterwalder and Pigneur [20] will be used for this research project. This is because their representation and proposed definition align and agree with most definitions in literature. Their research contribution has also received much global interest and it is widely accepted.

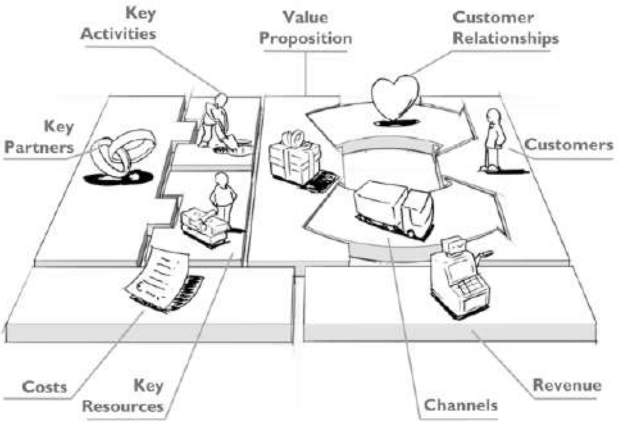


Figure 2: Business Model Canvas [20]

- **Customer Segments**: Any enterprise has groups of people known as a customer market or segment, which can also be organizations, that they aim to target and serve their needs. The customer market only exists if there is a need that asks for a value proposition. Customers form the heart of business models and without any customers that bring in profits, no enterprise will survive for longer periods.
- **Value Propositions:** It is the value proposition that fulfills the need or problem of the customer. Every isolated customer segment has specific requirements that are served by the value proposition that comprises a bundle of services or products. The value proposition can be seen as a 'bundle of benefits' provided by the enterprise to the customer.
- **Channels**: This building block describes the way an enterprise communicates with its customers, and how the value they offer reaches the customer. It is through a distribution channel that the value proposition is delivered to the customer. This interface between the enterprise and the customer consists of communication, distribution, and sales channels respectively.
- **Customer Relationships:** This building block defines the types of relationships the enterprise has with its customers. An enterprise must describe the types of relationships they have with their customer segments because they greatly influence the overall customer experience. The drivers for customer relationships are the following: customer acquisition, customer retention, and boosting sales.
- **Revenue Streams:** Revenue streams represents the cash an enterprise harvest from each of its customer segments who was willing to pay for the value proposition provided. The revenue streams are the arteries of the business model with the customers the heart of it.
- **Key Resources:** This building block depicts the most essential assets of an enterprise that are needed for the business model to work. It can be physical, intellectual, human, or financial assets. These key resources or assets allow for the enterprise to generate and profitably offer the value proposition, spreading it to the different customer markets, while maintaining customer relationships.
- **Key Activities:** This building block defines those activities which are essential to be completed for a business model to be successful. It is similar to key resources in the sense that it is also needed to generate and profitably offer the value proposition,

spreading it to the different customer markets, while maintaining customer relationships.

- **Key Partnerships:** Key partnerships outline the enterprise's network of partners and suppliers which allow the business model to function properly.
- **Cost Structure:** This describes all the expenses needed to make the business model work. Costs are incurred when a business creates and delivers value, when it maintains relationships, and when revenue is created.

4.2 Business Model Innovation (BMI)

> *"...business model innovation is about creating value, for companies, customers, and society. It is about replacing outdated models."* [20]

The concept of business model innovation refers to the reconfiguration or reconstruction of existing business models. According to Chesbrough [23] "A mediocre technology pursued within a great business model may be more valuable than a great technology exploited via a mediocre business model". One great example of this is Nestle's BM with Nespresso. They do not make amazing coffee, but by placing an aluminium coffee pod into some small machine, a sophisticated espresso is made instantly [24]. Nestle's Nespresso BM is one of the vibrant arguments that competitive advantage in the future is not so much impelled by innovative products or services, but rather by activities surrounding them [24]. The importance of the correct business model is quite evident in literature. Thus, the reconfiguration of outdated business models is just as essential. A business model of a company can either be a driving force for innovation or a subject of innovation [25]. Business model innovation is thus essential for a firm's success in this day's complex and ever-changing environment [26]. Ungerer [27] said that the origin of a firm's competitive advantage can start within the firm itself. The company's focus while being in a competitive environment must be to maximize and exploit its internal competencies and capabilities to get the better of its competitors. Considering this, BMI can thus be seen as the modification or rearranging of a company's internal mechanisms to gain a competitive advantage. Another point of view from which BMI can be seen is to scan the outside environment [27]. The nature of BMI can be of business model evolution or transformation, or of generating a whole new business model [6]. BMI usually occurs due to either a type of threat or a type of opportunity [28].

4.2.1 The Five-Phase BMI process

Osterwalder and Pigneur [20] provided a five-phase business model design and innovation process. They state that the five phases are very rarely executed linearly. They state that an innovation process is uncertain at the start and very messy until it has a single focal point of clarity with a mature design. See below in Figure 3 the five phases with a brief description of each phase.

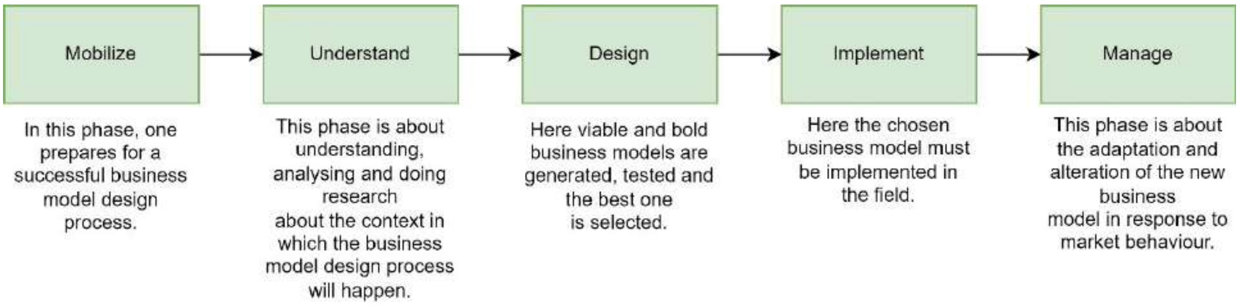


Figure 3: Five-phase BMI process [20]

4.2.2 *Framework for early-stage BMI*

Geterud and Tegern [29] built a framework that extensively focuses on a BMI process for analyzing, rethinking, and redesigning business models. Their proposed framework is built out of four phases as shown below in Figure 4. It consists of a lot of activity-specific tools which are not described in this article.

Figure 4: Framework for early-stage BMI [29]

4.2.3 *Iterative BMI process*

In their book, Johnson and Lafley [30] present a BMI process that relies not on intuition and luck to gain access to transformational growth, but rather it is a repeatable, iterative, structured, and systematic process ensuring predictability and repeatability. The BMI process consists of three basic phases of which the first is identifying an opportunity to get the job done for a customer. The question that must be asked is "What is the job that the customer wants to get done?", rather than "What is the need of the customer?". The jobs that must be done can be social, financial, or emotional in their nature. The second is to build a blueprint that illustrates how a company will satisfy the customer's need for a profit. For the blueprint, the following elements need to be done: design a new customer value proposition (CVP), design a profit formula, and identify key resources and key activities. The last phase is implementation where it is worked out how the abstract concepts of the new business model become a reality. This phase discloses whether or not all the various components can be integrated realistically into the business model. Assumptions made about key resources and key processes will be tested if they were identified correctly.

4.2.4 *The 4I-Framework*

In their article, Frankenberger et al. [31] developed a framework that explains the process stages of BMI along with the associated challenges in each phase. This framework is called the 4I-framework and supports companies in innovating their business models. The framework consists of four process phases describing the BMI process: 1) Initiation, 2) Ideation, 3) Integration, and 4) Implementation. See below in Figure 5 for a brief illustration of the 4I-framework.

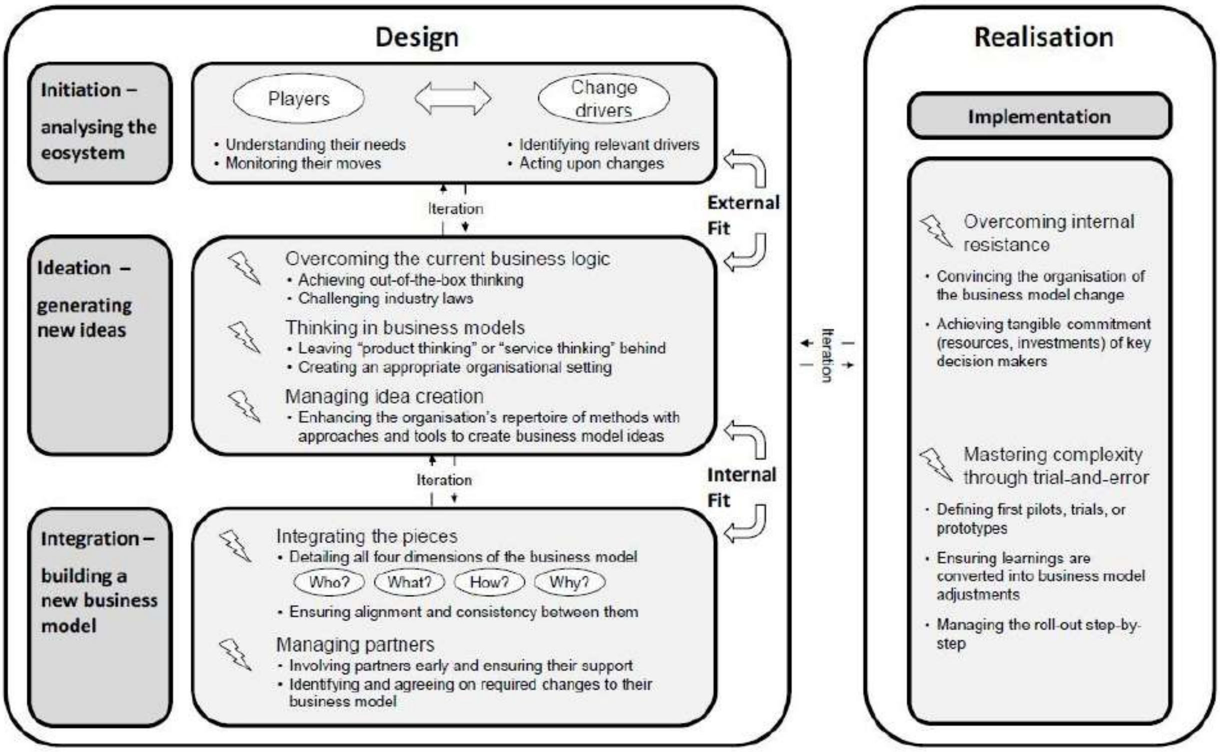
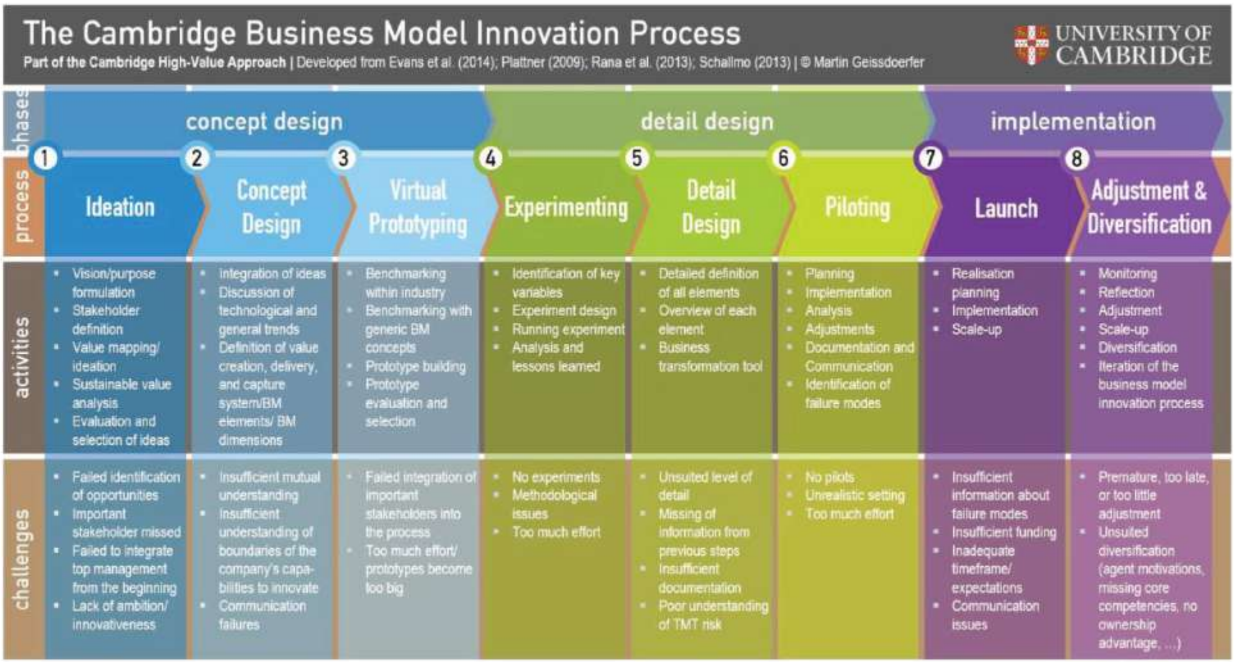


Figure 5: 4I-Framework [31]

4.2.5 The Cambridge BMI Process

Geissdoerfer et al. [32] developed the Cambridge BMI Process to guide businesses through a BMI process that results in sustainable business models. They aim to answer the following question with their framework which they developed from an extensive literature review: "How can organizations bridge the design-implementation gap of sustainable business model innovation?". The iterative BMI process consists of three high-level phases namely, concept design, detail design, and implementation. The process is further divided into eight steps as illustrated and briefly discussed in Figure 6.



The Cambridge Business Model Innovation Process

Part of the Cambridge High-Value Approach | Developed from Evans et al. (2014); Plattner (2009); Rana et al. (2013); Schallmo (2013) | © Martin Geissdoerfer

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phases	concept design			detail design			implementation	
process	1 Ideation	2 Concept Design	3 Virtual Prototyping	4 Experimenting	5 Detail Design	6 Piloting	7 Launch	8 Adjustment & Diversification
activities	Vision/purpose formulation Stakeholder definition Value mapping/ ideation Sustainable value analysis Evaluation and selection of ideas	Integration of ideas Discussion of technological and general trends Definition of value creation, delivery, and capture system/BM elements/ BM dimensions	Benchmarking within industry Benchmarking with generic BM concepts Prototype building Prototype evaluation and selection	Identification of key variables Experiment design Running experiment Analysis and lessons learned	Detailed definition of all elements Overview of each element Business transformation tool	Planning Implementation Analysis Adjustments Documentation and Communication Identification of failure modes	Realisation planning Implementation Scale-up	Monitoring Reflection Adjustment Scale-up Diversification Iteration of the business model innovation process
challenges	Failed identification of opportunities Important stakeholder missed Failed to integrate top management from the beginning Lack of ambition/ innovativeness	Insufficient mutual understanding Insufficient understanding of boundaries of the company's capabilities to innovate Communication failures	Failed integration of important stakeholders into the process Too much effort/ prototypes become too big	No experiments Methodological issues Too much effort	Unsuited level of detail Missing of information from previous steps Insufficient documentation Poor understanding of TMT risk	No pilots Unrealistic setting Too much effort	Insufficient information about failure modes Insufficient funding Inadequate timeframe/ expectations Communication issues	Premature, too late, or too little adjustment Unsuited diversification (agent motivations, missing core competencies, no ownership advantage, ...)

Figure 6: Cambridge BMI Process [32]

4.3 Innovation Management

It is commonly accepted by practitioners and scholars that innovation is a key ingredient to a competitive business that strives for a sustainable competitive advantage [33]. Jaruselski et al. [34] identified a common denominator present in successful innovations as: “a rigorous process for managing innovation, including a disciplined, stage-by-stage approval process combined with regular measurement of every critical factor, ranging from time and money spent to the success of new products in the market." Thus, the most renowned innovation frameworks were analysed.

4.3.1 The Fugle Model

The purpose of the model presented by Du Preez and Louw [35] is for organizations to recognize, examine, develop, install and utilize new products and services. The model is built around a generic innovation procedure where the convergent funnel start of innovation is merged with the divergent utilization part of innovation, also known as the bugle. The Fugle innovation model is briefly illustrated in Figure 7. The Fugle Model consists of two broad phases. Phase 1 (the funnel) focuses on the investigation and exploration of fresh market opportunities which results in the generation and selection of novel innovation ideas and concepts. Phase 2 (the bugle) entails the advancement, installation, commercialization, and utilization of the innovation projects that were declared feasible and realistic There is a Portfolio stage in the middle that connects the two phases.

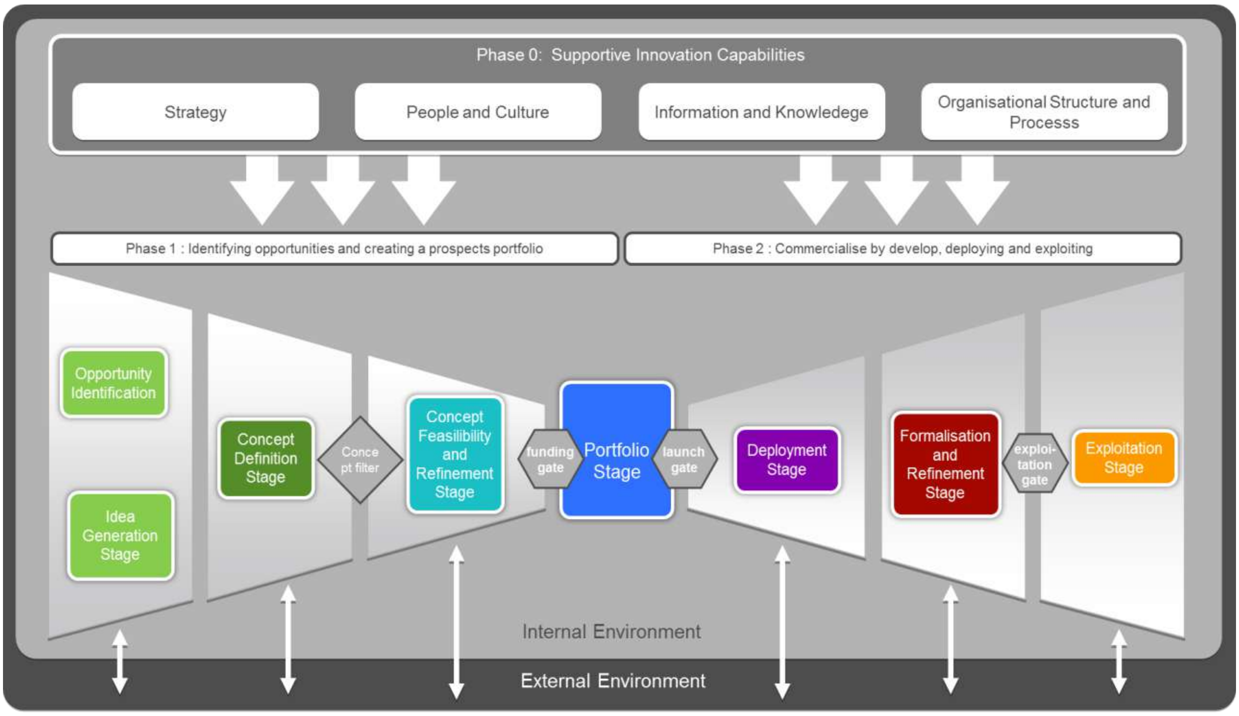


Figure 7: The Fugle Model [35]

4.3.2 The Aachen Innovation Management Model (AIM)

The AIM, also known as the W-model presented by Eversheim [36], is a systematic, standardized, and integrated methodology for organizing and utilizing product innovations successfully. The W-model for product innovation comprises seven phases that form a "W" as illustrated in Figure 8. As outlined by Du Preez et al. [37], the W-model focuses more on the initial blurry part of the innovation process, rather than on the in-depth implementation.

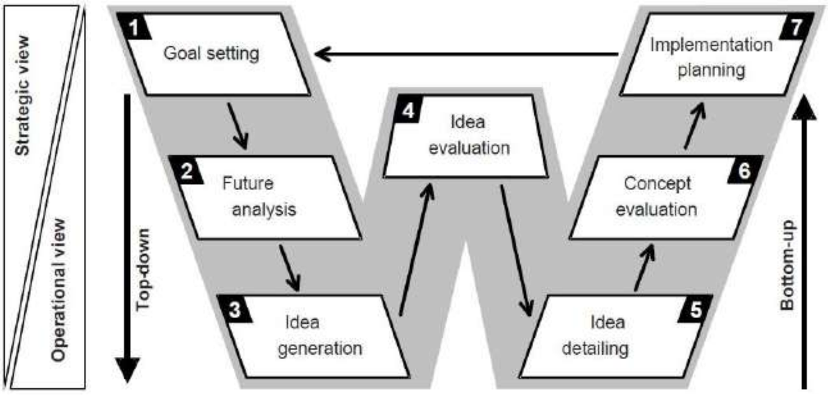
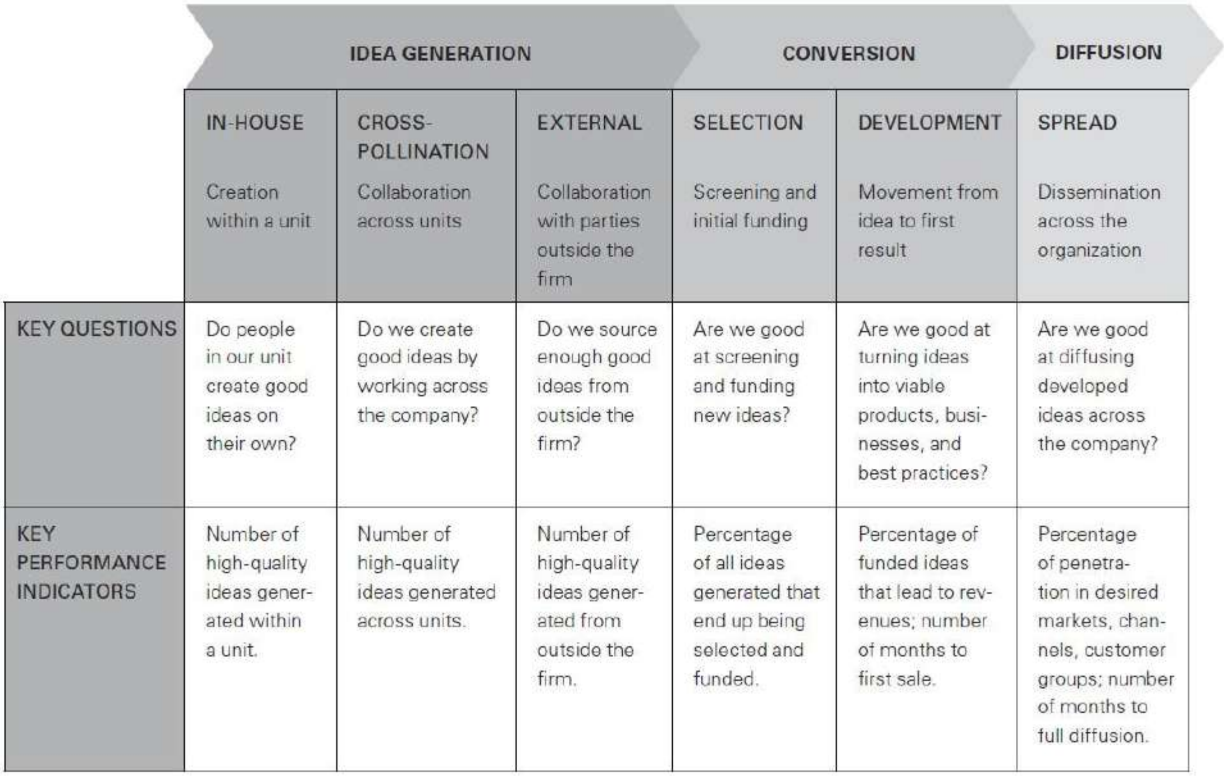


Figure 8: The W-model [36]

4.3.3 The Innovation Value Chain (IVC)

Hansen and Birkinshaw [38] recommended viewing the innovation process as a value chain. Their innovation process consists of three phases: idea generation, idea conversion, and idea diffusion. Over these three phases, six connecting activities should be performed: internal collaboration, cross-unit collaboration, external collaboration, idea selection, idea development, and the spreading of developed ideas [38]. See the framework briefly illustrated below in Figure 9.



	IDEA GENERATION			CONVERSION		DIFFUSION
	IN-HOUSE Creation within a unit	CROSS-POLLINATION Collaboration across units	EXTERNAL Collaboration with parties outside the firm	SELECTION Screening and initial funding	DEVELOPMENT Movement from idea to first result	SPREAD Dissemination across the organization
KEY QUESTIONS	Do people in our unit create good ideas on their own?	Do we create good ideas by working across the company?	Do we source enough good ideas from outside the firm?	Are we good at screening and funding new ideas?	Are we good at turning ideas into viable products, businesses, and best practices?	Are we good at diffusing developed ideas across the company?
KEY PERFORMANCE INDICATORS	Number of high-quality ideas generated within a unit.	Number of high-quality ideas generated across units.	Number of high-quality ideas generated from outside the firm.	Percentage of all ideas generated that end up being selected and funded.	Percentage of funded ideas that lead to revenues; number of months to first sale.	Percentage of penetration in desired markets, channels, customer groups; number of months to full diffusion.

Figure 9: The Innovation Value Chain [39]

4.3.4 *Disruptive Innovation Framework (DIF)*

Rasool et al. [39] presented a framework designed to identify disruptive innovation potential early which is built on the theoretical understanding of disruptive and dynamic innovation. The goal of disruptive innovation is to fundamentally change industries and the way business is done by expanding markets and obtaining new customers. The five steps for disruptive innovation are market observation, latent needs, customer value, idea generation, and disruptive potential scale.

4.4 Product-Service Systems (PSS)

The concept of a value offering consisting of the combination of tangible products and intangible services has gained more and more attention, turning into a dominating economic factor [40]. In the current age of data technology, digitization, increasing global competition, technological improvements, and consumer sophistication, business strategies are challenged and forced to make production in check with more complex demands, which asks for a switch from producing goods to providing knowledge-intensive solutions [41]. Even though many different definitions have been given for a PSS, there is some sort of consensus that a PSS is simply a combination of product(s) and service(s) presented as an integrated system to satisfy more complex customer needs [42].

A PSS is usually generated either by adding a service(s) to an existing product or integrate products into existing services. The ratio of product/service in the PSS can differ in economic value or purpose fulfilment, and it changes over time, due to advances in technology and the ever-changing needs of customers. Manzini and Vezzoli [43] stated that one of the most important concepts about a PSS to understand is that the customer need is fulfilled by selling satisfaction rather than a physical product. One main characteristic of a PSS is that it enhances the relationship and interaction between the firm and the customer [44]. Another prominent characteristic is the diversity in financial and ownership options. Kim et al. [44] state that the reason for this is because of the combined system of ownable tangible products and non-ownable intangible services. The last prominent characteristic that Kim et al. [44] point out is that the stakeholders of PSSs are very diverse. Mont [45] revealed a good understanding of what the core elements of a PSS are. See Figure 10.

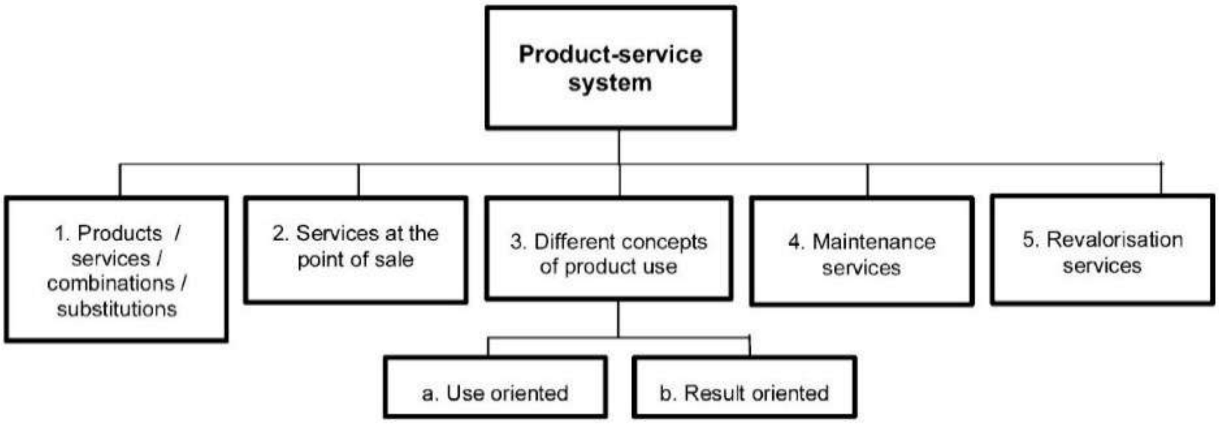


Figure 10: PSS Elements [45]

In his article, Tukker [14] presented eight archetypical models or types of PSSs. Most scholars agree on three central categories of a PSS [46]. See below in Figure 11 for an illustration of the categories. *Product-orientated* services have a business model that is equipped for product sales with additional services added. *Use-orientated* services have a business model where the ownership of the product stays with the producer, and the product is made available in various configurations. *Result-orientated* services have a business model where the customer and the provider are in accord on a result with no pre-agreed product included.

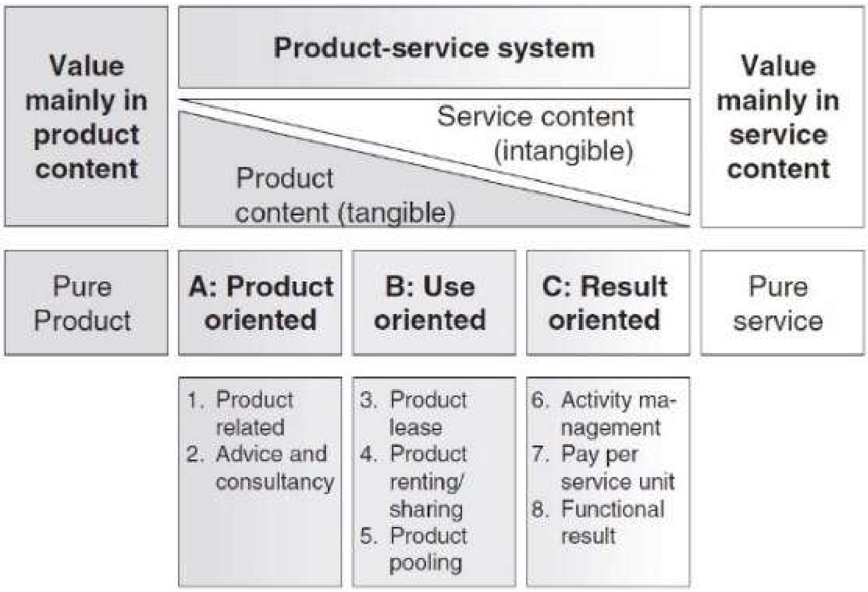


Figure 11: PSS Categories [14]

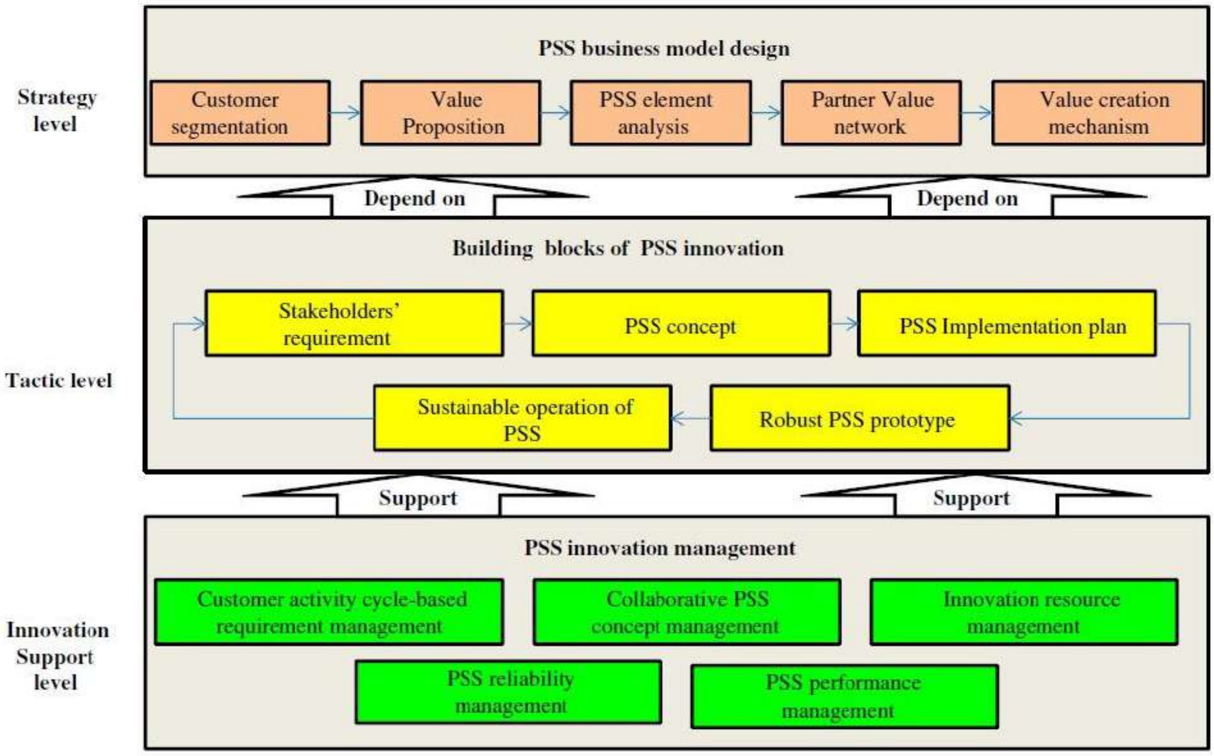


Figure 12: Framework for PSS Innovation Management [47]

Annarelli et al. [48] and Goedkoop et al. [7] did a systematic review on PSSs and identified a few PSS drivers. There are several barriers to PSS development and its application that managers and innovators need to be aware of. Mont [45], Annarelli et al. [48], and Beuren et al. [42] identified a few relevant barriers. The implementation of a PSS business model implies great alterations in business processes and thinking. In their article, Barquet et al. [49] analyzed a PSS business model extensively against model canvas elements [49]. Annarelli et al. [48] claim that a PSS has the potential to change and transform classic business models in a novel way and has characteristics that cause major changes in the value proposition. Song et al. [47] presented the most comprehensive framework for PSS innovation management. They do lack, however, a BMI perspective on the adoption and innovation of a PSS. Their framework comprises three levels: a strategy level, tactic level, and support level. The framework is illustrated in Figure 12.

Weking et al. [6] provided a framework for PSS business model innovation strategies as illustrated in Figure 13.

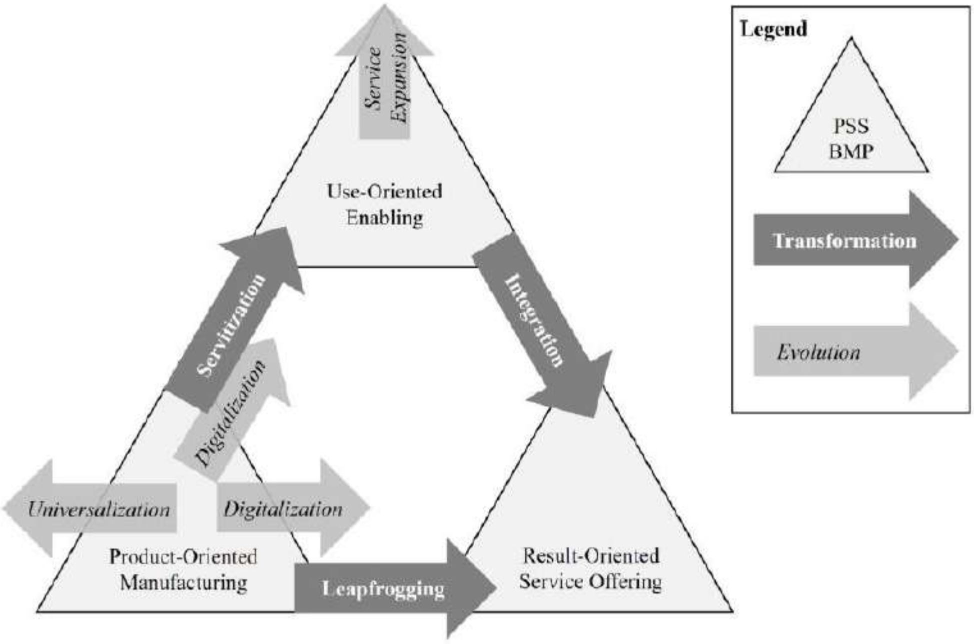


Figure 13: Framework for PSS BMI Strategies [6]

Still, the framework presented by Weking et al. [6] lacks comprehensiveness. It does, however, approach the process from a slight BMI perspective, but lacks the broader innovation phases part of an innovation process and BMI. The big issue is that the innovation and design of business models are absent. Since most of the current frameworks follow the pattern starting at requirement identification and ending with concept design, it will be valuable to provide a comprehensive, systematic, and closed-loop BMI framework giving overarching guidance for PSS BMI.

5 PSS BMI FRAMEWORK DESIGN

To address the problem that there exists a need for a BMI framework to seize and adopt a PSS business model, this section addresses the design of a framework to address this. The fundamental business model constitutional elements, design principles, and paramount process stages, described within the literature were extracted and used to design a BMI framework for seizing a PSS.

Since BMI is a type of innovation, it was decided to first analyse and examine established innovation and innovation management frameworks to comprehend the basic process of innovation and to provide a comprehensive and holistic solution. General high-level innovation phases common to these frameworks were identified to be included in and guide the proposed solution framework. Descriptive names reflecting the descriptions of the authors’ phases were given to the high-level innovation phases. Since a BMI framework is a type of innovation framework, relevant design requirements were extracted for the proposed framework. Through a cross-sectional analysis the occurrence of the high-level innovation phases was matched to the authors’ frameworks as shown in Table 1.

Table 1: Cross-sectional Analysis of Innovation Phases

	Framework and Source			
Innovation Phases	*Fugle Model -* Louw et al. [35]	*W Model -* Eversheim [36]	*IVC -* Hansen et al. [38]	*DIF -* Rasool et al. [39]
Initialization	✓	✓		✓
Identification	✓	✓	✓	✓
Transformation	✓	✓	✓	
Design	✓	✓	✓	
Implementation	✓	✓	✓	
Sustentation	✓	✓		

Secondly, the identified BMI frameworks were analysed and examined after which the prominent and common critical BMI stages were identified. These BMI stages are categorized into and form subcategories of the chosen high-level innovation phases. Descriptive names reflecting the descriptions of the authors' stages were given to the critical BMI stages. The relevant design requirements were also extracted from the BMI frameworks analysed for the proposed framework. Through a cross-sectional analysis, the occurrence of the critical BMI stages was matched to the authors' frameworks as shown in Table 2.

Table 2: Cross-sectional Analysis of BMI Stages

	Framework and Source				
BMI Stages	*5-Phase BMI -* Osterwalder et al. [20]	*Early Stage BMI -* Geterud et al. [29]	*Iterative BMI -* Johnson et al. [30]	*4-I Framework -* Frankenberger et al. [31]	*Cambridge BMI -* Evans et al. [32]
Assemble	✓	✓			
Understand /Observe	✓	✓	✓	✓	✓
Identify Ideas		✓	✓	✓	✓
Evaluate Ideas		✓	✓		✓
Conceptualize Ideas				✓	✓
Evaluate Concepts					✓
Strategize		✓			✓
Develop	✓	✓	✓	✓	✓
Evaluate Design		✓	✓		✓
Install	✓	✓	✓	✓	✓
Evaluate Operation					✓
Maintain /Improve	✓		✓	✓	✓

Thirdly, critical activities occurring in each BMI stage chosen were extracted. These common activities were predominantly taken out of the BMI frameworks, but some were also taken from the innovation frameworks. Where specific tools related to an activity, that aid in performing that activity, were found in literature, it was also documented. Basic requirements for the framework were also extracted when the activities and tools were examined.

Lastly, a thorough study was done on PSSs which include their characteristics, elements, types, drivers, barriers, business models, design, and innovation. Basic requirements for the framework were also extracted whilst going through this literature. Although a lot of the critical activities were customized to innovate, design, and adopt a PSS business model, many activities apply to generic BMI endeavors. This allows for the framework to also take on a general approach to BMI.

6 PROPOSED SOLUTION FRAMEWORK

A high-level introduction to the solution framework is provided in this section. The PSS BMI framework presented below in Figure 14 acts as a roadmap to navigate users through the process of business model innovation. It follows a structured and systemized decision-making process. This framework introduces a different innovation process for seizing PSS opportunities through a BMI perspective. There are six high-level innovation phases consisting of twelve BMI stages. Each stage has a few steps which again consist of multiple activities along with its associated tools. Only a brief description of the innovation phases and BMI stages will be given below, but the framework has much more detail when one zooms into the stages and steps.

A. **Initialization:** This phase sets the stage for a successful innovation endeavor by understanding and assembling all the essential elements needed. In the **Assemble** stage, A BMI team with certain goals and objectives is put together. The business is also structured pro-actively in a way that stimulates innovation. PSS innovation capabilities are developed, and the necessary information systems are installed. In the **Understand/Observe** stage, all the different influential aspects and actors in the environment in which the firm finds itself are examined. The industry, owners, customers, competitors, suppliers, and non-customers is studied. Their behaviour, needs, preferences, favourites, likings, and habits are analysed. Market research is done beyond traditional boundaries. The firm’s current business model and value offering are also studied together with the origins and triggers of BMI and PSS.

B. **Identification:** Before a business can perform BMI and adopt a PSS, they consciously and actively need to pursue the process of identifying and evaluating opportunities. In the **Identify Ideas** stage, the BMI team looks for PSS ideas and opportunities by holding workshops and assessing the firm, its business model, and its industry. They identify unfulfilled needs of customers and monitor PSS triggers and drivers. They also need to identify the specific involved parties and stakeholders such as the target customer group, competitors, suppliers, distributors, owners, investors, trade associations, government bodies, and local communities. In the **Evaluate Ideas** stage, all the ideas are evaluated for their suitability to be explored further. Each idea is then ranked and classified accordingly.

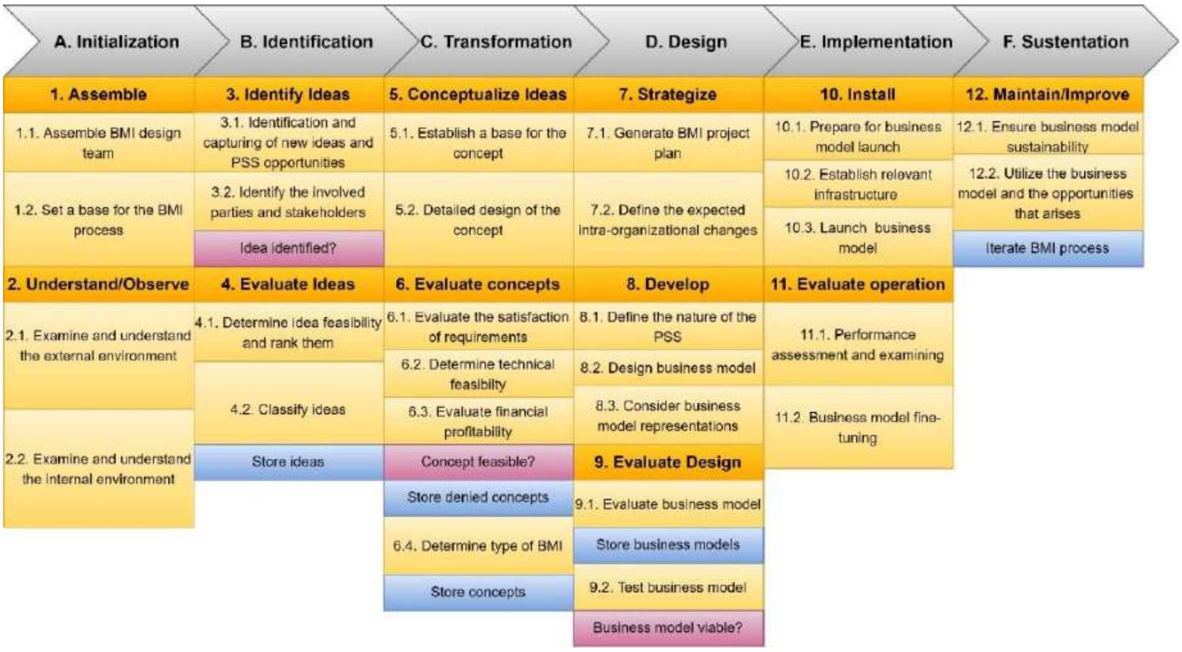
C. **Transformation:** Here the PSS opportunities and ideas identified are transformed into second-order ideas or concepts after which it is evaluated thoroughly. In the **Conceptualize Ideas** stage, relevant information to the planning of concepts is collected. Characteristics and applications of the new PSS value offering must be defined as well as the value creation, delivery, and capture mechanisms. Co-creation with stakeholders comes into play when detailed PSS requirements and concept activities are defined to formulate a draft business model. The **Evaluate Concepts** stage includes the evaluation of technical feasibility, financial profitability, and the satisfaction of stakeholder requirements. Whether a new business model is needed, transformations to the old one, or simply gradual evolution of the old one, is then decided.

D. **Design:** This phase includes the detailed design of the innovation identified and conceptualized. In the **Strategize** stage, the BMI project’s vision, purpose, objectives, rationale, marketing strategies, and scope are defined. Approval from top management is obtained. Expected organizational and relational changes are also outlined. The

Develop stage includes determining the PSS's type, ownership structure, ratio, and degree of servitization. The business model elements are then designed in detail including the customer value proposition, profit formula, and value creation and capture mechanisms. Functional integration with partners is established and market entry hurdles for competitors are built. The **Evaluate Design** stage includes the in-depth element evaluation of the new business model and a comparison with old or other business models. The business model is then tested in a foothold market to detect flaws and failures after which adjustments are made.

E. **Implementation:** This phase includes the complete roll-out and installation of the detailed designed business model across all associated platforms and markets. In the **Install** stage, the firm is prepared for launch by announcing the business model's arrival and overcoming internal resistance. A project budget, roadmap, key milestones, and installation method are set out. The relevant infrastructure needed like legal structures, project activities, resources, investments, rules, metrics, culture, skills, relationships, and staff is obtained. The business model with its pre- and post-sale value communication mechanisms is then implemented across all business units and the whole target market. In the **Evaluate Operation** stage, the newly installed business model's performance is assessed by monitoring it against the success indicators and by using customer feedback. Where errors and inefficiencies pop up, the necessary adjustments are made.

F. **Sustentation:** Here the business along with its business model is maintained and improved to secure sustainability for the business. The **Maintain/Improve** stage begins by monitoring PSS barriers and revisiting original plans and strategies. Distinctions from competitors are continually sought and protection mechanisms are put in place. Activities like taking products back, retrieving, recycling, renovating, and remanufacturing are managed. PSS triggers and BMI origins are again monitored, together with continuous market assessment to adapt accordingly. The PSS is further utilized through other novel markets and business models. Lastly, the BMI team is evaluated and adjusted accordingly where the iteration of the whole BMI process starts again.



A. Initialization	B. Identification	C. Transformation	D. Design	E. Implementation	F. Sustentation
1. Assemble	**3. Identify Ideas**	**5. Conceptualize Ideas**	**7. Strategize**	**10. Install**	**12. Maintain/Improve**
1.1. Assemble BMI design team	3.1. Identification and capturing of new ideas and PSS opportunities	5.1. Establish a base for the concept	7.1. Generate BMI project plan	10.1. Prepare for business model launch	12.1. Ensure business model sustainability
1.2. Set a base for the BMI process	3.2. Identify the involved parties and stakeholders	5.2. Detailed design of the concept	7.2. Define the expected intra-organizational changes	10.2. Establish relevant infrastructure	12.2. Utilize the business model and the opportunities that arises
2. Understand/Observe	Idea identified?	**6. Evaluate concepts**	**8. Develop**	10.3. Launch business model	Iterate BMI process
2.1. Examine and understand the external environment	**4. Evaluate Ideas**	6.1. Evaluate the satisfaction of requirements	8.1. Define the nature of the PSS	**11. Evaluate operation**	
2.2. Examine and understand the internal environment	4.1. Determine idea feasibility and rank them	6.2. Determine technical feasibilty	8.2. Design business model	11.1. Performance assessment and examining	
	4.2. Classify ideas	6.3. Evaluate financial profitability	8.3. Consider business model representations	11.2. Business model fine-tuning	
	Store ideas	Concept feasible?	**9. Evaluate Design**		
		Store denied concepts	9.1. Evaluate business model		
		6.4. Determine type of BMI	Store business models		
		Store concepts	9.2. Test business model		
			Business model viable?		

Figure 2: Proposed Solution Framework

7 CASE STUDY IMPLEMENTATION: ROLLS-ROYCE, NICHE AS A STRATEGIC ASSET

Further research is still being done on the thorough validation of the proposed solution framework, however, a very brief case study implementation is demonstrated in this section to show the solution's anticipated relevance and applicability.

When one thinks of a PSS, Rolls-Royce probably is a good example of successfully integrating services and products in their business model. Annarelli et al. [48] presents a case study of Rolls-Royce successfully adopting a PSS business model which they obtained on rolls-royce.com. A profitless and sinking British car company was turned into a global jet engine producer. Their success story will be mapped against the proposed solution framework to see if the core processes are present in both, or how these core processes can be applied.

The Case Study will be discussed using the lifecycle and stages in Figure 2 as the reference.

1. **Assemble**: The case study does not detail these initial activities, but one can derive from the literature that they were forced to make changes.
2. **Understand/Observe**: They applied this stage by realizing that the car industry was saturated at the time with many competitors in a competitive market. This happened after they examined their external and internal environments.
3. **Identify Ideas:** They identified and captured new innovative ideas like carbon blades and the change in jet engines by changing the pair of three-axle shafts as would be done in this stage.
4. **Evaluate Ideas:** The case study does not detail these core activities, but one can imagine that each new idea was thoroughly evaluated.
5. **Conceptualize Ide**as stage were applied. They quickly turned the idea into a detailed concept which resulted in a more efficient engine than any other engine at the time.
6. **Evaluate Concepts:** They also applied this stage where they determined that all customers' requirements were satisfied even though it was more a more expensive engine. Financial sustainability was also achieved by increasing profits through the addition of services such as maintenance and sale of spares.
7. **Strategize:** They only partially applied the **Strategize** stage because they anticipated major organizational changes. When they decided to move away from the sale of products-only to an integrated product/service solution, they officially adopted a PSS business model.
8. **Develop:** Rolls-Royce has already presented the "power by the hour" model where clients pay for maintenance of the engine based on the sum of hours it was used. Here they applied this stage by developing new business models that evolved into the "Total Care" model where every engine could collect data that can predict engine performance, thus evaluating it and providing services and adjustments where needed.
9. **Evaluate Design:** The Case Study does not detail how the design was evaluated, but what should have happened here the thorough evaluation of their new models before they were fully installed.
10. **Install**: A very large amount of internal and external resources was needed for such models such as skilled staff to analyse the data, and the associated information systems. Major intra-organizational changes were made. This are activities characteristic to this stage.
11. **Evaluate Operations:** They analysed and adjusted their implemented business model regularly. Post-sale long-term relationships were established in this way between the user and Rolls-Royce. Eventually, they ended up selling only the hours that the engine is used rather than the engine itself. They implemented these novel innovative models

across all business units of Rolls-Royce. Acting pro-actively saved Rolls-Royce from bankruptcy.

12. **Maintain/Improve:** To make themselves more inimitable they gradually integrated more services with their technology, thus they prominently applied this stage as well. Applying BMI and adopting a PSS was their way to business sustainability and a new competitive advantage.

Even though Rolls-Royce did follow a structured BMI process to adopt a PSS business model, they did what needed to be done to survive and unknowingly applied a lot of the essential and critical stages that are essential for successful BMI for PSSs. Thus, this case study confirms the presence of some of the most essential phases and stages in the proposed solution framework along with their relevancy.

8 CONCLUSION

The solution framework presented acts as a roadmap to navigate users through the BMI process. A detailed, well-defined, and comprehensive BMI framework - that consists of the suitable tools, fundamental design guidelines, and techniques to design and adopt a sustainable PSS business model was developed analytically and systematically. The focus of this article, however, is not on the in-depth and detailed designs and activities, but rather on the over-arching and high-level process flow of successful BMI for PSSs. As showed in the Rolls-Royce case, after a successful BMI endeavour to seize a PSS opportunity, business sustainability followed.

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A ZERO-WASTAGE APPROACH TO BENCHMARK COMPRESSED AIR SYSTEMS ON PLATINUM MINES

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ABSTRACT

Large industrial systems in deep-level mines contribute to the majority of mining utility costs. Optimising a system's energy efficiency can result in significant cost reduction and energy efficiency. This helps the struggling South African electricity provider, adds saving on utility cost reduction initiatives and improve Environmental, Social and Governance scores through decarbonisation. Optimisation through benchmarking is a common method used to identify inefficiencies by comparing similar systems. One pitfall of this method is the number of variables in each system. Normalising these systems has proven to be problematic due to limited data in the mining environment. This study proposes a new methodology to benchmark a mining system against its theoretical zero-wastage baseload. The proposed methodology was applied on a mine's compressed air system, achieving a theoretical 49% reduction. This resulted in a potential 72.7 MWh saving and a 78.5 ton CO_2 reduction over a 24-hour period.

Keywords: Energy efficiency, Platinum mines, Compressed air, Zero-wastage, Benchmarking

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1 INTRODUCTION

The electricity provider Eskom is responsible for approximately 95% of South African's electricity generation [1]. A lack of proper maintenance and planning resulted in Eskom being under enormous pressure to sustain a stable electricity supply since 2010 [2], [3], [4]. The power utility requires additional funds to solve the backlog in maintenance. This resulted in annual 8-15% increases in electricity tariffs over the last decade [5]. A direct result of these increases is the increased costs South African mines have to absorb [6].

In addition to increasing electricity tariffs which increased overhead costs, companies' income also take strain due to competition in the market [7]. Environmental, Social and Governance (ESG) is one of the compliance measures considered by the market when evaluating a company [8]. Lower ESG scores can lead to penalties due to higher CO_2 emissions and a potential loss in customers [9]. The Environmental component of ESG includes criteria such as the energy sources required, the amount of energy consumed, and the management of any waste products produced. Carbon dioxide (CO_2) emissions are included in the Environmental component of ESG and has become a significant focus point within larger companies to produce a cleaner product [9].

Due to the strain and challenges of rising electricity tariffs and ESG compliance, South African mines need to be more energy efficient to reduce electricity cost and improve on ESG scores [9], [10].

1.1 Background of study focus areas

The South African platinum mining industry is the largest in the world, producing 70% of the total annual export [11]. This makes it a very competitive industry, placing focus on components such as ESG scores and clean products.

The mining activity itself requires energy intensive systems such as compressed air, ventilation, dewatering and refrigeration. **Error! Reference source not found.** displays a breakdown of a typical South African platinum mine's energy distribution [12]. As indicated, the majority of electricity consumption is due to motor driven systems. Compressed air is the highest of these energy consumers, consuming 21% of the mine's total energy [13].

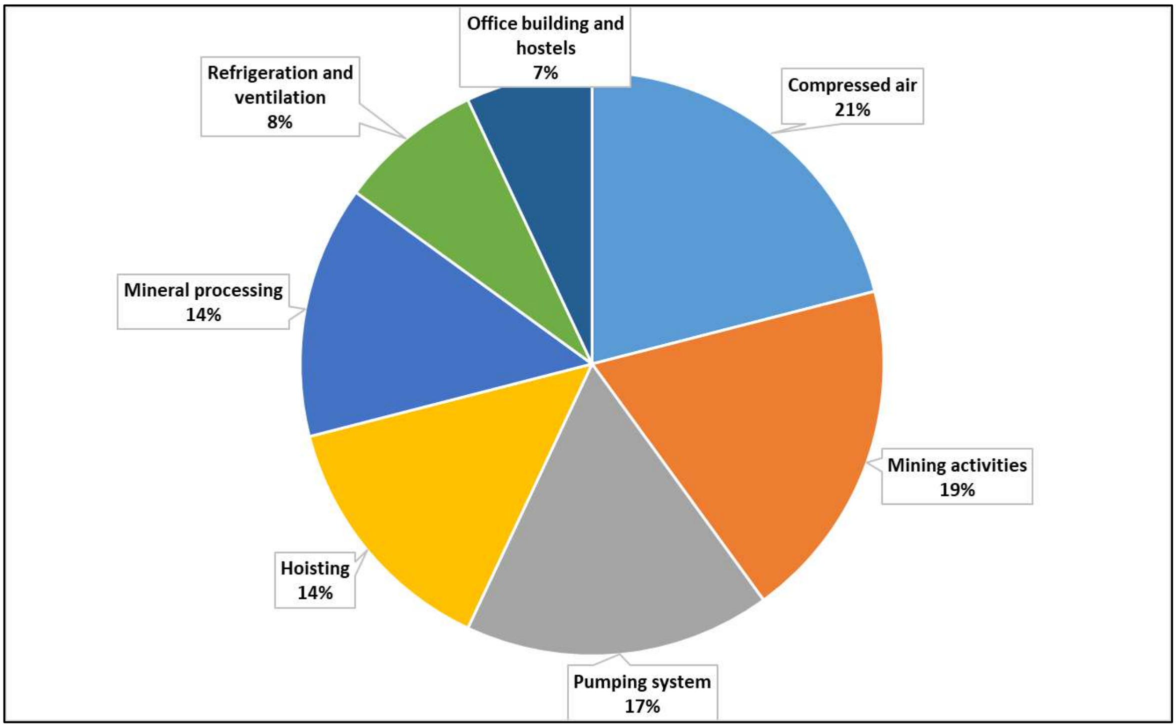

Figure 1: Platinum mining system energy division [13]

Compressed air is a critical component of key operations on a conventional mine [12], [14]. Due to the safety and expandability of a compressed air system, it is the preferable energy source for drilling and tramming [12], [14]. A typical compressed air system consists of a supply- and demand side.

The supply side consist of physical compressors and a network of pipes transferring compressed air to the demand side. South African deep-level mines prefer multistage centrifugal compressors as they can supply high compressed air flow at a required pressure set-point. A benefit to these compressors is the ability to vary air flow through guide vane control [12], [15]. This is useful when flow optimisation is required for the implementation of efficiency initiatives.

The demand side includes multiple users e.g. drills, loaders, refuge chambers, etc. [15]. These users typically operate in three different operational schedules on a conventional mine [14]:

- Drilling – Holes are drilled within the rock face to hold explosives set in the next shift.
- Blast – The holes drilled in the previous shift are charged with explosives and detonated.
- Cleaning – This shift consists of cleaning the blasted rock as well as tramming the rock to the loading areas.

Large steel pipes are used underground to transfer compressed air from surface to working areas. Figure 1 displays a high-level schematic of a typical underground compressed air system.

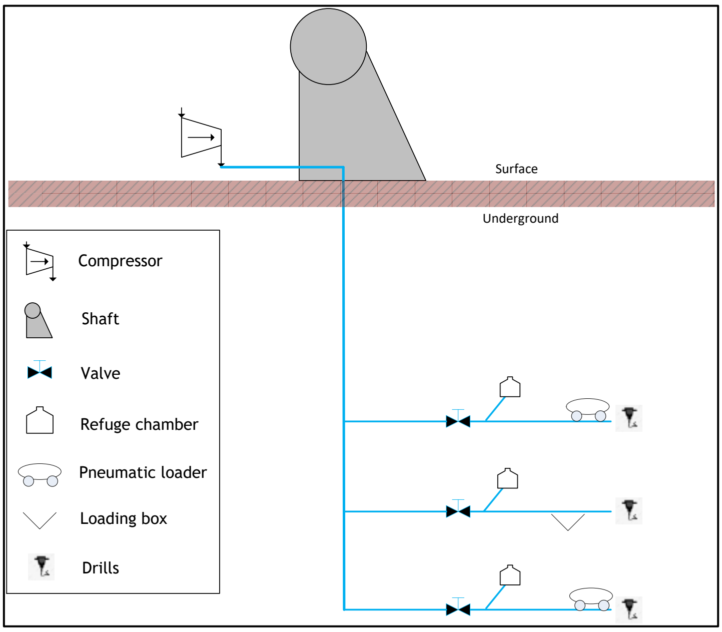

Figure 1: High-level underground compressed air network

Various studies found that compressed air in the mining environment is managed inefficiently [16], [17], [18], [19], [20]. Compressed air systems expand to adapt to ever-growing mining networks underground. Resulting in additional pipe connections and compressed air consumers. Over time this can result in more inefficiencies due to leaks and compressed air flowing in inactive mining areas [21].

Zietsman, found that auditing can assist with the identification of inefficiencies such as leaks [21]. Auditing will also assist in gaining knowledge and understanding of a vast compressed air network [21], [20]. Resulting in managing compressed air more efficiently [21].

Benchmarking techniques is another method that can be used to identify inefficiencies [12], [21]. This is done by identifying a best practice model through comparing inefficient systems to efficient systems, with the goal to identify the best industry practice [22], [23]. Performance indicators are used to compare two or more systems to identify inefficiencies and/or efficiencies within the systems [12].

This method usually requires a lot of accurate data from both systems to execute successfully [12]. This in turn requires sufficient metering and data management that is not always available in the mining environment [12].

In an ideal world the most efficient system will have zero waste. If zero-wastage is considered as a design principle, an entire system can be modelled to operate on its bare requirement [24]. Zero-wastage is then referred to as managing processes to eliminate and avoid any causes of wastage [25]. The information required to achieve this outcome is the total number of equipment used and their rated flow demand. This information is more easily obtainable on a mine than, for example, detailed flow data.

If a zero-waste model can be considered the most efficient version of a system, [24], it stands to reason that an existing system can be benchmarked against the most efficient version. Resulting in only one set of parameters needed and most normalising variables such as geological orientation, mining depth, scale of operation team dynamics and operation scale to be the same.

1.2 Need and Objectives

Considering all the background information, a need exists to improve compressed air efficiency in the platinum mining industry to reduce electricity cost and improve ESG scores. The objectives of this study are as follows:

- Use existing and available information for benchmarking; and
- Develop a zero-wastage benchmarking process that will allow a mine to be measured against the most efficient version of itself.

1.3 Literature linked to benchmarking in industry

Current benchmarking methods used in the mining industry generally compare high demand energy systems with each other to identify energy efficiency opportunities [12], [26], [27]. A challenge typically found with this method involves differences in normalising information between mines. The studies recommended that a normalised approach be followed to mitigate normalising variable requirements, however the methods required an extensive number of variables. As a result, challenges with data availability and accuracy can cause inaccurate benchmarking results [12].

Another benchmarking method common to the mining industry, is production benchmarking. This entails that production is utilized as the normalising variable used to benchmark different mines [28], [29]. The shortcoming with this method is that production is not the only variable affecting energy consumption [12]. Different equipment and normalising information also play a role. This method can result in inaccurate results, especially with larger operations.

Benchmarking in other industries were also considered to identify energy efficiency opportunities within hotels, offices and urban areas [27], [30], [31]. However, normalisation variables and external factors such as temperature had a large impact on these studies. This can lead to inaccurate results, especially with larger systems greatly affected by external factors.

With regards to ESG there is a renewed drive placed on industries to increase their ESG score and in doing so reduce their CO_2 emissions [10]. The CO_2 benefit resulting from energy efficiency can be calculated using the CO_2 /energy equivalent set by each country's energy provider. For South Africa this is Eskom. The national electricity provider stated that in 2021, 1.08 ton CO_2 is generated per MWh produced [32]. As a result, any energy efficiency saving achieved on compressed air will have a significant impact on CO_2 emissions.

With regards to zero-wastage benchmarking, very little literature is available, especially in the mining environment. Databases such as Google Scholar and Science Direct were used in combination with the following keywords: “zero-wastage benchmarking”, “mining” and “compressed air”. Articles published after 2010 found in primary sources were considered as they contain the most relevant information.

1.4 Compressed air in platinum mines

As mentioned, this study focusses on compressed air and demand side utilisation of the pneumatic equipment. The typical components that form a compressed air network are discussed below:

Rock drills

Use: To extract ore from a mine, the ore needs to be separated from the surrounding rock. This is done by inserting explosives within the rock. Rock drills are used to create a hole where the explosives are placed [12], [14], [33].

Misuse: The air supply feeding the drills is kept open after drilling shift is completed. This leads to compressed air leaking through the drills and various leaks within the working areas.

Pneumatic loaders

Use: Pneumatic loaders operate on a track. They contain a bucket-like scoop to load ore and waste into hoppers, usually at development end. The hoppers are transferred to the loading bays as they reach maximum capacity. The ore is then tipped via pneumatic cylinders into a loading box.

Misuse: No misuse of significant size was noticed.

Loading boxes

Use: The ore accumulated in the loading box are loaded into hoppers via a shoot that is controlled with pneumatic cylinders. The ore is transferred to surface with a winder. Loading boxes are located within working sections.

Misuse: No misuse of significant size was noticed

Agitators

Use: Agitation is the process where compressed air is released into dams to keep slurry from settling at the bottom of a dam. This ensure that the slurry water mixture can be pumped out to waste dams.

Misuse: In some cases, agitators are left open although the dams are clean. Resulting in unnecessarily wasting compressed air. Due to lack of measuring equipment, it is difficult to determine the amount of wastage.

Refuge chamber

Use: Refuge chambers are underground chambers with a compressed air feed to ensure positive atmospheric pressure. The positive atmospheric pressure ensures that hazardous fumes are kept from entering the chamber. Refuge chambers are required by law to keep employees safe in case of an underground emergency [12].

Misuse: In some cases, refuge chambers are supplied with larger pressures than required. Personnel open bypass valves to create a cooler environment to sit in.

Venturi blowers

Use: Due to increasing mining depths, temperatures within underground working areas are increasing. Venturi blowers authorised by mine management are placed in working sections to ventilate compressed air through the working sections to comply with ventilation requirements [21].

Misuse: Unauthorized venturi blowers are used to ventilate working sections that already have acceptable temperatures. This leads to lower compressed air pressures for drilling and unnecessary compressed air wastage.

Open ends

Misuse: Open ends are pipes connected to the compressed air supply used by employees to clean dust from development areas. However, this method is very ineffective in terms of energy management, as it leads to substantial compressed air wastage [12].

Leaks

Misuse: Leaks are common in an extensive compressed air network. Underground conditions cause compressed air pipes to corrode and form leaks. A substantial number of leaks can lead to a pressure drop across a compressed air network [12]. This can lead to additional energy consumption as compressors needs to work harder to sustain pressure. Leaks can be seen as a misuse of compressed air.

2 ZERO-WASTAGE BENCHMARKING PROCESS

In this section a generic method will be developed that utilise zero-wastage to determine efficiency potential within a compressed air network. Building on the lessons learned from literature, the process shown in Figure 2 was developed.

The goal of this process is to distinguish between the compressed air system's baseload and wastage. The baseload of the compressed air network is the actual consumption excluding wastage (Zero-wastage baseload). The wastage is considered as the inefficient operation which will be identified during the audit phase (efficiency potential).

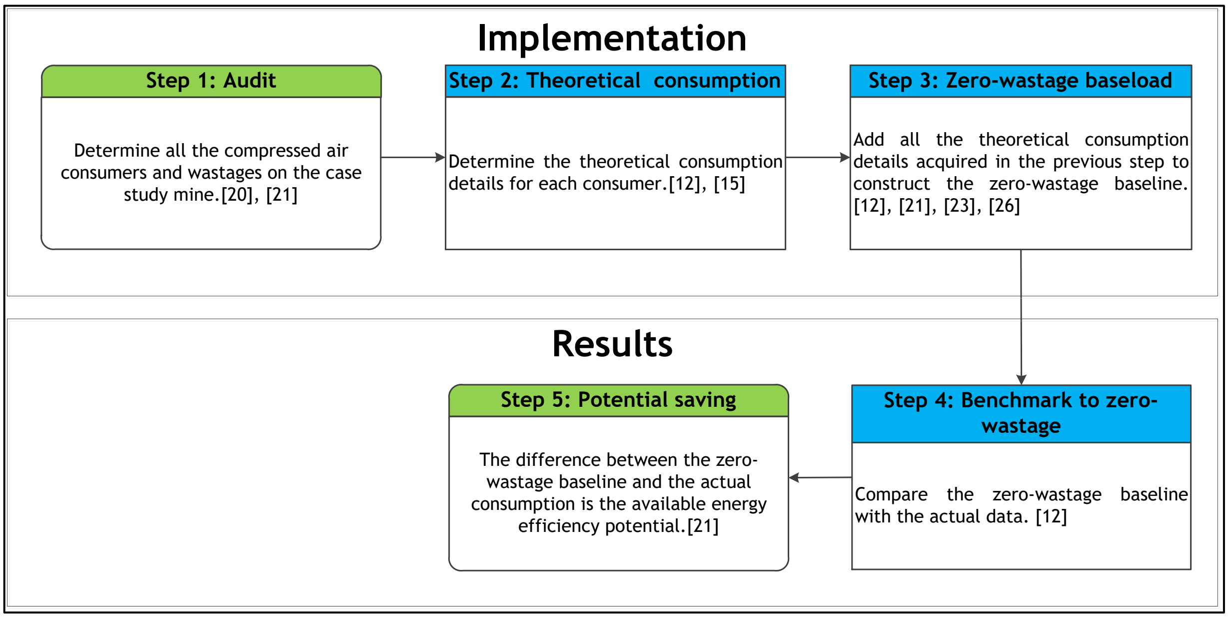

Figure 2: Zero-wastage process

Step 1: Audit - Reliable compressed air data is required. Auditing is a technique used to gather valuable information of a system [21]. Therefore, a detailed audit is conducted on the compressed air network. This verifies which compressed air consumers are operational as well as the condition of the compressed air network to identify any wastages. A typical audit will entail:

- Meetings and interviews – Meet with on-site personnel for site layouts and preliminary information.
- Visual inspections – Visually inspect the system in question, including underground site visits to identify equipment and infrastructure.
- Physical data gathering – Gather rated consumption details for all consumers identified in the visual inspection as well as operational schedules of each consumer. Pressure and flow measurements are required to identify inefficient areas within the compressed air network.
- Take notes and photos – Take notes of any wastage detected throughout the audit. Photos of wastages and identified consumers can be valuable to mitigate revisits.

Step 2: Theoretical consumption – To calculate the theoretical consumption of each consumer, the rated flow and the quantity of all the compressed air equipment identified in Step 1 is required. The theoretical consumption is calculated by multiplying the rated flow with the quantity of the specific consumer as seen in equation 1.

$$Theoretical\ consumption = f_{rated} \times \sum_{consumers} \tag{1}$$

Step 3: Zero-wastage baseload – The Zero-wastage baseload is calculated by creating a 24-hour profile consisting of the theoretical consumption details allocated to their respective operational schedule.

Step 4: Benchmark to zero-wastage – Compare the zero-wastage baseload with actual compressed air data found during the audit to locate inefficiencies. This will highlight the waste or potential saving.

Figure 3 displays an example of the variables after typical iteration of the Zero-waste process. As seen in the figure, the additional variable "Unknown" is added for the uncategorised consumption that could not be allocated after the initial audit. The "Unknown" usually result from a lack of accurate data or infrastructure missed during the initial audit. As auditing continue, the "Unknown" areas should become focus areas to reduce "Unknown" data. In an ideal system, the "Unknown" variable will reduce to zero, resulting in the efficiency potential being equal to the identified wastage.

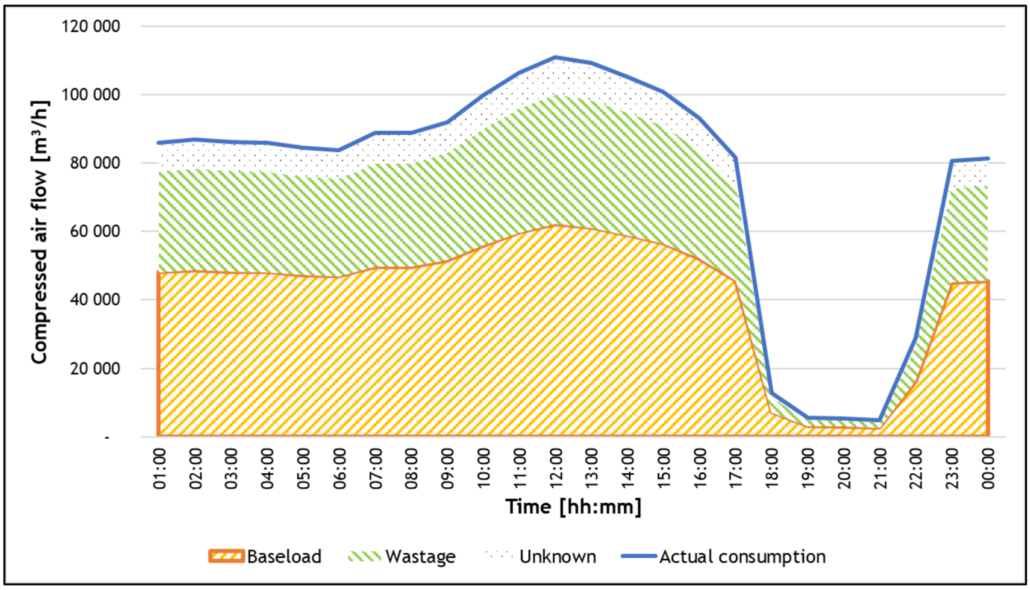

Figure 3: Zero wastage vs actual profile comparison

Step 5: Potential saving - The *Wastage* can be calculated by subtracting the *Baseload* and the "*Unknown*" from the *Actual consumption* as displayed in equation 2 [21].

$$Wastage = Actual\ consumption - (Baseload + Unknown) \quad \textbf{(2)}$$

The CO_2 reduction due to the energy efficiency improvement can be calculated with Equation 3, displaying the ratio between CO_2 and MWh for South Africa [32].

$$1.08\ ton\ CO_2e = 1\ MWh \quad \textbf{(3)}$$

3 IMPLEMENTATION OF ZERO-WASTAGE PROCCESS

The implementation steps (Step 1 - 3) of the zero-wastage process was implemented on a deep-level platinum mine and will be discussed in this section.

Step 1: Audit the system, in this case the compressed air network. Table 1 provides a summary of the audit results.

Table 1: Audit results

Consumer	Quantity
Rock drills	261
Refuge chamber	42
Authorised venturi blowers	2
Pneumatic loaders	10
Loading boxes	56

The identified compressed air consumers and equipment was divided between the three operating shifts of the mine. Figure 4 provides a visual indication of this operational schedule with its consumers.

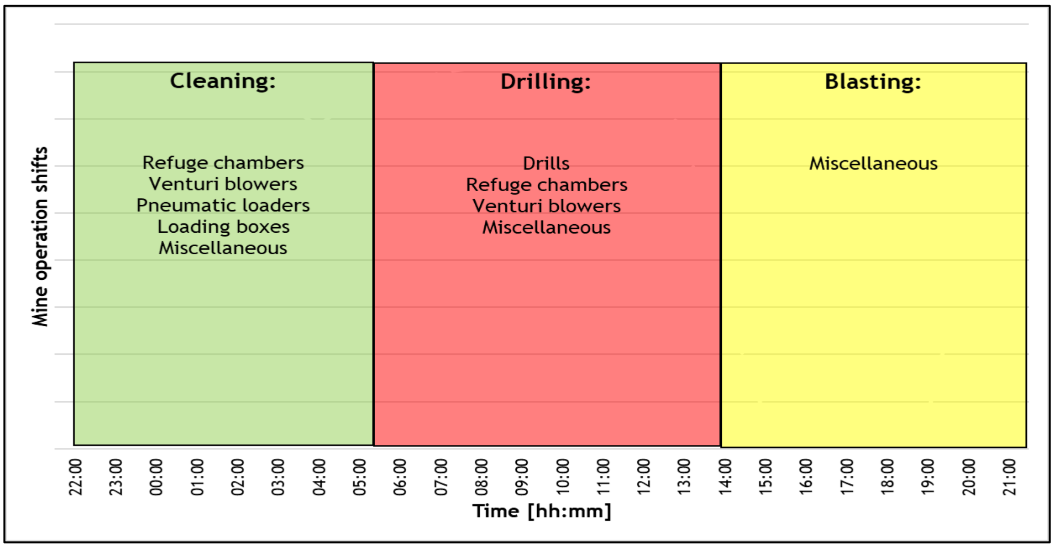

Figure 4: Mine operational schedule

Step 2: Identify the rated consumption details for each consumer. This information was gathered during the audit and direct communication with the equipment suppliers.

Refuge chambers

It was calculated that approximately 61.5 m³/h was consumed by each refuge chamber. The case study contains 42 refuge chambers underground. This entails that 2 585 m³/h are consumed by all the chambers.

Authorised venturi blowers

Venturi blowers consume an estimated 327.6 m³/h. The detailed audit revealed that the case study contains two authorised venturi blowers for cooling purposes. This means a total of 504 m³/h are consumed by authorised venturi blowers.

Rock drills

During the audit it was found that two different drills are used on the mine. The drills used are the S25 and the S215, allocated to development and stopping respectively. Table 2 provides a summary of the number of crews, the rated consumption per drill, the number of allocated drills per crew and the total compressed air consumption.

Table 2: Rock drills compressed air consumption

Crew	Crew number	Drill type	Rated consumption (m³/h)	Drills per crew allocated	Total consumption (m³/h)
Stopping	48	S215	198	4	38 016
On reef development	13	S25	246	2	6 406
Development	2		246	2	986
Waste development	13		246	3	9 610
Total	76				55 018

As indicated in Table 2, the mine contains 76 crews working in different sections across the mine. A theoretical compressed air consumption of 55 018 m³/h is consumed for drilling purposes.

Loading boxes

The rated flow for the specific loading box is between 2.16-50.4 m³/h at 350-600 kPa [15]. During the audit it was found that the loading boxes on the case study mine operates at 470 kPa. This entails that the loading boxes consumes an estimate total of 1 471 m³/h.

Pneumatic loaders

A pneumatic loader consumes an estimated 1 008 m³/h. The case study mine has ten loaders operating in cleaning shift. Thus, a total of 10 080 m³/h is consumed.

Miscellaneous consumers

During the audit 6 002 m³/h was noticed after the working levels where closed. This consists of miscellaneous underground operations such as compressed air and water pneumatic valves, compressed air leaks and open ends.

Table 3 provides a summary of the total theoretical compressed air consumption of each consumer calculated with equation 1.

Table 3: Theoretical consumption

Compressed air consumer	Theoretical consumption (m³/h)
Refuge chambers	2 585
Venturi blowers	504
Rock drills	55 018
Loading boxes	1 472
Pneumatic loaders	10 080
Miscellaneous consumers	6 002

Step 3: Calculate the baseload by adding the results indicated in Table 3 to the mine operations schedule in Figure 4. Figure 5 displays the zero-wastage baseline profile over a 24-hour period for the case study.

It was noticed that the loaders were not operational for the entire cleaning shift. An average operational time of three hours were noticed between 01:00 and 04:00, explaining the increased consumption between the specified period.

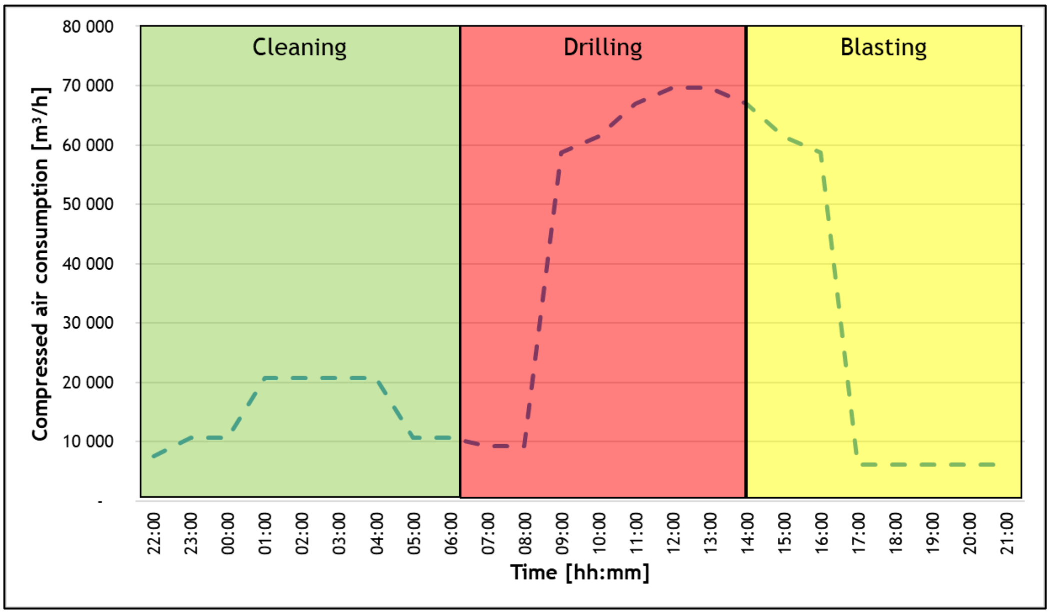

Figure 5: Zero-wastage baseline

The Result part of the zero-wastage process (Step 5 and 6) are discussed in the following section.

4 RESULTS

4.1 Zero-wastage compressed air system

Figure 6 displays the case study mine’s actual compressed air consumption compared to the zero-wastage baseline derived in Step 4. The actual consumption profile consists of a month’s average weekday data. As seen in the figure, the discrepancy between the cleaning shift (22:00-06:00) and the drilling shift (06:00-14:30) is minor. The majority of the potential is found within the cleaning shift, due to the large difference between the zero-wastage baseload and the actual consumption. This difference highlights the misuse and inefficiency within these times as pipes deteriorate over time without maintenance, as well as equipment and working areas being left open after use. The compressed air cannot be closed during cleaning shift as numerous equipment and employees underground require the compressed air.

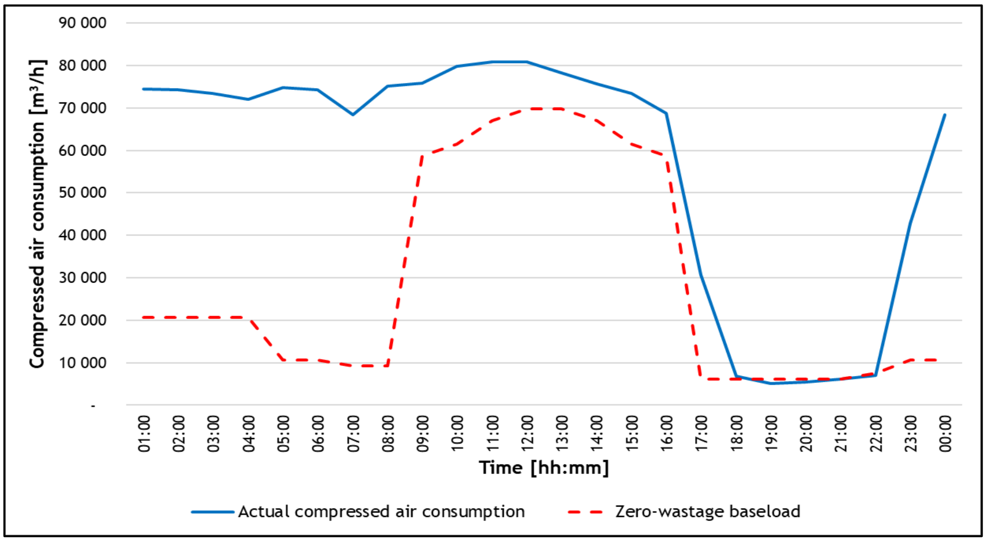

Figure 6: Actual consumption vs zero-wastage

As seen from Figure 6, the actual consumption profile is substantially higher than the zero-wastage profile, especially during cleaning shift. The case study consumed a total of 554 149 m^3 during cleaning shift compared to a total of 153 326 m^3 for the zero-wastage profile. This indicates that a possible reduction of 400 822 m^3 can be achieved during cleaning shift, if the compressed air consumption is managed correctly.

The mine in question consumed a total of 1 372 636 m^3 over the 24-hour profile compared to a total of 676 886 m^3 for the zero-wastage profile. A reduction of 49% can be achieved with the zero-wastage baseload. It was measured that the case study mine produced 9.3 m^3/kW. Meaning, the compressed air reduction is equivalent to a possible energy saving of approximately 72.7 MWh for the 24-hour period. This can result in a CO_2 reduction of approximately 78.5 for the 24-hour period.

4.2 Zero-wastage per-level

The benefit of the zero-wastage benchmarking method is that it is not limited to the overall compressed air system. The zero-wastage method can be applied on one working level, depending on the availability of data. This results in more accurately identifying the compressed air system's available efficiency. The Zero-wastage process was implemented on the case study mine's production levels and benchmarked based on their zero-wastage performance. Table 4 provides the results achieved from the per-level zero wastage implementation.

Table 4: Production level zero-wastage results

Production level	Level flow per 24-hour (m^3)	Zero-wastage baseload per 24-hour (m^3)	Saving (m^3)	Saving (kWh)
30	225 863	54 806	171 057	18 393
31	237 156	76 448	160 708	17 280
32	280 070	151 462	128 608	13 829
34	307 174	209 319	97 855	10 522
33	302 657	208 664	93 993	10 107

As seen in the table above, 30 level was identified with the most efficiency potential available. This is because the level contains the lowest zero-wastage baseload compared to the actual compressed air consumption.

Figure 7 displays 30 level's zero-wastage results compared to the level's actual compressed air consumption. As seen the zero-wastage baseload is lower throughout the entire 24-hour period. A possible efficiency of 171 057 m^3 can be achieved in an ideal scenario. Although this network will never reach the zero-wastage baseload, the Zero-wastage process can assist to identify inefficiencies throughout the compressed air network.

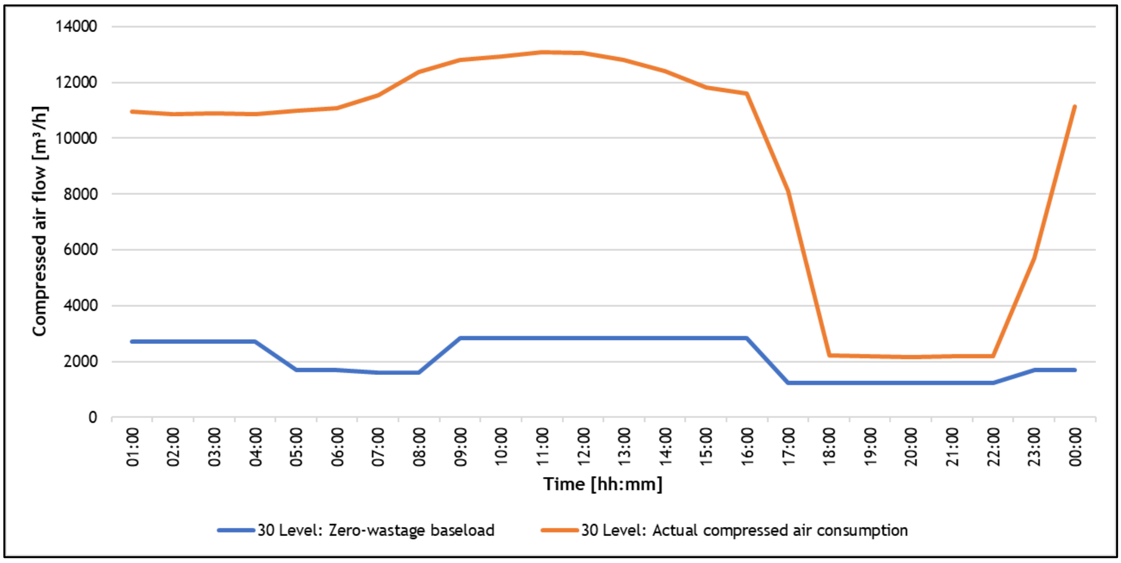

Figure 7: 30 Level Zero-wastage vs actual

5 CONCLUSION

Large industries such as the mining sector is under enormous pressure due to rising electricity tariffs. Additionally, stakeholders have placed more emphasis on ESG scores as it should result in a cleaner product that is more favourable in the markets.

Energy efficiency is a method that can assist industries to mitigate these challenges. Multiple studies focussed on benchmarking methods to identify energy efficiency potential by comparing different systems to each other. The issue with benchmarking mining operations, is that there are inaccuracies when considering numerous variables.

Platinum mines use various high energy consumption systems to extract ore from underground. The focus of this study was the development of a new method to identify available energy efficiency within a compressed air system on a platinum mine. The method consists of creating a zero-wastage baseload to compare a mining operation against its ideal self.

In the case study, a zero-wastage baseload was calculated from theoretical or rated consumption for a mine's compressed air consumers. The baseline indicated that a reduction in compressed air consumption of 49% can be achieved with zero-wastage. This results in a reduction of 72.7 MWh equating to a CO_2 reduction of 78.5 tons for the 24-hour period. From the results, it was seen that additional audits can increase the accuracy of the zero-wastage process.

Compared to the methods researched in the literature study, this method is less variable intensive as it only required data and information from the mine in question. There was no need for any normalisation, as the mine was effectively compared to itself. This greatly reduced the time and effort required to identify savings opportunities with a reduced risk of inaccuracies due to the reduction in required variables.

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REINFORCEMENT LEARNING IN INVENTORY MANAGEMENT

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ABSTRACT

This paper will explore the application of reinforcement learning in inventory management for public health pharmaceutical supply chains. The poor performance of pharmaceutical supply chains in the public sector due to lack of collective information sharing and inaccurate demand forecasting can lead to stock-outs. There is a need to balance between order quantities and reorder points in inventory management. Reinforcement learning using Q-Learning algorithm is proposed, which will learn from experience the optimum inventory policy and the near-optimal order sizes for every stock point, based on the respective inventory position. The supply chain will be modelled using Anylogic simulation software, and the Q-learning algorithm will be used to determine the optimal order quantities.

Keywords: inventory management, modelling, reinforcement learning

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1 INTRODUCTION:

With the introduction of 4IR, there has been a great advancement in technology. One of the benefits of this technological advancement is in support of inventory management and the development of new products and services. The majority of the public healthcare facilities in South Africa lack advanced information technology to better inform them on inventory levels in real-time across all levels of the supply chain. Machine learning and Big data analytics are making headways, and Industrial engineers should capitalise on this wave and come up with ways how to improve demand planning and inventory management by utilising these technologies.

Supply Chain Analytics (SCA) is a branch that deals with techniques and tools which are utilised in the improvement of operational performance by using data [1]. There is a growing interest in SCA in supply chain management, and businesses want to utilize the power of various analytical methods by leveraging the business value of supply chain data [2].

There are several challenges in supply chain management which relate to communication gaps within the supply chain, supply shortages, inadequate inventory planning, backlog orders, and demand fluctuation, to name a few. By leveraging machine learning and other artificial intelligence technologies, some of these problems can be solved. Intelligent supply chain planning and demand forecasting based on predictive analytics (data mining techniques and machine learning) are better at demand anticipation since it identifies and understands the patterns influencing it rather than projecting past demand.

There is a need to forecast expected demand in a supply chain in order to be competitive in the market, and forecasting accuracy is key. For all the players in a supply chain, there is a need to anticipate future demand and how this can affect their performance and profits [3]. Therefore there is a need for information sharing and coordination amongst all members of a supply chain [4]. If information sharing is important, then it is paramount that public health supply chains incorporate technologies that enable information sharing, as effects of any stock-outs can have dire effects.

Reinforcement learning is a method that aims to maximize a reward and interacts with an environment by means of actions. When an action is completed, the current state of the environment is updated, and a reward is given [5]. Reinforcement learning is able to maximize expected future rewards and, because of its sequential decision-making, can be a promising method to improve inventory management.

2 PROBLEM DESCRIPTION AND RESEARCH METHODOLOGY

This paper addresses the poor performance of the pharmaceutical supply chain in the public health sector, where there is insufficient information sharing and inaccurate demand forecasting and planning, which inevitably leads to stock-outs. The main focus is the information visibility between facilities and the Regional Pharmacy so as to drive the upstream activities based on this information. Most organizations are already using certain inventory policies to manage their inventory, and with them, they determine how much to order at a certain point in time, as well as how to maintain appropriate stock levels to avoid shortages. On the other hand, there are stock-out issues, and there is a need to balance between order quantities and reorder intervals. A system that can predict and reorder points and quantities while providing visibility within the supply chain, particularly between clinics and regional pharmacies, will assist in minimising stock-outs. Reinforcement Machine learning for stock level optimisation while creating visibility is a possible solution. There are three types, namely unsupervised, supervised and reinforcement learning. Every type of machine learning has its own approach and type of problem that can be solved. Figure 1 shows these three types of machine learning, areas of expertise and possible applications.

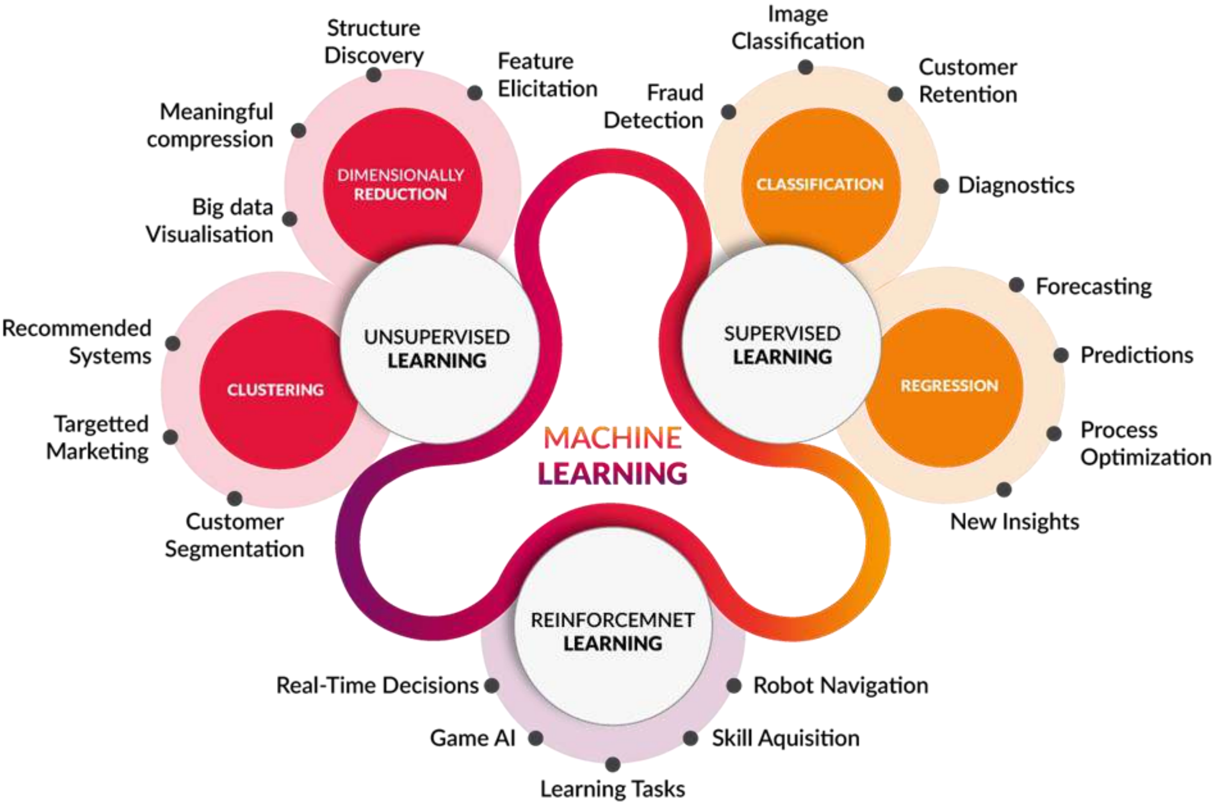


Figure 1: An overview of types and applications of machine learning. Adapted from [6].

3 LITERATURE REVIEW

3.1 Supply Chain

A supply chain is a network of business organizations that work together to convert and move goods from the raw material stage to the end user [7]. Other definitions state that it is a set of individuals and organizations who facilitate flows of products, information, raw materials and services from source to customer or vice versa through upstream (supply) and downstream (distribution) activities [8]. Some other key characteristics as part of a Supply Chain are the following,

- It coordinates intra- and inter-firm operations
- It promotes the creation of customer value and customer satisfaction [8].

The Council of Supply Chain Management Professionals (CSCMP) [9] defines supply chain as: "It encompasses the planning and management of all activities involved in sourcing and procurement, conversion and logistics management activities. It also includes coordination and collaboration with channel partners, which can be suppliers, customers or third-party service providers. It integrates supply and demand management within and across companies."

Supply chain management consists of the management of the movement and coordination of material, information and financial flows across the entire supply chain in a manner that maximizes supply chain value [10].

3.1.1 Pharmaceutical Supply Chain

Key characteristics of the Pharmaceutical Supply Chains (PSC) that can differ from other supply chains are the urgent nature of medicines, regulations, stringent transportation requirements, safety and storage [11]. It is defined as a combination of processes, organizations and operations that are involved in the development, design and manufacture of pharmaceutical drugs [12]. Therefore real-time information sharing and visibility are vital to facilitating an efficient supply chain network and fulfilling customers' requirements. There should be a link between PSC management and the accessibility of medications, as this paves the way for effective distribution, procurement and use of medications [13]. South African public healthcare system is experiencing a number of challenges, and one of them is distributing and managing the medicines at the right time [14]. This makes addressing and solving inefficiencies in supply chain operations very important. With the increase in demand variability and forecasting inaccuracies, practices in public health supply chains are failing to cope.

3.2 Reinforcement learning overview

Reinforcement learning can be defined as an exploration of an adaptive sequence of actions by an intelligent agent in an environment with a motivation to maximize a reward, and its action prompts a change in the state of the environment [15].

Reinforcement Learning (RL) describes an effective application of machine learning to solve decision problems [16]. Reinforcement learning encompasses learning what action is to be done in order to maximize a numerical value [16]. Decision-making is the agent's role, and everything that influences this decision-making is called the environment. Figure 2 shows an agent-environment interaction comprising the agent, its environment, actions and rewards. At the beginning of the learning process, the agent will be in state (s_t), and from each action (a_t), the agent moves to the next state, which is (s_{t+1}) [17]. The environment will produce a reward (r_t).

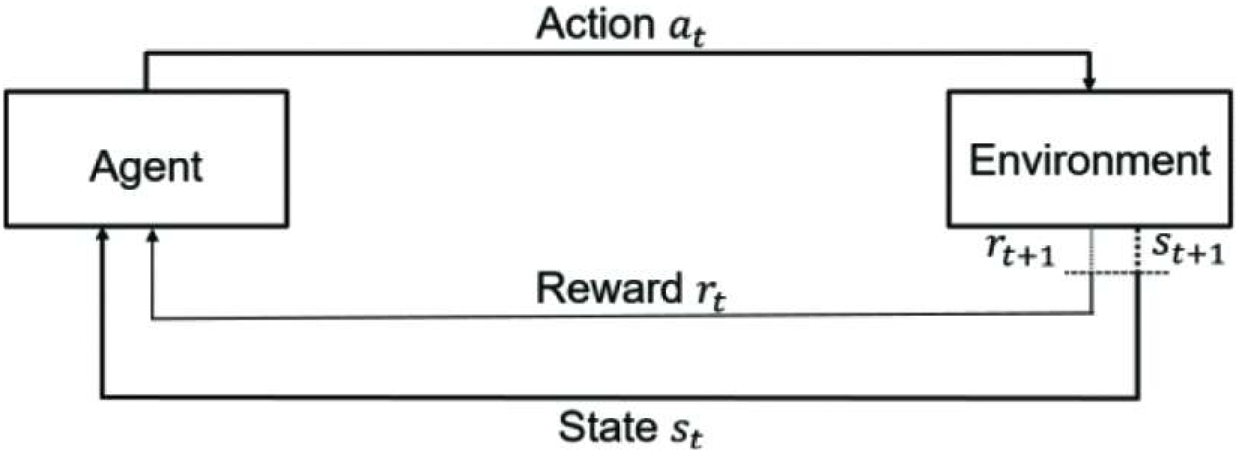


Figure 2: Agent-environment interaction in RL models [16]

3.2.1 Elements of Reinforcement Learning

The following definitions are obtained from Sutton and Barto [16]

The policy defines the behaviour of an agent at a specific time, and it involves coming up with actions to be taken at any given state [16]

Reward in an RL problem is the end goal, the environment sends out rewards every time step, and the goal of the agent is to maximise all rewards over a set period of time [16].

Value function derives its focus over a lengthy period of time which is contrary to rewards which look at the good at the moment [16]. The accumulative value of rewards defines the value of the state, which entails all relevant information on agent decision-making.

3.2.2 Markov decision processes (MDPs) and their relationship to reinforcement learning

According to Beysolow [18], MDPs are described as discrete time stochastic control processes. Discrete-time stochastic processes are defined as a random process in which the index variable is characterized by a set of discrete values in contrast to continuous values [18].

According to Sutton and Barton [16], a state signal that succeeds in retaining all relevant information is said to be Markov or to have the Markov property. According to Beysolow [18], mathematically, a state is said to have the Markov property if;

$$P\,[S_t + 1|S_t] = P\,[S_t + 1\,|S_1,..,S_t] \tag{1}$$

Markov processes themselves are considered to be memory-less in that they are random transitions from state to state [18]. They are considered to be a tuple (S, P) on a state space S where states change via a transition function P, defined as the following [18]:

$$P_{ss} = P\,[S_{t+1} = s'\,|S_t = s] \tag{2}$$

where S = Markov state, S_t = next state.

A reward is received from moving from one state to another, which can be defined mathematically as the following:

$$R_s = E\,[R_{t+1}\,|S_t = S], \tag{3}$$

$$G_t = R_{t+1} + \Upsilon R_{t+2} + \Upsilon^2 R_{t+3} + \cdots + \Upsilon^{k-1} R_{t+k} \tag{4}$$

where γ = discount factor, $\gamma \in [0, 1]$, G_t= total discounted rewards,

R = reward function.

A Markov reward process (MRP) can therefore be defined as (S, P, R, γ) [18].

3.2.3 Markov decision process (MDP)

An MDP comprises of a set of a set of possible actions A(s) in each state, fixed environment states S, a real-valued reward function R(s) and a transition model$P(s', s \mid a)$. [16].

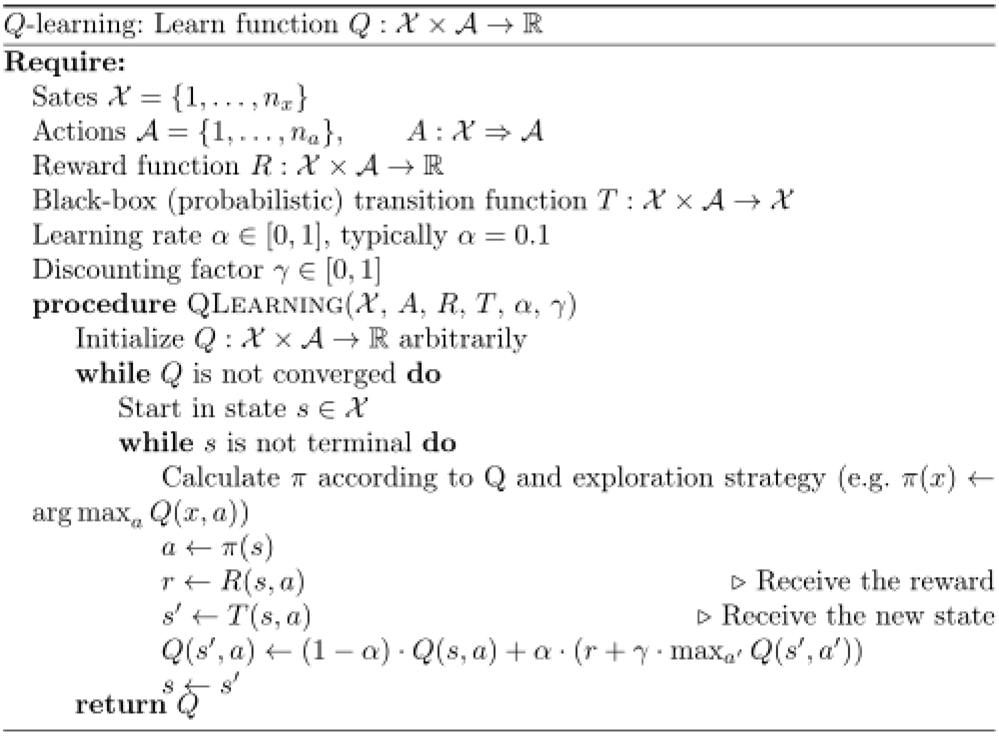
3.3 Q-Learning

Q learning forms part of model-free learning algorithms [19]. Its simplest form, one-step Q-learning, is defined by:

$$Q(St\,, At) \longleftarrow Q(St\,, At) + \alpha\,[R_{t+1} + \Upsilon \max Q\,(S_{t+1}\,, a) - Q(S_t\,, A_t)] \tag{5}$$

The learned action-value function, Q, directly approximates q, the optimal action-value function, independent of the policy being followed.

α refers to the learning rate (i.e. how fast are we approaching the goal)



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$Q$-learning: Learn function $Q : \mathcal{X} \times \mathcal{A} \to \mathbb{R}$
Require:
  Sates $\mathcal{X} = \{1, \ldots, n_x\}$
  Actions $\mathcal{A} = \{1, \ldots, n_a\}$,    $A : \mathcal{X} \Rightarrow \mathcal{A}$
  Reward function $R : \mathcal{X} \times \mathcal{A} \to \mathbb{R}$
  Black-box (probabilistic) transition function $T : \mathcal{X} \times \mathcal{A} \to \mathcal{X}$
  Learning rate $\alpha \in [0, 1]$, typically $\alpha = 0.1$
  Discounting factor $\gamma \in [0, 1]$
  procedure QLEARNING($\mathcal{X}$, $A$, $R$, $T$, $\alpha$, $\gamma$)
      Initialize $Q : \mathcal{X} \times \mathcal{A} \to \mathbb{R}$ arbitrarily
      while $Q$ is not converged do
          Start in state $s \in \mathcal{X}$
          while $s$ is not terminal do
              Calculate $\pi$ according to Q and exploration strategy (e.g. $\pi(x) \leftarrow \arg\max_a Q(x, a)$)
              $a \leftarrow \pi(s)$
              $r \leftarrow R(s, a)$                                ▷ Receive the reward
              $s' \leftarrow T(s, a)$                               ▷ Receive the new state
              $Q(s', a) \leftarrow (1 - \alpha) \cdot Q(s, a) + \alpha \cdot (r + \gamma \cdot \max_{a'} Q(s', a'))$
              $s \leftarrow s'$
      return $Q$
```

Figure 3: Pseudocode for Q Learning [20]

4 DESCRIPTION AND MODELLING

The model needs to solve an inventory problem where there is one supplier, one manufacturer and two clinics. The learning agent is the Regional pharmacy, and it will learn replenishment orders from the clinics/facilities and uses the information to order from its supplier (manufacturer), as shown in figure 4. The Regional pharmacy receives constant order demands, and the goal is to learn how much and when to order from its manufacturer.

The learning environment for the RL implementation will be in the Anylogic cloud AI environment, which is for developing and testing reinforcement learning algorithms. It also provides already built environments for experimentation and can be divided into the state space and action space.

4.1 State space

An agent's state entails all relevant information on agent decision-making. In this problem, we consider inventory level, backlog level and on-order amount, which is an amount of order that hasn't been fulfilled yet, as part of the state representation.

SAIIE 4.2 Action space

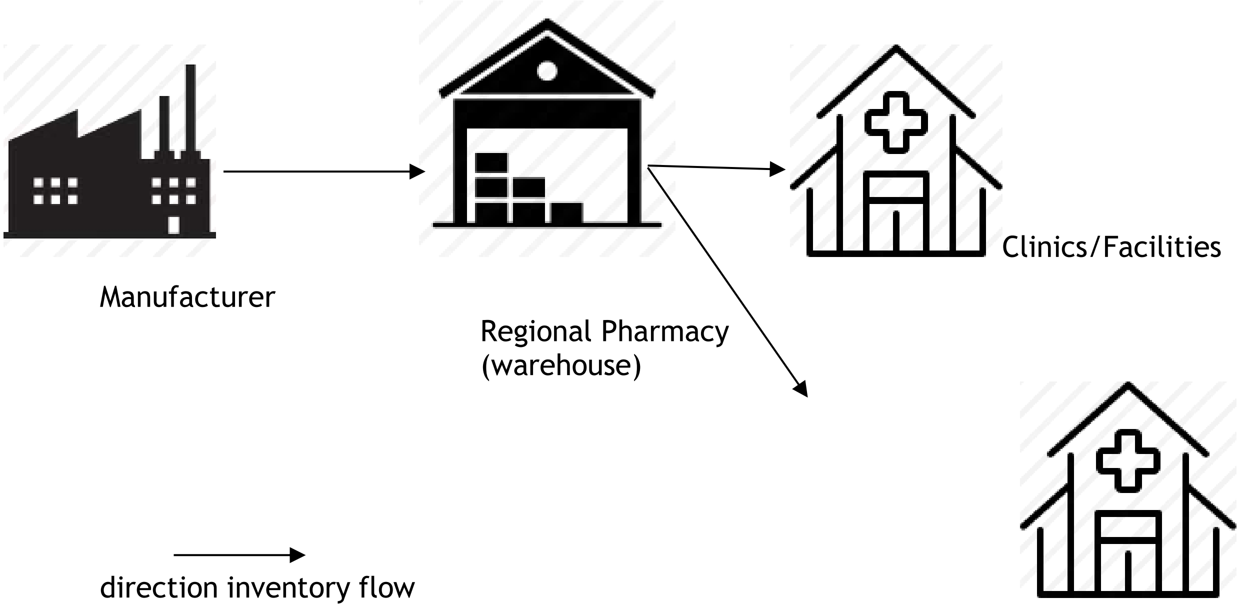

Figure 4: Supply chain illustration

A simple linear (vs. network) supply chain is considered in this paper, which consists of four levels, namely manufacturer, distributor/regional pharmacy, and retailer/facilities, with only one actor at each level. Fig. 4 shows the supply chain model and its parameters.

5 METHODOLOGY

The problem will be modelled as a Markov decision process and Q learning algorithm and will be used to determine the best inventory reorder levels. The environment for the simulation needs input data, and the beer game will be used as a case study for this paper, and it was developed by Jay Forrester at MIT. It has a linear supply chain with four levels; however, this paper will use three levels, and each actor's goal is to minimize inventory costs.

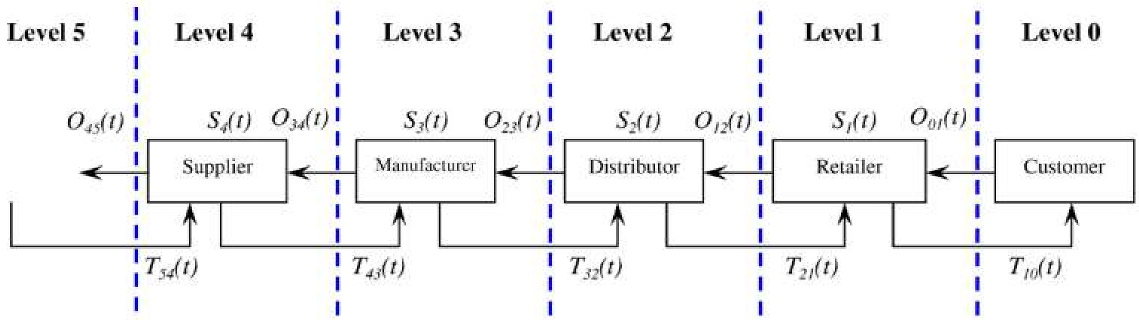

Figure 5: Supply chain model of the beer game from [20]

Three variables are then defined from figure 4 supply chain;

$Si(t)$ represents the point of inventory of level i in time step t, $(i = 1; 2; 3; 4)$

$Oi;j\ (t)$ represents the ordering size of level i to the higher level j, $(i = 0; 1; 2; 3; 4; j = i + 1)$

$Ti; j(t)$ represents the distribution amount of level i to the lower level $j, (i = 1; 2; 3; 4; 5; j = i - 1)$

The objective of supply chain ordering management is to determine the quantity of Oij in the way that the total inventory cost of the chain consists of inventory holding cost, and the penalty cost of backlog orders is minimized, which in turn reduces stock-outs:

$$Minimise\ \sum_{t=1}^{n}\sum_{i=1}^{4}[\alpha h_{\text{i}}(t) + \beta C_{\text{i}}(t)] \tag{6}$$

Where:

$$hi\ (t) = \begin{cases} Si\ (t),\ if\ Si\ (t) > 0 \\ 0,\ otherwise \end{cases} \tag{7}$$

$$Ci\ (t) = \begin{cases} |Si\ (t)|,\ if\ Si\ (t)\ \leq 0 \\ 0,\ otherwise \end{cases} \tag{8}$$

$h_i(t)$ is defined as the on-hand inventory of level i at time step t

Ci(t) is defined as backlog in level i at time step t. It is liable for the penalty cost. α and β are defined as the inventory holding cost of each actor in the supply chain

5.1 RL Variables

5.1.1 Reward function

The objective is to minimize total inventory costs; therefore, the reward function is defined as:

$$r(t) = \sum_{i=1}^{4}[h_{\text{i}}(t) + 2C_{\text{i}}\,(t) \tag{9}$$

Where r(t) is the reward function at time step t

6 CONCLUSION

This article is a work in progress, the problem has been formulated, and a simulation-based approach has been presented to determine replenishment quantities. An RL approach was used where the problem was modelled into a Markov decision process. Results are yet to be determined after experimentation. The Q- Learning algorithm will be used to find a policy that attains more reward over an extended time frame which is called the value. After the learning process, the action with the highest Q-function is selected for each arriving state. There are several environments that can be used, but for this paper, an Anylogic path mind will be used as the environment. The Q-learning will let the agent use the environment's rewards to learn. The highest action for any state is taken and stored in the Q-table. The Q-learning algorithm was introduced by Watkins [19], and Q-table is matrix n x m, where n is the total number of available actions and m is the state numbers in an environment [21].

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EXPLORING ELECTRIC VEHICLES NUANCES ON INFRASTRUCTURE REQUIREMENTS AND SUSTAINABILITY IN SOUTH AFRICA

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ABSTRACT

Technological advancements, crude oil price volatility and favourable policies are driving the widespread adoption of electric vehicles (EVs). However, South Africa (SA) is lagging in this respect. This discussion paper explores various EVs insights from literature and nuances around EVs infrastructure requirements and sustainability in SA. The study contributes to the knowledge and awareness of global EVs trends and status in SA. Charging infrastructure and favourable policy and regulatory framework significantly influence the large-scale deployment of EVs. Furthermore, policies supporting EV's public procurement schemes, carbon taxes, and financial incentives could stimulate EVs' acceptance. Although not exhaustive, presenting our discussion paper in the industrial engineering community could provoke the need for Industrial Engineers' participation in the country's EV policymaking and integration into the country's transport mix. In addition, the study paves the way for further inquiry and discourse among academics, practitioners, and policymakers on achieving sustainable EVs adoption.

Keywords: Electric vehicles, sustainability, charging infrastructure, logistics, South Africa.

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1 INTRODUCTION

The history of electric vehicles (EVs) stretches back to the nineteenth century [1], with noticeable floppy intake. However, the recent resurgence of EVs in the market is on an upward trend, with a prospect of staying. The exponential growth in the EVs market has been experienced since 2010 [2-7]. This trend has been driven by technological advancements, crude oil price volatility and favourable policies of many country governments, such as “emission reduction commitments, growing urban air pollution concerns” [2, 8]. Although the first commercial EV in South Africa (SA) was in 2013 [8], there has been a slow adoption of EVs. Raw & Radmore [2] pointed out that the lack of “policies, subsidies or incentives” contributes to the slow uptake of EVs in SA. In addition, deficiencies in EVs infrastructure, such as charging stations, significantly contribute to the inhibition of quick adoption of EVs in the country [9].

Contrary to the EVs market, the internal combustion engine (ICE) vehicles market in SA has a strong base, with the automotive sector employing more than 110 000 employees in 2018 [10]. The country significantly contributes to the global ICE vehicles market. The slow transition to the EVs market will significantly impact the automotive sector in the country due to a decrease in demand for ICE vehicles in the global market. Therefore, sustainable EV adoption in the country is inevitable for survival and competing in the global market.

The paper contributes to the knowledge and awareness of global EVs trends and status in SA. Industrial engineers play a significant role in integrating technology into society. Therefore, the paper could provoke the industrial engineers’ participation in the country’s EV charging infrastructure planning, policymaking and integration of EVs in SA’s transport mix.

2 PURPOSE OF THE STUDY

This discussion paper explores various EVs insights from literature and nuances around EVs infrastructure requirements and sustainability in SA. The following research questions (RQ) guide the paper:

- RQ1: How are EVs classified and what are the global trends in EVs adoption?
- RQ2: What is the impact of EVs on sustainability and logistics and supply chain management?
- RQ3: What are the EVs infrastructure requirements?
- RQ4: What is the status of EVs in SA? and
- RQ5: What are the factors that inhibit sustainable EV adoption in South Africa?

3 ELECTRIC VEHICLES INSIGHTS FROM LITERATURE

3.1 Classification of EVs

Electric vehicles can be classified according to their engine technology [11] and grouped into three classes [12]: pure electric vehicles, hybrid electric vehicles and fuel cell electric vehicles. Table 1 presents the types of EVs currently in the automotive industry.

Electric vehicles offer various advantages over ICE vehicles, such as cheaper operating costs, less interior and exterior noise, less vibration, mostly better low-speed acceleration, convenient home charging, excellent fuel economy, as well as no tailpipe emissions when the vehicle solely runs on its battery [13, 14].

Table 1: Electric vehicles classification

Full Name	Acronym	Description
Electric Vehicles or Battery Electric Vehicles	EVs or BEVs	EVs or BEVs are entirely powered by a battery, and they use one or multiple electric motors. They receive power by connecting to the grid and storing this power in a battery. EVs or BEVs do not have an internal combustion engine, do not use petroleum-based fuel while driving, and emit no exhaust emissions [11, 15, 16].
Plug-In Hybrid Electric Vehicle	PHEVs	PHEVs combine a gasoline or diesel engine and an electric engine with an electric motor and a battery that can be recharged by plugging into an electrical outlet or charging station. Conventional hybrid vehicles contain an electric motor and battery. They can switch running on electricity and fossil fuel [11, 15, 16].
Hybrid Electric Vehicle	HEVs	HEVs combine the conventional internal combustion engine and battery powered electric motors. HEVs differ from PHEVs because they cannot be plugged into the grid. The battery is recharged while driving. They use gasoline or diesel fuel in combination with a battery. In true hybrid vehicles, both power systems may propel the vehicle independently [11, 15, 16].
Fuel Cell Electric Vehicles	FCEVs	FCEVs generate their electricity from hydrogen and do not need to plug into the electricity grid to recharge. These cars use hydrogen from the natural gas, and with potential to near zero greenhouse gas emitters, with water as the only waste [11, 16, 17].
Extended-range electric vehicles	ER-EVs	ER-EVs differ from BEVs because they have a supplementary combustion engine used to charge the battery. The combustion engine is not connected to the wheels but is only used to charge the battery to extend the driving range [11, 17]

3.2 Electrical vehicles global status quo

Global EVs sales have been rapidly growing since 2010 [3-7], with a record increase of 6.8 million EVs in 2021 [7]. Figure 1 and Figure 2 present the global annual sales and total EVs trend for the past five years.

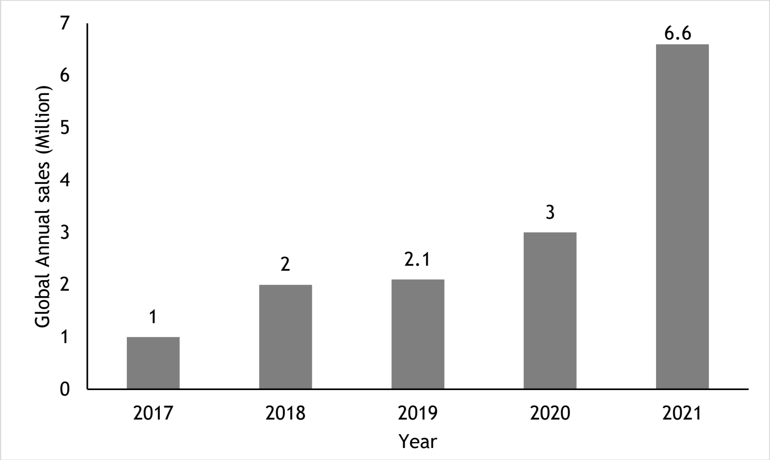

Figure 1: Global EV annual sales for the past 5 years [3-7]

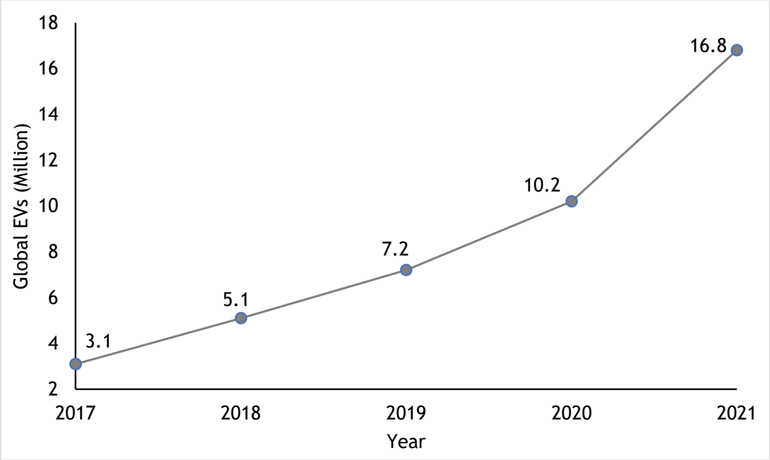

Figure 2: Total global EV for the past 5 years [3-7]

According to the International Energy Agency (IEA) [7], China is leading in the annual EV sales globally, doubling sales in 2021. Furthermore, there is a continuous increase in EV sales in Europe and the United States. Though there have been noticeable strides in adopting EVs in developed countries, developing countries such as SA have a slow uptake of EVs. The total estimated EV sales in Africa was 5100 in 2021 [7]. Although the total figures are significantly low, they account 90% increase in EV sales in Africa. The world is moving forward with the agenda of reducing and ultimately eliminating ICE vehicles on the road. The question to be answered is, will African countries such as SA catch up with the global trends, and how does such a global shift impact the ICE vehicles industry?

Globally, charging infrastructure accessibility significantly influences the adoption of EVs. The growth of EV charging infrastructure is a good indicator of EV uptake [3]. The total charging stations, both private and public, amounted to 5.2 million and 7.3 million in 2018 and 2019, respectively [4, 5]. Private charging stations account for 90% of global charging stations [5]. Figure 3 shows the global trend in the public fast and slow charging stations. Though the trends show a significant increase in public charging stations from 2017 to 2021, the global charging stations are relatively few and highly concentrated in countries such as China, Europe and the United States [7].

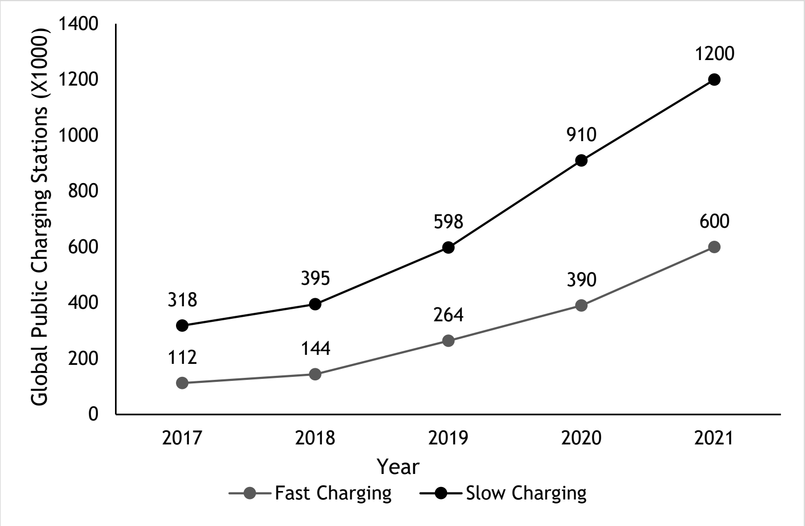

Figure 3: Global public fast and slow charging stations for the past 5 years

The European Union Alternative Fuel Infrastructure Directive recommends one public charging station for ten light-duty EVs [6, 7]. In 2021, the average European Union EVs charger ratio stood at 14 EVs per public charging station. The global average ratio is ten cars per charging station [6, 7]. Global trends suggest that countries with the highest EV penetration tend to have the highest EVs to public charging stations ratio. South Africa has approximately 6 EVs per public charging station [7], suggesting low EV uptake in the country. However, a low EVs to public station ratio could also be interpreted as the country's ability to respond to the increase in EVs to meet the charging needs. The chicken and egg situation in the rate of EVs uptake and charging station requirements suggests the need for policy that drive sustainable adoption and tracking of both charging infrastructure and EVs deployment. The global trends and statistics suggest that EV charging infrastructure is a global challenge that requires collaboration and support for developing countries to speed up EV uptake.

3.3 Electrical vehicles impact on sustainability

Internal combustion engine vehicles (ICE vehicles) significantly contribute to environmental pollution worldwide [9, 18]. Showers & Raji [9] pointed out that automotive is ranked third highest carbon dioxide emitter in SA. As the world is driving the green agenda, EVs contribute to mitigating challenges posed by ICE vehicles. Factors such as volatile fuel cost also promote EV adoption [9]. Sustainable adoption of technologies such as EVs encompasses the economic, environmental, and social dimensions [19].

3.3.1 Electric vehicles impact on environmental sustainability

Environmental sustainability encompasses reducing human activities contributing to greenhouse gas (GHG) emissions and protecting natural resources [20]. EVs have the potential to reduce greenhouse emissions significantly [1, 2, 8]. Although PHEVs and HEVs have an internal combustion engine, they can significantly lower emissions than ICE vehicles [1]. Thus, EVs could potentially drive environmental sustainability in the transport and logistics sector.

However, the contribution of EVs to environmental sustainability depends on the country's electricity generation mix. In countries dependent on fossil fuel electric generation mix, such as coal and gas, the positive impact of reducing emissions is noticeably compromised [1, 21]. Khan et al. [1] argued that higher EVs uptake would "result in increased demand along with an increase in absolute electricity industry", consequently increasing GHG emissions. Therefore, EVs must be combined with renewable energy charging systems to achieve environmental sustainability. Khan et al. [1] support this view by stating that "the combination of EVs and Photovoltaic power provides a unique opportunity for sustainable charging of electric vehicles".

South African energy sector is dominated by coal thermal power stations [8, 22], contributing "around 69% to the primary energy supply in 2016" [22]. Furthermore, the country faces generation and distribution challenges, failing to meet electricity demand. Consequently, this can significantly hinder the potential of EVs in mitigating environmental impacts posed by ICE vehicles in the country [23]. Tongwane & Moeletsi [23] and Grant [8] argued that charging EVs from the current electricity grid will emit GHG more than new ICE vehicles. Therefore, integrating renewable energy generation into EV charging infrastructure should be considered in SA.

3.3.2 Electric vehicles impact on economic sustainability

Economic sustainability involves "the upholding of competitive advantages and efficient market orientation while aiming at conserving resources and increasing the quality of life" [20]. South Africa is significantly reliant on foreign oil and is noticeably affected by international crude oil price shocks [8]. Currently, the country is experiencing volatile fuel prices [2], which impact the inflation of goods and services [24]. Moving towards EVs could mitigate economic performance pressure due to crude oil imports [8].

Khan et al. [1] argued that EVs provide less operating cost in the long run due to their noticeable efficiency. In the future, EV owners' economic gains can be leveraged through a possible reduction in EV costs due to mass production and better energy policies in various countries. Therefore, the potential for economic gains for consumers cannot be overstated.

Foltyński [15] pointed out that the "global population is increasingly concentrating" in urban areas. Consequently, vehicle mobility is highly concentrated in these areas. Furthermore, people's lifestyles and buying patterns constantly change, with most people opting for online purchases. These patterns result in the high cost of running urban freight and logistics. Adopting EVs could significantly contribute to efficient and sustainable logistics [15]. The economic gains could be more noticeable in countries with a better service economy.

The automotive sector in SA is dominated by ICE vehicles and contributes 29.9% of the country's manufacturing sector output and more than 6.8% of the country's gross domestic product in 2018 [10]. Furthermore, the country significantly contributes to the global ICE vehicles market. However, the global market of ICE vehicles is slowly decreasing, with many developed countries targeting significant strides by 2030. This development will reduce the automotive sector's contribution to the performance of the manufacturing industry. Consequently, this negatively impacts economic sustainability in the country.

3.3.3 Electric vehicles impact on social sustainability

Stock et al. [20] pointed out that social sustainability includes "the equitable inclusion of human resources, taking into account social classes, gender, age groups, and cultural and regional identity". SA is characterized by inequality, with only 16.5% population owning internal combustion vehicles [25]. The transition from electric vehicles entails a change of habits, such as driving patterns and fuelling habits [1], and change is not easily acceptable.

EVs acceptance must be addressed on three dimensions similar to other technologies: socio-political acceptance, community acceptance and market acceptance [1]. The socio-political dimension significantly influences the other two dimensions through institutional frameworks that stimulate "favourable conditions or impede the acceptance of the other two dimensions" [1]. Sustainable adoption of new technology should drive moving toward reducing social gaps in society, and acceptance is one factor that influences this phenomenon.

Transitioning from ICE vehicles to EVs can disrupt employment in the automotive sector [8]. The disruption has noticeable consequences that negatively impact social sustainability. Adoption of EVs must be strategized so that no net loss of jobs occurs. Such strategies could include formulating and implementing a skills transition framework that incorporates reskilling and upskilling.

3.4 Electrical vehicles in logistics and supply chain management

The logistics and transportation sector significantly contribute to world economies and impact societies' social and economic wellbeing [18]. The sector continuously evolves and goes through many innovations, including EVs use [26]. More organizations have recently begun focusing on increasing delivery vehicles' efficiency. Furthermore, people are shifting to online buying [26, 27], and this trend has been accelerated by COVID-19 [28]. Therefore, urban logistics become important and could noticeably contribute to customers' convenience [21]. Esmito [26] pointed out that EVs can disrupt the logistics and last-mile delivery industry.

Developed countries' logistics and transportation are characterized by ICE vehicles and EVs [18]. However, in developing countries, such as SA, logistics and transportation is dominated by ICE vehicles [21]. Therefore, this may hinder the drive toward smart cities in developing countries. Adopting EVs in logistics could potentially contribute to sustainable urban logistics [29], improve air quality, and reduce noise pollution in modern cities [16, 18, 30].

Electric vehicles have revolutionized automobile production and noticeably contributed to a clean and effective logistics business [31]. EVs are expanding and have a significant impact on supply chain distribution. EVs in logistics are adaptable and suited for a wide range of freight and parcel delivery applications. Due to their outstanding agility and low carbon footprint, EVs benefit last-mile deliveries [31]. Logistics companies such as DHL have explored and implemented environmentally friendly and greener ways in their last-mile deliveries using EVs [32]. EVs have the potential to bring considerable value to businesses by supporting ongoing cost reductions in operations and maintenance, enhancing delivery service routing efficiencies, and allowing businesses to expand their brand. Many logistics firms have recognized the advantages of EVs as a creative and long-term investment as they seek more effective, efficient, and trustworthy delivery services [31].

In congested inner-city traffic with multiple stops, EVs are an energy-efficient alternative that can help alleviate some of the challenges urban freight transportation produces. The benefits of EVs become even more apparent when transitioning to more effective methods for the last-minute delivery of goods or services in city centres [15]. Most of the developing countries economies, could be characterized as service economies. This implies that logistics and supply chain management efficiency become vital. Therefore, introducing EVs to logistics and transportation drives sustainable logistics [33].

Introducing EVs in logistics and transportation requires the provision of strategic charging stations to avoid interruptions [18]. The restricted driving range of EVs due to battery capacity enhances the need to efficiently design distribution routes differently from the ICE vehicles [21]. Therefore, significant decisions on the number of charging stations, capacity and their location are essential. Moreover, this makes the role of Industrial Engineers visible in integrating EVs into logistics and supply chain management.

4 ELECTRIC VEHICLES INFRASTRUTURE REQUIREMENTS

Sierzchula et al. [34] pointed out that charging infrastructure influences EVs adoption more than providing financial incentives. LaMonaca & Ryan [35] support that robust vehicle charging infrastructure is vital in advancing the widespread uptake of EVs. Furthermore, Greene et al. [36] acknowledged that charging infrastructure challenges are a significant barrier to EVs widespread. Literature [34, 35] reveals that per capita public infrastructure is the best national EVs market share indicator. According to Sierzchula et al. [34], the availability of charging infrastructure has an approximately double impact on EVs uptake compared to financial incentives. Therefore, provision and access to home and public charging infrastructure must be ensured to accelerate consumer confidence in the transition from ICE vehicles to EVs [35, 37]. Understanding EV charging infrastructure requirements stands pivotal in planning and achieving EV adoption.

4.1 Electric vehicles charging levels

Electric vehicle charging infrastructure can be tailored according to driver’s needs, such as “speed, cost and locations” [35]. EV charging infrastructure can be classified according to the charging levels: level 1 (slow charging) or level 2 (slow to fast charging using alternating or direct current fast charging).

Level 1 equipment requires a dedicated circuit and charges using a 120-volt (V) alternating current (AC) connector and offers a maximum intensity of 16 A, which has a maximum power of 1.8kW [11]. In most cases, Level 1 charging entails using a conventional household outlet. Level 1 charging equipment is standard on automobiles, making it portable and obviating the need for charging equipment installation [38, 39]. Level 1 charging can occur in workplaces or in the EVs owner's house [39, 40].

Level 2 equipment involves installing home charging or public charging equipment using a 240V AC outlet [11, 38]. The charging stations require a dedicated 40-amp circuit. All EVs and PHEVs can use Level 2 charging equipment. The cord used for Level 2 charging plugs directly into the car in the exact connector location as Level 1 equipment. Level 2 charging takes four to six hours to fully charge a drained battery, depending on the battery technology utilized in the car. When it is cold outside, charging time can take longer. Level 2 charges can be found in various venues, including homes, public parking lots, workplaces, and commercial establishments [39].

Providing energy from an appropriate off-board charger to the EV in private or public settings uses specialized direct current (DC) EV supply equipment. The conductive charging system architecture enables energy to be supplied via a suitable off-board charger. DC high-power levels are capable of recharging more than half of the capacity of an EVs battery in as little as 10 minutes. Level 3 charging is called "Fast DC charging" and has capabilities up to 50kW, which entails a 20/30-minute charge from a depleted battery to 80% complete [38]. The remaining 20% of DC charging takes a while; hence DC charging is measured chiefly up to 80%.

Plug-in models will require fast-charging stations, whereas battery exchange vehicles will need stations where depleted batteries can be swapped for fully charged batteries. Battery swap stations are commonly used in countries like China and are prevalent in public transport such as busses [30]. Both approaches would necessitate a contemporary energy system that allows adequate battery recharge at home or work [8]. Failure to provide consistent electric power either privately or from the national grid reduces the reliability of EVs. Therefore, to ensure support for EVs from the public consumers, the reliability of the national grid power supply in South Africa should be prioritized.

4.2 Electric vehicles charging station options

Electric vehicle users have optional access to a home, public charging and workplace charging stations depending on availability. Home charging is an efficient solution for early EV adopters due to the absence of public charging infrastructure [35], comprising both level 1 and level 2 chargers. Countries driving EVs adoption often subsidize users to install level 2 chargers at home [35]. Level 2 home chargers require access to a dedicated home parking spot such as a driveway or garage. Home charging infrastructure provides EVs users convenience and financial affordability compared to public charging stations.

Public charging stations comprise level 2 and direct current fast chargers. Public charging stations could be placed where vehicle owners park for long periods, such as in “shopping centres, airports, hotels, government offices, and other businesses” [35]. Fast chargers are frequently placed along highways to facilitate smooth long-distance travel. European countries impose directives that one public charger must be available for every ten EVs. Further directives include ensuring that every light-duty battery EVs and plug-in hybrid EVs must be allocated total power output of at least 1 kW and 0.66 kW, respectively, through publicly accessible charging stations [35]. In a qualitative study by Kester et al. [41], the availability of public infrastructure played a significant role in increasing EVs widespread in four countries investigated. Therefore, policies and directives on public charging infrastructure play an essential role in adopting EVs.

In countries with a noticeable EV uptake, workplace charging stations proved a better alternative for EV users who do not have home charging facilities. Workplace charging stations are commonly level 2 stations. Employers could promote the adoption of EVs by providing workplace charging facilities for their employees for free or subsidized costs [35]. When companies have shifted to renewable power generation, workplace charging can work as a strategy to increase power utilization during peak generation hours.

To ensure consumer confidence, governments should provide directives that promote the availability of public charging stations. The use of renewable power generation for electric vehicle charging stations could be explored in developing countries. With abundant sun exposure, developing countries like SA should take advantage of photovoltaic EV charging infrastructure.

5 ELECTRIC VEHICLES IN SOUTH AFRICA

5.1 Status of electrical vehicles in South Africa

In recent years, the number of public assessable charging stations in SA has continued to grow. Figure 4 presents a three-year progression of charging infrastructure in SA. It is undeniable that charging infrastructure has significantly grown over the years. However, compared to the global trends presented in Figure 3, the EV charging infrastructure in SA is relatively low.

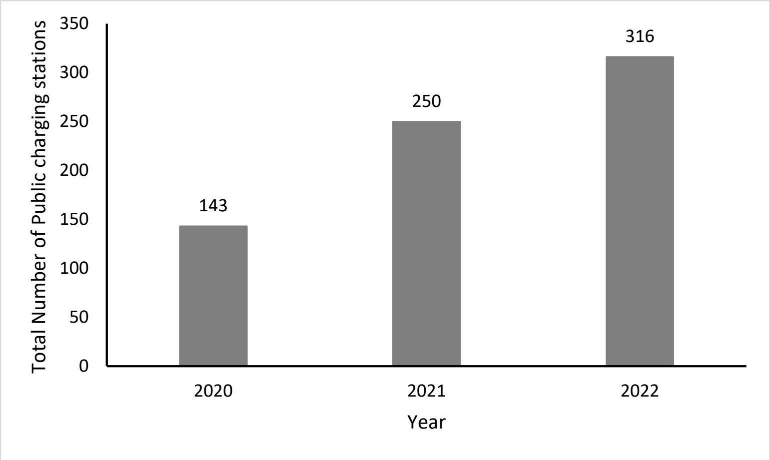

Figure 4 Total number of public charging stations in South Africa [2, 42, 43]

Figure 5 shows the distribution of public charging stations in South Africa. The distribution of public charging stations shows an uneven distribution across provinces and towns. A noticeable number of the public stations are in the Gauteng province [2, 42, 43]. The public charging stations are also distributed along the major highways and national roads spaced within 300km [43].

🟩 DC charging stations 🟧 AC charging stations

Figure 5 SA EVs public charging stations distribution [43]

Figure 6 shows EVs that run purely on electric engine sales in South Africa from 2018 to 2021, with a gradual increase in EV sales and a drop in 2020. The drop in sales could be attributed to the COVID-19 pandemic challenges. Comparing Figure 1 and Figure 6, SA's total pure EV sales suggest slow uptake relative to the global trends. In 2019, SA had a total sale of 407 of all EVs types.

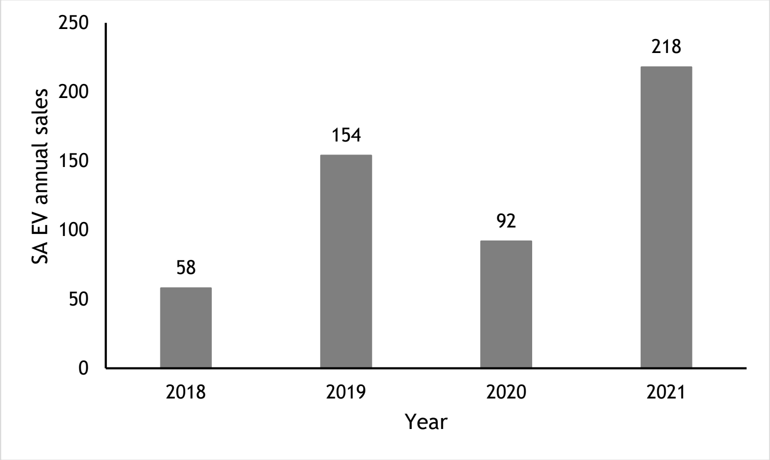

Figure 6 SA annual pure EV sales for the past five years [43, 45]

To support EV deployment in the country, the Department of Transportation has devised a plan to electrify up to 5% of government and state-owned enterprise vehicle fleets by 2030 [23]. Furthermore, the private sector in SA is launching a project to establish charging stations along three major highway corridors: Pretoria to Cape Town, Johannesburg to Durban, and Durban to Cape Town. The focus is currently on slow charging stations and for the Pretoria-Cape corridor [44]. In addition, Cape Town has launched an investigation into the cost structure of electricity used to charge EV batteries and how charging stations may be strategically placed for user convenience [23].

5.2 Factors that inhibit adoption of electrical vehicles in South Africa

The capital cost of EVs is estimated to be 30% higher than the cost of ICE vehicles [23]. Due to the socio-economic constructs in the country, the acceptance of EVs is sensitive to the capital cost of EVs. According to Kumalo [46], most South Africans in the working class cannot afford the current capital cost of EVs. This means EVs will only be affordable to the upper-class segment of the South African population.

Furthermore, South Africa imposed high customs duties and taxes on imported EVs. Internal combustion engine vehicles imported from Europe and other regions are subject to an 18% customs levy, whereas EVs are subject to a 25% customs duty [23]. This has hampered EV adoption because it is more expensive to import EVs into the country [9].

A significant inhibitor to the adoption of EVs is the availability of the infrastructure required to support a smooth transition from ICE vehicles to EVs [9, 23]. Although the current ratio of EVs to the public charging stations in SA meets EU standards, the question is whether this is due to sufficient charging stations or low uptake of EVs in the country? Figure 5 raises significant concern about the uneven distribution of the charging stations in the country. This makes it challenging to travel to places such as the Northern Cape, Free State, Namibia, Limpopo, and Northwest, as there are insufficient charging stations.

In addition, social scepticism on EVs' driving range and charging time contribute to inhibiting the quick adoption of EVs in SA. EVs' potential consumers perceive charging as time-consuming and inconvenient [9] compared to ICE vehicles on the go refilling capabilities. Driving range anxiety is significant among consumers who want to use EVs for long distances.

Integrating EVs into the grid imposes an additional load as they require power from the grid [23, 38]. SA is currently faced with energy supply challenges from the national electricity grid and is characterized by significant load-shedding [23]. Furthermore, the country's national grid dependence on fossil fuels hinders the sustainability of EVs.

The adoption of EVs in SA is relatively slow due to insufficient national government policy and regulatory framework and a lack of political will [9]. Although the Department of Transport has started initiatives to move towards clean technologies [23], there is still a lack of firm policies that attract consumers to own EVs. Furthermore, there are no clear targets and requirements for EVs. Currently, the charging station model in South Africa is mainly run by the private sector, with limited government support [2, 9].

6 DISCUSSION

According to the IEA [47], South Africa is the largest energy consumer in sub-Saharan Africa. Furthermore, as the first IEA associate member in the sub-Saharan African countries, South Africa is a critical partner in launching and delivering initiatives such as clean energy transitions across the continent [47]. Therefore, South Africa has the mandate to support and lead by example in clean energy initiatives, including the adoption of EVs.

Government policies and regulatory frameworks significantly influence EV deployment, exemplified by China and the European Union setting 2030 mandates. Other developing countries, such as India, have also announced their electrification of vehicle targets [3]. The global widespread of global EVs can diminish SA ICE vehicles' market share. Therefore, coining policies and regulatory frameworks should aim to achieve a timely and sustainable transition from ICE vehicles to EVs. Lagging in embracing the EVs market could have profound economic implications in the country due to a decrease in ICE export share.

South Africa is in its early stage of adopting EVs and could implement policies that attract consumers and businesses, such as:

- EVs' public procurement schemes include government vehicles and public transport operators.
- Implement carbon taxes incentives that reflect a policy environment which supports EVs uptake.
- Implement financial incentives when purchasing EVs and provide complementary benefits that provide value propositions for driving EVs, such as road toll rebates, parking priorities and building charging facilities.

Policymakers should set a conducive environment that allows viable and various business models that attract various players' engagement and allow smooth integration of EVs in the country's electric grid operations. The current generation mix in the country cannot achieve sustainable integration of EVs. However, the country has recently driven toward renewable energy with significant wind and photovoltaic plant commitments. Furthermore, the COP26 political declaration on energy transition signed between South Africa, the United Kingdom, the United States, France, Germany, and the European Union shows commitment to decarbonising the country's energy system [47]. Policymakers could leverage this move to integrate EV charging infrastructure with renewable energy generation. International partnership in moving toward clean energy could be manipulated to stimulate partnership in constructing EV charging infrastructure. Such a move could result in the sustainable adoption of EVs in the country. The view is supported by Funke et al. [37] when they argued that the impact of EVs on environmental sustainability can be enhanced by coupling widespread with the uptake of renewable energy.

The local and international collaboration between energy companies, automotive companies, government, and other private stakeholders could fast-track EVs' infrastructure development. We agree with LaMonaca & Ryan [35] on the point that "clear roles should be assigned to the individual public and private actors and funders, [in order] to achieve efficient development of the required infrastructure for large-scale EV deployment". Public charging station accessibility should be evenly distributed across the South African road network.

Building the nation's capacity to manufacture and assemble EVs in SA could drive economic and social sustainability. SA should maintain its capability to export assembled vehicles into the global market by meeting the new demands of EVs. Therefore, the government should establish transition policies that facilitate the current automotive companies to shift from ICE vehicles to EVs.

Social inequalities characterize South Africa, and EVs adoption should consider not widening the gap through job losses. The automotive sector and the government should develop and implement a skills framework that facilitates reskilling and upskilling to facilitate employees' smooth transition. Furthermore, social construct challenges such as social scepticism could be mitigated by increasing public awareness of the advantages of EVs.

7 CONCLUSION

The research questions presented in Section 2 were answered accordingly by exploring the literature and discussing the nuances of EVs. Section **Error! Reference source not found.** provided an overview of EVs classification, while section 3.2**Error! Reference source not found.** addressed the global trends on EVs adoption and charging infrastructure availability (RQ1). The impact of EVs on economic, social, and environmental sustainability and logistics and supply chain management (RQ2) were addressed in sections 3.3 and 3.4. Charging infrastructure significantly impacts the acceptance and deployment of EVs, and infrastructure requirements (RQ3) were presented in section 4. Sections 5.1 and 5.2 presented the status of EVs in South Africa and factors that inhibit the adoption of electric vehicles in South Africa.

The paper raised awareness of EV global trends and the need to embrace large-scale EVs' deployment in SA. Although not exhaustive, presenting our discussion paper in the industrial engineering community could provoke the need for Industrial Engineers' participation in the country's EV charging infrastructure planning, policymaking, and integration of EVs in the South African transport mix. Although the paper did not include empirical input from various stakeholders, it paves the way for further inquiry and discourse among academics, practitioners, and policymakers on achieving sustainable EVs adoption in SA. The world is progressing fast in EV deployment, and can SA remain a spectator in adopting EVs on a large scale?

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OPTIMISATION OF A FLEXIBLE MANUFACTURING SYSTEM THROUGH THE APPLICATION OF GREEDY KNAPSACK HEURISTIC

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ABSTRACT

The global manufacturing industry is currently facing intense competitive pressure that requires better efficiency, effectiveness and continuous improvement of the manufacturing systems. Production planning in flexible manufacturing systems is crucial for the efficient organisation of production resources to ensure economic effectiveness and meet schedule requirements without violating capacity constraints. The objective of this paper is to develop a cost-effective assignment of parts to a flexible manufacturing system (FMS) through the application of Greedy Knapsack heuristic. A production planning problem was formulated, the objective function and associated constraints were stated and an Excel based tool was developed to generate solutions Greedy Knapsack heuristic. The tool would assign the best-selected parts to the semi-automated FMS in an optimal manner to the production plan. The sample computational results were presented for Greedy Knapsack heuristic, and conclusions were drawn for the flexible manufacturing system.

Keywords: flexible manufacturing system; Greedy Knapsack heuristic; optimisation

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1 INTRODUCTION

The automotive manufacturing industry is one of the competitive industries since global forces have put due pressure on manufacturers to derive a delicate tradeoff between profitability and cost effectiveness [1]. Some automotive manufacturers shed off the first-tier market thereby giving second-tier manufacturers an opportunity to compete for more contracts [2]. Second-tier suppliers re-vitalised their business processes to increase part quality in order to win these contracts, while improving process stability, cost per part, and reliability. A flexible manufacturing system (FMS) that is fully automated and characterised by reliable machining centres would render automation to be possible. Flexible manufacturing systems have the potential to enhance the quality and productivity of products and would change the dynamics of the employees in a firm and thereby create supplementary, higher-order jobs. It is imperative for organisations to embrace FMSs to handle rapid market fluctuations, lower volume and lower production costs as well as increase competition on the international platform [3]. Additionally, an FMS would aid an organisation in attaining enriched market response, and enhance flexibility in production quantities and product quality. Flexible manufacturing systems also have the potential to satisfy the customer needs with ease, reduce production time, costs incurred and reduce labour cost. It is against the backdrop of increased operational costs and heightened product defects that the case in point automotive component manufacturer was prompted to investigate its effectiveness, striving to improve operational performance. The objective of this paper is to develop a cost effective assignment of parts to a flexible manufacturing system (FMS) through the application of Greedy Knapsack heuristic.

2 RELATED LITERATURE

An FMS is an array of automated processing machines that are interconnected by a material handling system and a central computer system to coordinate the production activities [4]. The manufacturing process of an FMS is characterised by a blend of workstations and possibilities of routing paths, provided by a material handling system and automatic inspection stations whereby the rejected parts must return for further processing while approved parts exit the FMS. An FMS can process different part types concurrently at several workstations that can be adjusted automatically when unexpected variations in the volume of orders or in the mix occurs [5]. Due to their ability to economically process intermediate volume and product variety, cellular layouts are preferred for FMS.

FMSs are characterised by machine tools that integrate the machine and controllers, the tool and the part to be processed. The fundamental elements of the FMS would include machine base, tools and automatic tool changer, parts handling devices, logic-programmable commands and sensors, as well as drive units and controls [6]. The setup in FMS workstations is automatic and instantaneous, requiring minimal or no human attention on the CNC machine tools that are equipped with tool magazines to perform multiple sequential operations such as turning milling, etching and drilling.

The material handling system for an FMS is characterised by pallets and containers, transported by conveyors or automated guided vehicle systems (AGVS). The AGVS would reduce labour cost, accidents, and improve the speed and accuracy of transportation in FMSs since they are unmanned and would follow a guided inductive path in automated facilities [7]. Under the coordination of a central computer system, the main functionalities of AGVS in FMSs include traffic management to avoid collisions, optimisation of the route, and loading and unloading of materials. Conveyors transport standard loads through fixed paths that are shaped by rollers, casters, sloping mats, chains to complement AGVS, and provide bi-directional horizontal and vertical transport and direction changes. Robotic arms are also used in material handling systems and an industrial robot can be programmable, characterised by anthropomorphic features such as response to sensory stimuli, arm resemblance, decision-making ability and communication with other machines [8]. The main tasks performed by robots in flexible manufacturing systems for the automotive industry are welding, painting, palletising, handling, and assembling. Another key feature of FMS is an automated storage and retrieval system that comprise storage structures, transelevators and stacker cranes suitable for receiving and storing standardised loads from pallets and containers [6]. FMSs are also characterised by automated inspection stations that perform faster and more reliable final quality inspection procedures using automated devices and software tools to execute quality verification of parameters, such as shape of parts and dimensions [9].

There are different forms of flexibility that characterise an FMS and these include material handling flexibility, process flexibility, machine flexibility, product flexibility, volume flexibility and operation flexibility [10]. Regarding material handling flexibility, the path followed by the product or part between machines is of concern, while process flexibility embraces flexibility in a particular part to be processed by different types of processes. Machine flexibility is concerned with machine capability to accommodate the different product mix. Routing flexibility pertains to different achievable routes that a part or product can follow while operation flexibility is concerned with the varying processing plans with respect to production of a part [11]. Expansion flexibility relates to the capacity of production and without the variation in capital of the equipment, production flexibility can also be achieved for all types of parts.

Considering the analysis of 0-1 knapsack problems, Ezugwu et al. [12] presented results of meta-heuristic optimisation algorithms, namely, simulated annealing (SA), genetic algorithms (GA), dynamic programming, branch and bound, Greedy algorithm, and a hybrid GA-SA. The results demonstrated superior performance from the hybrid algorithm when compared with individual algorithms, show-casing that hybrid algorithms can be deployed as an alternative to solve 0-1 knapsack problems. Singh et al. [13] conducted a critical review of scheduling machine loading problems in FMS as a manufacturing strategy for obtaining an optimal balance between productivity-flexibility requirements. The FMS problem was concerned with part type selection, production ratio, machine grouping, resource allocation and loading scenario. Binghai et al. [14] developed a heuristic for loading and batching problems in an FMS with the objective to minimise the number of tool changes and reduce line imbalance considering that machine loading and part type selection are key problems in production planning of FMS. Windmann et al. [15] also developed a model-based routing approach for an FMS with substitute routes for the parts that underwent several processing steps, whereby each processing step could be accomplished on alternative workstations. The proposed heuristic would derive energy efficient and fast routes for the parts in the conveying system leading to reduction of energy consumption in the FMS. This study adopted the Greedy algorithm since it has the advantage of simplicity and has less computational cost compared to other heuristic algorithms. The use of the Greedy algorithm for local or instant results aids in deriving better results.

3 RESEARCH METHODS

3.1 Background

The case in point automotive component manufacturer produces different types of crankshafts in batch mode for engines to satisfy local orders. Root cause analysis was conducted to identify the problems of waste in existing crankshaft fabrication process and it was noted that high cycle time, unnecessary additional processing time, more workers than required and too much work-in-process and scrap could be the main sources of increased operational costs. The scope of this study is a semi automated flexible manufacturing cell (FMC) that was used to produce three different types of crankshafts. The quantitative analytical modelling approach was adopted for the optimisation of a flexible manufacturing system. Initially, a deterministic bottleneck model was deployed to U-shaped layout FMS and the research approach commenced with identifying the equipment and number of workers for the semi automated flexible manufacturing cell. A work study was thereafter conducted to establish the the station processing times, part mix for FMC, operation frequency and the routes for the part styles. The subsequent steps were characterised by identifying bottlenecks through computation of station workloads against the number of servers and thereafter assessing the utilisation of the FMC. Lastly, after noting the opportunity to improve the cell utilisation, the Greedy Knapsack heuristic was deployed to assign some additional parts to the FMS.

3.2 Bottleneck Analysis

Table 1 shows a summary of the description of activities and number of servers, the crankshafts are loaded and unloaded by one human worker and thereafter machined by two automated stations followed by oil hole drilling at two servers and lastly taken for manual grinding. In this sense, servers refer to number of machines that have the capability to perform the same operation. The mechanised carts move tote bins with crankshafts as the primary material handling system between FMC stations.

Table 1: Description of activities and number of servers

Station	Description	Number of servers
1	Load and unload	1 human worker
2	Turning	2 servers
3	Oil hole drilling	2 servers
4	Grinding	1 human worker
5	Transport	2 carriers

A work study was conducted and the results for the part styles as well as the routes followed were established. Table 2 shows the station processing times and part mix for FMC and the operation frequency is 1 for all the operations. All the parts would follow the sequence: 1 → 2 → 3 → 4 → 1 and the mean transfer time of the mechanized cart between stations was established as 2.5 minutes.

Table 2: Station processing times and part mix for FMC

Part	Part mix	Station 1	Station 2	Station 3	Station 4	Station 1
		Processing time in minutes				
Crankshaft X	0.25	2	2.5	1.5	4	3
Crankshaft Y	0.45	2.5	3	2.2	7	3
Crankshaft Z	0.3	1.5	2	1.5	5	3

It was therefore imperative to establish the bottleneck station in the FMC, also considering that the material handling system could also bottleneck the process. It was also important to establish the overall production rate of the system and if any recommendations could made to improve the efficiency or reduce the cost of operating the FMC by addition of other parts that could be processed by the system. The workload for the stations was computed as:

$$WL_i = \sum_j \sum_k t_{ijk} f_{ijk} p_j \qquad \textbf{(1)}$$

where t_{ijk} is the processing time , i refers to station, j is part k is the sequence of operations for the process route, f refers to operation frequency, and, p refers to part type or style.

The material handling system that was used to transport the crankshafts within FMC was regarded as a special workstation and designated as station *n+1*. The workload for the special station was computed as:

$$WL_{n+1} = n_t t_{n+1} \tag{2}$$

where

$$n_t = \sum_i \sum_j \sum_{k-1} f_{ijk} p_j \tag{3}$$

and for a given process routing, t_{n+1} is average transportation time needed to convey a crankshaft from one workstation to another.

3.3 Assignment Of Parts To Fms

Thereafter, a Greedy Knapsack heuristic was deployed for cost effective assignment of parts to the FMS, through ranking or ordering the part types and selecting the part type while ensuring that inclusion was feasible. Greedy heuristics can simply solve optimisation problems by choosing the most immediately attractive parts that could be added to the FMC to enhance its effectiveness and reduce operational costs. The savings per period in this case, per month were computed through the following steps:

Define:

$$p_i = \frac{hours}{unit} \times \frac{unit}{period} = \frac{hours}{period} \tag{4}$$

$$s_i = \frac{Savings}{unit} \times \frac{unit}{period} = \frac{Savings}{period} \tag{5}$$

$$\frac{Savings}{unit} = Purchase\ cost - [material\ cost + processing\ cost] \tag{6}$$

where

$$Processing\ cost = Cell\ overhead\ rate \times Production\ time \tag{7}$$

and

$$\frac{Savings}{hour} = \frac{Savings}{period} \div \frac{hour}{period} = \frac{s_i}{p_i} \tag{8}$$

The Knapsack Problem was then defined as:

$$\max \sum_{i=1}^{n} s_i x_i \tag{9}$$

$$subject\ to\ constraints\ \sum_{i=1}^{n} p_i x_i \le P \text{ and } x_i \in \{0,1\}$$

where P = Production capacity, x = Decision variable for adding parts to FMC

Equation (1) sums the savings resulting from assigning part types to FMS. Equation (2) fills the knapsack with the most valuable items (Largest s_i) without violating its size P.

The Greedy Knapsack heuristic followed two basic steps that are:

Step 1. Order part types *i* such that

$$\frac{s_1}{p_1} \ge \frac{s_2}{p_2} \ge \cdots \dots \dots \dots \dots \dots .. \ge \frac{s_n}{p_n} \tag{10}$$

Step 2. For $= 1\ to\ n$

Select part type i if $s_i \ge 0$ and inclusion is feasible.

Feasible inclusion means that no savings/unit < 0 and no $p_1 > P$.

4 RESULTS AND DISCUSSION

The results for the average workload for a given station were computed as the average total time spent at the station by each of the crankshafts, and are thus shown below:

$$WL_1 = (2+3)(0.25 + 0.45 + 0.3) = 5.0\ min$$

$$WL_2 = 2.5(0.25)(1.0) + 3(0.45)(1.0) + 2(0.3)(1.0) = 2.6\ min$$

$$WL_3 = 1.5(0.25)(1.0) + 2.2(0.45)(1.0) + 1.5(0.3)(1.0) = 1.8\ min$$

$$WL_4 = 4(0.25)(1.0) + 7(0.45)(1.0) + 5(0.3)(1.0) = 5.7\ min$$

$$WL_5 = 2.5(4) = 10.0\ min$$

Station 5 was characterised by the highest work load while station 3 had the least workload. The production rate of the FMC was noted as being constrained by the station with highest work load per server, that is the the bottleneck station.

Table 3: Summary of workload to number of servers ratio

Description	Station	WL_i/s_i ratio	
Load and unload	1	5.0/1 = 5 min	
Turning	2	2.6/2 = 1.3 min	
Oil hole drilling	3	1.8/2 = 0.9 min	
Grinding	4	5.7/1 = 5.7 min	← Bottleneck
Transport	5	10.0/2= 5.0 min	

Table 3 shows a summary of workload to number of servers (s_i) ratio and the results indicate that the grinding operation is the bottleneck station in the FMC. The average production rate of the FMC was computed as:

$$R_p^* = \frac{s^*}{WL^*} = 1/5.7 = 0.176\ crankshafts/min = 10\ crankshafts\ /hr$$

Excluding the material transport system, the proportion of time that the servers at the station are working and not idling was computed as mean utilisation, U_i of each workstation:

$$U_1 = (5.0/1)(0.176) = 0.884 = 88\%$$

$$U_2 = (2.6/2)(0.176) = 0.2278 = 23\%$$

$$U_3 = (1.8/2)(0.176) = 0.1606 = 16\%$$

$$U_4 = (5.7/1)(0.176) = 1.0 = 100\%$$

These results demostrate gross under-utilisation of the oil hole drilling that was found to have a utilisation of 16%, as well as under-utilisation of the turning station that had a utilisation of 23%.

The average station utilisation for the FMC was computed as:

$$\overline{U}_s = \frac{\sum_{i=1}^{n} s_i U_i}{\sum_{i=1}^{n} s_i} = \frac{1(0.884)+2(0.228)+2(0.161)+1(1.0)}{4} = 0.665 = 66.5\%$$

The average station utilisation for the FMC displays that there is room to explore automated options for the grinding operation. It is worth noting that grinding applications are generally not cost-effective or practical for automation since they may be characterised by gross part complexity or high product mix. Technological advances have proliferated hence more potential for automated grinding. However, it is crucial to consider the factors of any abrasive application, including application force, abrasive speed, horsepower, torque requirements, disc backup plates, part temperature, expected life of the abrasive, and the expected part finish. The latest abrasive technology can significantly reduce grinding time, reduce the number of passes and heat generated. It is also worth noting that ergonomics and safety considerations are imperative any manual grinding operation. Hence, automated grinding provides better grinding paths for the grind tool, paths that would be impossible or uncomfortable to perform by human operators. Therefore, with automated grinding, no manual operator is available, hence no need to factor ergonomic considerations in the operation.

Given the room for more utilisation of the FMC, apart from the crankshafts, it was proposed to add some additional parts that could be processed by the FMC and six parts that were initially sourced from a vendor were considered for an automated FMS. The FMC was available 180 hours / period and charged at R400 / hour. The information regarding the purchase price, material cost if made inhouse and demand was pulled from the organisation's database and Table 4 shows a summary of the part purchase price, material cost and demand.

Table 4: Part purchase price, material cost and demand

	Part type					
	1	**2**	**3**	**4**	**5**	**6**
1. Purchase price / unit	1500	1200	2000	1000	2500	650
2. Material cost	300	250	1000	400	1000	200
3. Demand / period	70	40	35	50	25	20
4. Hours / unit	1	2	3	1	2	1

Using the row rumnbers, we need to compute the following:

5. Savings / unit = (1) – [(2) + R400 × (4)]
6. Hours / period, p_i = (3) × (4)
7. Savings / hour = (5) / (4)
8. Savings / period = (5) × (3)

The numbers in brackets, 1 to 5 refer to the variables or expressions indicated in the first column of both Table 4 and Table.

An Excel spreadsheet was used to determine necessary data for the heuristic assignment problem as shown in Table 5.

Table 5: Excel spreadsheet summary for computational results

	Part type					
	1	2	3	4	5	6
1. Purchase price / unit	1500	1200	2000	1000	2500	650
2. Material cost	300	250	1000	400	1000	200
3. Demand / period	70	40	35	50	25	20

	Part type					
	1	2	3	4	5	6
4. Hours / unit	1	2	3	1	2	1
5. Savings / unit	800	150	-200	200	700	50
6. Hours / period, p_i	70	80	105	50	50	20
7. Savings / hour	800	75	-	200	350	50
8. Savings / period, s_i	56000	6000	-	10000	17500	1000
9. s_i / p_i	800	75	-	200	350	50

Applying the Knapsack heuristic to optimise the utilisation of the FMC:

Step 1 - Order part types in descending order of savings per hour to give:

800 > 350 > 200 > 75 > 50; excluding negative values

Hence the sequence is {1, 5, 4, 2, 6}

Step 2 - Select part types while ensuring that inclusion is feasible without violating capacity constraints:

1st, Part 1 is assigned, with resource usage (6) = 70 hours

2nd , Part 5 is assigned, with resource usage = 70 + 50 = 120 hours

3rd, Part 4 is assigned, with resource usage = 120 + 50 = 170 hours

4th, Part 2 is not assigned, with resource usage requires 80 hours (only 10 hrs available)

5th, Part 6 is not assigned, with resource usage requires 20hrs (only 10 hrs available)

Hence only parts 1, 5 and 4 are added to the FMS using 170 hours out of 180 hours available.

Savings is row (5) × row (3) i.e.

$$\sum s_i = s_1 + s_5 + s_4 = [800 \times 70] + [200 \times 50] + [700 \times 25] = R\,83\,500$$

These results demonstrate that the organisation could improve the effectiveness and utilisation of the FMC, and concurrently derive some savings by addition of parts that could be processed by the FMC.

5 CONCLUSION

A quantitative analytical modelling approach, using a deterministic bottleneck model was deployed to U-shaped layout FMS. These results demostrated that the grinding operation was the bottleneck station and the process was characterised by gross under-utilisation of the oil hole drilling and turning stations of the FMC. A cost effective assignment of parts to a flexible manufacturing system was accomplished through the application of Greedy Knapsack heuristic. The results also demonstrated that there was room for improvement with regards to the effectiveness and utilisation of the FMC, and concurrently derive some savings by addition of parts that could be processed by the FMC. Further research would embrace digital twin manufacturing paralleled with 5G to optimise operations for automotive component manufacturers.

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APPLICATION OF A3 METHODOLOGY TO IMPROVE BUSINESS PROCESSES AT XYZ LOGISTICS

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ABSTRACT

XYZ Logistics is obligated by law to operate on a 95% delivery standard. In short, 95% of all items posted through the XYZ Logistics network should reach their final destinations on time. The challenge at play is that XYZ Logistics only delivers 85% of items on time and this creates not only reputational damage but compliance challenges with severe penalties attached to poor performance. A pilot study has been selected for the ABC region, which is the biggest region of XYZ Logistics, and which is perceived to have more problems and complexities; improvement of the ABC region will positively impact national delivery standards. This paper explores the implementation of an A3 methodology to improve the outbound stream at XYZ Logistics, ABC region. A3 methodology resulted in improvement of delivery standards in the ABC region, this improvement can be attributed to improvement in Overall Equipment Effectiveness (OEE) and transport network streamlining.

Keywords: Overall Equipment Effectiveness, A3 methodology, lean thinking

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1 INTRODUCTION

XYZ logistics is a postal services company, the biggest mail centre in the country was failing to operate on a 95% delivery standard required. They were only delivering 85% of items on time and this created not only reputational damage but compliance challenges with severe penalties attached to poor performance for XYZ logistics. Thus, A pilot project was implemented at ABC region, which is the biggest region of the Postal services and is perceived to have more problems, considering improvement of ABC region will positively impact on national delivery standards. The objective of this study was the improvement in Overall Equipment Effectiveness (OEE) and transport network streamlining. The methodology adopted for this study was the A3 methodology and the value engineering method for root cause analysis common technique of using the “5 Why’s” method implemented during the RCA workshop. On completion of the study, lean thinking through an A3 report improvement written on an A3-sized paper was produced, outlining all the achievements. The practical contribution of this work is that the proposed A3 problem-solving methodology can serve as a guide for managers to implement or improve business processes. Recommendations were made to monitor the machine’s OEE indices, monitor the improvements implemented and continuously explore ways to improve the current state.

2 LITERATURE REVIEW

A3 is not a standard document format perse, but rather a way of thinking, it ought to be implemented where there a knowledge gap has been identified among co-workers [1], The A3 report is written on an A3 report; thus, the naming convention [2] Some of the benefits in the application of the A3 methodology are attributed to financial savings, increased process understanding, reduced inventory, less process waste, reduced lead-time, and less rework [1] It was found that the A3 problem-solving report tool can be used organization-wide for continuous improvement as it has the capability to document the important results of problem-solving efforts summary and exemplifies a thorough problem-solving methodology that begins with a deep understanding of the way the work is currently done [2].

Lean thinking is a process improvement concept that is carried out by eliminating waste and focusing more on things that create values [1]. Lean management focuses on the elimination of waste [3]. Lean is the automobile manufacturing production system of Toyota Motor Corporation [4], the approach of lean thinking in a production system focuses on the company’s core competence and consumers to create value effectively and efficiently [1]. The key elements to sustain lean improvements are standard work, employee involvement, and continuous improvement [5]. Presented a model that ascertains that management exposure to external information sources and commitment to lean both influence lean thinking within organizations. Furthermore, an indirect relationship exists, where increased exposure to sources of lean information increases management commitment to lean and, ultimately, the extent of lean thinking in the organization in the automotive industry [6]. A study conducted in the food industry found that a lack of active involvement and supervision by the top management results in limited success [7], and thus losses are measured in terms of time losses [8].

OEE is a performance tool [8] that can be used as a measure can identify which machine performance is worst If the machine’s process works individually [9]. When measuring OEE, the accuracy of the data collection determines the validity and usefulness of OEE measure as it is an important phase of performance measurement and continuous improvement, this is since one cannot improve what has not been measured [8]. OEE indicates areas of process improvement [8]

Business Process (BP) in automotive industries were typically improved through methodologies that focused on possible automation of control flows, this case illustrates a need for a dual-type BP improvement method. Highly structured processes. BP improvement focused on process-related knowledge as the key source of competitive advantage. Decision and improved decision-making support an important aspect of BP improvement [8].

[2] highlights the benefits of RCA as the:

- Reduction of the number of incidents and failures
- Reduction of expenses and deferred production associated with failures.
- Improvement of reliability, safety, and environmental protection.
- Improvement of efficiency, profitability, and productivity [3].

3 METHODOLOGY

This study was undertaken and is classified under the applied/action research as it seeks to solve the root cause problem of postal services to meet the 95% delivery standard required. Steps in Applied/action research [1], the research methodology took place in three phases:

- The application of the value engineering methodology to understand the root cause of problems, the “5 Why’s” method technique was used for RCA
- Lean thinking through A3 report
- The implementation of the A3 methodology

This approach utilized qualitative techniques.

3.1 Value Engineering methodology- The root cause analysis (RCA):

A value engineering workshop was carried out with the affected employees, and an RCA was established using the 5 Why’s method, as is a common technique for root causes. Table 1 lists the root cause searching techniques:

Table 1: Root Cause Searching techniques

Quantitative	Qualitative
Fault tree analysis (FTA)	Analysis of the 5 whys
Pareto analysis	Ishikawa Diagram (Cause and Effect)
Bayesian Inference	HAZOP
	PROACT

3.2 Lean thinking

Application of lean thinking through an A3 report to improve the ABC region that positively impacted the national delivery standards and eliminated waste.

3.3 Application of A3 Methodology:

The pilot study implemented the A3 report approach for the improvement of the ABC region that positively impacted the national delivery standards.

4 RESULTS AND DISCUSSIONS

The results for the value engineering methodology highlighted the basic function is non-compliance to operational procedures in the mail centre, and that issue is the prime cause of many of the difficulties experienced by the mail centre regarding poor delivery service.

Results are presented in detail in 4.1. Whilst the RCA process implementation identified three problems, the results are presented in Table 1:

- Trucks arriving late
- CFC machines cutting off after midnight
- OCR/IVR/HSLSM machines cutting off late

4.1 Value Engineering Methodology

The objective of the value engineering workshop was to understand the XYZ Logistics network operations and problem areas. A workshop was conducted with the responsible personnel that identified the following wastes presented in **Error! Reference source not found.**, and potential solutions were proposed for implementation in the improvement process. Figure 1 outlines the value engineering methodology results.

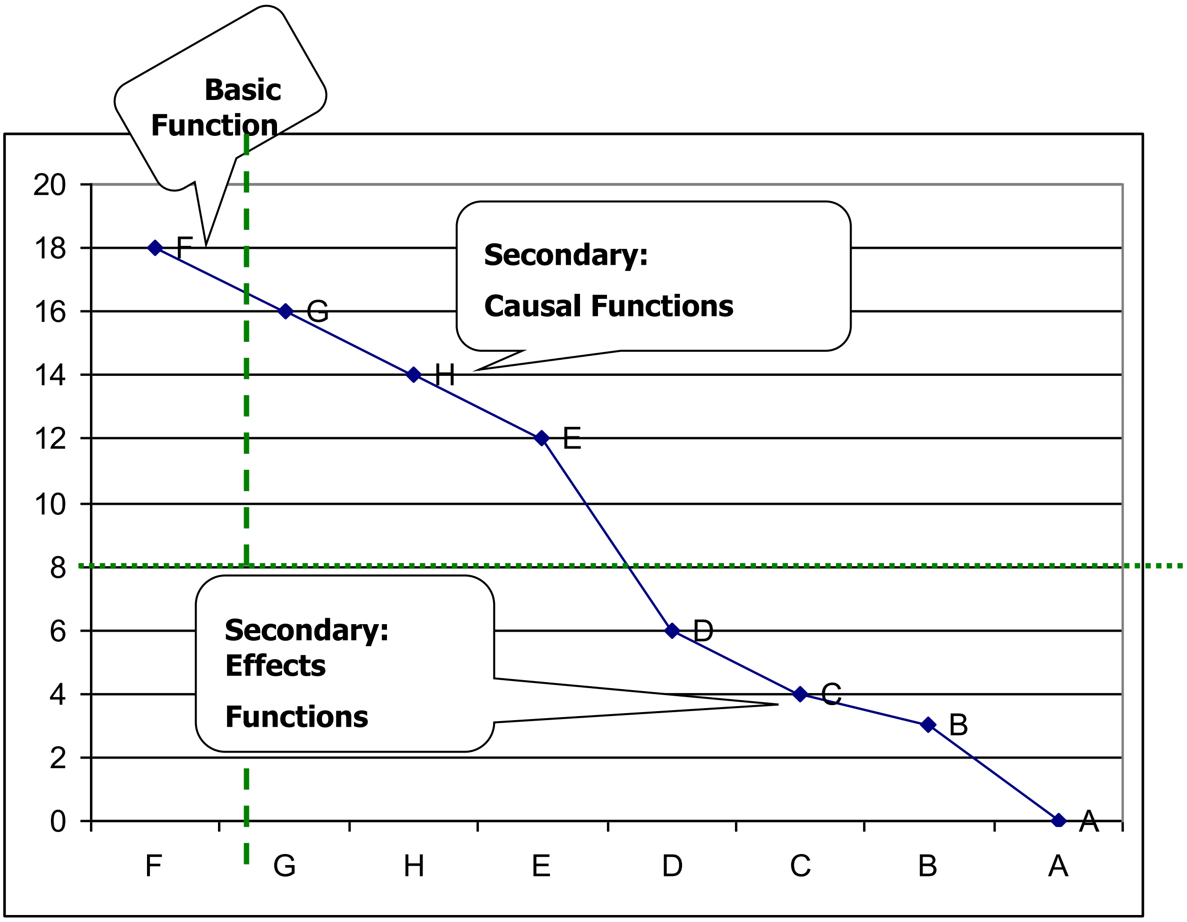

Figure 1: Tool Coordinate System

Figure 1 shows the basic function is non-compliance to operational procedures in the mail centre, and that issue is the prime cause of many of the difficulties experienced by the mail centre regarding poor delivery service.

4.1.1 OEE (Machine utilization)

Figure 2 depicts machine utilization:

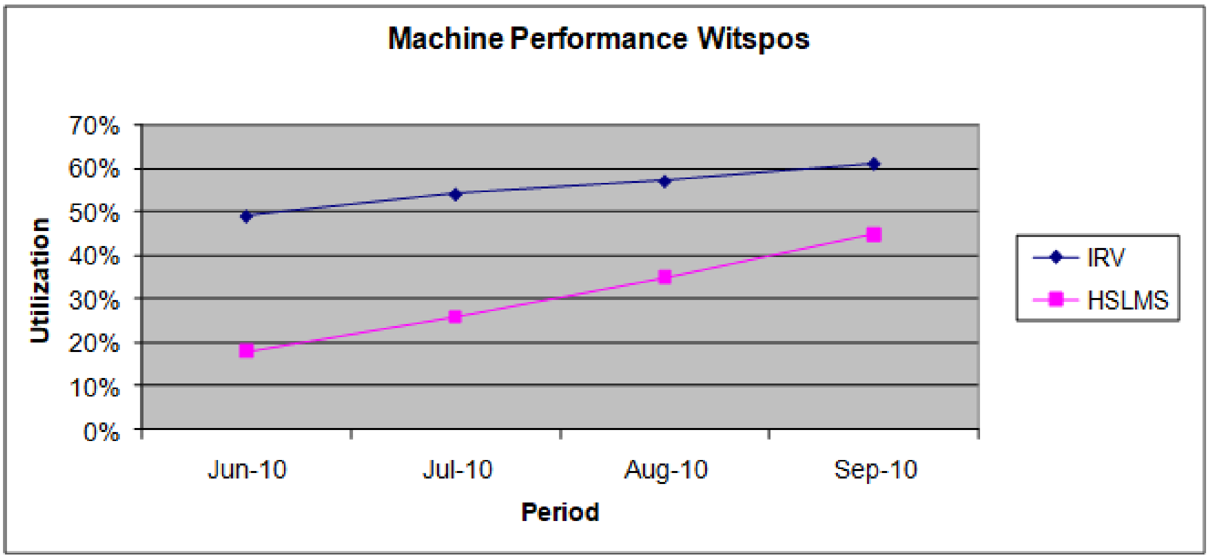

Figure 2: Machine utilization

Figure 2 outlines the following:

- The IRV machine utilization has been on an upward trend since the ABC region Optimization Project started and now standing at 62% as compared to 49% when the pilot project started.
- The HSLSM machine utilization has been on an upward trend since the ABC region Optimization Project started and now standing at 45% as compared to 18% when the project commenced.

4.1.2 Delivery Standards

The delivery standards are depicted in

Figure 3:

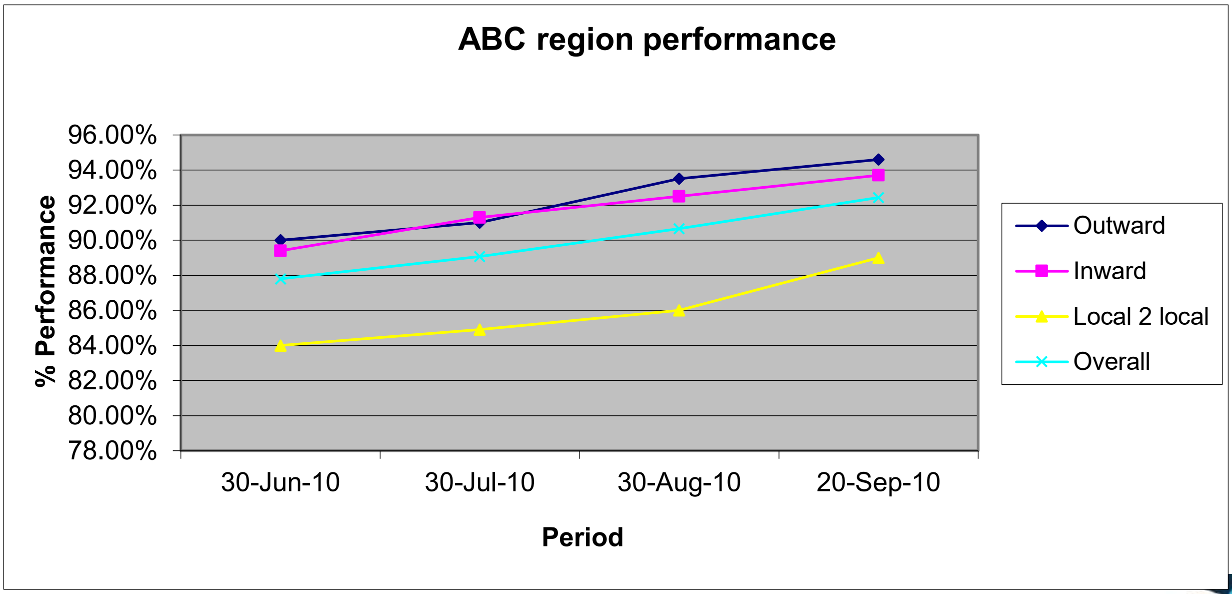

Figure 3: Machine performance

Figure 2 outlines the following:

- The delivery standards of ABC region have been on an upward trend since the ABC region Optimization Project started, and we are now standing at overall performance of 90.6% as of 20 September 2010.
- The delivery standards of the Post Office are monitored by an external company appointed by the Post Office, which measures performance by sending out electronic test mail, which measures the time a letter takes from one point to another point.

4.2 Root Cause Analysis

An RCA was carried out, and three problems were identified: Trucks arriving late, CFC machines cutting off after midnight, OCR/IRV/HSLSM Machines cutting off late, summarized using the 5 Why's:

4.2.1 Trucks arriving late

The 5 why's technique was used to identify the wastes; the responses are presented in Table 2:

Table 2: 5 Why – Truck arriving late

5 Why's	Responses
Why?	The port 1 truck must pass via port 2 to collect mail
Why?	There is no truck to pick up mail from port 2 hub
Why?	For the maximizing of space in port 1 struck
Why?	To save on operational costs
Why?	To save the company money

While trying to save the company money, the company cut on functionality in favour of reducing costs, and as a result, mail reaches the destination late. Value = Function/cost, and in this case, we reduced costs at the expense of functionality, and as a result, the value of the service was compromised. A truck from port 1 is arriving at the depot by 17h00 compared to the previous time of arrival of 19h00, a 2-hour improvement in the process was achieved post-pilot implementation

4.2.2 *Culling, Facing and Cancelling (CFC) machines cutting off after midnight*

The 5 why's technique was used to identify the wastes; the responses are presented in Table 2:

Table 3: 5 Why - CFC machines cutting off after midnight

5 Why's	Responses
Why?	Because of high volumes

5 Why's	Responses
Why?	Because of trucks arriving late
Why?	Because trucks do not adhere to cut-off times
Why?	Because of general disregard of operating procedures
Why?	Because of poor line management

- CFC Machines to cut-off by 21h00

4.2.3 Optical Character Reader (OCR)/ Integrated Reading Video (IRV)/High-Speed Letter Sorting Machine (HSLSM) Machines cutting-off late

The 5 why's technique was used to identify the wastes; the responses are presented in Table 4:

Table 4: 5 Why - CR/IRV/HSLSM Machines cutting-off late

5 Why's	Responses
Why?	Because of high volumes
Why?	Because mail is left unattended for long periods
Why?	Because of poor discipline
Why?	Because of poor line management
Why?	Because line management does not enforce standard operating procedures

Procedure to adhere to OCR; IRV, and HSLSM Machines

- All OCR/IRV and HSLSM machines to cut off at 24:00
- A new shift that is manned by casual workers is to be introduced to process mail that is piling up from 11h00 on OCR mode (automatic mode)

The results of the RCA are presented in Table 5 with identified potential solutions:

Table 5: Value Engineering wastes identified

Waste identified	Potential solutions
1. Delay of mail (Wastage of waiting) 2. Overproduction (processing too much mail only to be constrained by the next process) 3. Wastage of defects (Mail having to return to machines after the discovery at ABC region consolidation that they are not direct trays but have mixed machinable mail) 4. Duplication 5. Unclear communication	1. Process mail just-in-time 2. Identify bottleneck and let bottleneck dictate the pace of processing 3. Proper screening at revenue protection for direct trays (Proper sampling) 4. Streamline processes to ensure double handling is avoided 5. Communicate and enforce standard operating procedures

4.3 A3 Methodology (report)

An A3 report was compiled, which highlighted all the information contained in the study as part of Business Process improvement with the following results: The RCA correlate to the value engineering workshop results, which pinpoints non-adherence to operational procedures. The following was achieved post-pilot improvement implementation:

1. Transport - Trucks arriving late

A 2-hour improvement in the process was achieved post-pilot implementation

2. Machines - CFC machines cutting off after midnight and OCR/IRV/HSLSM Machines cutting-off late

- CFC cut-off around 21h00 due to adherence to operational procedures.
- Mail from Port 3 is processed as it arrives instead of the 12-hour delay
- Revenue Protection carries inspection on direct trays, and those trays with mixed mail are immediately separated from direct trays and sent to the OCR/IRV machines for processing
- The Overall Equipment Effectiveness has been improved regarding machine utilization indicators. IRV improved from 46% utilization to 59% utilization, and HSLSM improved from 15% to 21% in a spate of a few weeks. It is envisaged that if the standard operating procedures are monitored and enforced by line management, improvements will be exponential.

3. High-value receipt area

Capacity in the form of an additional resource has been increased at the high-value receipt area to double current capacity and optimize the bottleneck

5 CONCLUSION

To meet the research objectives of this study, a research model was set up through a comprehensive review of the literature on OEE, lean thinking and A3 methodology/report. The implementation of the A3 methodology to improve the outbound stream at XYZ Logistics, ABC region was achieved. All the identified problems in the RCA correlate to the value engineering workshop results, which pinpoint non-adherence to operational procedures. The RCA section summarises using the 5-Why's. The results in this paper suggest that there is value in lean production combined with improved decision making thus the proposed next steps are:

- Monitor the machine's OEE indices
- Monitor the improvements implemented
- Continuously explore ways to improve the current state

The practical contribution of this study is that the proposed A3 problem-solving methodology can serve as a guide for managers to implement or improve business processes.

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ORDER PICKING'S SHORTEST PATH IDENTIFICATION USING ANT COLONY OPTIMIZATION ALGORITHM

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ABSTRACT

In this paper, the Order Picking process was investigated to identify the shortest path of the picking journey. This research study was conducted to improve the performance of a company's warehouse process, focusing on the Order Picking process. The Ant Colony Optimization algorithm was applied to determine the shortest route that an order picker should take to be efficient. The MATLAB software was used to perform the analysis, with the results represented in the form of an itinerary or route to be followed during the Order Picking process. An illustration of the Travel Salesman Problem and a hypothetical scenario of a day-to-day Order Picking activity were considered to illustrate the approach proposed in this study. This study provides an insight into the influence of ACO model parameters on the accuracy of the results. The accuracy of the proposed approach was validated with the specialised GAMS software package.

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1 INTRODUCTION

In the logistic system of most companies, warehouses are considered to be one of the most important assets. Warehouse management costs can account for approximately 20% of the logistic costs [1]. In the USA, 22% of the logistics system's expenses are attributed to the capital and operating costs of warehouses. In Europe, it is estimated at 25%. Therefore, warehouse management costs have a crucial impact on a company's overall expenses [2]. Thus, a well-designed warehouse can generate cost-saving for companies due to process efficiencies. Although a warehouse generates high costs for a company, there is a need for a well-managed warehouse system. It is a key requirement for modern supply chain systems and is one of the major elements that could lead the company to achieve its industry success in the modern world of business [3].

In a warehouse, there are six basic procedures to consider: receiving, putting away, storing, order picking, packing, and shipping. Out of the aforementioned processes, Order Picking has been pointed out as the activity that is the most labour-intensive and expensive in most warehouses. Order Picking can account for up to 55% of all the operating expenses in a warehouse. Therefore, the input of the Order Picking process in a warehouse is very significant. Any underperformance in the process leads to poor service and excessive operational costs for the warehouse, and in the worst-case scenario, the entire supply chain. According to [4], 60% of all labour tasks are consumed by Order Picking in a warehouse. It is, therefore, crucial to focus great attention on the Order Picking process and its design which must be robust and optimally controlled [4].

Order Picking is defined as the process of finding and extracting products from a warehouse to respond to a customer's need or order [5]. Order Picking systems are not the same everywhere; they differ from warehouse to warehouse. Nowadays, the noticeable difference in Order Picking operations is automation encouraged by technological innovations. In the former manual Order Picking systems, items were physically picked by humans. Today, automated Order Picking no longer involves human picking orders. It involves machines such as a conveyor belt or a system of robot arms [6].

Many researchers have acknowledged the significance of Order Picking based on cost, time, and labour productivity [7]. Order Picking can account for between 50% - 75% of the total operational costs of a warehouse [8]. When compiling the budget of a warehouse's operations, the majority of the budget is dedicated to Order Picking and its associated assignments [9].

The problem this study is seeking to address can be formulated as follows: Pickers in the warehouse spend so much time travelling between aisles, and as a result, the warehouse efficiency decreases. They are unable to pick up all orders on the picking list within the required time. They will follow longer routes as there are no structure (sequence of picks) and instructions on the route to be taken. They randomly go through aisles and search for items.

This study aims to explore the order picking process and apply the Ant Colony Optimization (ACO) in order to find the shortest path for pickers to follow. This study focuses on two objectives namely: 1) Identify the shortest route and 2) Perform analysis through different configurations in different scenarios. In addition, a mathematical programming model was developed and implemented in the specialized software package GAMS (General Algebraic Modeling System) to compare the approximation made with the ACO algorithm to the exact solution computed by GAMS.

Ant colony optimization algorithm is defined as processing operations, which is one of the presumed intelligent computing. It is built from the principle of swarm intelligence and is mostly used for routing in graphs [10]. An ant colony is highly organized, because of the interactions between ants through pheromones within the colony. Despite the fact, that ant species are naturally almost blind, communication with the environment and amongst them is feasible by leaving behind pheromones on the routes they follow. The pheromone trails are great stimuli for other ants, which are more inclined to follow pathways with a high concentration of pheromones. As a result, an ant that has opted to follow a path because of the pheromone trail already on that way strengthens the path even more by putting down its pheromone [11].

Ants are insects known for their ability to live in colonies and be cooperative. As they live in groups, they are capable of performing multiple tasks that could be difficult to be achieved by an individual, thus operating as such a strong community. The fact that they can determine the quickest route from the anthill to the food supply is an example of what they can achieve. They easily adjust themselves to any environmental changes, and it is done with no visual indication. For example, when finding a new route to their food source because they have encountered obstacles that could prevent them from exiting. They make those changes of routes easily and without visual signals. The process is explained in the next paragraphs and refer to figure 1 as an illustration [12].

Suppose a brand-new scenario with no past information, where the first ant leaving the anthill to go look for food, not knowing where the food source is located and has no trace from any predecessor information or pheromone. In this case, the ant has to choose a random route, and if on its way it senses the presence of food nearby, it will take the food and head back to the anthill. It will follow its pheromone to find its way back (they can recognize their pheromones), which were left on the road while looking for food [12].

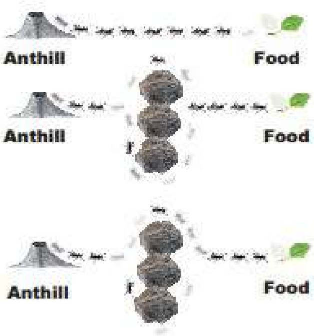


Figure 1: Illustration of ants travel path (Adapted from [13])

Once the first ant returns, the other ants leave the anthill to go look for food. Fortunately for them, they do not have to wonder about what path to take as they could use the pheromone trail that the predecessor (first ant) has left. Therefore, there is an increase in the probability of accessing the food sources that were found earlier by the first ant (predecessor).

It could happen in certain cases that the environment changes or an obstacle appears on their way that did not exist before. This results in giving the ants no choice but to change directions or to take another route. The first ant originally selected its route randomly, which created equality in either finding the shortest or longest path (50 % of chance for each). Some ants that took the shortest path will quickly meet the lost pheromone trail. As it is the shortest route, it will have a high concentration of pheromone (per unit time) left by the previous ants. This makes it much more appealing for the following ants and the majority of them will take that path [14].

The ant systems (ant algorithms) resolve problems with high complexity that deterministic algorithms failed to solve. They are used to resolve problems such as Traveling Sales Problems (TSP), Connectionless Network Routing, Knapsack problems, Scheduling problems, Optical Network Routing, etc. Thus, they are efficient tools able to solve NP-complete problems [15]. Details on the advantages and disadvantages of ACO are reported in reference [16].

When examining the suitable use of the ACO algorithm, it is critical to identify significant features of a warehouse architecture. It is critical to highlight only a subset of the necessary information that provides a good description of the warehouse layout explicitly and that can easily be analysed by the ACO algorithm. This is the reasoning backing the first step of the method used.

The layout of a warehouse comprises a certain number of longitudinal aisles aligned in parallel, which have the same length. Those aisles have storage locations on each side where items or products are stored [9]. Therefore, the critical data needed to describe a warehouse layout includes the following: number of storage locations per aisle side, number of aisles, and number of blocks where applicable. But for this study, the number of storage locations and aisles were the only elements considered. Figure 2 illustrates a typical warehouse layout with the critical information identified as follows: three aisles, twelve storage areas on each aisle side, and two blocks. Aisles give the pickers easy access to the storage locations and hence point out the place where picking activities occur. The picker starts from a picking aisle depending on the warehouse layout and enters one or two picking lanes.

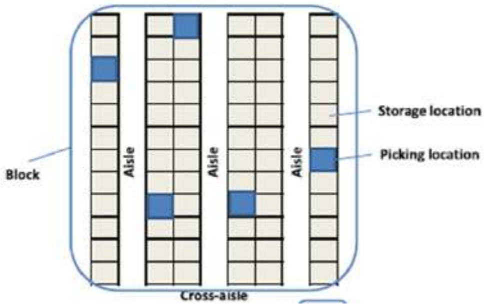


Figure 2: Typical warehouse layout (Adapted from [15])

2 METHODOLOGY

2.1 Flowchart of typical ACO approach

A pictorial representation showing the steps adopted to develop a model and compute the results is shown in Figure 3. The ACO model was implemented in the software MATLAB. The identification of the shortest path was considered the primary goal of our study for improving Order Picking performance in typical warehouses.

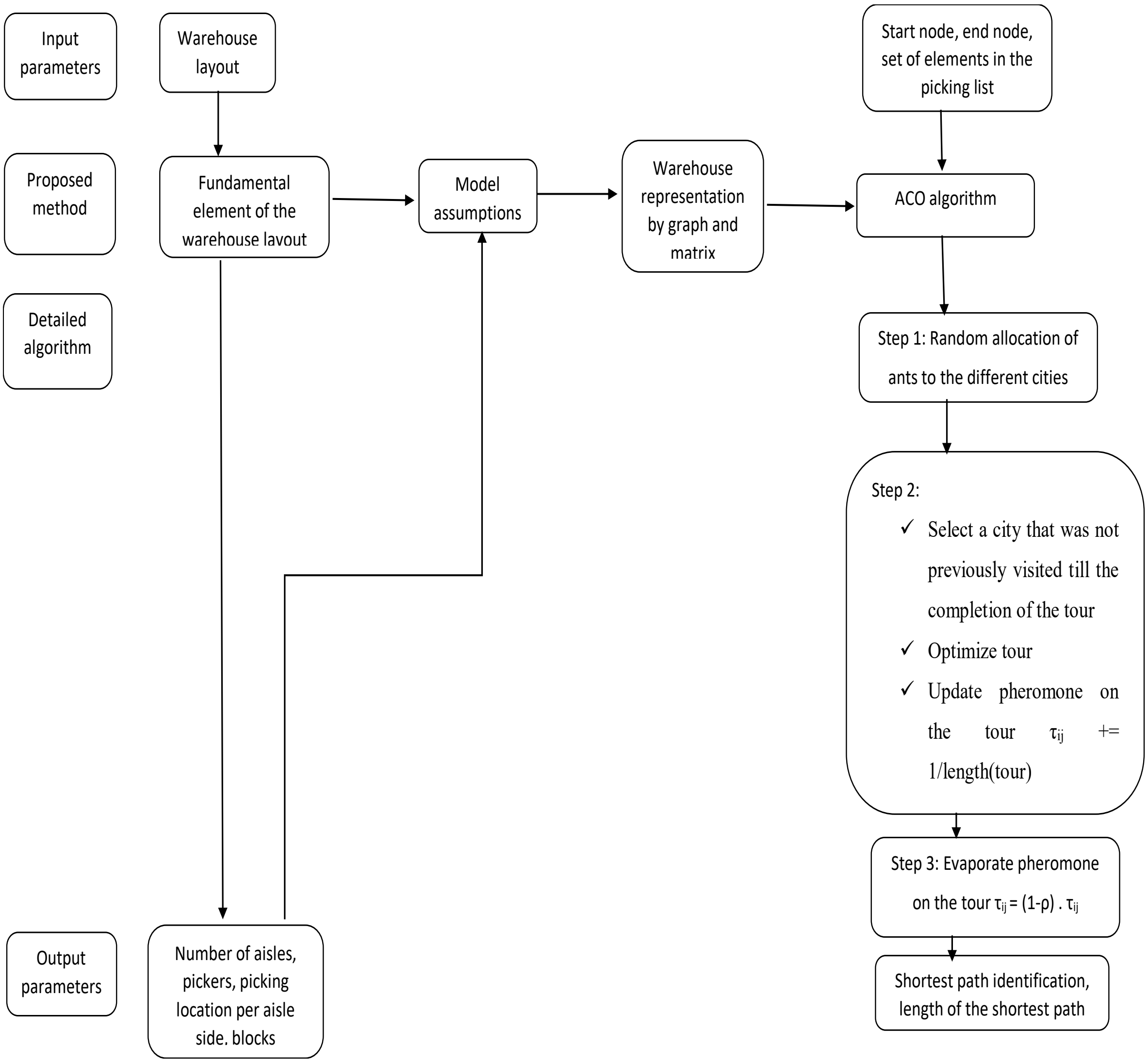


Figure 3: Flowchart describing the proposed method

The steps of an ACO algorithm to find the shortest path can be summarised as follows [17]:

1. Randomly distribute ants between picking locations;
2. Considering each ant:
   - Select a picking location that was not previously visited till the completion of the tour
   - Optimize tour
   - Update pheromone on the tour
3. Evaporate pheromone on the tour.

Figure 4 provides the details of the process flowchart illustrating the working procedure of ACO.

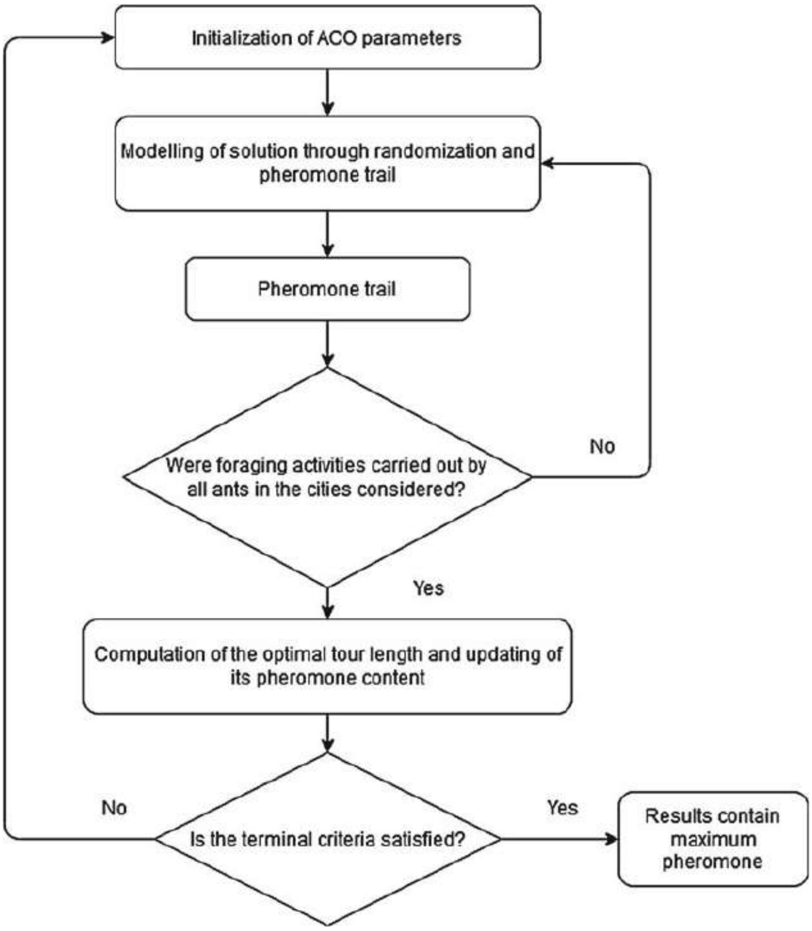


Figure 4: Flowchart of ACO algorithm (Adapted from [17])

2.2 Model assumptions

This work is built upon the following assumptions and requirements:

1. The warehouse has a rectangular shape (regular) with aisles that are parallel and longitudinal; the warehouse consists of 20 picking locations.
2. The ACO model will be used to minimize the travel distance of the picker, with all the picking locations provided. These locations have to be visited to complete a trip;
3. The distances between picking locations are the travelling distances of the picker taking into account the warehouse layout.
4. Only one picker was considered at a time to avoid any form of congestion in the picking process [15] with wide enough longitudinal aisles to enable the picker to access items from each side of aisles;
5. The journey begins at the depot and is ended when the picker goes back to the depot after he has picked the required items or products from the picking list;
6. The picker is allowed to change direction in the aisle;
7. Picking locations cannot be visited twice on its itinerary. The order picker has a list of orders, and has to go to the location that has the highest number;
8. The aisle can be travelled in both directions;
9. Picking orders must be done manually;

2.3 ACO mathematical formulation

ACO will be used in this study to compute the minimum distance in Order Picking when looking at parameters such as distance between aisles, the distance between blocks, and lengths that affect the order picker's journey. The use of the algorithm has helped in finding the shortest path from a myriad of paths that an order picker could take. The principles described briefly in the previous sections are converted into a mathematical expression, which is adopted in this study to find the picker's shortest path.

The probability of an ant k located at the node r to select the destination represented by node s is given by the following equation [17]:

$$\rho_k\,(r,s) = \begin{cases} \tau(r,s)^{\alpha}\,\eta\,(r,s)^{\beta} / \sum_{u \epsilon Mk} \tau(r,u)^{\alpha}\,\eta\,(r,u)^{\beta} & , for\ s \epsilon M_k \text{ otherwise,} \\ 0, & \end{cases} \quad \textbf{(1)}$$

In this equation:

- α corresponds to the level of pheromone concentration τ,
- β represents the level of visibility,
- while Mk is the ant's remembrance,
- *η(r,s)* corresponds to the visibility of picking locations *r* and *s*.
- *η(r,u)* corresponds to the pheromone train on edge *(r,u)* is *τ(r,u)* whereas a heuristic function is represented Both locally and worldwide, the pheromone trail is vulnerable to change.

The visibility is calculated by [17]:

$$\eta = 1/\ (\text{distance between node r to node s}) \quad \textbf{(2)}$$

On their journey to the anthill, ants leave pheromone on each segment. To calculate the quantity of pheromone on a segment ij, the following Equation was used [17]:

$$\tau_{i,j} \leftarrow \tau_{i,j} + \Delta\tau^{k} \quad \textbf{(3)}$$

As pheromones accumulate on a segment, there is more probability for it to be chosen by the following ants. After passing a node, the pheromone evaporation occurs. It is calculated as follows [17]:

$$\tau_{i,j} \leftarrow (1-\rho)\,\tau_{i,j}, j;\ \forall\,(i,j) \in \mathrm{A} \quad \textbf{(4)}$$

The following Equation is used to calculate the updated pheromone level τ. The pheromone train on edge *(r,u)* is represented by *τ(r,u)* whereas a heuristic function is represented by *η(r,u)*. Both locally and worldwide, the pheromone trail is vulnerable to change. If *Δτ(r,s)* reflects the quantity of pheromone deposited on each visited edge by the best ant, then this value is inversely proportional to the length of the trip. The following equation expresses global trail updating [17]:

$$\tau_{r,s} \leftarrow (1-\rho)\tau_{r,s} + \sum_{k=1}^{N} \Delta\tau_{r,s}^{k} \quad \textbf{(5)}$$

Δ act for the segment that ants have already passed on their way to the anthill. When pheromone evaporates it gives ants the chance to explore other paths in their journey to the anthill. The additional pheromone on the segment *ij* is calculated as follows [17]:

$$\Delta\tau_{i,j}^{(k)} = \frac{Q}{L_k} \tag{6}$$

Q represents a constant while L_k represents the overall distance travelled by ants making their way back to the nest. The user often determines the Q value. In many instances, this value can be equated to 1 to get good results.

Different steps were identified in the ACO algorithm to find the shortest path [17]. The steps are outlined as follows:

1. Randomly distribute ants between picking locations;
2. Considering each ant:
    - Select a picking location that was not previously visited till the completion of the tour
    - Optimize tour
    - Update pheromone on the tour
3. Evaporate pheromone on the tour.

A tutorial describing the steps of the ACO algorithm is provided by Santosa [17]. Details of the MATLAB codes used in this study are available in reference [18].

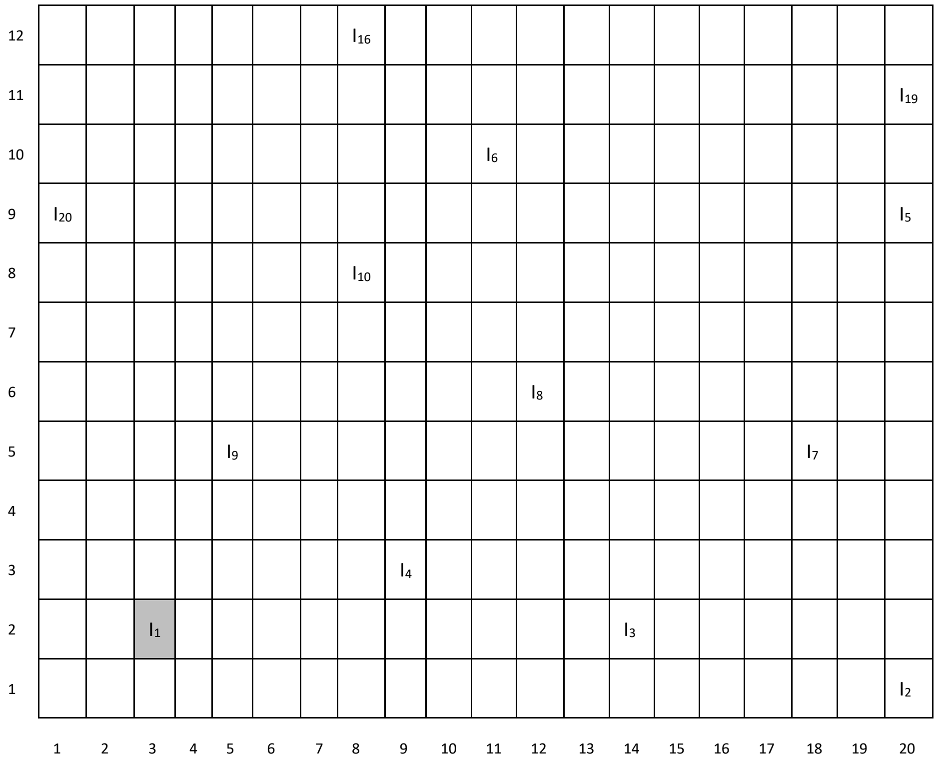
2.4 Hypothetical scenario of picking locations

The ACO approach described in the previous section was applied to a hypothetical case of a warehouse. A picker is given a picking list and has to go through each shelf to pick articles to complete his trip. In general, the Order Picking routing strategy adopted is the S-shape routing, where the picker commences his trip at the depot and has to go through every aisle, entering from one end and leaving from the other that requires a pick before heading back to his starting point [19]. In the scenario described in this study, the picking list contains 20 items to be picked and the picker has several aisles to go through. He is most concerned about finding the shortest path to be efficient in his work.

The warehouse consists of 20 rows and 20 columns as shown in Table 1. The 20 items are labelled to track the path of the picker as he moves around the shelves. Each shelf contains different products that are randomly allocated. The locations of items are attributed to the following coordinates: (I_1, I_2, I_3, I_4, I_5, I_6, I_7, I_8, I_9, I_{10}, I_{11}, I_{12}, I_{13}, I_{14}, I_{15}, I_{16}, I_{17}, I_{18}, I_{19}, I_{20}) = [(3,2), (20,1), (14,2), (9,3), (20,9), (11,10), (18,5), (12,6), (5,5), (8,8), (19,20), (17,17), (6,16), (2,20), (8,19), (8,12), (12,14), (17,13), (20,11), (1,9)]. The first picking point is I_1.

Table 1: Location of items

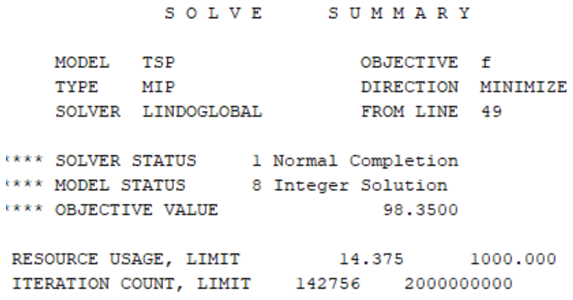
20		I_{14}																	I_{11}	
19								I_{15}												
18																				
17																	I_{12}			
16						I_{13}														
15																				
14												I_{17}								
13																	I_{18}			



3 FINDING AND DISCUSSION

3.1 GAMS approach

The use of the software package GAMS for solving the problem was proposed to validate the results reported by the ACO algorithm. The goal was to compute the optimal solution corresponding to the shortest path. The problem was formulated as Mixed-Integer Problem (MIP) and solved by GAMS 23.8.1, using the LINDOGLOBAL solver. The distances between each item were calculated and inserted in GAMS in tabulated format. Details of the matrix showing the distances between each item are given in Appendix 1. The mathematical programming model (GAMS code) is provided in Appendix 2. The summarised results are shown in Figure 5. The objective value which represents the shortest distance was approximately 98.35.



```
              S O L V E      S U M M A R Y

     MODEL   TSP                 OBJECTIVE  f
     TYPE    MIP                 DIRECTION  MINIMIZE
     SOLVER  LINDOGLOBAL         FROM LINE  49

**** SOLVER STATUS     1 Normal Completion
**** MODEL STATUS      8 Integer Solution
**** OBJECTIVE VALUE              98.3500

 RESOURCE USAGE, LIMIT         14.375      1000.000
 ITERATION COUNT, LIMIT    142756    2000000000
```

Figure 5: GAMS results

3.2 Parametric analysis of ACO model parameters

Metaheuristic approaches provide results that are dependent on the parameters adopted to develop the model. In order to analyse the influence of the ACO model parameters on the accuracy of the predicted total distance, the number of ants was adjusted. The total number of iterations was 300, the pheromone exponential weight was equal to 1, and the evaporation rate of the pheromone was equal to 0.05. Figure 6, Figure 7, Figure 8, Figure 9 and Figure 10 show the convergence plots and the retrieval path corresponding to 10 ants, 20 ants, 40 ants, 60 ants and 100 ants respectively.

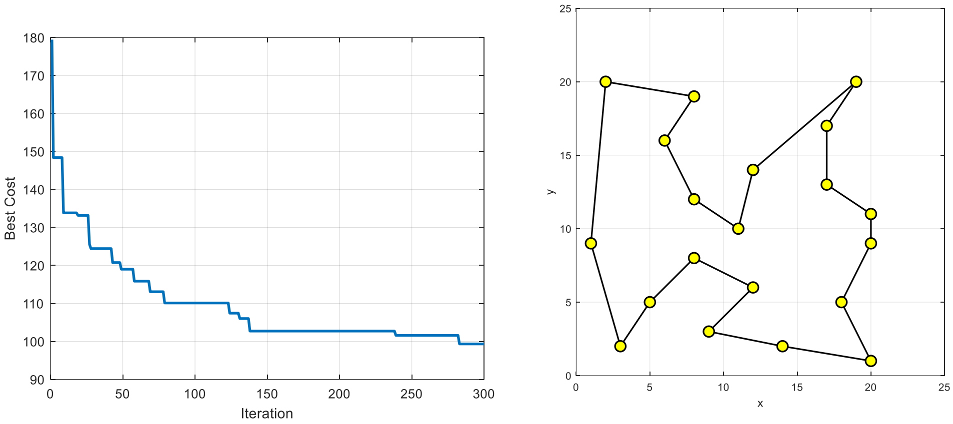


Figure 6: Convergence plots and the retrieval path nAnts = 10

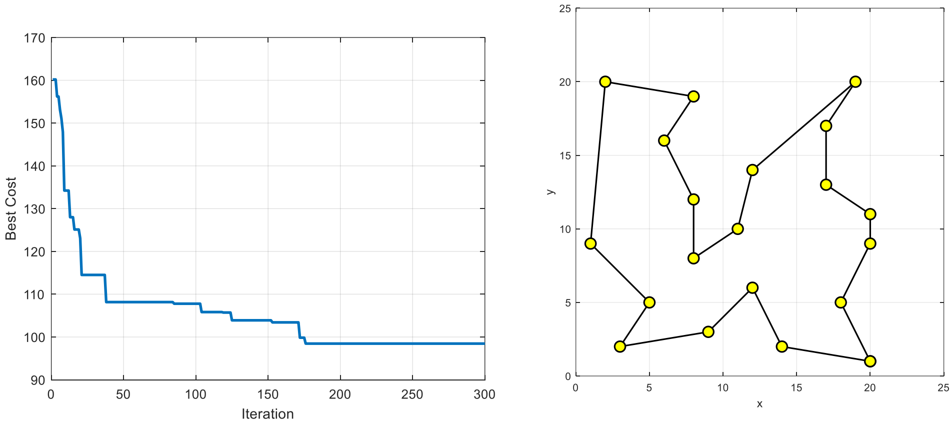


Figure 7: Convergence plots and the retrieval path nAnts = 20

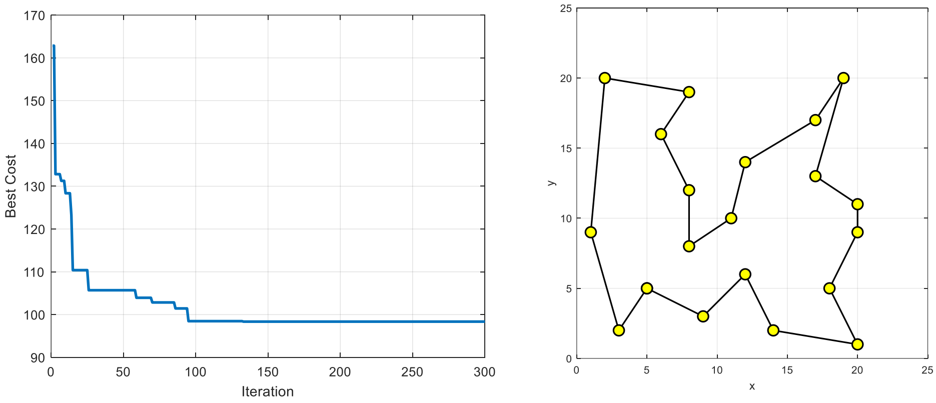


Figure 8: Convergence plots and the retrieval path nAnts = 40

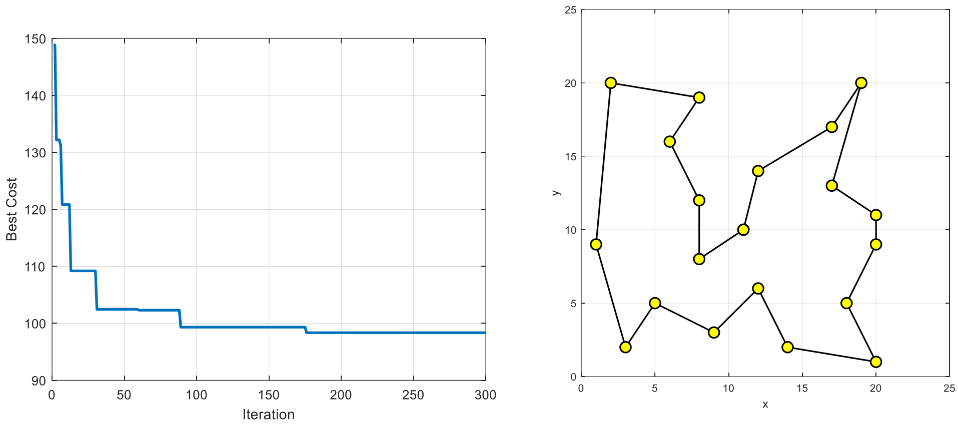


Figure 9: Convergence plots and the retrieval path nAnts = 60

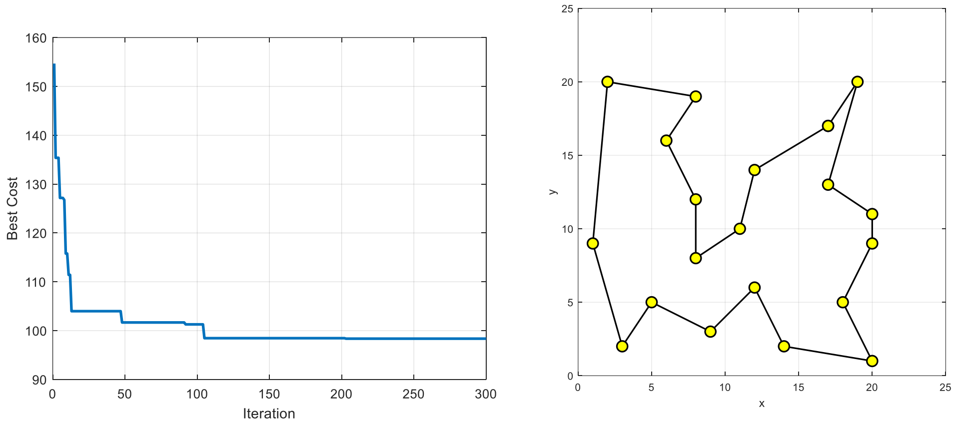


Figure 10: Convergence plots and the retrieval path nAnts = 100

These figures reveal that the results converge relatively quickly as the number of ants increases. The shape of the retrieval path was the same when the number of ants increased beyond 20. The total distances corresponding to the number of ants of 10, 20, 40, 60 and 100 were 99.3342, 98.4521, 98.3562, 98.3562, and 98.3562 respectively. Figure 11 shows the sensitivity analysis result conducted in order to assess how the parameter of the ACO model namely the number of ants affects the results reported. This result shows that the total distance was relatively the same beyond 40 ants.

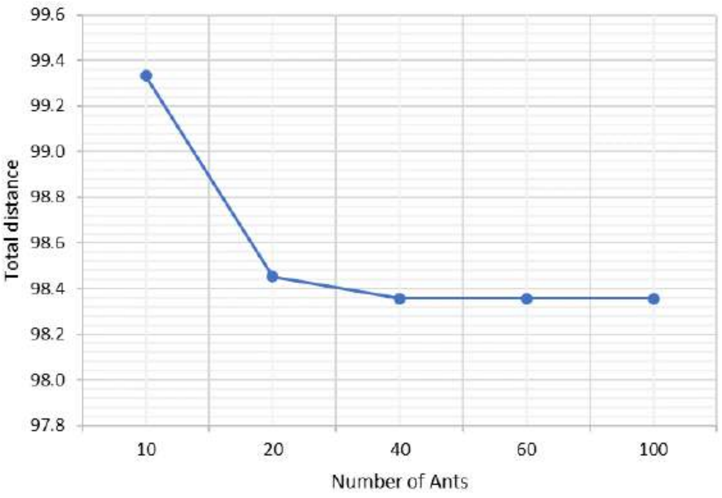


Figure 11: Influence of the number of Ants on the accuracy of the total distance

The comparison between the GAMS (98.35) and ACO (98.3562) results shows that the proposed approach provides an acceptable solution. The discrepancies could be attributed to the rounding off carried out on the distances between items to two decimals (Annexure 1). This study reveals that the ACO algorithm is suitable to address the order picking problem provided that the parameter of the model, such as the number of ants, be selected appropriately. The ACO model would be simpler to implement as opposed to the mathematical programming model formulation which would be too complex to develop (as shown in Appendix 2).

4 CONCLUSION AND RECOMMENDATION

The first objective aimed at finding the shortest route that could help in minimizing Order Picking time or distance. As discussed in the literature, pickers spend so much time searching for products or travelling long distances throughout the warehouse, which can be classified as a non-value-adding activity. To achieve this objective, this study explores the use of an existing algorithm to find the shortest path. The Ant Colony Optimization (ACO) algorithm is the approach adopted in this study. This study provides the details that demonstrate the possibility to identify the shortest Order Picking path using this algorithm and when considering measurable elements such as distance. The second objective was to perform an analysis with different scenarios and configurations. This analysis reveals that the identification of the shortest route depends on the number of ants. This shows that the selection of a relatively higher value of the number of ants improves the accuracy of the total distance computed by an ACO model. Therefore, the number of ants constitutes an important parameter of the ACO model in the computation of the shortest distance. It appears that the picking locations of items in specific warehouses would be sufficient to ease the journey of pickers and identify the shortest route within a warehouse irrespective of the order priority and the items' location. The optimal solution estimated with ACO was validated with the specialised GAMS software package that computes exact solutions. The closeness between the results demonstrates that the ACO algorithm is a suitable complement to solving order-picking problems while maintaining the quality of the solution. The ACO approach proposed in this work would assist managers to promote batch picking that allows pickers to pick different items at once, which will contribute to a reduction in the overall travel time of pickers and an improvement in efficiency.

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APPENDIX 1: DISTANCES BETWEEN ITEMS

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	0	17.03	11	6.08	18.38	11.31	15.3	9.85	3.61	7.81	24.08	20.52	14.32	18.02	17.72	11.18	15	17.8	19.24	7.28
2	17.03	0	6.08	11.18	8	12.73	4.47	9.43	15.52	13.89	19.03	16.28	20.52	26.17	21.63	16.28	15.26	12.37	10	20.62
3	11	6.08	0	5.1	9.22	8.54	5	4.47	9.49	8.49	18.68	15.3	16.12	21.63	18.03	11.66	12.17	11.4	10.82	14.76
4	6.08	11.18	5.1	0	12.53	7.28	9.22	4.24	4.47	5.1	19.72	16.12	12.37	18.38	16.03	9.06	11.4	12.81	13.6	10
5	18.38	8	9.22	12.53	0	9.06	4.47	8.54	15.52	12.04	11.05	8.54	15.65	21.1	15.62	12.37	9.43	5	2	19
6	11.31	12.73	8.54	7.28	9.06	0	8.6	4.12	7.81	3.61	12.81	9.22	7.81	13.45	9.49	3.61	4.12	6.71	9.06	10.05
7	15.3	4.47	5	9.22	4.47	8.6	0	6.08	13	10.44	15.03	12.04	16.28	21.93	17.2	12.21	10.82	8.06	6.32	17.46
8	9.85	9.43	4.47	4.24	8.54	4.12	6.08	0	7.07	4.47	15.65	12.08	11.66	17.2	13.6	7.21	8	8.6	9.43	11.4
9	3.61	15.52	9.49	4.47	15.52	7.81	13	7.07	0	4.24	20.52	16.97	11.05	15.3	14.32	7.62	11.4	14.42	16.16	5.66
10	7.81	13.89	8.49	5.1	12.04	3.61	10.44	4.47	4.24	0	16.28	12.73	8.25	13.42	11	4	7.21	10.3	12.37	7.07
11	24.08	19.03	18.68	19.72	11.05	12.81	15.03	15.65	20.52	16.28	0	3.61	13.6	17	11.05	13.6	9.22	7.28	9.06	21.1
12	20.52	16.28	15.3	16.12	8.54	9.22	12.04	12.08	16.97	12.73	3.61	0	11.05	15.3	9.22	10.3	5.83	4	6.71	17.89
13	14.32	20.52	16.12	12.37	15.65	7.81	16.28	11.66	11.05	8.25	13.6	11.05	0	5.66	3.61	4.47	6.32	11.4	14.87	8.6
14	18.02	26.17	21.63	18.38	21.1	13.45	21.93	17.2	15.3	13.42	17	15.3	5.66	0	6.08	10	11.66	16.55	20.12	11.05
15	17.72	21.63	18.03	16.03	15.62	9.49	17.2	13.6	14.32	11	11.05	9.22	3.61	6.08	0	7	6.4	10.82	14.42	12.21
16	11.18	16.28	11.66	9.06	12.37	3.61	12.21	7.21	7.62	4	13.6	10.3	4.47	10	7	0	4.47	9.06	12.04	7.62
17	15	15.26	12.17	11.4	9.43	4.12	10.82	8	11.4	7.21	9.22	5.83	6.32	11.66	6.4	4.47	0	5.1	8.54	12.08
18	17.8	12.37	11.4	12.81	5	6.71	8.06	8.6	14.42	10.3	7.28	4	11.4	16.55	10.82	9.06	5.1	0	3.61	16.49
19	19.24	10	10.82	13.6	2	9.06	6.32	9.43	16.16	12.37	9.06	6.71	14.87	20.12	14.42	12.04	8.54	3.61	0	19.1
20	7.28	20.62	14.76	10	19	10.05	17.46	11.4	5.66	7.07	21.1	17.89	8.6	11.05	12.21	7.62	12.08	16.49	19.1	0

APPENDIX 2: MATHEMATICAL PROGRAMMING MODEL IMPLEMENTED IN GAMS

```
$title TSP
Sets
i index /1*20/
alias (i,j);
sets offdiag1(i,j)
     offdiag2(i,j);
offdiag1(i,j)=yes;
offdiag1(i,i)=no;
offdiag2(i,j)=offdiag1(i,j);
offdiag2(i,'20')=no;
offdiag2('20',j)=no;
table c(i,j)
      1       2       3       4       5       6       7       8       9       10      11      12      13      14      15      16      17      18      19      20
1     0       17.03   11      6.08    18.38   11.31   15.3    9.85    3.61    7.81    24.08   20.5    14.32   18.02   17.72   11.18   15      17.8    19.24   7.28
2     17.03   0       6.08    11.18   8       12.73   4.47    9.43    15.52   13.89   19.03   16.28   20.52   26.17   21.63   16.28   15.26   12.37   10      20.62
3     11      6.08    0       5.1     9.22    8.54    5       4.47    9.49    8.49    18.68   15.3    16.12   21.63   18.03   11.66   12.17   11.4    10.82   14.76
4     6.08    11.18   5.1     0       12.53   7.28    9.22    4.24    4.47    5.1     19.72   16.12   12.37   18.38   16.03   9.06    11.4    12.81   13.6    10
5     18.38   8       9.22    12.53   0       9.06    4.47    8.54    15.52   12.04   11.05   8.54    15.65   21.1    15.62   12.37   9.43    5       2       19
6     11.31   12.73   8.54    7.28    9.06    0       8.6     4.12    7.81    3.61    12.81   9.22    7.81    13.45   9.49    3.61    4.12    6.71    9.06    10.05
7     15.3    4.47    5       9.22    4.47    8.6     0       6.08    13      10.44   15.03   12.04   16.28   21.93   17.2    12.21   10.82   8.06    6.32    17.46
8     9.85    9.43    4.47    4.24    8.54    4.12    6.08    0       7.07    4.47    15.65   12.08   11.66   17.2    13.6    7.21    8       8.6     9.43    11.4
9     3.61    15.52   9.49    4.47    15.52   7.81    13      7.07    0       4.24    20.52   16.97   11.05   15.3    14.32   7.62    11.4    14.42   16.16   5.66
10    7.81    13.89   8.49    5.1     12.04   3.61    10.44   4.47    4.24    0       16.28   12.73   8.25    13.42   11      4       7.21    10.3    12.37   7.07
11    24.08   19.03   18.68   19.72   11.05   12.81   15.03   15.65   20.52   16.28   0       3.61    13.6    17      11.05   13.6    9.22    7.28    9.06    21.1
12    20.52   16.28   15.3    16.12   8.54    9.22    12.04   12.08   16.97   12.73   3.61    0       11.05   15.3    9.22    10.3    5.83    4       6.71    17.89
13    14.32   20.52   16.12   12.37   15.65   7.81    16.28   11.66   11.05   8.25    13.6    11.05   0       5.66    3.61    4.47    6.32    11.4    14.87   8.6
14    18.02   26.17   21.63   18.38   21.1    13.45   21.93   17.2    15.3    13.42   17      15.3    5.66    0       6.08    10      11.66   16.56   20.12   11.05
15    17.72   21.63   18.03   16.03   15.62   9.49    17.2    13.6    14.32   11      11.05   9.22    3.61    6.08    0       7       6.4     10.82   14.42   12.21
16    11.18   16.28   11.66   9.06    12.37   3.61    12.21   7.21    7.62    4       13.6    10.3    4.47    10      7       0       4.47    9.06    12.04   7.62
17    15      15.26   12.17   11.4    9.43    4.12    10.82   8       11.4    7.21    9.22    5.83    6.32    11.66   6.4     4.47    0       5.1     8.54    12.08
18    17.8    12.37   11.4    12.81   5       6.71    8.06    8.6     14.42   10.3    7.28    4       11.4    16.55   10.82   9.06    5.1     0       3.61    16.49
19    19.24   10      10.82   13.6    2       9.06    6.32    9.43    16.16   12.37   9.06    6.71    14.87   20.12   14.42   12.04   8.54    3.61    0       19.1
20    7.28    20.62   14.76   10      19      10.05   17.46   11.4    5.66    7.07    21.1    17.89   8.6     11.05   12.21   7.62    12.08   16.49   19.1    0
scalar n;
n=card(i);
Variables f, y;
Binary variable x;
Equations
ohr1(j)
ohr2(i)
anti(i,j)
ucel;
ucel.. f=e=sum((i,j),c(i,j)*x(i,j));
ohr1(j).. sum(i,x(i,j)$offdiag1(i,j))=e=1;
ohr2(i).. sum(j,x(i,j)$offdiag1(i,j))=e=1;
anti(offdiag2(i,j)).. y(i)-y(j)+n*x(i,j)=l=n-1;

Model TSP /all/;
Solve TSP using MIP minimizing f;
Display x.l, f.l;
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A HOLISTIC FEASIBILITY ASSESSMENT OF THE SOUTH AFRICAN COAL-TO-CARBON INDUSTRY

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ABSTRACT

This study explores the feasibility of the coal-to-carbon industry in South Africa through the eyes of the industry's experts. The aim is to assess the feasibility of South Africa's coal-to-carbon industry by exploring the market, technical, economic, environmental, and operational feasibility factors. Semi-structured interviews were conducted with industry experts and academics in the field. Purposive sampling was used alongside snowballing to reach participants most suited to provide relevant information to the study. A total of 13 interviews were conducted for this study. Interpretive thematic analysis was used, and the findings are presented using emergent themes and rich, narrative descriptions. The findings show that South Africa has skills, feedstocks for carbon products and supporting industries, which are feasibility enablers. The major feasibility barrier is the environmental factor as the current processes in the production of carbon precursors produce significant amounts of greenhouse gases. Recommendations are made for the collaboration of key stakeholders to bridge the coal-to-carbon industry narrative gaps.

Keywords: Coal, Carbon, Coal-based products, Feasibility, South Africa

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1 INTRODUCTION

1.1 Background

Coal resources are plentiful in South Africa [1]. They contribute significantly to the country's economy as applications in power generation, steel making, and cement production, and have wider implications for industrial development [2]. However, coal usage has negative effects on the environment from the production and release of greenhouse gases. To combat these effects, the world formulated interventions through the Paris agreement in 2015 [3] and, lately, the 26th conference of parties [4]. These interventions are encouraging a shift away from coal utilisation.

There are tangible adverse effects of shifting away from coal use in power generation, and other industrial uses as South Africa is a coal-dependent economy. Rademeyer [5] highlights the potential subsequent deterioration in international coal trade on South Africa's coal market and economy. When faced with declining demand for exported coal, the supply of coal for local power stations would decline due to decreasing profits for mines leading to the eventual closure of higher-cost mines [5].

The Covid-19 pandemic has exacerbated the current situation [6]. These factors indicate a need to diversify our use of coal to include more sustainable utilisation methods. The challenge for South Africa is developing a feasible and sustainable economic development model that encourages a shift away from unabated coal usage. By pursuing alternative coal uses, new job opportunities could be created in South Africa's competitive job market, which could act as a stepping stone to new applications of advanced forms of carbon [7].

Amidst all these challenges facing the coal industry, a market exists to obtain more value from coal by extracting carbon and producing carbon-based products. The coal-to-carbon industry converts coal or precursors (the raw material used to make carbon products) from coal into useful and valuable carbon products. The coal-to-carbon industry presents many opportunities in advanced markets for coal-derived products. The coal to solid carbon products global market is estimated to consume between 300-400 million tons per annum of coal, and the major areas are chemicals, fuels, and fertilisers [8]. Coal offers opportunities for both reducing the cost of manufacturing carbon products and, in many instances, providing a superior quality carbon feedstock [8]. Coal is also less expensive ($12-$50/ton) in many advanced market applications than traditional feedstocks such as petroleum ($400-$500/ton) [8].

1.2 Motivation for the study

The coal-to-carbon industry offers significant opportunities for coal and is an alternative to South Africa's current coal utilisation. Sales for carbon nanotubes are currently in excess of $2.5 billion [9]. As South Africa has excellent coal resources that contribute significantly to the country's economy, it would be valuable to assess the feasibility and prospects of the coal-to-carbon industry. Smaller amounts of coal can generate more revenue in carbon products than larger amounts of coal when used as a feedstock in electricity and fuel generation. In South Africa, 53% of coal is used for power generation [10], 33% for fuel production, 12% for metallurgical industries, and 2% for domestic use. The purpose of this study is to explore the feasibility factors affecting the South African coal-to-carbon industry from the viewpoints of experts in the industry.

This study aims to answer the following questions.

- What is the status of the South African coal-to-carbon industry?
- What are the holistic feasibility barriers and enablers of the coal-to-carbon industry in South Africa?
- What are the opportunities offered by the coal-to-carbon industry in South Africa?

2 LITERATURE

2.1 Coal-to-carbon Industry

The coal-to-carbon industry focuses on non-energy products, advanced carbon materials, and products. The secondary sector, which is the conversion of beneficiated coal into final products, is the niche sector as it is still developing or in the feasibility phase globally [8]. The industry is relatively new, with various technologies still in development and testing stages [11]. However, some of the technologies used to produce carbon precursors are relatively old. The industry employs various pathways to produce value-added carbon products and incorporates many different technologies to produce the carbon products from coal. The high-value carbon products from coal include activated carbons, carbon fibres and composites, carbon nanomaterials, carbon black, carbon electrodes and carbon foams [8] [12] [9].

2.2 Feasibility

Factors that impact feasibility emanate from increasingly pressing global sustainability challenges, accelerating technological evolution, and escalating commercial and geopolitical competition [13]. Assessing feasibility with rigour is dependent upon looking at the many interlinked factors that contribute to long-term life cycle success, drawing upon many perspectives and inputs [13]. This study incorporates feasibility criteria relevant to the coal-to-carbon industry. Table 1 shows feasibility types and the rationale for their selection for the study.

The study assesses the technical viability of the industry. It also incorporates economic and operational feasibility and environmental and market feasibility. Critical to the coal-to-carbon industry is the environmental feasibility as coal is a feedstock that draws criticism due to its contribution to greenhouse gas emissions [14] and particulate matter emissions [15]. The abovementioned feasibility criteria are combined to comprehensively assess the factors relevant to the coal-to-carbon industry.

Table 1: Feasibility types and their specifications

Feasibility type	**Specifications**	**Rationale**
Technical	Technical readiness level Physical-technical constraints and alternatives	To determine the suitability of technologies available in South Africa [13]
Economic	Cost-benefit analyses	To determine cost-effectiveness of the venture [16]
Operational/Organisational	Stakeholder identification	Helps identify key stakeholders to the industry [16]
Environmental	Sustainability, lifecycle assessment	To determine potential environmental effects and emissions [14] [15]
Market	Market research, total addressable market	To identify and segment the market for the products [17]

Coal is well suited to produce high-value carbon products because of its inherent high carbon content. There are various technically feasible products that can be produced from coal that includes carbon fibres and carbon-based electrodes [18]. However, some of the current coal-to-carbon applications and processes are uneconomical as they are energy and capital intensive [18].

There are high costs involved in the production of these products but coal as a cheaper feedstock has the potential to reduce the overall production costs. Coal-based advanced carbon materials and chemicals from coal offer significant opportunities and there is a huge market globally for products and materials from coal [8] [19].

3 RESEARCH METHODOLOGY

3.1 Research Approach

The research follows a qualitative approach. The coal-to-carbon industry serves as an area of interest explored with the aid of experts in the field to provide valuable insights into this industry. The study presented in this paper forms part of a larger triangulated qualitative study that has also used literature review. A literature review was conducted preceding the empirical research reported in this paper. Various feasibility factors were surveyed focusing on the market, technical, operational, environmental, and economic aspects. This paper reports on findings from semi-structured interviews [20], [21] conducted with carbon experts from the South African industry and academia.

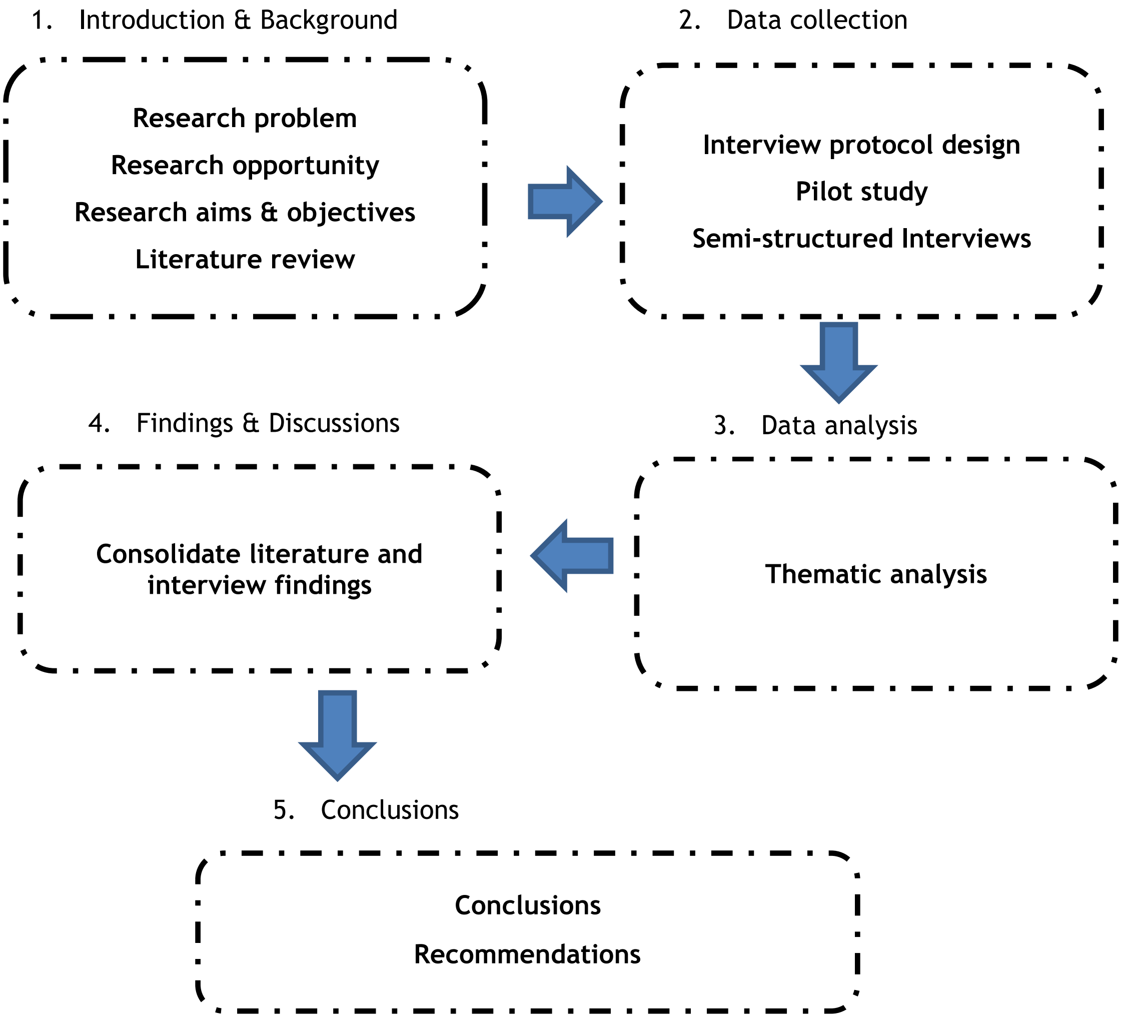

Figure 1: Visualised research method

3.2 Method

A semi-structured question guide with 13 questions was developed from literature using the research questions and objectives as a guide. The questions focused on the various feasibility criteria to cover the topic holistically. The interviews were hosted in a Zoom environment, recorded, and later transcribed. The list of questions is provided in Appendix A.

3.3 Data Collection and Sampling

The target population of this study are experts in the coal-to-carbon industry in South Africa including practitioners working with coal conversion technologies and expert researchers in coal-based carbon materials and or products. The industry is highly specialised, and therefore, a purposive sampling [20] method was utilised to select participants well positioned to provide data relevant to the study. The participants were continuously sourced until data saturation was reached. The LinkedIn platform was utilised to reach out to the participants and the snowballing method [20] was used to reach out to a wider area of eligible participants. At the end of the interview, the researcher would ask participants to refer others to the study.

There were 13 participants, 38.5% were practitioners, 38.5% were academics, and 23% were both practitioners and academics with experience ranging between 3 and 30 years. Participants P1, P2, P5, P7 and P10 were practitioners and participants P3, P4, P11, P12 and P13 were academics. Three participants in the study were both practitioners and academics, P6, P8 and P9.

3.4 Data Analysis

The analysis centred on the views and opinions of the participants. The researcher followed a thematic analysis process to capture the meanings of participants in the industry [22]. The process immersed the researcher in the data to identify multiple concepts and themes on the topic. The researcher went over the data several times to become acquainted with it. The data analysis was not a linear process, but rather a recursive one in which the researcher moved back and forth as needed through the various phases of the study [23]. The researcher first listened to the interview recordings and then read the transcripts taking notes of thoughts related to the dataset.

The researcher explored the diversity and patterns of meaning in the dataset, resulting in over one hundred and fifty formulated codes [22]. Each data item was read, and all the segments of text with meaning relevant to the research questions were labelled. This process was repeated, producing over two hundred codes, as the researcher gained new insights into the data. Next, there was engagement with data codes to discover similarities and meanings [22]. All potentially connected codes were clustered into initial themes. The coded data was revisited to improve and or clarify the code clusters. Some themes were dropped that were not relevant to the research questions. Lastly, the researcher refined, defined, and named the themes from the data set. The final thematic analysis reflects only the themes and subthemes that were articulated by our sample.

4 FINDINGS AND DISCUSSIONS

This section presents identified themes and sub themes from the data set using quotations as supporting evidence. Quotations are referenced back to the participants P1 to P13. The interview questions focused on the South African utilisation of coal resources in the production of carbon products, the feasibility factors and the opportunities offered by the coal-to-carbon industry. Table 2 shows the themes from the dataset and corresponding sub-themes.

Table 2: A list of themes and sub-themes

THEMES	SUB-THEMES
1. ENABLER	Availability of feedstocks
	Availability of skilled personnel
	Availability of supporting industries
	Market availability
	Coal is a cheaper feedstock
2. CHALLENGES	Environmental
	Funding
	Markets
3. COMPETITION	Feedstocks
	Markets
4. INDUSTRY GAPS	Lack of carbon manufacturing industries
	Lack of visibility
5. COAL UTILISATION	Primary, predominant and /traditional uses
	High-value utilisation

4.1 Coal-to-carbon industry status

Coal utilisation

South Africa has abundant coal resources and reserves [1], and the participants highlighted their extensive use in power generation, synthetic fuel production, steel making and the export market. South Africa boasts high utilisation of coal resources compared to other countries having pioneered the synthetic fuel production alongside other uses. The notion of extensive use of the coal resources was based on the current utilisation in South Africa.

> *"Because these are the technologies that are available for power generation and for coming up with fuel so basically based on the technologies that we have, we are using it to the fullest." (P3)*

Comparing the country's resources of coal to the production of coal-based materials and products, other participants' opinions showed that the utilisation was less than optimum. The production of carbon products from coal is generally lacking in South Africa. Therefore, the optimum use of coal resources could be reached by leveraging this resource in the production of high-value carbon products. The low ash South African bituminous coals are excellent starting materials to manufacture high-value carbon products that are exported to international markets.

Overall, there seemed to be no agreement among the participants on whether coal resources are being utilised to the fullest in South Africa. There is much potential to use available coal resources to produce carbon products. The underutilisation could be attributed to various interrelated reasons as cited by the participants. Lack of knowledge regarding the use of coal to produce carbon products was cited as a reason for the underutilisation and coal resources are largely used for traditional purposes. The local coal conversion industry lags when it comes to innovation.

> *"In South Africa,… most of the companies haven't been innovating in that they don't do R and D (research and development). Whereas overseas, most industries actually support, and are highly innovative."(P9)*

Lastly it was pointed out that the current use of coal is heading for a change in the future with some utilisation processes coming to a halt. Chemical production and carbon materials production are some of the potential future uses of coal in South Africa. The 26th conference of parties held in Glasgow in 2021, resolved to pursue the reduction of unabated use of coal. As a result, the traditional use of coal in power generation and or other applications which pollutes the environment could decline.

> *"In my opinion over the course of the next let's say 10 to 20 years, there is going to be a shift from industries that use coal and emit a lot of carbon dioxide and if coal is to have a future it's not in combustion or gasification it's going to be chemicals production and carbon materials production." (P6)*

4.2 Feasibility enablers

The coal-to-carbon industry in South Africa is well-positioned to be vibrant and competitive as it has extensive industry enablers, as indicated by the study's participants. Coal conversion into valuable carbon products requires skills, technologies, and resources among other requirements for success. The participants identified the following enablers of the South African coal-to-carbon industry. The first enabler is the availability of feedstocks or carbon precursor-producing facilities or entities. Coal as a feedstock is abundant in South Africa [1]. High-value carbon products can be produced from feedstocks with high carbon content, and South African coking coals are a source of this carbon.

Carbon precursors from coal, such as the pitches, and tars from Sasol and ArcelorMittal, were singled out as a major industry enabler. Coal-tar pitch is a precursor used to produce advanced carbon materials [9]. The tar from the carbonisation process, chars and coke are currently being used in the production of synthetic carbon materials [24] [25].

Carbon precursor producing facilities are key in the production processes of high-value carbon products, and South Africa has Sasol that produces tars, pitches, and light charcoal. High-temperature pitches from the coking processes at ArcelorMittal can be used to produce carbon fibres and other carbon nanomaterials. The cokes from the same process can produce activated carbons and carbon electrodes.

South Africa was cited for having skilled personnel in the field of manufacturing. The participants referred to the state-of-the-art manufacturing facilities run by experts in various fields. As technologies are developing and becoming more advanced, South Africa is also training personnel to operate these technologies. The technologies mentioned include Sasol's Fischer Tropsch technology, the nuclear power stations, and Eskom power plant technologies. With an extensive base of skilled personnel in the field of coal conversion, South Africa can build on this to grow the coal-to-carbon industry. The necessary technologies for high-value carbon product production can be developed or acquired.

Within the coal-to-carbon industry, nanomaterials are high-value products that show great promise and South Africa has an enabling environment to support the production of these materials. The government has invested in this industry, there are research entities specialising in nanotechnology and there are facilities producing nanomaterials utilising other feedstocks. With expertise in the field it's a significant boost to the industry.

> *"So what we got is many people who understand nanotechnology . . . High tech carbon is nanotechnology basically. Its just a component, nanotechnology is the overiding issue so carbon is one component of it." (P4)*

The availability of supporting industries to the coal-to-carbon industry was highlighted as another enabler to the feasibility of the coal-to-carbon industry. The supporting industries are key to the success of any industry and in South Africa, there are industries that provide the carbon precursors, input suppliers like stable electricity and industries that take up the products. The carbon products are utilised as raw materials to the various industries in South Africa. The vibrant South African automotive sector is a leading market for high-value carbon products.

> *"…you've already got some industries you can go to." (P2).*

The international market and the local market came out as complementary enablers to the industry. The local market can readily absorb the relatively cheaper carbon products while the international market can support high-value products. Participants were positive that if products are of high quality, the international market could take them.

> *"I think high tech you('ve) got to go to the international market. The low tech you got a local market. Remember you can use these high-tech materials if you can make them cheaply, they may have properties that you want so you may want to put high-tech carbon into low-tech places." (P4)*

The study assesses the feasibility of carbon products production from coal. Another enabler to the industry is that coal is a cheaper feedstock. Coal is also less expensive ($12-$50/ton) compared to other traditional feedstocks such as petroleum ($400-$500/ton) [8]. This gives an advantage to coal as a precursor to carbon material production, considering the production costs.

4.3 Feasibility barriers

4.3.1 Competition

Competition in the coal-to-carbon industry is twofold, the competition for the precursors to produce carbon products and final product competition. The production of high-value carbon products is dependent on carbon found in feedstocks. The petrochemical industry is a supplier of carbon-containing feedstocks, and therefore this industry is a direct competitor to the coal-to-carbon industry.

In the production of some carbon products, there are other feedstocks that are already established. In the production of carbon fibres, polyacrylonitrile currently accounts for 90% of all feedstocks followed by Rayon [9]. Activated carbon can also be produced from various trees in South Africa, which are abundant biomass materials.

The market is an important factor for the success of an industry. The South African coal-to-carbon industry's market battle is against advanced economies in Europe, the United States of America and Asia. Countries that have more advanced carbon products producing industries pose stiff competition to the South African coal-to-carbon industry. With advanced manufacturing capabilities, these economies dominate the advanced carbon material markets. Therefore, it will be difficult for South Africa to venture into carbon fibre products and secure markets against these established economies.

> *"You are competing with international people, and you've got to look at your markets, so you know the type of thing is the low-level stuff is easier to get a handle on because the market is here." (P4).*

4.3.2 Challenges

There are many challenges regarding the feasibility of the coal-to-carbon industry in South Africa. The most significant of these, as cited by the study's participants, were environmental. The current processes producing carbon precursors in South Africa produce substantial greenhouse gases. Coal carbonisation and liquefaction technologies that produce the tars and pitches also emit large quantities of carbon dioxide and sulphur into the atmosphere. This is a major challenge that the industry needs to overcome to be successful.

"It's a fossil fuel and it's a major cause because I mean in South Africa it contributes quite a lot to see $C0_2$ emissions. Right, that is one of the biggest challenges with this industry." (P7)

Investment in carbon capture and sequestration technologies could be an option for the South African context. This technology captures and stores carbon dioxide and other greenhouse gases from the production of carbon products and is one potential solution to these environmental concerns.

Another challenge that faces the feasibility of the coal-to-carbon industry is also fuelled by environmental concerns. New coal projects struggle to access finance due to perceived environmental issues. It emerged that funding for coal-based projects may be limited due to the transition from unabated coal use. However, the participants argued that for sustainable coal projects, funding is accessible.

Although the products for the carbon industry are high value, the market is relatively small. The local carbon market is still significantly small due to various reasons. Traditional materials such as steel, aluminium, and concrete dominate the market. However, carbon materials and products can increase their market share, as they have superior properties.

"The market is there, but it's small. It's not sustainable." (P13)

4.4 Opportunities for the coal-to-carbon industry

Industry gaps

Some gaps must be filled for the South African coal-to-carbon industry to be fully functional. Currently, only a fraction of the industry is functioning, with the production of carbon precursors being the most significant segment of the industry. The industry lacks: there is need to optimize the industry’s value chain. The participants pointed to the gaps and or sectors in the industry narrative. The most visible gap is the lack of carbon manufacturing industries. The final carbon products that South Africa is currently producing include carbon black and activated carbon. It lacks in the production of other carbon products that are of high value. South Africa generally lacks carbon technologies.

The coal-to-carbon industry lacks visibility as it is a niche part of the coal conversion industry that is relatively unknown. The local coal producers utilise typical traditional markets for the predominant traditional coal utilisation, instead of the coal-to-carbon industry, a market that takes up coal as a feedstock.

"I think in terms of market availability that is also where there is a very big gap there. The coal producers in the country do not know, they're not necessarily aware of all the different markets that they could sell their product into." (P1).

The country has invested extensively in coal research, but there is still a gap in carbon products produced from coal. Extensive research in the field of coal conversion was never implemented:

"In South Africa, there's really nobody who does it because we don't even do it." (P9)

A concept that was echoed by most of the participants is the need for collaboration or participation between the various stakeholders in the industry. The South African coal-to-carbon industry needs stakeholders to come together and take the industry to the next level.

"So, I think those are some of the issues that need to be . . . collaboration between the universities, research institutions, the industry, the government is key also to ensure success in this program." (P13)

4.5 Further discussion

Collaboration is significantly important to the feasibility of the coal-to-carbon industry in South Africa. The study identified the top stakeholders and formulated their relationships. These stakeholders can work collectively to develop the coal-to-carbon industry in South Africa. The key stakeholders to the coal-to-carbon industry and their relationships are shown in figure 2. The government, research institutions including tertiary institutions and funding agencies comprise top stakeholders to coal-to-carbon industry.

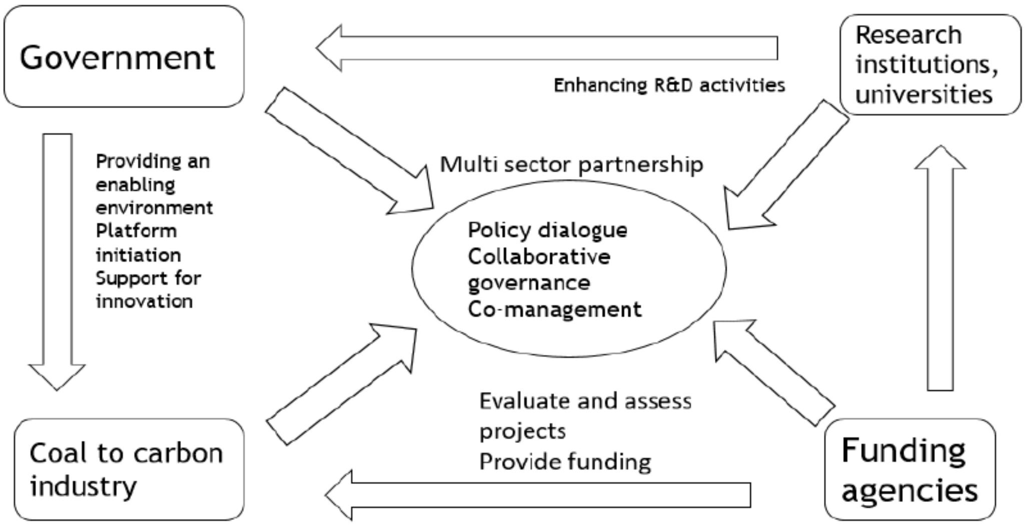

Figure 2: The industry stakeholders' relationships

5 CONCLUSIONS

The findings of this study on expert opinions and views of the feasibility of the coal-to-carbon industry in South Africa show that the South African coal-to-carbon industry is still in its infancy and generally lacks appropriate carbon technology. These technologies can be acquired from other advanced economies, and utilise the available cheaper feedstock, to optimise the enablers to the industry.

There are various feasibility enablers for the industry. The necessary building blocks for a fully optimised, productive industry are available but there is a need for stakeholders to collaborate and close the gaps within the industry. On the other hand, there are also feasibility barriers with the leading factor being environmental. The production of greenhouse gases and particulate matter in the production of carbon products is currently the limiting factor against the industry.

Lastly, the South African coal conversion industry is highly competitive globally, with a capacity to innovate and upgrade to leverage resources to develop the coal-to-carbon industry. There is potential to use available coal resources to produce carbon products. The recommended route is the simultaneous pursuit of differentiation and low cost to open new markets and create new demand for the industry.

This study used a novel approach that applied a feasibility framework relevant to the coal-to-carbon industry. The holistic approach allowed the most crucial feasibility aspects to be discussed. This exploratory study has set the stage for further investigation into the industry's potential.

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APPENDIX A

1. South Africa has abundant coal reserves and resources; do you think they are being utilized to their fullest? Why do you believe this is the case?

2. In terms of coal conversion into useful products, South Africa has excelled with its leading coal to liquid industry, what do you think of the coal-to-carbon industry?

3. What do you believe are the coal-to-carbon industry key success factors?

4. How do you see the current size and growth potential of the market for coal-based products in South Africa?

5. As an expert in the coal conversion industry, you may have witnessed or experienced some of the challenges currently facing this industry. Can you share some of these instances?

6. Would you like to share some thoughts on the feasibility of technologies in the production of valuable coal products?

7. I would like us to consider the environment as we look at the feasibility of the coal to carbon industry. From this perspective what do perceive as critical issues that may affect the coal-to-carbon industry?

8. Are there any operational issues on the feasibility of the coal-to-carbon industry that you might want to discuss?

9. From studies done in other regions, the coal conversion industry is rapidly growing, what are your thoughts on South Africa’s competitiveness globally in production of valuable coal-based products?

10. The coal conversion industry is capital intensive which makes it a high-risk business. In the current economic and political environment, would you tell us reasons why you would either invest or not invest in this industry?

11. What do you think are the benefits of the coal-to-carbon industry to the South African economy?

12. To what extent do you think the coal-to-carbon industry has potential to disrupt the coal conversion industry?

13. According to you, how can the coal to carbon industry best realize its full potential in South Africa?

TEACHING 3IR COMPETENCIES TO TRANSITION TECHNOLOGISTS INTO 4IR PROFESSIONALS

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ABSTRACT

The impact of the three waves of COVID-19 infections has led to the dearth of public healthcare provision in South Africa. Healthcare management has discovered that traditional healthcare service processes are incapacitated by the inefficiencies and bottlenecks in the current traditional service delivery process. In response to the impact of the COVID-19, healthcare service and facilities managers are confronted with addressing the three main core healthcare processes in the South African healthcare context. This is an action research case study that applies a qualitative approach to problem solving. The research will explore and explain how the impact of COVID-19 on public healthcare provision can be mitigated adequately. The research will establish the three most critical processes that must be entrenched in healthcare service-delivery institutions, to enable the alleviation of the impact of COVID-19. The integration of the three core processes results in a management paradigm that can optimize care service delivery.

Keywords: Healthcare, COVID-19, Digitization, Infection, Data.

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1 INTRODUCTION

Healthcare facilities such as hospitals are always overcrowded, and service delivery is poor. Facilities are under-resourced and over-stretched. Communities that are in the catchment area of the hospital service cannot access the service in hospitals because of unavailability of the medical service required. This is due to overcrowding, lack of resources, shortages of medical supplies and medical staff, and poor service delivery. Poor service delivery is the source of the bottleneck experienced in the healthcare service process. The bottleneck is caused by three factors that impede execution of operational healthcare programs in healthcare.

Public healthcare systems are complex by design, for this is where individual work and group coordinated activities that occur within groups are more often executed simultaneously [22]. The South African healthcare system is hindered by the repercussions of policies made in the Apartheid era. Since, the mission was to focus on segregation and expansion of healthcare benefits for the minority population [7]. The healthcare system continues to suffer setbacks in the post-apartheid era, with corruption crippling the system's ability to deliver service. Therefore, the complexity of healthcare service is compounded by policies and management activities executed within the system.

It is this complexity of the system and the compounding effects of policies and corruption that leads to inappropriate information within a healthcare delivery system [10]. Therefore, an experienced poor healthcare service delivery, that manifest due to bottlenecks and a mediocre execution of service delivery processes, is apparent. Compounding the complexity of the environment is the impact of COVID-19 infections, which has led to the dearth of public healthcare provision in South Africa. In response to the impact of the COVID-19, healthcare service and facilities managers are confronted with addressing the three main core healthcare processes in the South African healthcare context.

Healthcare management has discovered that traditional healthcare service processes are incapacitated by the inefficiencies and bottlenecks in the current traditional service delivery process. Thus, the focus of this research is relevant and significant in enabling an establishment of a remedy for the challenges encountered. Previous studies on the impact of COVID-19 on healthcare, dealt extensively with the impact on mental health, the impact on health works and, the economic impact. The impact on healthcare specialist practices, on healthcare professionals, on wellness, technology, and availability service, is also included. A limited number of studies were conducted on the utilization of service and service delivery processes.

Bohmer et al. [4] argued that COVID-19 resulted in an untenable demand spike for the already constrained healthcare service. An untenable demand it seems, because Public Healthcare facilities are still overcrowded, and service delivery is still poor. It does seem like facilities are under-resourced and over-stretched. Therefore, current themes of research, as indicated earlier, are not adequate to mitigating the dearth of public healthcare service delivery. Thus, this research focus on the three main core healthcare processes in the South African healthcare context, will present an integration approach as a panacea to the dearth of public health service delivery.

COVID-19 has an unexpected and astonishing impacted on healthcare delivery service processes management [16]. The impact directly affects service delivery execution, due to an unprecedented patient demand for healthcare service, and an increased demand for capacity and resources. This impact is not surprising and unexpected, since globally, research and the scientific community reported serious concerns about the capacity of a fragile, already overburdened healthcare system. Particularly, as cases began to rise in low-resource settings, such as South Africa and the African diaspora [17]. Thus, this project focus area is a perfect fit for the South African healthcare research context and a significant addition to the research body of knowledge.

Preliminary qualitative research and documented systematic reviews about the impact of Covid-19 on Public Healthcare, suggests that the African voice is underrepresented in medical literature related to the burden of Covid-19 on public healthcare [17]. Since the beginning of the pandemic only one (1) out of five (5) African COVID-19 papers had no African author and 66.1% of authors on African papers were not from Africa [17]. It is not surprising therefore, for South Africa and the African Diaspora to follow the suggestion of flattening the curve to delay the pandemic impact on public healthcare, instead of identifying and optimizing the core enabling process in public healthcare service delivery.

This research endeavours to develop a South African solution for public healthcare, and for the African diaspora, by focusing and addressing the three main core healthcare processes in the South African healthcare context. The processes are identified and established as the main drivers of public healthcare delivery and a process of integration of the three core processes is implemented. The integration process results in a management paradigm that can be applied to optimize healthcare service delivery interventions. The solution will further demonstrate that adopting the level loading principle (Flattening the curve), was a misdiagnosis for South Africa and for all low-resource settings.

2 LITERATURE REVIEW

Bohmer et al. [4] referred to the impact of COVID-19 results on public healthcare as untenable for the already constrained public healthcare service. An untenable increase in demand for capacity responsiveness, during untenable events, it seems [16]. Carvalho et al. [8] argues that when the outbreak develops into the epicenter of COVID-19 infections, healthcare capacity to manage the unbearable and untenable demands, must be activated. The fact that Public Healthcare facilities are still overcrowded, and service delivery is still poor, and it seems like facilities are under-resourced and over-stretched. This is evidence that healthcare is experiencing the proverbial operational dilemma of demand vs. capacity [16].

It is this dilemma in healthcare operation execution and the increased untenable and unbearable increase in demand for capacity responsiveness that is the fundamental reason and purpose for this research. The research attempts to establish how can the impact of COVID-19 on public healthcare provision be mitigated adequately? It is apparent, as indicated by Naidoo et al. [17], that very insignificant African COVID-19 research, by Africans has been produced to date, and that public healthcare is experiencing the proverbial operational dilemma, as postulated by Leite et al. [16]. Thinking along the same research line with numerous researchers and authors, this research attempts to establish a solution for this dilemma.

The solution is in support of the research conclusions and established postulates of published work in African COVID-19 research by numerous researchers and authors (e.g., Naidoo et al. [17]; Leite et al. [16]; Carvalho et al. [8]; Bohmer et al. [4]; Covadia et al. [7]; Fawcett et al. [10]; Stoop [22]); and many more). Applying a conceptual framework established from the work of these authors, this research identifies relevant research literature, key ideas, school of thoughts and debates in research about African COVID-19 and its impact on public healthcare. The main theories and how they are applied in current and previous research are studied. In this analysis, gaps in current knowledge are identified and the relevance of this research is confirmed.

To begin answering the research question this research defines the focus and boundaries of the research work done. The focus of the research is on addressing the three main core healthcare processes, and only in the South African healthcare context, and the research presents an integration approach as a panacea to the dearth of public health service delivery. Although the research context is South African, this research is supported by international agencies recommendations for strengthening healthcare demand capacity responsiveness, as postulated in CDC [5], WHO [24] & [25]. Thus, the research engages issues of demand capacity increase, as measured by healthcare resources availability during increased demand capacity, as recommended by William et al. [26].

African literature about African COVID-19 is spread very thin, with results from top ten (10) journals suggesting that African representation in African COVID-19 literature is insufficient [17]. It is apparent that an African voice and research is needed to guide an African response to the pandemic [18]. Relevant research literature on COVID-19 addressed various issues such as the disruptive nature of the pandemic, on the economy, the governments, health systems, etc. [20]. Thunstrom et al. [23] deliberated on the cost of flattening the curve for COVID-19 and Adams [1] focused on the cost of private healthcare insurance premiums during the pandemic.

Bohmer et al. [4] focused on Low-Resourced Settings (LRS), such as Africa and argued that the pandemic might result in increasing poverty and reducing access to the most needed healthcare. Evans and Over [9] predicted that the ramifications of the pandemic, in LRS, will be felt far beyond COVID-19. Analysis of relevant and current literature on COVID-19 in Africa is subject to the comments and recommendation postulated in literature, although, there are very few research guidelines specific to Africa. It is nevertheless evident that in South Africa COVID-19 has driven the healthcare system beyond the limit. Thus, the socio-economic implication of the virus is also a mutual concern for South African leadership and the leadership in the international community [16].

The consequences of a dual effect of the lack of research guidelines for COVID-19 in Africa and the disruptive effects of the pandemic, let South Africa to resort to implementing strategies that will aid in flattening the curve of infections [2]. These strategies include social distance and lockdown, which meant countries had to accept the cost of an economic pullback [20]. These strategies proved to be inadequate in preparing public healthcare for the untenable increasing demand for healthcare service and for protecting healthcare operations from the severe impact of the pandemic. Since there is no strategy in place to aid, public healthcare capacity had to deal with the unbearable demands [8].

Globally, research communities published recommendations on how to strengthen healthcare system responses [5]; [24], [25]. IN South Africa and the African diaspora there is a gap about strategies for mitigating the impact of the pandemic on public healthcare and an efficient utilization of healthcare capacity and resources. Therefore, this research is relevant and fits the requirements of South African healthcare context, with regards to how the impact of COVID-19 to public healthcare provision can be mitigated adequately. The research will add to the body of knowledge regarding the impact of the pandemic on South African and Africa's public healthcare.

3 RESEARCH METHOD

To achieve the aim and objectives of the research and satisfy the requirements of the primary research question and the hypothesis, a research paradigm is developed. This paradigm is used to explain the nature of the scientific truth, the theoretical framework, methodology and the data collection tools applied in the research. This will enable the researcher to explore the definition of reality of the research and deliberate on the following questions: what and how is the knowledge acquired. The procedure, tools and techniques used to acquire this knowledge, and the data collection process used is explained.

Thus, this research requires a methodology that takes a broader perspective than a single primary research study focused on a particular direction. The goal of the research is to explore and explain how the impact of COVID-19 to public healthcare provision can be mitigated adequately? The outcome of the research and analysis is the data collected through the application of a qualitative research method, tools, and data collection techniques. The data will serve as a validation of the propositions that led to the development of a conceptual framework of the study and therefore, rival and/or contesting hypothesis will be accepted or rejected.

This research adopts a qualitative case study research approach because it enables researchers to establish an understanding of the phenomenon from the perspective of those experiencing it [3]; [11]. The shared purpose of qualitative research studies, depicted by Baxter & Jack [3], increases the plausibility of adopting qualitative case study research methodology. After adopting a qualitative research approach for this study, numerous qualitative research methods are considered and analyzed (e.g., Phenomenology, Grounded Theory, etc.). Thus, this research is poised to focus on a qualitative research approach, using action research methodology (AR) and a case study approach.

AR is a qualitative research method adopted because it seeks to improve practice and is appropriate when the intention is to study and analyze the impact of the action taken [21]. Action research is a perfect fit for the research because when engaged, solutions are developed and applied to practical problems in a particular setting [21]. In this AR intervention, a case study method is applied. Case study method applies the science of singular, which aims to understand what is distinctive of a particular case, defined as a complex functioning system [13]; [15]. Qualitative case study method enables researchers an opportunity to explore and explain a case within its context using a variety of data sources [6]; [15].

The hallmark of this case study is the use of multiple data sources [27]and [19], which is a strategy that enhances data credibility [19] and [27]. This case study will employ the following triangulation of data sources: i) document analysis and archival records analysis; ii) Journal publications and field notes analyses; iii) patient journey process observation and analysis through, Selection, Recording, Examination, Development, Implementation, Maintain and Monitor (SREDIMM) technique. A combination of data sources and data collection methods in a study of a single phenomenon enables researchers to draw upon multiple sources of evidence [12] and therefore, enables them to seek convergence and corroboration. Using different data sources data credibility is achieved [19] and [27] and the culmination of a triangulated data capturing method is a holistic picture of the case under study.

A qualitative case study is argumentative by nature and therefore, there is a fair amount of competing hypothesis and evidence that is to be disconfirmed. Thus, the research follows the theoretical propositions leading to the original objectives, the design of the case, the research question, and the literature reviews, to define and assess rival explanations and theories. The proposition that the integration of the three-core process will result in a management paradigm that can optimize care service delivery, is assessed and rival and contesting hypothesis are analyzed. Validation of the propositions that lead to the development of the conceptual framework of the study is engaged and then, the rival and contesting hypothesis is nullified or accepted.

In this qualitative action research case study, data is collected through a triangulation of qualitative research data collection tools. The tools employed begin with the analysis of archival records and document. The aim of this data collection techniques is to uncover various perspectives of role players in this research niche and incorporate these ideas in the solution proposal. The second techniques applied is an analysis of field notes of other researchers and an extensive review of journal publications, data collected with this second techniques clarify the progress of work done in this area of research and provides the latest information that forms the body of knowledge.

The last technique applied is the observation and analysis of the patient journey process using the SREDIMM method. To apply this technique, the research must be inducted in the healthcare processes in a hospital or center of service delivery. The induction enables the research to select the correct healthcare process to study for the purpose of delivering a solution required to remedy the problem. SREDIMM is an acronym for Select, Record, Examine, Design & Develop, Implement, Monitor and Maintain. The research data collection method followed when SREDIMM is applied is as follows:

1) First, a patient journey process is selected as a unit for case study research,
2) Second, the current “As Is” process is recorded and a process analysis of the current patient journey process activities is established,
3) Third, the current “As Is” patient journey process is examined through the application of time and method improvement techniques,
4) Fourth, a future-state patient journey process is developed through the application of the TOC thinking process and an improved process developed,
5) Fifth, an efficient and improved future-state patient journey process is established and implemented,
6) Sixth, a new patient journey process is monitored and managed to maximize the efficiency of the healthcare service delivered.
7) Seventh, Efficiency of the new and improved patient journey is maintained through continuous improvement initiatives.

4 RESULTS

Analysis of the current ‘as is’ patient journey reveals three core processes in the healthcare service delivery system. The core processes established are patient data capturing throughout the patient journey, this process is paper based and manual. Patient data capturing throughout the patient admin process, from entrance admin through to pharmacy’s medicine dispensary. The orientation of the patient journey is based on a push service delivery system principle. This means patients are pushed through the system without assessing the system capability to accommodate the volumes pushed through. System’s capability, i.e., KPAs and KPIs is not documented. This patient service delivery process is characteristic of a patient journey that is not data driven. Thus, there are no execution efficiency plans.

The current patient journey process is characterized by a high percentage of transport activity, high storage activities and a low percentage of operation activities. This is indicative of the long waiting lines at every service point in the service delivery system. The current reality of the system is captured as it is observed. This is evidence that the “as is” exemplifies the most feasible chain if cause and effect in a given rigid, fixed, and complex environment. The current reality of the “as is” patient journey is that the there are no process controls and process measurements are poor or in certain cases non-existent. The current process is a typical push system service process and thus, there are no efficiency plans.

Current reality of the patient journey enables a deeper understanding of the patient journey and enables the identification of undesirable effects in the system. The fact the patient journey is a push system process, that there are no efficiency improvement plans, such as demand plans, capacity plans and throughput plans. It is a clear indication of the source of undesirable effects such as bottlenecks and system constraints. The results of the application of the TOC thinking method and the process analysis techniques are to establish the simplest change required to improve and optimize the patient journey process and systems. In this case it is identified that the configuration of patient journey generates undesirable effects that constraint the efficiency of the system.

The three healthcare core service processes are also enablers of the healthcare service delivery in that they form the building blocks of the patient journey through which the healthcare service-delivery process is executed. Healthcare service delivery in a healthcare facility depends on the 1) Execution of the patient journey, 2) the capturing of patient data, and 3) directing patience through a healthcare system. The execution results of these three processes enable medical staff to encounter patients and to administer medicine to their patients. Through the execution of the service process some patients go through to pharmacy and then-after leaving the system. Some patients go to the wards for a longer stay in the healthcare system.

Analysis of the current reality of the care service delivery, presents numerous measurement that are specific to medical service processes delivery, such as a measurement of patient length of stay (LOS), patients leaving the system without being seen (LWBS), Patience dying before being seen (DWBS) and the measurement of serious adverse event (SAE). These measurements, like many other measurements in the healthcare system have very insignificant impact on the efficiency with which healthcare service delivery is executed. Thus, in the analysis of undesirable events cause by the configuration of the health care service execution, there is an apparent absence of demand management plan, capacity planning, replacement of a push system with a pull system, Data driven processes and management decision making.

5 DISCUSSION

The advent of COVID-19 revealed that a continuous increase of patients' numbers in the system creates an operational bottleneck [16]. Applying classic terms of factory physics, as stipulated by Hopp et al. [14], when healthcare facility capacity utilization and service demand is high. There will be a manifestation of long queues of patients in the system, who are waiting to receive healthcare service, e.g., Treatment. Public healthcare capacity utilization, in this case, is defined as the ability to deal with a considerable influx of patients. It is measured by the availability of healthcare facility resources, such as beds, medical staff, medical equipment, ICU facilities, etc. [16]. Thus, with the advent of COVID-19, long queues are evidence that there are bottlenecks in this system.

The manifestation of an operational bottleneck in a healthcare facility, due to an exponential increase of the influx of patients, can be scientifically proven, using factory physics and queuing theory. What needs to be established is why queues manifest when there is a continuous influx of patient in a system and what is the root cause of operational system's bottlenecks in the healthcare system. The context prevailing in the South African Healthcare facility setting is characterized by the execution of three core processes that enables operationalization of service delivery. The disposition of the core processes is the source of high inefficiency and the concomitant repercussions, e.g., Bottlenecks, overcrowding and poor service delivery.

Currently, in most public hospitals, the patient journey is a distinctive 'Push System' process, in which patient's volumes are pushed through a customer service process. Execution of the process is done without measuring the system capability using demand plans and capacity plans. Thus, when there is high influx of patients in the healthcare facility, such as a hospital, the resultant is long queues because of bottlenecks manifesting at various service points in the patient journey. A bottleneck in the patient journey is a visible cause of long queues and long queues result in overcrowding and consequently poor service delivery. The underlying cause of the bottleneck and the resultant poor service is systematic and central to the design structure of the patient journey.

The absence of demand plans and capacity plans that are critical for executing the patient journey are indicative of a push system characteristic of the patient journey. Thus, when volumes of patients are pushed through a patient journey system, the resultant is a bottleneck. Bottlenecks manifest as overcrowding and consequently a poor healthcare service delivery. The lack of execution plans, critical for operationalizing the patient journey is an indication of the absence of data management strategies and an apparent indication that patient journey is not data driven. Not surprising that the patient journey is not controlled or measured through demand and capacity plans.

The dilemma of operations supply vs demand in a patient journey process is, therefore, apparent. This is a confirmation of systematic process design inefficiencies that leads to untenable and unbearable effects of the impact of COVID-19 on South African healthcare. To answer the question, how can the impact of COVID-19 to public healthcare provision be mitigated adequately, requires an integration approach to the execution of the core patient journey processes. Documented research on managing supply and demand, including capacity management in healthcare operations, suggests addressing arrival rate variability at patient end and minimizing process variability issues within the healthcare service execution system.

Although this research supports the approach, it is discovered in the analysis of patient journey that there is a conundrum that needs to be addressed before embarking on applying control charts and process variability techniques, to increase efficiency. The conundrum emanates from attributes of the 'as is' patient journey, these are the following: The lack of process digitization, especially the patient journey; healthcare processes are not data driven; patient journey is a 'push system' and not a 'pull system' process; and Healthcare service-delivery centers and facilities, e.g., Hospitals, lack the discipline of getting things done. The influx of patients due to the pandemic is just a compounding effect to already existing challenges, such as bottlenecks and overcrowding.

Therefore, to mitigate the impact of COVID-19 on healthcare provision, the conundrum must be addressed adequately. This research postulates that the conundrum must be addressed through an integration approach because an individualized solution approach of each attribute of the conundrum has been seen to fail to achieve the desired efficiency. In fact, solutions to all attributes of the conundrum are implemented in various hospitals and institutions of healthcare service delivery. But, because of this peace-meal approach to implementing solutions to one attribute of the conundrum, there is no effective efficiency derived from the implementation of solutions to the attributes of the conundrum.

An integration approach implies implementing solutions to all three attributes of the conundrum, that is, improving the efficiency with which the core healthcare service delivery processes are executed. To improve the efficiency of execution of the healthcare service process, the patient journey must be digitized. The patient journey must be data driven and patient journey must be transformed from a push service process system, into a pull system. Integration means bringing together components into a single system that functions as one. Therefore, after introducing digitization, and when the system is converted into a data driven system and it is transformed into a pull system, integration of these components must be embedded into the healthcare service process.

Currently, many healthcare facilities, under study, employ paper-based healthcare service systems and processes. The paper-based filling system is used throughout the patient journey, for capturing patient data, referring patients to the doctors and clinics and for dispensing medicine in the pharmacy. The paper-based system is a source of a bottleneck, which leads to inefficiencies in executing activities in the patient journey, and consequently delivering a mediocre healthcare service. Paper systems have a lot of problems, which range from duplicating files, losing files, hindering synthesis of information and poor information storage. One of the worst problems in hospitals is that medical staff is unable establish a pattern from scattered information in the paper files.

When the patient journey is digitized, filing is electronic, duplication is eliminated, and information synthesis is facilitated and supported. Digitization ranges from simple low-level status, i.e., data Collection, in which data is converted from paper files to electronic files. Up to advance levels where there is document and data intelligence, i.e., data Analytics. At any level of digitization of the patient journey, there is a data management structure established, access to patient files is optimized, automatic processing is possible, and process intelligence is facilitated. Digitization enables a value stream identification and mapping, which can lead to process map optimization. Digitization enables data structures formation, which is critical for establishing KPIs such as demand plans and capacity plans.

KPIs are the building blocks of a data driven process, in a healthcare setting. Capturing data electronically, when patients enter the system at the admin section, enables management to measure the capacity of the process and the capacity of the facility. Capacity plans enable management planning in which a hospital can establish the amount of work that can be completed given the total amount of resources available and upcoming time constraints. This simply means the number of patients a hospital can process based on the resources, i.e., medical staff, ICU rooms, medical equipment, and the time available. Data driven process systems enable an improved patient journey and facilitate a reduction of activity cycle time, process optimization and productivity improvement.

Once the patient journey is digitized and it is data driven, the process can be transformed from a push system process into a pull system process. While a push system controls information in the direction of a patient, in a pull system each activity makes an order request of information from a preceding activity. This means when patients enter the system, data captured creates an order for capacity in the succeeding activity and the succeeding activity reacts to the demand of the preceding activity. Therefore, demand plans and capacity available regulates execution of the patient journey. When a patient journey process execution is characteristic of a pull system, bottlenecks and constraints are eliminated. Therefore, a digitized, data driven, pull system patient journey is elastic to patient demand.

The solution proposed in this research report postulates that, to mitigate the impact of the pandemic to healthcare provision in a South African context, the healthcare delivery process, e.g., patient journey, must be transformed, garnished, and developed into an elastic process. When the patient journey is made elastic, the responsiveness of the process to service demand and an increased influx of patients, is optimized. That means the process, e.g., patient journey can increase the capacity of the system to manage influx of patients and a concomitant increase in demand, by using data driven demand plans and capacity plans. Therefore, the system is enabled to predict the responsiveness required by the quantity demanded or quantity supplied of patients and resources, respectively.

Although, the research pertains to a South African healthcare context, the major findings of the study, that of transforming healthcare service processes through digitization, data driven systems and from a push to a pull system, can be replicated is all process driven operations. When the solution to components of the conundrum is applied to make systems and processes elastic, the impact of COVID-19 to healthcare provision, is mitigated. Mitigation of the impact manifest when the three core processes of healthcare provision are optimized through digitization, and through implementing data driven systems and transforming care delivery systems from a push system into a pull system. This transformation of service processes in healthcare provision enables a patient journey to achieve elasticity.

6 CONCLUSION AND RECOMMENDATIONS

Findings of this research, respond to how to mitigate the impact of the pandemic on South African healthcare. Combining these findings with current and relevant literature, schools of thought and key researcher's propositions, in the field, proves to add value to the current body of knowledge. Ideas and schools of thought relative to the gap in African literature resonate with an African solution to the impact of COVID-19 in a South African context. Propositions by researchers such as Leite Higor, Lindsay Claire and Kumar Maneesh's 2020, support the declaration that the impact of COVID-19 induces the proverbial operations dilemma of demand vs capacity. This research finding, supports assertions by authors such as Naidoo AV, Hodkinson P, King LL, and Wallis LA, that Africa must find an African voice in

COVID-19 research and develop African research guidelines on how to address the impact of the pandemic in an African context.

Therefore, the propositions of this research, that to mitigate the impact of COVID-19 on healthcare provision requires healthcare service provision processes and system be transformed and made elastic, through digitization, data driven strategies and altering service systems from a push into a pull system processes. To achieve this proposition, the research findings propose that an integration approach must be adopted in the implementation of solutions to the conundrum manifesting. This conundrum is found by this research to emanate from attributes of the 'as is' patient journey studies and analysis, and that the proposed solution to the attributes of the conundrum, will enable healthcare service-delivery centers and facilities, e.g., Hospitals, to attain the discipline of getting things done, i.e., execution.

The combination of findings of the research and the literature review, leads to a conclusion that the contribution of this research to the body of knowledge is the establishment of a systematic approach to mitigating the impact of the pandemic on South African healthcare provision. Due to limitations of the research that emanate from the vast and eclectic nature of the research, and the dynamic disposition of the research field, authors in this niche recommend that areas of further research, to ascertain that the desired levels of healthcare optimization and elasticity are attained, must include knowledge development in the following research topics.

- Levels of digitization and the appropriate implementation protocols for healthcare
- How to transform process systems from push to pull systems and execute
- Development and implementation of data driven process and systems

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CULTIVATING AMBIDEXTERITY IN INDUSTRIAL ENGINEERING TECHNOLOGY EDUCATION

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ABSTRACT

The mission of engineering technology education is to produce technologist to work with current technology. Therefore, engineering curricula must be a combination of applied engineering theory and a hands-on instruction. Courses on mechanical drawing and design of engineering equipment must be core in the instruction of engineering technologist. Engineering design is linear and morphological process that requires a hands-on approach in instruction. It is mission critical for engineering technology instruction to emphasize more on synthesis as opposed to analysis, that is, course content must include design thinking related courses rather than scientific analysis and mathematical modelling. This research paper presents a comprehensive example that illustrates one of the methods used to study AI in Industrial Engineering tuition. The research employs the use of Lego designs, machines learning concepts and programming languages such C++ and Python. The result is engineering graduates acquire a capability in engineering equipment production, automation, and innovation.

Keywords: Engineering, Education, Ambidexterity, programming; Technology

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1 INTRODUCTION

Transformations in the educational process promoted by higher education institutions (HEI) has two outstanding features, privatization, and institutional fragmentation. Over the years, the high market demand for qualified engineering skills and government incentives on high education industry led to the participation of new social actors, market players and institutional investors in the industry. By considering the two mentioned aspects, several questions were raised. Among those, some refers strictly to the faculty performance [24] and graduate attributes of new engineering professionals.

As a case study, this paper reports an innovative action that is being implemented in an undergraduate first year industrial engineering course offered in an Online Distance electronic Learning (ODeL) institution. This initiative seeks to improve the Human dimension of Intellectual Capital by developing an enabling a context of knowledge sharing environment, through ambidextrous learning. Both brain hemispheres are engaged based on the exploitation-exploration model innovation practices. These practices state that it could be better to be prepared to explore conjointly new possibilities (exploration) than just only to exploit old certainties (exploitation).

Regarding the higher education context, lecturers are core knowledge workers, and they are tasked to develop new ideas and processes, by identifying, capturing, distributing, sharing, and encouraging knowledge development. Therefore, this implies adopting practices consistent with individual and organizational knowledge creation and learning processes [13]. However, the inconsistencies, polarities, dichotomies, and oppositions related to knowledge creation should not be considered improper, since they are formed by two complementary components: the tacit and the explicit knowledge [16]. Sveiby [26], highlights that the practical knowledge is largely tacit, that makes the process of discussing knowledge even more complex.

In short, it can be said that tacit knowledge is internalized by the individual in a unique and personal way; therefore, it is not very easily articulated. It results from individual configurations done through data provided by the environment the individual is inserted in, thus it is almost impossible for two or more people to develop the same knowledge when they receive the same information [21]. That is why such issue should be carefully treated when discussing the learning processes, hence the focus of this study. Nonaka & Takeuchi [14], believe that the explicit or codified knowledge which refers to the knowledge transmitted through systematic and formal language, only exists in, lies on and is created by individuals. Explicit knowledge may be embedded, but its construction takes place when an individual interacts within a certain community.

Thus, the explicit knowledge can be expressed in words, numbers or even sounds that are often shared as data, manuals, audio-visual, and scientific formulas. In this sense, developing knowledge means expanding artifacts created by a group of individuals within organizations. This is what Von Krogh et al. [27] call enabling context. According to their view, academic perspective, is the enabling context and is composed of cooperative style, of networking activities, of team building and of the support given to learning schemes such as mentoring and coaching (learning relationship that takes place when a more experienced professional takes the mentor/coach position and shares knowledge with the fresh player).

These features promote an environment where ideas are naturally created, since knowledge is related to human actions and, its development process depends on the participants and the action they take [27]. The complexity of the knowledge transmission process that contemplates the learning process, its requirements and facilitators form an enabling context for ambidexterity. This requires the use of Intellectual Capital (IC) taxonomy in three dimensions [18]. Since it is one of the most accepted bases for studying the intangible assets and their impact on the value creation.

According to Faste [6], the meaning of ambidextrous thinking encompasses possibilities inherent to the proficient use of both hands in performing an activity. By extension, the use of the whole body and even the mind leading to wider possibilities linked to synesthesia as a way of learning. This means, resorting not only to the symbolic level but to the sensory level that is inherent to recognizing the importance of the brain hemispheres and modes as basis for decision making [8]. The judgement and decision-making process represents the essence and the excellence of the role played by the synesthesia in the Neuro-economics [8].

Didactic pedagogy and conceptual distance between lecturers and students focused on this practice and practices focused on the theory creates pedagogical noise regarding the practice of an academic unit of an undergraduate engineering course. As for an equivalent point of view, Bartunek [2] discusses the need for pracademics in teaching and in the final delivered product from a university of technology [14]. This transformational paradigm would be achieved by developing an ambidextrous mental model, able to mediate and bring together logics and boundaries that delimitate the academic and the corporate worlds, which are, at first, exclusionary [18].

Scientific rationality and instrumental rationality would need to be reviewed and realigned to get better results in the professional education of engineering technologists (from simple training courses to post-doctoral activities, specifically passing by baccalaureate) and allow generating and improving theories that fit into practitioners' daily needs. The inability to deal with the increasing gaps between knowledge produced in universities of technology and that needed, have the industry blocking the research agenda with discussions on relevance and rigor, when, in fact, it should focus on debating relevance and applicability [15].

The application of ambidextrous learning and its impact on the pedagogical proposals for generation Y, which takes photos of objects and people, calculates values, schedules numbers, names, and appointments, captures music from the Internet, records voice, video, and text files, creates different identities, moderates online communities, participates in several social networks simultaneously, is complex [19]. It is a complex and critical area of research for ODeL institutions engaged in engineering education. Ambidextrous thinking concepts applied to education may go beyond the application of didactic and pedagogical practices in the operational context. It must strategically reach the way and the process from which new projects are developed within the education sector.

An ambidextrous perspective would allow escaping the teaching and learning (T&L) traditional logic of industry positioning and operational efficiency planning by providing the institution with good conditions to innovate through exploration and exploitation, alternately. Education institutions would find in the ambidextrous thinking a settlement between managers and educators, and an effective tool to survive in times of great transformations in students' profile by communicating with them and with the prospects through guidance based on engineering education authorities such Engineering Council of South Africa (ECSA). More so this, forecasting the opportunities will come from the internet of things (IOT) and the fourth industrial revolution (4IR).

2 LITERATURE REVIEW

According to Yamaoka et al [29], ambidexterity would result from an integrated set of procedures related to the knowledge management, innovation, learning and competencies that would compose the taxonomy of contents needed to develop the strategies and operations within an organization. Whether they are settled and/or under construction, in use or stored, under the control of the entity or not. As highlighted by Kurtz and Varvakis [12], the experience of mentality and dynamics based on organizational ambidexterity would enable creating richness in contexts of turbulence and technological breakthroughs.

Since it would enable strategic reorientations in the short term with long-term effects. Therefore, this would be an extremely useful capability which should be studied in depth and learned as a topic in management studies. Kang and Snell [9], developed two Intellectual Capital and ambidextrous learning conceptual constructs that formed the basis for the current investigation; they take under consideration the Intellectual Capital dimensions as Human, Social (Relationship) and Organizational (Structural), as suggested by Stewart [22], and establish classifications based on previous studies.

Thus, they objectively identify the features found in the exploitation and exploration models and then merge the proposals [9]. On the other hand, exploitation means reuse, i.e., the intensive adoption of the knowledge already obtained and detained. Thus, in this case, the preferred professional group is the specialist, who knows a specific subject in a deep way. Furthermore, it is believed that corporativism will allow sharing the specialists' knowledge to do similar things. However, it requires more control from each part of the processes and that is why the mechanistic system is mentioned as its representative [22].

The concept of ambidexterity is perceived as novel and progressive, because of is its versatility. The original meaning of ambidexterity was an individual's capacity to be equally skillful with both hands. This has been adapted to mean an organization's capacity to do two different things equally well (Gulati [7]). But of course, organizations are attempting to address many types of dualities (Gulati [7]), such as efficiency and flexibility, adaptability and alignment, integration and responsiveness, and exploration and exploitation. The roots of ambidexterity, as an organizational concept, are well documented.

O'Reill et al. [17]. first coined the term ambidextrous organization in a book chapter as a way of describing the "dual structures" many companies put in place to manage activities that involve different time horizons and managerial capabilities. Twenty years later, Mike Tushman and Charles O'Reilly et al. [17], picked up on the concept in a California Management Review article and a related book, with a focus on understanding how companies could manage both evolutionary and revolutionary change processes. Their approach, like O'Reill et al. [17], emphasized structural separation between the two different types of activities and Christensen [4], labeled it disruptive technologies.

Meanwhile, a stream of research had begun to emerge building on March's 1991 paper, Exploration and Exploitation in individual and Organizational Learning [28]. This paper is a natural extension of many of March's earlier notions of bounded rationality, problem-based research. It argued that there are fundamental incompatibilities between exploration and exploitation modes of learning with ambidexterity approach. As scholars started to mull over the notion of ambidexterity, March's [14] theoretical ideas proved to be a useful anchor. But it was, Marshall Schminke who had the bright idea to describe the phenomenon as contextual ambidexterity, as distinct from the more structure-oriented approach to ambidexterity that Tushman and O'Reilly [22] had described.

Suddenly, ambidexterity was not just a structural construct, it was about the multitude of ways that learners sought to manage the tensions involved in doing two different things at the same time. While not everyone agreed with the notion of contextual ambidexterity, the publication of Birkinshaw et al. [3], helped to broaden the appeal of ambidexterity as a research topic, and March [14] provided the necessary theoretical gravitas for the concept to be taken seriously. A further proliferation of papers exploring additional aspects of ambidexterity and, in addition, several attempts to pursue convergent, rather than divergent, agendas. This included several special issues or themed sections in journals.

Ambidexterity is an academic construct. A discussion of the underlying meaning of ambidexterity must begin from theory. Therefore, ambidexterity research has an opportunity to show that it offers insights that could not be established from one of other similar perspectives, e.g., punctuated equilibrium [3]. To summarize the argument so far, ambidexterity is an organization's capacity to address two multiskilling labor and leadership in organizationally incompatible objectives equally well. Ambidexterity is an important and alluring concept, but the way it is defined makes it overlay flexibility. It can be used to study labor and organizational research, and the tension of multiskilling and attending to two divergent strategic issues.

Note that the standards set for technology education are used by governing bodies such as ECSA to improve the quality of graduates that come from institutions of technology. Therefore, the value of applying ambidexterity in teaching and learning is measured against the resultant effect of applying ambidexterity and is measured against the graduate attributes and the exit level outcomes set by governing bodies. The intrinsic value developed by applying ambidexterity in educating technicians and technologist is that it enables graduates to meet the graduate attributes espoused by ECSA. And more critical, producing engineering graduates with a capability in engineering equipment production, automation, and innovation. These graduates will understand the impact of 4IR on the economy and the drastic changes in industry that the fourth industrial revolution is putting on our doorstep.

The aim of the research is to improve students' Human dimension of Intellectual Capital by developing an enabling context of knowledge sharing environment, through ambidextrous learning. The exploitation-exploration model of innovation practices is applied in the teaching and learning program that engages both brain hemispheres. Furthermore, the research enables faculty to prepare students for new possibilities in industry, rather than just to exploit old certainties. This implies an establishment of a teaching program that conjointly engages exploitation and exploration methods is established and applied, through an innovation action using ambidexterity in engineering technology education. This research project aims to satisfy the requirements for engineering instructors to develop innovative ideas and processes by encouraging new knowledge development.

The research is presented as follows heading III is the research method. The research method applied allows the researcher to explore the phenomenon in its context, so that both contextual ambidexterity and structural ambidexterity is engaged. Heading IV is a teaching and learning experiment, applying ambidexterity. The thrust of heading IV is the use of ambidexterity to train technicians and technologist so that the result is they acquire two distinguishable skills from one program. Heading V is a discussion of the resultant effect and heading VI is the conclusion. The conclusion will clarify the debate whether ambidexterity delivers the results that improve the graduate attributes of technicians and technologists.

3 RESEARCH METHOD

Qualitative case study methodology affords researchers opportunities to explore and explain a phenomenon within its context using a variety of data sources [1]. This approach ensures that the phenomenon under study is explored through a variety of lenses that allows an in-depth understanding and allows multi facets of the case under study to be revealed and understood [1]. The case study approach aligns to the goals of this research in that the focus of the study is to explore and explain with the aid of a comprehensive example that illustrates whether and how one of the methods used to study AI in Industrial Engineering tuition impacts, aligns, and integrate theory and practice systematically. This type of research approach covers the contextual conditions in which the phenomenon under study occurs [23].

The unit of analyses in this study is the impact of Ambidexterity integration, through vertical and horizontal activity integration, into engineering education. The attributes of this research satisfy the definition of a case as stipulated by Patton [20], and they are in line with Yin [30] and Stake [23] stipulations concerning setting boundaries for cases in a case study research approach [1]. The research also appeals to boundaries stipulated by Creswell, those of time and place [1]. In line with the boundaries of the definition and context, and the research question (What is the impact of ambidexterity on training technologists?), the type of case study research adopted, aligns with explanatory and exploratory or descriptive case study as categorized by Yin [1].

Yin [30] and Patton [20] stipulate that a hallmark for case study research is the use of multiple data sources. A strategy that enhances data credibility [1]. This case study will apply a triangulation of the following data sources i) document analysis and archival records and ii) field notes and journals; and iii) observation and assessment of technologists in training. It is rational to apply document analysis in this research since it is often used in combination with other qualitative research methods as a means of triangulation. The combination of data collection methods in the study of one phenomenon enables researchers to draw upon multiple sources of evidence and, to seek convergence and corroboration with different data sources [1].

This approach ensures improved data and decision credibility and eliminates researcher bias in recommendations and conclusion. Based on the theoretical framework established by various authors indicated above, the research adopted a qualitative case study approach in which a desktop research approach is engaged. The research applies data collection and analysis method of i) document analysis and archival records, to establish literature reviews and the status in the teaching and learning in technology education. Then, ii) field notes of previous researchers are examined to capture the reality and the essence of teaching and learning in the Distance Education institutions and technology teaching and learning in action.

This method is applied to ensure understanding of the context in which teaching and learning activities take place, to enable superior activity integration in the technology-based teaching and learning design. The last data collection method is iii) the observation of technologists teaching and learning training and assessment process. This method is applied to collect data required in the design of the technology teaching and learning system, and to identify all the required process steps in the application of ambidexterity in the teaching and learning processes. The data collection tools will enable the research to be approached in three ways and therefore the resultant is an improvement in data integrity.

The decision to gather and analyze archival records is linked to the research propositions developed in the conceptual framework of this study. The use of archival data is supported by the claim that archival data is an increasingly viable resource because of an ever-greater amount of archival verbal and visual material that has become universally available with the information proliferation attributes of the internet. Archival data comprises of wide array of empirical data created by researchers for their personal use or on behalf of an organization. Contents of an archive that is applicable in this research consist of various material. Archival data will be used to develop an understanding of the research context and where applicable to inform the development of concepts and theories.

The rational to apply field notes is supported by Patton [20] reflections that field notes are applied in qualitative research to understand the true perspective of the subject being studied and that they allow the researcher to access the subject and records of what they observe in an unobtrusive and nonreactive manner. Patton [20] stipulates that field notes are rich, detailed descriptions, including the context within which the observations were made, and they consist of activities, behaviors, actions, conversations, interpersonal interactions, organizational or community processes, or any other aspect of documented human experience in the field. This research requires an in-depth understanding of researcher’s experiences.

Observation of technologists when teaching, learning, training, and assessment process are executed is an enabler for the development and establishment of the assessment results that are used to measure whether the aims and objective of the study have been achieved. That is a measurement of whether the infusion of ambidexterity in engineering technology education has improve students’ Human dimension of Intellectual Capital, and to prove whether the exploitation-exploration model of innovation practices applied in the teaching and learning program enabled the engagement both brain hemispheres. This is a measurement of the impact of a teaching program that conjointly engages exploitation and exploration methods, through an innovation action using ambidexterity in engineering technology education.

4 TEACHING AND LEARNING EXPERIMENT: APPLYING AMBIDEXTERITY

In an endeavor to ensure that technology instruction emphasizes more on synthesis as opposed to analysis, that is, course content includes design thinking related courses rather than scientific analysis and mathematical modelling. The curriculum employs a comprehensive project base tuition that institutes ambidexterity in Industrial Engineering instruction. The curriculum employs the use of Lego designs, machines learning concepts and programming languages such C++ and Python. The teaching and learning program are divided into three (3) subsets, that is, theory related to manufacturing and automation; engineering programing languages; and design for manufacturing and assembly. In design manufacturing and assembly, students use engineering drawing and sketching and Lego design building.

In manufacturing and automation theory, students are introduced to technical feasibility. Then, developing and deploying both hardware and software and then, the supply and demand dynamics of automation. The last part is instructing students engineering programming languages such as Python and C++. The last part of the program is the design for manufacturing and assembly hands- on program. The final part of the program requires students to build a functioning machine/equipment for their final assessment project. During the program students design and build robotic parts of equipment of their choice. The final project requires students to integrate and apply all the theory and practice they have experience.

Students are trained in automation technology to acquire skills to apply Enterprise Resources Planning (ERP) and engaged in Game based learning and simulation activities. The aim is to prepare student for real life programs such as the fresh connection (TFC), Work skills Global Challenge, etc. These programs are used to advance students cooperative and work-integrated skills. In the programs mention student learn about real-life work challenges that need solutions. In the TFC student work in Groups of five (5) to solve a supply chain business problem and to make the business profitable. The simulation projects enable student to experience working in groups and solving business challenges. In the Work skills global challenge, students are given a challenge by a corporate blue-chip organization, and they work in groups 5 to 10 from all over the world. Students experience dynamics of consulting work and intercultural environment dynamics.

The teaching and learning program

Figure.1: Automation technology application in a Digital Game based learning

In automation and manufacturing students learn about technical feasibility. The main aspects of the teaching and learning process is based on the 5WH of automation. That is, What, When Why, Where, Who and How. Students learn smart technology systems such as thermostat automation for controlling a boiler, automatic smart control systems such temperature control of a household fridge. Application of mechanical, hydraulic, electrical, electronic devices and computers.

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BEGIN
  LED
    Port: A
    State: On For Duration
    Delay (s): 0
    Duration (s): 10
    AFTER PREVIOUS
  LED
    Port: 3
    State: On For Duration
    Delay (s): 0
    Duration (s): 10
    WITH PREVIOUS
  LED
    Port: B
    State: On For Duration
    Delay (s): 0
    Duration (s): 5
    AFTER PREVIOUS
  LED
    Port: 3
    State: On For Duration
    Delay (s): 0
    Duration (s): 5
    WITH PREVIOUS
  LED
    Port: C
    State: On For Duration
    Delay (s): 0
    Duration (s): 10
    AFTER PREVIOUS
  LED
    Port: 4
    State: On For Duration
    Delay (s): 0
    Duration (s): 10
    WITH PREVIOUS
END
```

Figure.2: Computer Workstation for engineering programming languages

Python language is popular because of its simplicity and major applications in the real world. Robotics, web scanning, artificial intelligence, machine learning and software development are the key application areas of python language. C/C++ are the ancestors of these languages like python and JAVA, however they both still finds applications in industries because of their salient features. For expertise in software development or web app development Java is good and MATLAB is more specialized and specific language for mathematical and numerical analysis only. Students learn and apply a programming language in their projects.

When manipulating the robot kits, you can train your student's ability to design, build, and program equipment. Students cultivate and establish new method to build and program robots to perform various tasks. Besides basic programming ability, they also get components assembling skills. Assembling a robot helps to set up that patience and resilience. This attribute established in the robot assembly section, will help students to develop life skills, needed for success in a workplace. Thus, for 4IR programs the use and development of technology is very essential for engineering technology students. That is the reason why so many universities teach programming in engineering. Seemingly, there's nothing quite like the thrill of watching a physical machine act out your commands in the real world.

Figure.3: Box of Lego-Robot pieces for building robot structures.

In the design manufacturing and assembly (DFMA), students use engineering drawing, sketching and Lego design building components to apply theory learned. A big advantage of using a physical model that is really going to be program is that there is a much stronger focus on the modelling process. The students build their own LEGO robots, make programs for the robots using machine learning concept and languages, and operate them. By creating these LEGO robots, the students become more motivated, learning the basic concepts of embedded systems and how these concepts can be applied to real world problems.

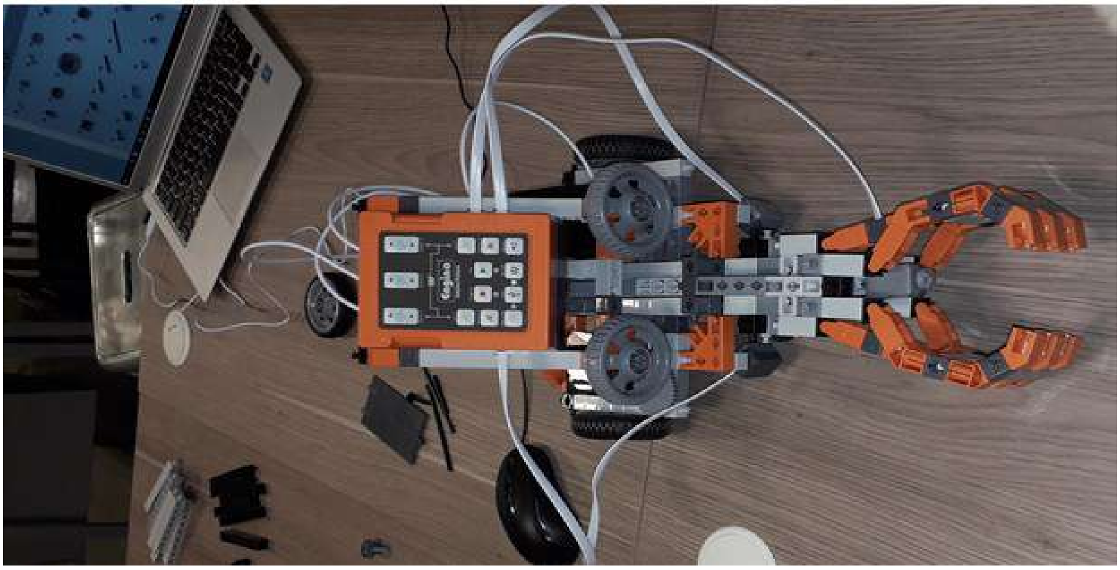

Figure.4: Final Project model

Students are expected to design a unique system for each project, but for the same robot competition project, most robots had a very similar shape. Creativity was difficult to evaluate, and along with other evaluation aspects which were not clear. Various suggestions for grading are made by students for the course when future research is continued. A course designed to teach embedded systems using LEGO Mind storms is applied.

The students in this course designed their own embedded systems using LEGO Mind storms. Lego based engineering curriculum is an efficient system to teach the students about embedded systems, automation, and robotics [10]. Through this course, students learn and acquired ambidexterity skills and improve their programming skills. Although the workload of this course was quite heavy, students enjoyed this course greatly, and this is observed in the student retention percentages and the active participation students throughout the course.

Figure.5: Final year projects motorized by linking models to computer language programs

5 DISCUSSION

The desire to embed ambidexterity in industrial engineering tuition let to an inclusion of explicit design instruction in undergraduate industrial engineering curricula programs along with the use of design exercises within the technological subjects. The use of a generic engineering technology like Lego allows a usage across a wide range of engineering disciplines [9], but, more importantly, it allows for the introduction of design skills in technology and engineering programs, which has the following advantages:

- Engenders the creative spirit at an early stage.
- Demonstrates the essence of engineering to first year students, which may not become obvious through the normal range of technological subjects for some time.
- It is an enjoyable practical experience, which can assist with student retention percentages.
- Provides a meaningful group exercise, with all the characteristics of a professional engineering project (teamwork, communication, etc.), which can help to bond the class body and integrate disparate student groups.

On a wider scale, bodies which accredit undergraduate engineering programs (e.g., ECSA), have and continue to play, a role in how engineering academics incorporate design in their syllabuses. Ambidexterity offers sufficient flexibility to implement an enormous range of designs for a variety of engineering problem solving domains (Knudsen [10]). It is highly visual and intuitive since it is based on a learning toy which many students will already have some familiarity with. While the ability to incorporate AI through programming software is both attractive and characteristic of most modern engineering applications [11].

6 CONCLUSION

Teaching introductory programming skills and embedded systems design to undergraduate engineering students in a variety of disciplines requires delivering the teaching content according to their learning styles [5]. This paper describes how the LEGO robots' programs were introduced as hands-on educational technology (ambidexterity) to computers, systems, and engineering curricula. These programs are assessed to provides student feedback measurements on the effectiveness of using the LEGO robots for teaching and learning in engineering education.

Students tend to learn information they are being taught when it is delivered in a way that they are at ease with. Active and sensational learners, as opposed to reflective and intuitive learners, respond favorably to learning while doing something that requires their hands and eyes [5]. Students responded very favorably to using LEGO robots to learn design thinking application and introduction to embedded systems design hands-on. The use of off-the-shelf robotics kits, such as the LEGO robots, is qualitatively effective as a learning object for technology centered education in industrial engineering, in general, and not solely for robotics games.

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ANALYSIS OF A SUSTAINABLE SME DEVELOPMENT PROGRAM: THE CASE OF ESD COMPANY

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ABSTRACT

The purpose of this paper was to analyze a sustainable SME development program for the ESD Company. The study was a mixed-method desktop study, and it focused on two categories of SMEs: timber growers and recyclable paper suppliers. The research was conducted by reconstructing historical information on the development and implementation of the enterprise and supplier development program. The data was collected through the review of company documents from 2019 to 2021. Quantitative data were analyzed through descriptive analysis, and the qualitative data were analyzed through thematic analysis of the reviewed material. The assistance that the SMEs got helped them access; seedlings, interest-free loans, and equipment and machinery. This assistance improved the SME operational efficiencies and production output. However, a better understanding of the impact of the enterprise and supplier development program will be realized when the study's scope spreads out to cover several economic sectors.

Keywords: SME Development program, Local communities, KwaZulu Natal

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1 INTRODUCTION

ESD Company was established more than 80 years ago and has a footprint in the timber industry in Southern Africa. It owns more than 784 000 hectares of timber in South Africa. In addition, it works with contract farmers who own more than 140 000 hectares of timber. Both plantations supply over 6 million tons of timber to their pulp and paper mills. The company's pulp and paper mills have a combined annual production capacity of; 102 000 m^3 of structural timber, 690 000 tons of paper, 665 000 tons of pulp, and over 1 million tons of dissolving pulp [1]. It also manufactures; newsprint, graphic paper, agricultural packaging products, convenience paper, confectionery, cosmetic, and household use paper for the markets in the Southern African region [1].

To ensure a sustainable supply of timber, ESD Company participates in reafforestation and research and development programs. It introduced genetically improved plant stocks that are not susceptible to diseases, pests, and adverse climatic changes. The afforestation projects are done in collaboration with local communities and local governments.

1.1 Enterprise Supplier Development Program

To complement its in-house operations, ESD Company introduced an Enterprise and Supplier Development (ESD) unit that implemented the ESD program. The ESD program was designed to develop the capacity of Commercial timber suppliers, cardboard box recyclers, and local SMEs in the construction, engineering, and transport sectors. In addition, the program contributes to economic development and job creation in the communities in the vicinity of its plantations and the pulp and paper mills.

1.1.1 The Growers Program

Eleven percent (11%) of the timber output is from the contracted SME growers and 29% from the commercial timber farmers. The SME growers comprise 5 065 individuals who complement the timber supplies that ESD Company gets from commercial timber farmers and its plantations. This program provides SMEs with several business development support arrangements. This includes the provision of seedlings and funding to ensure the continued supply of quality timber.

1.1.2 The Refibre Program

ESD Company's pulp and paper mills get 160 million tons of timber per annum. An additional 20 000 tons of recyclable cardboard board (K4 fiber) is supplied by 40 contracted SMEs. Just like in the grower's program, SMEs in the Refibre program are given business development support, access to the market, and preferential trading terms. Machinery and equipment are also leased to start-ups and to SMEs that seek to expand their businesses.

1.2 What Prompted the Development of Enterprise and Supplier Development Program

Since 2017, the company experienced an influx of community members looking for business linkage opportunities. Although the ESD company supported the local communities by contracting several SMEs involved in the provision of cleaning and maintenance services, the local communities looked up to the company for additional support. The ESD Company responded with the Enterprise and Supplier Development program. Besides addressing employment concerns, the ESD program bolstered the company's B-BBEE status. The ESD Company was also able to strengthen the production capacities of the growers and Refibre programs.

1.3 The Aim of this Study

The study aimed to analyze the effectiveness of the ESD program with specific focus on :

1. the contribution that it made to the company's B-BBEE profile and status,
2. the development of sustainable and competitive local SMEs,

3. creation of sustainable employment, and
4. improvement of the relationship between the company and its immediate communities.

1.4 Research Questions

The aim of the study was achieved by answering the following research questions:

- What attributes does the ESD program at ESD Company have?
- How successful has the ESD program been in sustaining established SMEs?

1.5 The Significance of the Study

South Africa had an unemployment rate of 34,9% in November 2021 [2]. In comparison with other developing economies with a Gini coefficient of 63, the country is one of the most unequal countries in the world [3]. SME failure rate in South Africa is at a staggering 75% [4]. The above issues are attributed to the current socio-economic conditions in the country, and this strains the relationship between communities and Corporates, including ESD Company.

Although ESD Company's efforts were to make an impactful change in community relations through the SME development program, it also contributed to addressing the national societal challenges. This study showed the need for all stakeholders to do their part in improving the economic situation through a structured and well-thought plan of action.

2 LITERATURE REVIEW

Enterprise and Supplier Development program is meant to assist SMEs to attain financial and operational independence from the entity that provides development support [5]. Whilst the organization providing SME development gets recognition in terms of the Broad-Based Black Economic Empowerment, other potential benefits which are beyond just legislative compliance are:

- Commercial benefit through local responsiveness, especially if SMEs are sourced within the closer proximity of the procuring entity,
- Empowerment of local communities as well as job creation is crucial for sustainable community relations.

The social component's true value within the transformation efforts is at times lost in the process, but it is now becoming clear as organizations are seeing a need to look beyond just profits and embrace the shared value principles [6].

Various transformational regulations are legislated by the South African government to address the imbalances of the past, the B-BBEE Act is one such legislation. In this paper, the focus is on the enterprise and supplier development pillar of the B-BBEE Act. The Act requires that all entities operating within the borders of South Africa, comply with the set regulatory requirements which are applicable within their operating economic sector. While the B-BBEE Act doesn't prescribe or specify the locality aspect, it is worth noting that other pieces of legislation are very specific on the matter and prescribe locality based on kilometres radius from their operations or communities where they source labor [7]. Like the mining companies, ESD Company has a huge focus on localization given the intricacies of its operating environment wherein it shares boundaries with communities, and the notion of localization is seen as a tool for business competitiveness and sustainability [8].

Enterprise and Supplier Development has specified objectives as well as recognizable contributions by the Act, which the organization can apply and claim as part of their legislative compliance audit. However, it does not specify the how part and leaves that to the prerogative of the measured entities to formulate a program that addresses their strategic objectives in consideration of pertinent factors including those mentioned in section 1.

SME development programs have been implemented in South Africa in various forms and shapes since the inception of the B-BBEE act in 2009. What sets apart the programs is the approach/plan as well as the implementation process which determines the program outcome. With South Africa's current situation from the economic stability perspective and the history of high SME failure rate, one is inclined to think that there should be due consideration of various factors when developing an SME development program, especially if sustainability is the expected outcome. Owing to the SME sector's importance to South Africa's sustainable economic growth given the 2030 NDP objectives, it is almost expected for ESD to feature in business strategies, especially from a sourcing perspective [9].

3 METHODOLOGY

This is a case study that sought to analyze a sustainable SME development program at ESD Company. The study was a mixed-method desktop study on enterprise and supplier development, and the focus was on two categories of SMEs. The first group was 5 065 SMEs that supplied timber to ESD Company, and the second group was a group of SMEs that supplied recycled cardboard material to the pulp and paper mills at ESD Company. The case study was an autonomous research project that sought to understand the ESD program at ESD Company. The research was conducted by reconstructing historical information on the development and implementation of the ESD program. The research questions that guided the data collection and analysis are:

- What attributes does the ESD program at ESD Company have?
- How successful has the ESD program been in sustaining established SMEs?

Both research questions contributed to achieving the following aim:

To analyze the sustainable SME development program at ESD Company.

It was not the intention of the researchers to generalize the results from the studied case to a larger set of cases. However, the findings from the research project provide tangible and helpful lessons to companies that seek to design similar or more extensive enterprise and supplier development programs. The project research provides knowledge that can be used in effecting practical SME development and sustenance programs.

3.1 Data Collection

The study is descriptive and exclusive use was made of company documents. The data was collected through the review of company documents and databases from 2019 to 2021.

The material reviewed was purposefully selected, and special attention was on the development, implementation, maintenance, and outcomes of the enterprise and supplier development program. The domain of the research was the ESD program that was developed for the SMEs in the growers and Refibre business segments of the business, and the themes and outcomes that guided the review are shown in Table 1. For each theme, the researcher stopped collecting additional material after achieving saturation.

Table 1: Themes and outcomes that guided the review of documents at ESD Company

Theme	Outcome
ESD Development	- SMEs' growth in turnover and employment numbers - Social impact
ESD Implementation	- SME skills levels, competency, and capacity
ESD sustenance	- Stakeholder Value, sustainable communities' relations - Increase in asset value and asset utilization - SME competitiveness - Legislative compliance and stakeholder value

3.2 Data Analysis

Quantitative data were analyzed through descriptive analysis, and the qualitative data were analyzed through thematic analysis of the reviewed material. When the analysis was conducted, it was not about a theory. There was no intention of theory construction or testing. The enterprise and supplier development program at ESD was analyzed and described using everyday terms, without scientific abstraction.

The outcomes of the analysis were interpreted to give a clearer understanding of the attributes of the ESD program at ESD Company. The analysis also revealed how successful the ESD program was in sustaining established SMEs at the ESD Company.

3.3 Ethical Considerations

Approval was sought from the company's senior management before conducting the study.

4 FINDINGS

The enterprise and supplier development program that is run by the ESD Company started in 2019 and, below are some of the key objectives it seeks to achieve:

- What attributes does the ESD program at ESD Company have?
- How successful has the ESD program been in sustaining established SMEs?

4.1 Types of SMEs Supported by the ESD Program

The SMEs that the company supported were construction, civil works, transport services, garden services and silviculture, timber growers, road maintenance, office and industrial cleaning, cardboard recycling, and plant maintenance. As part of the medium to a long-term plan, opportunities are continuously being identified parallel to the development of SMEs.

4.2 ESD Company's SME Development Model

ESD Company's ESD program sought to develop sustainable relationships with communities that operate in the locality of the ESD Company business units, plantations, and pulp and paper mills. Key parameters used to define locality are the distance of communities from the company's operation, and this must not exceed 50 km. Municipality council wards were used to identify candidates to work within the program.

While the type of SME support given by plantations differs from that given by the pulp and paper mills, the support models followed similar principles. The pulp and paper mills operated in small and fixed locations, whilst plantations occupied large hectarage. This explains why the engagement with SMEs was done through community and business forums.

The communities around the plantations were generally rural, and those around the pulp and paper mills were semi-rural. The communities around the plantations always engage with the ESD Company on the following issues:

- SME participation in the ESD program
- Community development opportunities
- ESD program implementation and progress

Formal meetings are scheduled with communities every quarter.

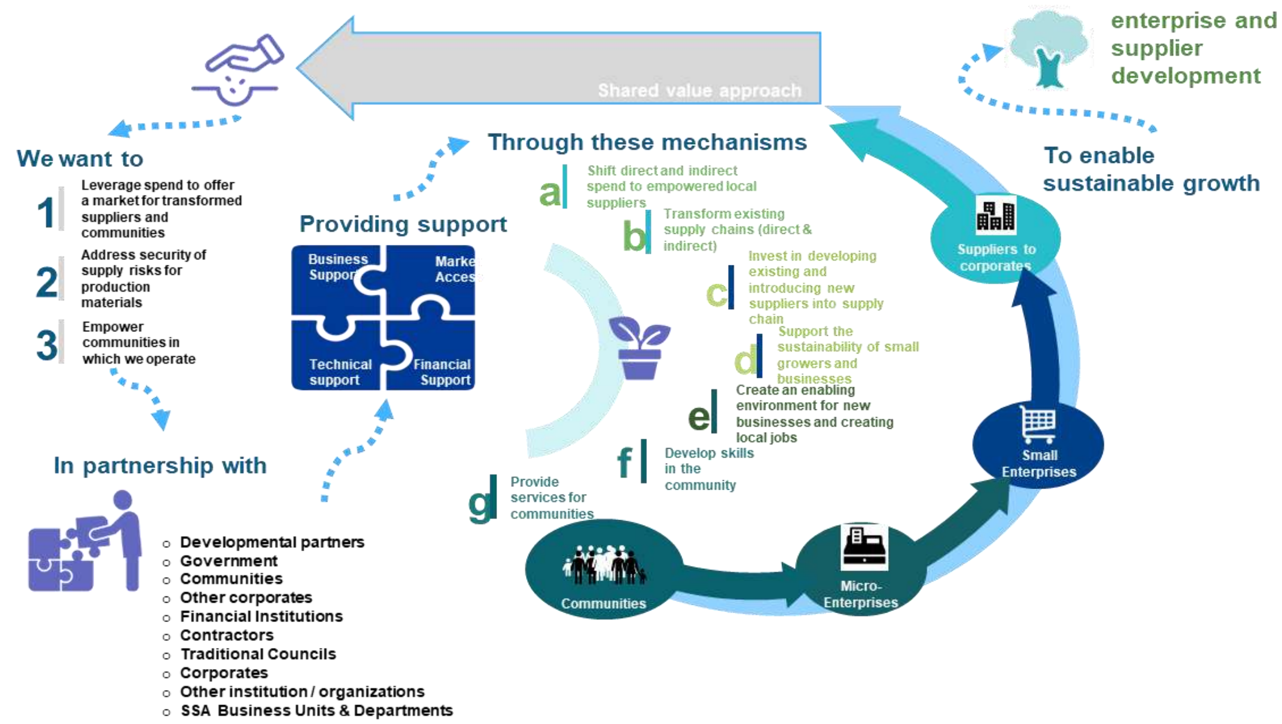

Figure1: ESD program implementation model [10].

ESD Company developed an ESD implementation model that guided the SME development program. Policies and procedures that defined the assistance given to these SMEs emanate from this model. The model was anchored on three key principles, which are:

1. Adherence to sustainable procurement principles, security of supply, competitiveness, and transformation of the supply chain.
2. Collaboration with stakeholders to ensure program sustainability through business and technical assistance as well as through access to markets and finance.
3. Community development through the creation of sustainable community-based micro-enterprises.

4.2.1 Principle 1

The ESD processes were aligned with the company procurement processes, policies, and procedures. All SMEs in the ESD program received training on the code of conduct and safety management systems as part of the onboarding program. The ESD company was able to maintain an exceptional Broad-Based Black Economic Empowerment (B-BBEE) rating. However, there was a lot of work to be done to integrate SMEs into the core of the supply chain. The challenges could not be addressed in a short space of time. Moreover, development gaps were identified during the implementation phase of the program. The gaps that required close attention were price competitiveness, quality, and compliance with regulatory and safety requirements.

4.2.2 Principle 2

ESD Company forged strategic partnerships with many business entities. The partnerships were established to address the key gaps identified during the implementation process. Many partners participated in the program in line with the ESD model focus on business finance, business development, access to the market, and technical skills. The collaborations between the ESD Company and the stakeholders were either formal working arrangements or Memoranda of Understanding (MoU) that were formalized and signed by the two parties. ESD Company signed formal MoUs with; Small Enterprise Development Agency (SEDA), National Youth Development Agency (NYDA), National Business Initiative (NBI), and Ithala Bank. Industrial Development Corporation (IDC), Small Enterprise Finance Agency (SEFA), and First National Bank (FNB) were on a working arrangement that would be formalized when both parties saw it fit.

Mutual discussions between ESD Company and local communities culminated in the signing of the MoUs. The traditional councils were engaged and onboarded onto the program for awareness and program reporting purposes. The MoUs were signed with the integrated community structure, and this established the collaborative relationship between the two parties.

The ESD program had several positive outcomes. It secured; R1.9m partner funding for SME training interventions from Small Enterprise Development Agency (SEDA) and First National Bank (FNB), and R36m SME asset finance from Ithala Bank and Industrial Development Corporation (IDC).

The ESD program on the timber growers and the Refibre projects created 973 temporary and permanent jobs. This represents forty percent (40%) of the jobs created in the two sectors. However, 90% of the procurement opportunities that were awarded to the growers and the Refibre projects, were awarded on an Ad hoc basis. This hurt the creation of sustainable jobs.

Not everything was rosy with the recycling sub-program. The SMEs had challenges overcoming the volatility of the paper supply. The volatility was caused by the changes in industry regulations and irregular supply and demand of recycled material. The covid-19 pandemic also caused huge disruption to businesses in the 2020 to 2021 period. It caused a 15% drop in the supply of recycled material. This led to 3 SMEs closing down.

4.2.3 Principle 3

This principle has relevance to supplier development and enterprise development of SMEs. However, ESD Company did not invest sufficient resources to implement sustainable enterprise development initiatives, except where there were corporate social investment (CSI) requests. There were limited procurement opportunities for SMEs given the capability and capacity challenges that the SMEs experienced.

The paper recycling and timber grower’s sub-programs were strategic to ESD Company and the input material demand for the manufacturing process. ESD Company targeted to source at least 11% of the input material from the SMEs. To achieve this, the ESD program onboarded 500 community-based SMEs. However, developing reliable SME suppliers to ESD Company and other corporates was a major issue of concern. This was worsened by the fact that sixty-five (65%) percent of procurement opportunities were ad hoc. That way, it was a challenge for the SMEs to have medium to long-term financial planning.

4.3 Types of Support Given to SMEs

SMEs that were onboarded onto the ESD program was offered a broader scope of business development support. The program had mandatory training programs that were in line with business operating standards and business compliance. Some interventions were linked to the gaps identified during the SME assessment process.

The ESD Company's internal business support focused on:

- Safety compliance and management training.
- Code of conduct, and site regulations awareness training.
- Tailor-made technical mentorship and coaching.

Third-party service providers were contracted to provide business development support to identify gaps. The following are the popular business support interventions provided by third-party service providers:

- Business management systems training and implementation.
- Financial management, pricing and costing, and business compliance.
- Human resources management systems training and implementation.
- Technical skills training, mentorship, and coaching.
- Safety management systems implementation and maintenance.
- Business growth plan, marketing, and promotion.
- Access to finance through other partner institutions.
- Quality management systems implementation.

4.3.1 Additional support for paper recycling and timber supply SMEs

- Provide seedlings and plantation support services.
- Provision of an interest-free loan.
- Equipment leasing (bailing machine and accessories)
- Equipment maintenance.
- Operational support.

4.4 The Impact of the Support on the Community

Table 2 Shows the SMEs' participation in the program from the 2019 to 2022 financial years (FY). Each financial year runs from October of one year to September of the following year.

The company categorized procurement opportunities in line with SME capacity. This was the basis for forming the ESD intervention plans for the set spending target, training, and development interventions. Implementing these intervention plans closed skills gaps that hindered effective service provision. For the 3 years running, SME procurement expenditure increased exponentially from zero to R53 million in the first year and R413 million in the fourth year.

Table 2: SME program participation record

Performance Indicator	Total	FY 2019	FY 2020	FY 2021	FY 2022
Number of SMEs onboarded on the program	327	131	98	65	33
Number of SMEs on the program	166	32	50	36	48
Number of SMEs integrated into Supply Chain	149	32	52	36	29
Total number of SMEs/annum	642	195	200	137	110
Total ESD spent to date	R413 100 000				

ESD Company SME onboarding tracker [11]

4.4.1 Hectarage of the Timber Growers on the program

The total hectarage used by the 1600 timber suppliers was 36000 hectares. These suppliers were onboarded on the program based on; their ability to access land to plant trees, having water rights, and the distance of their plantations from the timber delivery point. SME growth potential and financial capacity were other criteria used to select SME suppliers. Out of the 1600 SMEs and individual growers, a total of 75 SMEs were purposively sampled for this study. This illustrates that the minority of the growers, 5 % accounts for a 3rd of the allocated funding for the timber supply sub-program.

Table 3: Timber Supplier Summary

Category	Total Growers Percentage)	Funding Budget (percentage)
Formal SME Entities	5%	33%
Individual Growers	95%	67%

All the SMEs that supplied timber depended on ESD Company to finance their short-term operating expenses. Although the program was running in Eastern Cape, Mpumalanga, and KwaZulu-Natal, Table 3 summarizes statistical figures on timber supplies from KZN. It shows that 5% of the growers consumed a 3rd of the funding allocated to the timber supply subprogram.

Cumulatively the total planted hectarage for the formal and informal groups was 36 670 hectares. All the participants were given seedlings, training, and financial assistance. The loan would be recovered on harvesting.

4.4.2 Paper Recyclers on the program

From the ESD program's inception in 2019, 28 paper recycling SMEs were onboarded. The SMEs were onboarded to improve their operational efficiencies and production output. The ESD program team in collaboration with the paper recyclers conducted demand analysis for each enterprise and then set supply targets per SME. The set targets were achieved through the provision of business development support. The support included; the provision of mentorship and coaching, and the acquisition of equipment to help them increase their capacity.

Table 4 shows a 3-year impact on the 28 SMEs that were supported through the ESD program.

Table 4: Three-year SME performance record

Indicator	2019	2020	2021
ESD Company's demand for recycled paper	34202	40637	3374
The tonnage of recycled paper supplied by established Suppliers	27628	26197	2480
The tonnage of recycled paper supplied by SMEs	6574	14440	894
Contribution by the SMEs (tonnage percentage)	19%	36%	26%

Source: Author's analysis of SME performance records

Some of the key findings from the review done on the paper recycling SME development sub-program are as follows:

- 85% of the SMEs depended on leasing ESD Company's processing equipment.
- Over 50% of the SMEs were not able to meet demand targets.
- 2% of the SMEs could not compete, and they closed their businesses.
- Other SMEs could not secure funding to purchase equipment and delivery vehicles for their produce.

4.5 Opportunities for improvement of the ESD program

Based on the continuous engagement with local communities and other strategic partners within and outside of the company, the following were identified as the key improvement areas.

- The findings in this paper raise a need to conduct a full review of the technical skills competency of local SMEs to identify skills necessary to exploit the opportunities.
- There were several instances where SMEs were not able to fulfill the demands due to a lack of funds. In this regard, there is a need for the ESD program to assist SMEs with access to funds. This will improve their capacity to deliver the required products.
- Technical skills development is another focus area given the low levels of technical skills in certain fields. With this being the case SMEs are not able to participate in procurement opportunities that require some level of technical competency, and this becomes a barrier to entry and SME spend growth as most opportunities that are technically less demanding have already been implemented.
- While the ESD program has been able to recruit a significant number of community-based SMEs who eventually became suppliers and contributed to the exponential increase in SME procurement spending; the overarching program objectives in line with the implementation model have not been achieved, thus creating sustainable SMEs.
- Entrepreneurial ability and business management skills for SMEs require attention. There is a need to improve; business administration, legal compliance, planning and execution of work, and customer relations.

5 CONCLUSIONS

The ESD program supported SMEs in construction, civil works, transport service, garden services, silviculture, timber growing, road maintenance, office and industrial cleaning, cardboard recycling, and plant maintenance. The SMEs that benefited from the program were growth-oriented, located within a radius of 50 km from ESD Company plantations and pulp and paper mills. The program was designed to develop sustainable SMEs through the provision of training on; business management; human resources, financial management training, and quality management. The ESD Company support SMEs with accessing; seedlings, interest-free loan, and equipment and machinery.

In the three years that the SMEs were supported, they did not go beyond the fledgling stage. 85% of the SMEs depended on leased equipment for survival. They also looked up to the ESD Company for financial support. They did not have enough money to finance their operational needs.

The ESD program benefited SMEs by improving operational efficiencies and production output. A small number (2%) of the onboarded SMEs failed to compete, and they closed their business. The survival rate was 98%.

6 RECOMMENDATIONS

- Although the ESD program supported several SMEs in different economic sectors, this study focused on timber growers and paper recyclers. A better understanding of the impact of the study will be seen when a study is conducted across the economic sectors supported.
- The analysis of the ESD program was done based on a few metrics. There is a need to assess other metrics such as growth in employment, revenue generated, increase in capital equipment, cost reduction, and revenue generated. This will give a better view of the competitiveness of SMEs.
- The study covered 3 years. This is not long enough. Better results would be obtained if the program was studied over a long period, say 5-to-10-year period.

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THE IMPACT OF COVID-19 INFECTIONS ON HEALTHCARE SERVICE DELIVERY IN SOUTH AFRICA

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ABSTRACT

The impact of the three waves of COVID-19 infections has led to the dearth of public healthcare provision in South Africa. Healthcare management has discovered that traditional healthcare service processes are incapacitated by the inefficiencies and bottlenecks in the current traditional service delivery process. In response to the impact of COVID-19, healthcare service and facilities managers are confronted with addressing the three main core healthcare processes in the South African healthcare context. This is an action research case study that applies a qualitative approach to problem solving. The research will explore and explain how the impact of COVID-19 on public healthcare provision can be mitigated adequately. The research will establish the three most critical processes that must be entrenched in healthcare service-delivery institutions, to enable the alleviation of the impact of COVID-19. The integration of the three core processes results in a management paradigm that can optimise care service delivery.

Keywords: healthcare, COVID-19, digitisation, infection, data

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1 INTRODUCTION

Healthcare facilities such as hospitals are always overcrowded, and service delivery is poor. Facilities are under-resourced and over-stretched. Communities that are in the catchment area of the hospital service cannot access the service in hospitals because of the unavailability of the medical service required. This is due to overcrowding, lack of resources, shortages of medical supplies and medical staff, and poor service delivery. Poor service delivery is the source of the bottleneck experienced in the healthcare service process. The bottleneck is caused by three factors that impede the execution of operational healthcare programs in healthcare.

Public healthcare systems are complex by design, for this is where individual work and group coordinated activities that occur within groups are more often executed simultaneously [22]. The South African healthcare system is hindered by the repercussions of policies made in the Apartheid era. Since the mission was to focus on segregation and expansion of healthcare benefits for the minority population [7]. The healthcare system continues to suffer setbacks in the post-apartheid era, with corruption crippling the system's ability to deliver service. Therefore, the complexity of healthcare service is compounded by policies and management activities executed within the system.

It is this complexity of the system and the compounding effects of policies and corruption that lead to inappropriate information within a healthcare delivery system [10]. Therefore, an experienced poor healthcare service delivery, that manifests due to bottlenecks and a mediocre execution of service delivery processes, is apparent. Compounding the complexity of the environment is the impact of COVID-19 infections, which has led to the dearth of public healthcare provision in South Africa. In response to the impact of COVID-19, healthcare service and facilities managers are confronted with addressing the three main core healthcare processes in the South African healthcare context.

Healthcare management has discovered that traditional healthcare service processes are incapacitated by the inefficiencies and bottlenecks in the current traditional service delivery process. Thus, the focus of this research is relevant and significant in enabling an establishment of a remedy for the challenges encountered. Previous studies on the impact of COVID-19 on healthcare, dealt extensively with the impact on mental health, the impact on health works and, the economic impact. The impact on healthcare specialist practices, healthcare professionals, wellness, technology, and availability of service, is also included. A limited number of studies were conducted on the utilisation of service and service delivery processes.

Bohmer et al. [4] argued that COVID-19 resulted in an untenable demand spike for the already constrained healthcare service. An untenable demand it seems because Public Healthcare facilities are still overcrowded, and service delivery is still poor. It does seem like facilities are under-resourced and over-stretched. Therefore, current themes of research, as indicated earlier, are not adequate for mitigating the dearth of public healthcare service delivery. Thus, this research focuses on the three main core healthcare processes in the South African healthcare context and will present an integration approach as a panacea to the dearth of public health service delivery.

COVID-19 has an unexpected and astonishing impact on healthcare delivery service processes management [16]. The impact directly affects service delivery execution, due to unprecedented patient demand for healthcare services, and increased demand for capacity and resources. This impact is not surprising and unexpected, since globally, research and the scientific community reported serious concerns about the capacity of a fragile, already overburdened healthcare system. Particularly, as cases began to rise in low-resource settings, such as South Africa and the African diaspora [17]. Thus, this project focus area is a perfect fit for the South African healthcare research context and a significant addition to the research body of knowledge.

Preliminary qualitative research and documented systematic reviews about the impact of Covid-19 on Public Healthcare, suggest that the African voice is underrepresented in medical literature related to the burden of Covid-19 on public healthcare [17]. Since the beginning of the pandemic only one (1) out of five (5) African COVID-19 papers had no African author and 66.1% of authors on African papers were not from Africa [17]. It is not surprising, therefore, for South Africa and the African Diaspora to follow the suggestion of flattening the curve to delay the pandemic impact on public healthcare, instead of identifying and optimising the core enabling process in public healthcare service delivery.

This research endeavours to develop a South African solution for public healthcare, and a panacea for the African diaspora, by focusing on and addressing the three main core healthcare processes in the South African healthcare context. The processes are identified and established as the main drivers of public healthcare delivery and a process of integration of the three core processes is implemented. The integration process results in a management paradigm that can be applied to optimise healthcare service delivery interventions. The solution will further demonstrate that adopting the level loading principle (Flattening the curve), was a misdiagnosis for South Africa and for all low-resource settings.

2 LITERATURE REVIEW

Bohmer et al. [4] referred to the impact of COVID-19 results on public healthcare as untenable for the already constrained public healthcare service. An untenable increase in demand for capacity responsiveness, during untenable events, it seems [16]. Carvalho et al. [8] argue that when the outbreak develops into the epicentre of COVID-19 infections, healthcare capacity to manage the unbearable and untenable demands, must be activated. The fact that Public Healthcare facilities are still overcrowded, and service delivery is still poor, and it seems like facilities are under-resourced and over-stretched. This is evidence that healthcare is experiencing the proverbial operational dilemma of demand vs. capacity [16].

It is this dilemma in healthcare operation execution and the increased untenable and unbearable increase in demand for capacity responsiveness that is the fundamental reason and purpose for this research. The research attempts to establish how can the impact of COVID-19 on public healthcare provision be mitigated adequately. It is apparent, as indicated by Naidoo et al. [17], that very insignificant African COVID-19 research, by Africans, has been produced to date, and that public healthcare is experiencing the proverbial operational dilemma, as postulated by Leite et al. [16]. Thinking along the same research line with numerous researchers and authors, this research attempts to establish a solution for this dilemma.

The solution is in support of the research conclusions and established postulates of published work in African COVID-19 research by numerous researchers and authors (e.g., Naidoo et al. [17], Leite et al. [16], Carvalho et al. [8], Bohmer et al. [4], Covadia et al. [7], Fawcett et al. [10], Stoop [22]), and many more. Applying a conceptual framework established from the work of these authors, this research identifies relevant research literature, key ideas, school of thoughts and debates in research about African COVID-19 and its impact on public healthcare. The main theories and how they are applied in current and previous research are studied. In this analysis, gaps in current knowledge are identified and the relevance of this research is confirmed.

To begin answering the research question this research defines the focus and boundaries of the research work done. The focus of the research is on addressing the three main core healthcare processes, and only in the South African healthcare context, and the research presents an integration approach as a panacea to the dearth of public health service delivery. Although the research context is South African, this research is supported by international agencies' recommendations for strengthening healthcare demand capacity responsiveness, as postulated in CDC [5], WHO [24] & [25]. Thus, the research engages issues of demand capacity increase, as measured by healthcare resources availability during increased demand capacity, as recommended by William et al. [26].

African literature about African COVID-19 is spread very thin, with results from top ten (10) journals suggesting that African representation in African COVID-19 literature is insufficient [17]. It is apparent that an African voice and research is needed to guide an African response to the pandemic [18]. Relevant research literature on COVID-19 addressed various issues such as the disruptive nature of the pandemic, on the economy, the governments, health systems, etc. [20]. Thunstrom et al. [23] deliberated on the cost of flattening the curve for COVID-19 and Adams [1] focused on the cost of private healthcare insurance premiums during the pandemic.

Bohmer et al. [4] focused on Low-Resourced Settings (LRS), such as Africa and argued that the pandemic might result in increasing poverty and reducing access to the most needed healthcare. Evans and Over [9] predicted that the ramifications of the pandemic, in LRS, will be felt far beyond COVID-19. Analysis of relevant and current literature on COVID-19 in Africa is subject to the comments and recommendations postulated in literature, although, there are very few research guidelines specific to Africa. It is nevertheless evident that in South Africa COVID-19 has driven the healthcare system beyond the limit. Thus, the socio-economic implication of the virus is also a mutual concern for South African leadership and the leadership in the international community [16].

The consequences of a dual effect of the lack of research guidelines for COVID-19 in Africa and the disruptive effects of the pandemic, let South Africa to resort to implementing strategies that will aid in flattening the curve of infections [2]. These strategies include social distance and lockdown, which meant countries had to accept the cost of an economic pullback [20]. These strategies proved to be inadequate in preparing public healthcare for the untenable increasing demand for healthcare service and for protecting healthcare operations from the severe impact of the pandemic. Since there is no strategy in place to aid, public healthcare capacity had to deal with the unbearable demands [8].

Globally, research communities published recommendations on how to strengthen healthcare system responses [5], [24], [25]. In South Africa and the African diaspora, there is a gap about strategies for mitigating the impact of the pandemic on public healthcare and an efficient utilisation of healthcare capacity and resources. Therefore, this research is relevant and fits the requirements of South African healthcare context, with regard to how the impact of COVID-19 to public healthcare provision can be mitigated adequately. The research will add to the body of knowledge regarding the impact of the pandemic on South Africa and Africa's public healthcare.

3 RESEARCH METHOD

To achieve the aim and objectives of the research and satisfy the requirements of the primary research question and the hypothesis, a research paradigm is developed. This paradigm is used to explain the nature of the scientific truth, the theoretical framework, methodology and the data collection tools applied in the research. This will enable the researcher to explore the definition of reality of the research and deliberate on the following questions: what and how is the knowledge acquired. The procedure, tools and techniques used to acquire this knowledge, and the data collection process used is explained.

Thus, this research requires a methodology that takes a broader perspective than a single primary research study focused on a particular direction. The goal of the research is to explore and explain how the impact of COVID-19 to public healthcare provision can be mitigated adequately? The outcome of the research and analysis is the data collected through the application of a qualitative research method, tools, and data collection techniques. The data will serve as a validation of the propositions that led to the development of a conceptual framework of the study and therefore, rival and/or contesting hypothesis will be accepted or rejected.

This research adopts a qualitative case study research approach because it enables researchers to establish an understanding of the phenomenon from the perspective of those experiencing it [3], [11]. The shared purpose of qualitative research studies, depicted by Baxter & Jack [3], increases the plausibility of adopting qualitative case study research methodology. After adopting a qualitative research approach for this study, numerous qualitative research methods are considered and analysed (e.g., Phenomenology, Grounded Theory, etc.). Thus, this research is poised to focus on a qualitative research approach, using action research methodology (AR) and a case study approach.

AR is a qualitative research method adopted because it seeks to improve practice and is appropriate when the intention is to study and analyse the impact of the action taken [21]. Action research is a perfect fit for the research because when engaged, solutions are developed and applied to practical problems in a particular setting [21]. In this AR intervention, a case study method is applied. Case study method applies the science of singular, which aims to understand what is distinctive of a particular case, defined as a complex functioning system [13], [15]. Qualitative case study method enables researchers an opportunity to explore and explain a case within its context using a variety of data sources [6], [15].

The hallmark of this case study is the use of multiple data sources [27] and [19], which is a strategy that enhances data credibility [19] and [27]. This case study will employ the following triangulation of data sources: i) document analysis and archival records analysis; ii) Journal publications and field notes analyses; iii) patient journey process observation and analysis through, Selection, Recording, Examination, Development, Implementation, Maintain and Monitor (SREDIMM) technique. A combination of data sources and data collection methods in a study of a single phenomenon enables researchers to draw upon multiple sources of evidence [12] and therefore, enables them to seek convergence and corroboration. Using different data sources data credibility is achieved [19] and [27] and the culmination of a triangulated data capturing method is a holistic picture of the case under study.

A qualitative case study is argumentative by nature and therefore, there is a fair amount of competing hypothesis and evidence that is to be disconfirmed. Thus, the research follows the theoretical propositions leading to the original objectives, the design of the case, the research question, and the literature reviews, to define and assess rival explanations and theories. The proposition that the integration of the three-core process will result in a management paradigm that can optimise care service delivery, is assessed and rival and contesting hypothesis are analysed. Validation of the propositions that lead to the development of the conceptual framework of the study is engaged and then, the rival and contesting hypothesis is nullified or accepted.

In this qualitative action research case study, data is collected through a triangulation of qualitative research data collection tools. The tools employed begin with the analysis of archival records and documents. The aim of this data collection techniques is to uncover various perspectives of role players in this research niche and incorporate these ideas in the solution proposal. The second technique applied is an analysis of field notes of other researchers and an extensive review of journal publications, data collected with this second technique clarify the progress of work done in this area of research and provides the latest information that forms the body of knowledge.

The last technique applied is the observation and analysis of the patient journey process using the SREDIMM method. To apply this technique, the research must be inducted in the healthcare processes in a hospital or centre of service delivery. The induction enables the researcher to select the correct healthcare process to study for the purpose of delivering a solution required to remedy the problem. SREDIMM is an acronym for Select, Record, Examine, Design & Develop, Implement, Monitor and Maintain. The research data collection method followed when SREDIMM is applied is as follows:

1) First, a patient journey process is selected as a unit for case study research,
2) Second, the current "As Is" process is recorded and a process analysis of the current patient journey process activities is established,
3) Third, the current "As Is" patient journey process is examined through the application of time and method improvement techniques,
4) Fourth, a future-state patient journey process is developed through the application of the TOC thinking process and an improved process developed,
5) Fifth, an efficient and improved future-state patient journey process is established and implemented,
6) Sixth, a new patient journey process is monitored and managed to maximise the efficiency of the healthcare service delivered.
7) Seventh, the Efficiency of the new and improved patient journey is maintained through continuous improvement initiatives.

4 RESULTS

Analysis of the current 'as is' patient journey reveals three core processes in the healthcare service delivery system. The core processes established are patient data capturing throughout the patient journey, this process is paper based and manual. Patient data capturing throughout the patient admin process, from entrance admin through to pharmacy's medicine dispensary. The orientation of the patient journey is based on a push service delivery system principle. This means patients are pushed through the system without assessing the system capability to accommodate the volumes pushed through. System's capability, i.e., KPAs and KPIs is not documented. This patient service delivery process is characteristic of a patient journey that is not data driven. Thus, there are no execution efficiency plans.

The current patient journey process is characterised by a high percentage of transport activity, high storage activities and a low percentage of operation activities. This is indicative of the long waiting lines at every service point in the service delivery system. The current reality of the system is captured as it is observed. This is evidence that the "as is" exemplifies the most feasible chain if cause and effect in a given rigid, fixed, and complex environment. The current reality of the "as is" patient journey is that there are no process controls and process measurements are poor or in certain cases nonexistent. The current process is a typical push system service process and thus, there are no efficiency plans.

The current reality of the patient journey enables a deeper understanding of the patient journey and enables the identification of undesirable effects in the system. The fact the patient journey is a push system process, that there are no efficiency improvement plans, such as demand plans, capacity plans and throughput plans. It is a clear indication of the source of undesirable effects such as bottlenecks and system constraints. The results of the application of the TOC thinking method and the process analysis techniques are to establish the simplest change required to improve and optimise the patient journey process and systems. In this case it is identified that the configuration of patient journey generates undesirable effects that constrain the efficiency of the system.

The three healthcare core service processes are also enablers of the healthcare service delivery in that they form the building blocks of the patient journey through which the healthcare service-delivery process is executed. Healthcare service delivery in a healthcare facility depends on the 1) Execution of the patient journey, 2) the capturing of patient data, and 3) directing patience through a healthcare system. The execution results of these three processes enable medical staff to encounter patients and to administer medicine to their patients. Through the execution of the service process some patients go through to pharmacy and then-after leaving the system. Some patients go to the wards for a longer stay in the healthcare system.

Analysis of the current reality of the care service delivery, presents numerous measurement that are specific to medical service processes delivery, such as a measurement of patient length of stay (LOS), patients leaving the system without being seen (LWBS), Patience dying before being seen (DWBS) and the measurement of serious adverse event (SAE). These measurements, like many other measurements in the healthcare system have very insignificant impact on the efficiency with which healthcare service delivery is executed. Thus, in the analysis of undesirable events cause by the configuration of the healthcare service execution, there is an apparent absence of demand management plan, capacity planning, replacement of a push system with a pull system, data driven processes and management decision making.

5 DISCUSSION

The advent of COVID-19 revealed that a continuous increase in patients' numbers in the system creates an operational bottleneck [16]. Applying classic terms of factory physics, as stipulated by Hopp et al. [14], when healthcare facility capacity utilisation and service demand is high. There will be a manifestation of long queues of patients in the system, who are waiting to receive healthcare services, e.g., Treatment. Public healthcare capacity utilisation, in this case, is defined as the ability to deal with a considerable influx of patients. It is measured by the availability of healthcare facility resources, such as beds, medical staff, medical equipment, ICU facilities, etc. [16]. Thus, with the advent of COVID-19, long queues are evidence that there are bottlenecks in this system.

The manifestation of an operational bottleneck in a healthcare facility, due to an exponential increase of the influx of patients, can be scientifically proven, using factory physics and queuing theory. What needs to be established is why queues manifest when there is a continuous influx of patients in a system and what is the root cause of operational system's bottlenecks in the healthcare system. The context prevailing in the South African Healthcare facility setting is characterised by the execution of three core processes that enables operationalisation of service delivery. The disposition of the core processes is the source of high inefficiency and the concomitant repercussions, e.g., Bottlenecks, overcrowding and poor service delivery.

Currently, in most public hospitals, the patient journey is a distinctive 'Push System' process, in which patient volumes are pushed through a customer service process. Execution of the process is done without measuring the system capability using demand plans and capacity plans. Thus, when there is high influx of patients in the healthcare facility, such as a hospital, the resultant is long queues because of bottlenecks manifesting at various service points in the patient journey. A bottleneck in the patient journey is a visible cause of long queues and long queues result in overcrowding and consequently poor service delivery. The underlying cause of the bottleneck and the resultant poor service is systematic and central to the design structure of the patient journey.

The absence of demand plans and capacity plans that are critical for executing the patient journey are indicative of a push system characteristic of the patient journey. Thus, when volumes of patients are pushed through a patient journey system, the resultant is a bottleneck. Bottlenecks manifest as overcrowding and consequently a poor healthcare service delivery. The lack of execution plans, critical for operationalising the patient journey is an indication of the absence of data management strategies and an apparent indication that patient journey is not data driven. Not surprising that the patient journey is not controlled or measured through demand and capacity plans.

The dilemma of operations supply vs demand in a patient journey process is, therefore, apparent. This is a confirmation of systematic process design inefficiencies that leads to untenable and unbearable effects of the impact of COVID-19 on South African healthcare. To answer the question, how can the impact of COVID-19 on public healthcare provision be mitigated adequately, requires an integration approach to the execution of the core patient journey processes. Documented research on managing supply and demand, including capacity management in healthcare operations, suggests addressing arrival rate variability at patient end and minimising process variability issues within the healthcare service execution system.

Although this research supports the approach, it is discovered in the analysis of patient journey that there is a conundrum that needs to be addressed before embarking on applying control charts and process variability techniques, to increase efficiency. The conundrum emanates from attributes of the 'as is' patient journey, these are the following: The lack of process digitisation, especially the patient journey; healthcare processes are not data driven; patient journey is a 'push system' and not a 'pull system' process; and Healthcare service-delivery centres and facilities, e.g., Hospitals, lack the discipline of getting things done. The influx of patients due to the pandemic is just a compounding effect to already existing challenges, such as bottlenecks and overcrowding.

Therefore, to mitigate the impact of COVID-19 on healthcare provision, the conundrum must be addressed adequately. This research postulates that the conundrum must be addressed through an integration approach because an individualised solution approach of each attribute of the conundrum has been seen to fail to achieve the desired efficiency. In fact, solutions to all attributes of the conundrum are implemented in various hospitals and institutions of healthcare service delivery. But, because of this peace-meal approach to implementing solutions to one attribute of the conundrum, there is no effective efficiency derived from the implementation of solutions to the attributes of the conundrum.

An integration approach implies implementing solutions to all three attributes of the conundrum, that is, improving the efficiency with which the core healthcare service delivery processes are executed. To improve the efficiency of execution of the healthcare service process, the patient journey must be digitised. The patient journey must be data driven and patient journey must be transformed from a push service process system, into a pull system. Integration means bringing together components into a single system that functions as one. Therefore, after introducing digitisation, and when the system is converted into a data driven system and it is transformed into a pull system, integration of these components must be embedded into the healthcare service process.

Currently, many healthcare facilities, under study, employ paper-based healthcare service systems and processes. The paper-based filling system is used throughout the patient journey, for capturing patient data, referring patients to the doctors and clinics and for dispensing medicine in the pharmacy. The paper-based system is a source of a bottleneck, which leads to inefficiencies in executing activities in the patient journey, and consequently delivering a mediocre healthcare service. Paper systems have a lot of problems, which range from duplicating files, losing files, hindering synthesis of information and poor information storage. One of the worst problems in hospitals is that medical staff is unable to establish a pattern from scattered information in the paper files.

When the patient journey is digitised, filing is electronic, duplication is eliminated, and information synthesis is facilitated and supported. Digitisation ranges from simple low-level status, i.e., data Collection, in which data is converted from paper files to electronic files. Up to advance levels where there is document and data intelligence, i.e., data analytics. At any level of digitisation of the patient journey, there is a data management structure established, access to patient files is optimised, automatic processing is possible, and process intelligence is facilitated. Digitisation enables a value stream identification and mapping, which can lead to process map optimisation. Digitisation enables data structures formation, which is critical for establishing KPIs such as demand plans and capacity plans.

KPIs are the building blocks of a data driven process, in a healthcare setting. Capturing data electronically, when patients enter the system at the admin section, enables management to measure the capacity of the process and the capacity of the facility. Capacity plans enable management planning in which a hospital can establish the amount of work that can be completed given the total amount of resources available and upcoming time constraints. This simply means the number of patients a hospital can process based on the resources, i.e., medical staff, ICU rooms, medical equipment, and the time available. Data driven process systems enable an improved patient journey and facilitate a reduction of activity cycle time, process optimisation and productivity improvement.

Once the patient journey is digitised and it is data driven, the process can be transformed from a push system process into a pull system process. While a push system controls information in the direction of a patient, in a pull system each activity makes an order request of information from a preceding activity. This means when patients enter the system, data captured creates an order for capacity in the succeeding activity and the succeeding activity reacts to the demand of the preceding activity. Therefore, demand plans and capacity available regulates execution of the patient journey. When a patient journey process execution is characteristic of a pull system, bottlenecks and constraints are eliminated. Therefore, a digitised, data driven, pull system patient journey is elastic to patient demand.

The solution proposed in this research report postulates that, to mitigate the impact of the pandemic to healthcare provision in a South African context, the healthcare delivery process, e.g., patient journey, must be transformed, garnished, and developed into an elastic process. When the patient journey is made elastic, the responsiveness of the process to service demand and an increased influx of patients, is optimised. That means the process, e.g., patient journey can increase the capacity of the system to manage influx of patients and a concomitant increase in demand, by using data driven demand plans and capacity plans. Therefore, the system is enabled to predict the responsiveness required by the quantity demanded or quantity supplied of patients and resources, respectively.

Although, the research pertains to a South African healthcare context, the major findings of the study, that of transforming healthcare service processes through digitisation, data driven systems and from a push to a pull system, can be replicated is all process driven operations. When the solution to components of the conundrum is applied to make systems and processes elastic, the impact of COVID-19 to healthcare provision, is mitigated. Mitigation of the impact manifest when the three core processes of healthcare provision are optimised through digitisation, and through implementing data driven systems and transforming care delivery systems from a push system into a pull system. This transformation of service processes in healthcare provision enables a patient journey to achieve elasticity.

6 CONCLUSION AND RECOMMENDATIONS

Findings of this research, respond to how to mitigate the impact of the pandemic on South African healthcare. Combining these findings with current and relevant literature, schools of thought and key researcher’s propositions, in the field, proves to add value to the current body of knowledge. Ideas and schools of thought relative to the gap in African literature resonate with an African solution to the impact of COVID-19 in a South African context. Propositions by researchers such as Leite et al. [16], support the declaration that the impact of COVID-19 induces the proverbial operations dilemma of demand vs capacity. This research finding, supports assertions by authors such as Naidoo et al. [17], that Africa must find an African voice in COVID-19 research and develop African research guidelines on how to address the impact of the pandemic in an African context.

Therefore, the proposition of this research, that mitigating the impact of COVID-19 on healthcare provision requires healthcare service provision processes and system to be transformed and made elastic, through digitisation, data driven strategies and altering service systems from a push into a pull system processes. To achieve this proposition, the research findings propose that an integration approach must be adopted in the implementation of solutions to the conundrum manifesting. This conundrum is found by this research to emanate from attributes of the ‘as is’ patient journey studies and analysis, and that the proposed solution to the attributes of the conundrum, will enable healthcare service-delivery centres and facilities, e.g., Hospitals, to attain the discipline of getting things done, i.e., execution.

The combination of findings of the research and the literature review, leads to a conclusion that the contribution of this research to the body of knowledge is the establishment of a systematic approach to mitigating the impact of the pandemic on South African healthcare provision. Due to limitations of the research that emanate from the vast and eclectic nature of the research, and the dynamic disposition of the research field, authors in this niche recommend that areas of further research, to ascertain that the desired levels of healthcare optimisation and elasticity are attained, must include knowledge development in the following research topics:

- Levels of digitisation and the appropriate implementation protocols for healthcare.
- How to transform process systems from push to pull systems and execute.
- Development and implementation of data driven process and systems.

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CONCEPTUALISING A LEARNING FARM: A CONTEXTUAL ADAPTION OF A LEARNING FACTORY FOR AGRICULTURE DEVELOPMENT

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ABSTRACT

This paper presents the conceptual design and planning for a Learning Factory in the agricultural context – a Learning Farm. The Learning Farm concept is designed to effectively transfer theoretical and practical knowledge applicable to the agricultural industry and to incorporate the three most important characteristics of a traditional Learning Factory: research, education, and innovation. The purpose of this learning farm focuses on resource efficiency, sustainability, data analytics, lean philosophy, and the integration of 4IR technologies. The Learning Farm aims to support skills development to address many of the challenges facing the agricultural sector in South Africa using a collaborative model. This includes training and experiential learning opportunities, research, technology development, and consulting work. This conceptual paper contextualises the need and value of the Learning Farm concept and presents a preliminary business model that will be used for the next phase of this project.

Keywords: Agriculture, Learning Factory, Learning Farm, Industrial engineering

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1 INTRODUCTION

1.1 Context

One of the key problems of traditional education is bridging the gap between what is taught in the classroom and what students need in real-life [1]. For students to progress and continually adapt to the changing circumstances of the world, practical quality education is needed. This educational and developmental gap is not only observed among students but also in the agriculture sector.

The agricultural industry is an essential element of South Africa's economy. The Gross Domestic Product (GDP) of South Africa declined by 51% in the second quarter of 2020 while the agriculture sector expanded by 15.1% [2]. According to the Department of Agriculture, the sector is key to economic growth, sustainable development, and independence [3]. As a food supplier, the sector plays a pivotal role, especially as concerns about food security rise globally [4]. The industry is also one of South Africa's biggest employers, employing 4.6 percent of the total labour force in comparison to mining and manufacturing, employing 2.3 percent and 11.8 percent of the labour force, respectively [2]. Many other industries are also branching into the agricultural industry, including manufacturing, supply chain, and logistics.

In President Cyril Ramaphosa's latest State of the Nation Address (SoNA), he challenged the agricultural sector to grow the economy and create jobs. He also acknowledged that smallholder farmers require more aid [5]. For this to happen, there needs to be a step-change in skills, knowledge, technology adoption and innovation in the sector, as it adapts to farm for the future. Agriculture 4.0 must urgently be adapted by employees in the South African agriculture sector [6].

Better utilisation of resources and increased yields can have an impact on the economy and food security. In South Africa however, there remains a significant gap between productivity and profitability in the agricultural sector [7]. South Africa’s identified digital skills gap can further limit the integration of technological advancements [8].

China, one of the leading countries in agricultural development, has developed farming techniques from which countries worldwide, including South Africa, could benefit. Chinese farmers use the advancements of the Fourth Industrial Revolution to streamline operations, increase water efficiency, produce high-quality crop variations and farm sustainably. These advancements contributed to 57.5 percent of China's agricultural growth in 2020 [9]. This is in comparison to South Africa's 15.1 percent agricultural growth [2].

There is therefore an increasing need to upgrade the skill and education level of farmers in Africa, where 80% of farm cultivation is done using hand tools and animal-powered technologies [10]. Furthermore, improved farming technologies are key to improving agriculture for small farmers. However, poor rural farmers in South Africa scarcely benefit from improved farming technologies, due to cost [11]. Thus, increased skill and education levels are of the greatest importance to these rural and developing farmers.

1.2 Motivation for the study

The motivation for this study is to identify how this educational and agricultural gap can be diminished. One way is using Learning Factories. Learning factories have a physical or virtual environment that represents the real manufacturing world within an educational environment by providing practical hands-on experience. Learning factories provide participants with valuable learning and training experience in a practical setting. In general, a Learning Factory setting is based on real industry sites, has a changeable, modular environment, is used for teaching and training, applies theoretical knowledge practically, uses an interactive problem-based learning approach, and supports multi-disciplinary, formal or informal learning [12]. Learning factories can be physical or virtual. Physical learning factories provide a value chain for a physical on-site product, while virtual learning factories are less hands-on. The advantage of virtual learning factories is that they are more scalable, customisable, and have a bigger scope of problems to solve. `

Exposure to new concepts in a particular context can have a significant effect on the learning that takes place and the application and transferral of the skills and knowledge that are obtained in different contexts [13]. Exposure to principles, philosophies and techniques within a particular context can give learners the impression that the learning applies only to that context. Learners can, therefore, often struggle to transfer learning to new contexts. Since agriculture and manufacturing are very different, there is the potential that the transfer of learning will be limited due to the mindset associated with factories or manufacturing. The proposal for this conceptual design, therefore, aims to adapt the learning context so that it is more familiar and improves the potential for learning to be transferred and applied in agriculture. The idea for a Learning Farm, therefore, builds on the concept of a Learning Factory, adapting the concept to match the needs of an agricultural context. It is believed that the construction of a Learning Farm would be the first concept, globally, that does this.

The Learning Farm has many potential benefits and creates opportunities for a university. The Learning Farm enables practical and experiential learning for industrial engineering students at an undergraduate level, building stronger links between theory and practice. The Learning Farm can also be used for research at the final year and postgraduate level. Research opportunities are likely to extend beyond industrial engineering with the potential for multi-disciplinary and trans-disciplinary projects. Learning factories are typically designed to connect universities with industry through research and training opportunities for external stakeholders. It is envisaged that this Learning Farm could be used for short learning programmes and other training opportunities for both established and emerging stakeholders in the agricultural industry. Closer collaboration with this industry naturally opens doors for research, innovation, technology development, and income-generating consulting work. Collaboration with industry will further improve the agriculture sector by progressive and increasing agriculture research and innovation originating from collaboration.

1.3 Aim

The aim of this paper is to present the conceptual design of a feasible and flexible Learning Factory matched to the needs of agriculture, a Learning Farm. The design should effectively transfer theoretical and practical knowledge within an agricultural context to support the development of competencies to farm for the future. Multidisciplinary students and operational agriculture stakeholders will be equipped with industrial engineering tools, skills, and knowledge, to guide improvement. Additionally, the Learning Farm is a mechanism to encourage and nurture collaboration and innovation in the agricultural sector in South Africa.

2 LITERATURE REVIEW

It is important to understand why a Learning Factory is valuable for educational teaching and training. This is done through investigating the need for quality education, the learning environment, the overall principles, development, and considerations of a Learning Factory, and the paired challenges and opportunities that it brings.

2.1 The need for quality education

A study conducted on 50 emerging farmers in South Africa by Khapayi, M & Celliers (2016) led to significant insight into the need for quality education and the current lack of education among farmers. 124 farmers were identified within the rural areas of King William's Town in the Eastern Cape Province but only 50 farmers were willing to be a part of the study. These 50 farmers were all engaged in livestock rearing, with 30 also engaged in crop production. The study showed that there is a gap in the education level, especially for small and rural farmers. This gap does not only include farming skills and experience, but also business management and productivity skills. In terms of business and labour management, marketing, and record-keeping, all farmers lacked experience but agreed that these skills are critical for successful farming. There is a need to support previously excluded farmers in the agricultural economy. This can be done through education and information access. The lack of trained human resources is limiting agriculture development and can be counterworked through education. This need for quality education also applies to students – including industrial engineering and agricultural sciences. The ability of a company is dependent on the ability of employees. Similarly, the ability of the agriculture sector is dependent on the ability of farmers, future farmers, and students to find solutions to problems and the ability to function sustainably. A new learning approach is needed as traditional teaching methods have shown limited effect [15].

2.2 Importance of a Learning Environment

The need for quality education is imperative for the improvement of the agriculture sector. Thus, the learning environment in which this education is obtained plays a crucial role. Quality education can be achieved by encouraging students to apply theoretical knowledge to real-life problems, develop sense and judgment, learn to function within teams, learn from mistakes, and discover realities for themselves. The authenticity of the environment is an important factor that facilitates multi-purpose training that can be varied through information, communication, and different interpretations [16]. The self-directed nature of the learning environment also adds to sustainable learning for participants.

According to ElMaraghy & ElMaraghy (2015), it is vital to provide the opportunity of an environment to apply the theory that will allow a meaningful hands-on learning experience [17]. A realistic manufacturing environment modernises the whole learning process, making it easier to apply knowledge within the real world. The capabilities of participants are improved and lead to better problem-solving skills, increased innovation, and competitiveness [15]. This is also known as scenario-based learning (SBL) – which is established in situated learning and cognition theory. SBL shows that learning is most effective in its natural environment where the learnt knowledge is to be applied. SBL, furthermore, provides ample opportunities for feedback and discussions.

Jaeger et al. (2012) describe the effectiveness of several types of learning methods. The lowest forms are reading with 10% effectiveness, hearing with 20%, followed by demonstrations with 30%. Thereafter, the combination of seeing at the practical location is 50% and participating in the discussion is 70%. The highest effectiveness of 90% is seen in practice doing, simulating the real experience, and doing the real thing. Thus, learning in a real-life environment delivers the best results [16].

To further justify that a learning environment is important, Smeds et al. (2015) conducted an analysis with school pupils in a farm environment. The analysis tested if the pupils displayed better learning results compared to a theoretical environment. As a result, it was found that pupils exhibited significantly better results in an authentic learning environment. Being able to study a subject first-hand lead to long-term retention of information. The versatile environment also supports pupils with different learning preferences. Pupils cannot fully understand theory without experiencing it as all their senses are not activated [18]. Theory and practice must not be separated but built on each other. In this study, the classroom alone delivered low understanding and information retention. The practical environment alone delivered much more short-term understanding and good information retention. However, the combination of both theory and practical application delivered a similar short-term understanding as with the practical environment but the best result for long-term information retention [18].

2.3 Technological development

Digitalisation innovation is needed to increase agricultural sustainability and is considered the fourth revolution in farming [19]. An educational environment also allows for a more collaborative environment through virtual and augmented reality [20]. Virtual reality (VR) increases digital learning by enhancing visual software and enabling visualisation. Virtual and augmented reality can be used for virtual layout planning, task simulation, and design evaluation [21]. Digitalisation further includes using big data, Internet of Things (IoT), automation, data-driven farming, chatbots, simulation, cybersecurity, cloud computing, apps to link production processes and quality management, and other aspects within the value chain [22] [19] [20].

Integrating these technologies into the Learning Farm help farmers identify the technologies they need to apply. In real-life applications, De Clercq et al. (2018) have categorised certain technologies according to certain applications. To bring food production to consumers with increased efficiency, technologies to explore are vertical farming, 3D printing, and genetic modification. To incorporate cross-industry technologies and applications, drone technology, data analytics, IoT, precision agriculture, nanotechnology, AI, food sharing and crowd farming, and bio chain is valuable [20].

Technological applications can primarily be distinguished according to recording and mapping technologies, tractor GPS and guiding mechanism, apps and farm management and information systems (FMIS), and autonomously operating machines. These technologies are classified as smart farming technologies (SFT). Unfortunately, there is a great knowledge and skill gap to use SFT. Farmers are more interested in tools for farming that can tell them “why” and then what to do, than only “what”. Technology does not yet fit the needs of farmers [19]. If, however, the adaption into a digitalised environment can be initiated, the change to autonomous technology will be much easier in the future.

2.4 Industrial Engineering principles

Certain Industrial Engineering (IE) principles are key to effective farming. According to the Institute of Industrial Engineers “Industrial Engineering is concerned with the design, improvement, and installation of integrated systems of people, materials, information, equipment and energy. It draws upon specialized knowledge and skill in the mathematical, physical, and social sciences together with the principles and methods of engineering analysis and design, to specify, predict, and evaluate the results to be obtained from such systems.” [23]. The main objectives of IE relate to increased productivity, eliminating waste, and improving the effective utilization of resources. The Learning Farm concentrates on 14 IE principles to achieve the training of these objectives [24], namely:

1. Work design & measurement
2. Operations research & analysis
3. Engineering economic analysis
4. Facilities engineering & energy management
5. Quality & reliability engineering
6. Ergonomics & human factors
7. Operations engineering & management
8. Supply chain management
9. Engineering management
10. Safety
11. Information engineering
12. Design manufacturing engineering
13. Product design & development
14. System design & engineering

2.5 Learning Factory considerations

To begin the process of setting up a real-life Learning Factory, there are key considerations. Key strategies for productivity and transformative enablers include flexibility, changeability, and reconfigurability of scenarios and the environment itself. It is desirable to construct the Learning Factory in a way that makes it easy to reuse in various research and learning cycles. These are known as Changeable Learning Factories (CLF) to support students through different scenarios, in various modules by incorporating the concepts of adaptability, flexibility, and reconfiguration [17]. It is also important to support the needs of the industry throughout the whole life cycle of the Learning Factory [25].

Furthermore, key features of a Learning Factory are displayed in Figure 1. The main goals of a Learning Factory are either organisational or technological innovation or effective competency development [15]. The design of these features is further explained within the conceptual design of the Learning Farm.

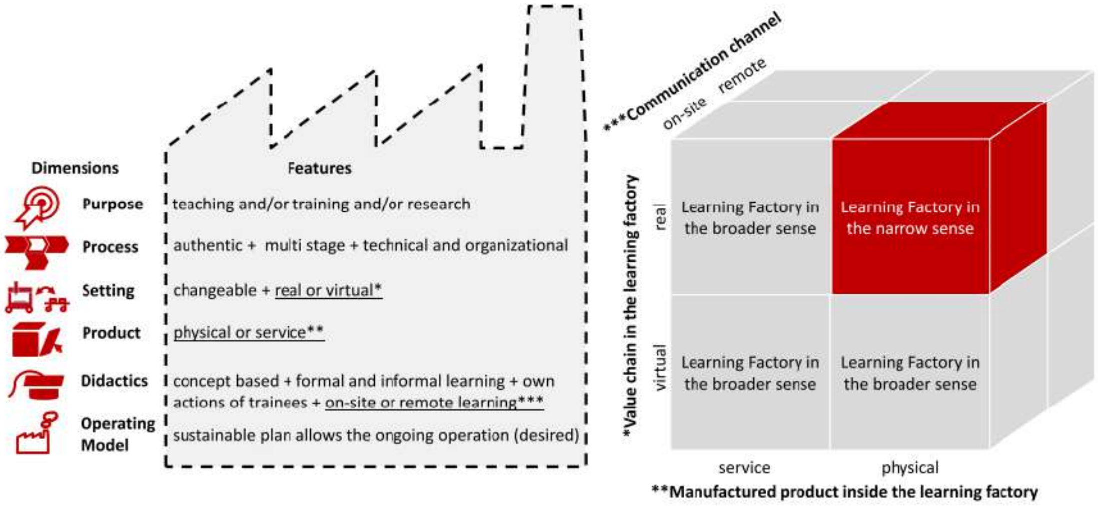

Figure 1: Key features of a Learning Factory [15]

2.6 Learning Factory curriculum guide

To ensure that the impact of a Learning Factory is valuable and sustainable, a didactic approach must be followed to set up the curriculum and environments within the Learning Factory. Figure 2 displays the curriculum guide to follow. The relevant modules must be identified, keeping in mind their present and future importance. The specific competencies can then be defined as learning objectives and can be developed with the help of conditions, such as participation, technology, and location. The competencies are formulated according to specialist and methodological, personal, activity- and application-oriented, and social-communicative competencies [26].

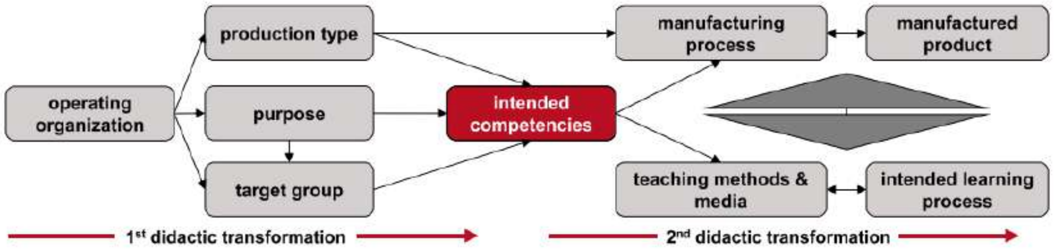

Figure 2: Learning Factory curriculum guide [26]

Within the first didactic transformation, the potential target group initially focuses on undergraduate and postgraduate students and later expands to external industry partners. In the second didactic transformation, based on the competencies selected, the teaching methods, learning processes, and modelling of the environment are constructed to develop the competencies best. A combination of formal and informal teaching can be used. Formal teaching is action-oriented and includes problem-solving. Informal learning is portrayed through hands-on training [26].

As mentioned in the IE Principles, lean manufacturing principles and philosophy is important and can be applied in various ways within the Learning Factory. Lean manufacturing focuses on continuous improvement and waste elimination. These lean principles are achieved by identifying the needs of stakeholders, identifying the flow of value in production, determining the type of flow needed, adjusting the production according to demand, and continuously reviewing opportunities to eliminate waste. During the whole process, the performance of the lean tools must be calculated or based on the key performance index (KPI) [27].

2.7 Critical success factors and benefits of a Learning Farm

2.7.1 Critical success factors

The critical success factors for setting up a Learning Factory are as follows [28]:

- Identify the correct resources needed for the Learning Factory
- Map ability in the Learning Factory to address all challenges in the industry
- Scalability and mobility of the Learning Factory approach
- Effectiveness of the Learning Factory

2.7.2 Benefits

The benefits of a Learning Factory can be summarised as follows [29]:

- Maximize the educational value as the environment is specifically tailored
- Address the exact needs of the Faculty
- Facilitate realistic, authentic processes in a practical environment
- Provide an ideal testing ground for new ideas
- Support efficient and effective training
- Provide a similar-to-real-life environment to inform decision-making that relates to the physical world [28]
- Increase collaboration, support, and development of external stakeholders

From the literature, it is apparent that improved learning techniques, and a Learning Factory can provide quality education to students and the agriculture sector.

3 METHODOLOGY

To set up the conceptual design of the Learning Farm, a six-step approach is followed. The flow of these six steps is displayed in Figure 3. The literature review and stakeholder visits make it possible to set up a Core Value Proposition for the Learning Farm and determine the phase development for setup. All four steps then flow into the conceptual didactical design. The didactical design incorporates key characteristics and features for the Learning Factory that can then be used to finally develop the business case and detailed design. The flow in Figure 3 explains how the six steps integrate.

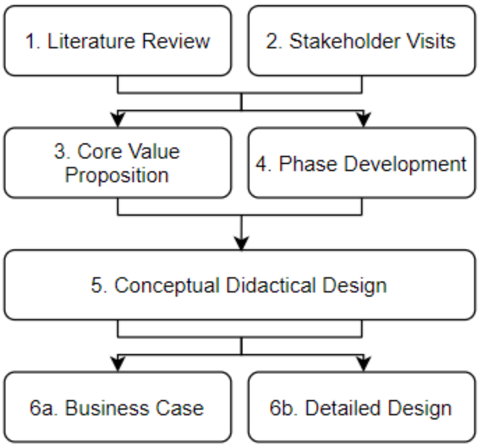

Figure 3: Learning Farm setup methodology

3.1 Literature review

This was used to understand the context and strategies behind Learning Factory design, the process of setting up a Learning Farm, and key considerations throughout this process. For this, the agriculture sector, current industry 4.0 technologies, existing Learning Factories and industrial engineering techniques and tools were researched.

3.2 Stakeholder visits

Engagement with stakeholders, including mega and small and medium-sized farmers, government institutions, and agricultural consultants to understand the needs and potential opportunities. Further engagement included visiting other South African institutions that have developed or are using Learning Factories to understand the requirements, approaches and challenges of designing the Learning Farm. These visits gave great insight into the setup phases of a Learning Factory and the needs of the agriculture sector.

3.3 Core value proposition

The Core Value Proposition of the learning links the challenges faced by the agriculture sector and their needs to overcome these challenges, as well as the value added in doing so.

3.4 Phase design

The purpose of the phases was to break the setup into smaller, more achievable tasks. The first phase looks at the internal setup and support for the Learning Farm. The second phase looks at the external expansion and support for the Learning Farm. The third phase then looks at further growth and larger niche areas.

3.5 Didactical design

Morphology analysis is used to include all the characteristics and features that will be integrated into the Learning Farm. The seven dimensions of the didactical design include the [15]:

- Operating model
- Purpose and targets
- Process
- Setting
- Product
- Didactics
- Metrics

3.6 Business case and detailed design

The last step is to develop a business case and a detailed design. However, as this is the output of this paper, it falls outside the scope of this paper.

4 LEARNING FARM CONCEPTUAL DESIGN

The Learning Farm conceptual design is the preliminary design of a Learning Factory, adapted for the agricultural sector. The phases and activities within each phase, industry interest and considerations, and the didactical design is considered.

4.1 Industry interest and considerations

As explained in the methodology, universities with Learning Factories were visited to learn from existing expertise. After all the visits, the key considerations were to start small with a simple Learning Factory and build and expand the concept into a professional Learning Farm. Further considerations based on the students are that the module knowledge should be structured in the context of its practical application, students should gain effective problem-solving competencies, the knowledge acquisition process should include self-directed learning, and the practical application should motivate students to learn.

For the initial setup and continuous operation of the Learning Farm, different revenue streams can be incorporated. The first revenue streams are internal to the University – this is initial funding and undergraduate modules, postgraduate student projects, and research opportunities. The second revenue stream is external – courses open to the agricultural sector for advanced training and skill development. The third revenue stream is internal or external – funding received for specific research, innovation, and consulting to be conducted in collaboration with industry partners.

4.2 Core value proposition design

The value of the Learning Farm is depicted in the Core Value Proposition in Figure 4. The customer segment is from the perspective of the agriculture sector and potential stakeholders. The value proposition shows the value of the Learning Farm and the service and experience that will be received. This Core Value Proposition further highlights that even though there are challenges that will arise within the Learning Farm, the services received, and value-added for stakeholders will be much greater. Challenges such as lack of research, education, and innovation for the agriculture sector will be overcome with the gains represented in Figure 4.

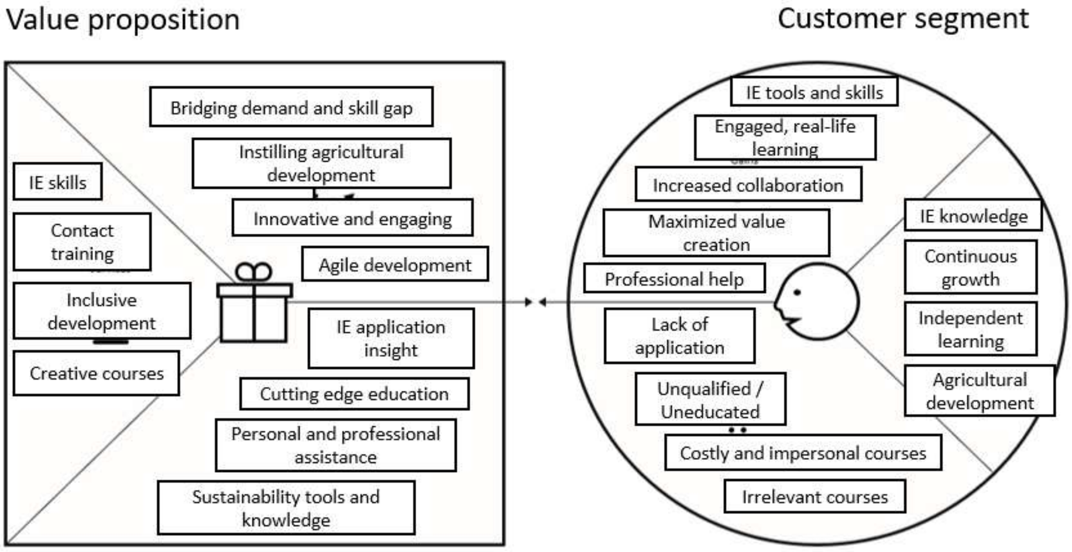

Figure 4: The Learning Farm value proposition

4.3 Phase design

Based on the stakeholder input, the Learning Farm setup was divided into a three-phase approach to focus on the correct elements throughout each phase. The focus of Phase 1 is on setting up the initial Learning Farm internally within the University. This is to construct the Learning Farm and incorporate continuous improvement before expanding to external parties. Phase 2 then concentrates externally and identifies the needs of the agricultural sector and integrates their needs into the expansion of teaching, research, consulting, and industry collaboration. Phase 3 further focuses on growth into a larger niche area that brings together teaching, research and innovation, consulting, and industry collaboration in a multi-disciplinary and cross-functional way. Table 1 represents the phases used to set up the Learning Farm. The timeline of these phases is shown in Figure 5.

Table 1: Learning Farm phase design

Phase	Milestones	Activities	Deliverables
PHASE 1: Internal Focus (Learning Factory setup)			
Requirements analysis and preliminary design	1. Identify requirements for a conceptual Learning Factory design. 2. Compile a high-level budget 3. Consider requirements and risks and design a detailed Learning Factory setup	1. Engage with agriculture stakeholders to identify their overall needs and requirements. 2. Brainstorm with lecturers to identify curricula requirements 3. Discuss the requirements, potentials, and limitations of the current set-up of Learning Factory experts and developers that have their Learning Factories.	1. High-level project plan 2. Business plan 3. Preliminary Learning Factory design
Detailed conceptual design	1. Develop a detailed design containing all components of the Learning Factory.	1. Incorporate the feedback from industry and experts into the design 2. Develop a detailed conceptual design of the Learning Factory, sufficient to develop a test model. 3. Acquire advice and feedback from industry experts for evaluation 4. Design the final, detailed plan of the Learning Factory as a whole to compile a business proposal and cost-benefit analysis for Phase 2.	1. Detailed Learning Farm design 2. Facility layout design 3. Curriculum plan
Construction	1. Identify a building site 2. Compile a list of software, hardware, and equipment to be used in the Learning Farm for cost estimation	1. Engage with industry experts to define the most appropriate hardware and software to be used 2. Discuss building/ setup sites 3. Acquire material for setup	1. Hardware and software specifications 2. High-level budget 3. The physical setup of the Learning Factory
Use of the Learning Factory	1. Appropriate use of the Learning Factory	1. Train staff how to use the Learning Factory	1. Implemented Learning Factory 2. Trained staff
PHASE 2: External focus (Expand Learning Factory into a Learning Farm)			
Needs analysis and expansion	1. Needs analysis 2. Expansion focused on the agriculture sector	1. Conduct a thorough needs analysis for the agricultural sector	1. Needs analysis 2. Expansion: SLPs, industry training,

		2. Follow Phase 1 milestones to expand	consulting, collaboration
PHASE 3: Growth & continuous expansion			
Investigation for growth	1. Investigate future growth possibilities	1. Explore larger teaching, consulting, and collaboration	1. Expansion

In Figure 5, it is shown that all the phases start with an investigation phase. Once the investigation phase is completed and approval is granted, implementation can commence. During the final stages of the implementation, the investigation for the next phase can commence.

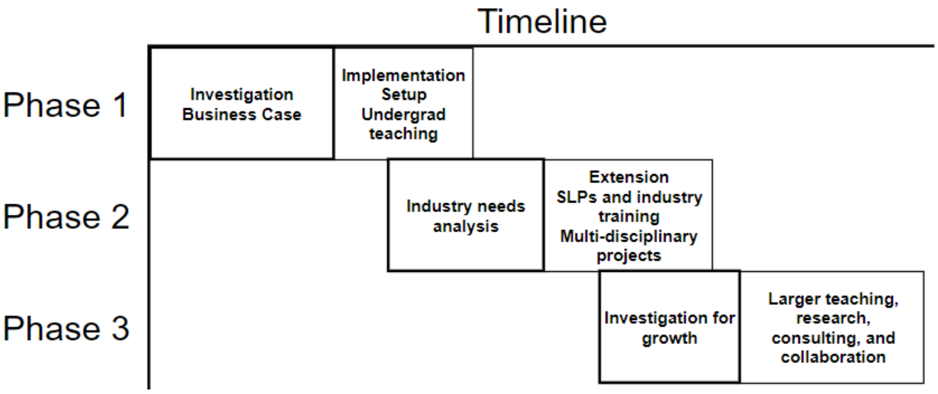

Figure 5: Timeline of the Learning Farm phase

4.4 Didactical design

A Learning Factory can be implemented in various ways. A morphology analysis helps with the implementation process by describing the complex system of a Learning Factory and including all relevant characteristics, features, and attributes. For the Learning Farm specifically, a didactical morphology, based on the structure of Tısch et al., (2015), is set up. This morphology is based on seven design dimensions and requirements of the Learning Farm – operating model, purpose and targets, process, setting, product, didactics, and metrics [15].

Within the didactical design of the Learning Farm, it is important to identify focus areas that link to a morphology analysis to understand the details to describe each dimension. Possible focus areas for the Learning Farm will include:

- Resource efficiency – Introduce efficient ways to improve the utilisation of resources
- Agriculture 4.0 – Incorporate technological advancements the 4IR brings to the agricultural world and how to use these tools effectively.
- Sustainability – Economic, environmental, and social sustainability aspects.
- Data analytics – Improve the collection, analysis, and use of data to improve decision making
- Lean philosophy – Introduce elements of the Lean philosophy to develop continuous improvement skills and culture Lean principles and philosophy (JIT, VSM, Kaizen, Kanban, 5Why's, 5S, Poka Yoke solutions, line balancing, TQM, six sigma, reasoning, self-evaluation, etc.)

The first dimension is the Operating Model. The Learning Factory must consider various aspects such as finances (either funded or self-sustaining), supporting existing industries, having a sustainable and quality operation, technical expertise, and the personnel operating the programmes [30].

The second dimension is Purpose and Targets. Education development can be based on competency development or innovation, as well as secondary purposes such as industrial demonstrations, production, and/or testing for companies [30]. Table 2 depicts the operating model and purpose and targets for the Learning Farm.

Table 2: Learning Farm morphology: Operating Model and Purpose & Targets

<table>
<tr><th>Dimensions</th><th colspan="6">Descriptions</th></tr>
<tr><td colspan="7">1. OPERATING MODEL</td></tr>
<tr><td>Operator</td><td colspan="3">Academic institution: University</td><td colspan="3">Profit-oriented operator: Consulting</td></tr>
<tr><td>Trainer</td><td colspan="3">Professor</td><td colspan="3">Educationalist</td></tr>
<tr><td>Development</td><td colspan="3">Own development</td><td colspan="3">External assisted development</td></tr>
<tr><td>Initial funding</td><td colspan="6">Internal funds</td></tr>
<tr><td>Ongoing funding</td><td colspan="3">Public funds</td><td colspan="3">Company funds</td></tr>
<tr><td>Funding continuity</td><td colspan="2">Short-term funding: Single events</td><td colspan="2">Mid-term funding: Projects and programs <3 years</td><td colspan="2">Mid-term funding: Projects and programs >3 years</td></tr>
<tr><td>The business model for training</td><td colspan="6">Open models: Course fees</td></tr>
<tr><td colspan="7">2. PURPOSE AND TARGETS</td></tr>
<tr><td>Main purpose</td><td colspan="2">Education</td><td colspan="2">Research</td><td colspan="2">Agriculture progression</td></tr>
<tr><td>Secondary purpose</td><td colspan="6">Innovation transfer</td></tr>
<tr><td>Target groups for education & training</td><td colspan="3">Students: Undergrad & Postgrad</td><td colspan="3">Employees: Skilled, semi-skilled, & unskilled workers, & managers</td></tr>
<tr><td>Group constellation</td><td colspan="6">Heterogenous</td></tr>
<tr><td>Targeted industries</td><td colspan="2">Agriculture</td><td colspan="2">Logistics</td><td colspan="2">Supply chain</td></tr>
<tr><td>Subject-related learning & research contents</td><td>Product project mgmt. & org.</td><td>Lean mgmt.</td><td>Resource efficiency</td><td>Optimisation</td><td>Forecast. & scheduling</td><td>Facility design</td></tr>
<tr><td>Role of LF for research</td><td colspan="6">Enabler</td></tr>
</table>

The third dimension is Process and relates to the boundaries of the Learning Farm regarding the product, material flow, process type, manufacturing methods, technology, and lifecycle [30].

The fourth dimension is Setting and describes the learning environment and its features. This can either be a physical or virtual environment and relates to the flexibility and changeability of the Learning Factory [30].

The fifth dimension is the Product which must be suitable to support knowledge transfer. The product also influences difficulty, variability, and operational costs [30]. The product is chosen to relate to the agriculture sector. Table 3 illustrates the process, setting and product for the Learning Farm.

Table 3: Learning Farm morphology: Process, Setting, and Product

3. PROCESS						
Product life cycle	Product planning		Manufacturing	Assembly	Logistics	Recycling
Factory life cycle	Factory concept	Maintenance				Recycling
Order life cycle	Configuration & order	Order sequencing, production planning & scheduling				Picking & packaging
Technol. life cycle	Planning	Virtual testing				Modernisation
Indirect functions	Supply chain mgmt.		Quality mgmt.			
Material flow	Continuous production					
Process type	Small series production					
Manufacturing org.			Flow production			
Degree of autom.	Partly automated/ hybrid automation					
Manuf. methods	Additive manuf.		Joining			
Manuf. technology	Physical					

4. SETTING			
Learning environment	Purely physical: Planning & execution	Physical, supported by the digital factory (later on)	
Environment scale	Scaled-down		
Work system levels	Factory		
Enablers for changeability	Mobility & modularity	Scalability	Universality
Changeability dimensions	Layout & logistics	Product features, design, & quantities	Technology
IT-integration	IT before SOP: CAD, CAM, simulation		

5. PRODUCT		
Materiality	Material: Physical product: Model tractor	
Form of product	General cargo	
Product origin	Own development: Agriculture inspired	
Marketability of product	Available on the market but didactically simplified	
Nr. of different products	1 product (can extend into egg packaging)	
Nr. of variants	2-4 variants	
Nr. of components	6 -20 components	
Further product use	Re-use / recycling	Exhibition / display

The sixth dimension is Didactics which describes the learning outcome, as well as the methods and conditions [30].

Lastly, the seventh dimension is Metrics which is quantitative and is used as a description model for the Learning Factory [29] (floor size, average participants, etc.). Table 4 displays the didactics and metrics for the Learning Farm.

Table 4: Learning Farm morphology: Didactics and Metrics

6. DIDACTICS				
Competence classes	Technical & methodological	Social & communication	Personal	Activity & implementation
Dimensions learning targets	Cognitive	Affective		
Learning scenario strategy	Instruction	Demonstration	Open scenario	
Type of learning environment	Greenfield			
Comm. channel	Onsite learning			
Degree of autonomy	Instructed	Self-guided & regulated		
Role of the trained	Presenter	Instructor		
Type of training	Tutorial	Practical lab course	Workshop	Project work
Standardisation of training	Standardised training	Customised training		
Theoretical foundation	Prerequisite	In advance		
Evaluation levels	Feedback of participants	Learning of participants	The economic impact of training	
Learning success evaluation	Knowledge test (oral)	Written report	Oral presentation	
7. METRICS				
Nr. of participants per training	>30 participants			
Nr. of standardised training	5-10 training			
The average duration of a single training	1-2 days	3-5 days	>20 days	
Participants per year	201-500 participants			
Capacity utilization	51-75%			
Size of LF	500-1000sqm			
Full-time eq. of LF	<1			

Looking at the Learning Farm business model, the advice and feedback from industry partners from their own existing Learning Factories are key elements for the setup of the Learning Farm. Their insights led to the phase and didactical design of the Learning Farm which specifies which tasks must be implemented within certain phases and timeframes, as well as the specific details regarding the seven key dimensions - operating model, purpose and targets, process, setting, product, didactics, and metrics - of a Learning Factory.

5 CONCLUSION

Traditional education creates a gap between what is taught in the classroom and how various skills and knowledge is needed in real life. This gap is not only identified at an academic level but also within the agriculture sector. The agriculture sector in South Africa needs improvement, progression, and innovation. This gap can be filled by using a Learning Farm to equip farmers and students for the future of agriculture. Through creating a real-life environment that incorporates IE principles and looks towards technological development, quality and sustainable education are provided.

The conceptual design of the Learning Farm provides insight into phasing, key considerations for setup and a didactical design. This didactical design describes a morphology analysis that includes seven design dimensions and requirements - morphology is based on seven design dimensions and design requirements of the Learning Farm – operating model, purpose and targets, process, setting, product, didactics, and metrics [15].

This Learning farm has the potential to facilitate the improvement and sustainable development of the agricultural section in South Africa through education, research, and innovation. It provides a unique opportunity for multiple stakeholders to come together to contribute to economic development and food sustainability in South Africa.

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USING A REGRESSION MODEL TO ASSESS LEADERSHIP STYLE ON THE LEVEL OF EMPLOYEE ENGAGEMENT AND JOB SATISFACTION

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ABSTRACT

The successful operation of the state-owned enterprises (SOEs) in South Africa is of critical importance as their performance contribute to the economic growth of the country. Of late, poor performance has been observed at various state-owned enterprises, and they need to improve their operational performance to achieve maximum value. The purpose of the study was to identify the leadership style employed at the SOEs and recommend a suitable leadership style that could be used to enhance employee engagement and job satisfaction. A quantitative approach and a self-administered online questionnaire were used to measure the impact of leadership style on employee engagement and job satisfaction. Cronbach's alpha co-efficient was used to measure the robustness and reliability of the questionnaire and the regression model revealed that there is a positive relationship between leadership style and employee engagement and job satisfaction at a state-owned enterprise.

Keywords: leadership, employee engagement, job satisfaction, state-owned enterprise, regression model

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1 INTRODUCTION

SOEs have become a major point of concern in South Africa, and poor performance is observed in several SOEs, thus affecting the investment and economic growth of South Africa. Stats SA [1] reported that South Africa's annual average GDP growth rates have fluctuated from 1.4%, 2.9%, 4.3% to 2.2% during the periods of 1980-1993, 1994-2000,

2001-2007 and 2008-2012, respectively. The GDP growth rate performance from 2016 to 2021, as stated on figure 1, and the results indicate that GDP has not been stable for the past five years and it has taken a major knock in the year 2020 due to the Covid-19 pandemic [1]. The figures are then extrapolated for the years 2022 to 2026 to indicate the GDP growth.

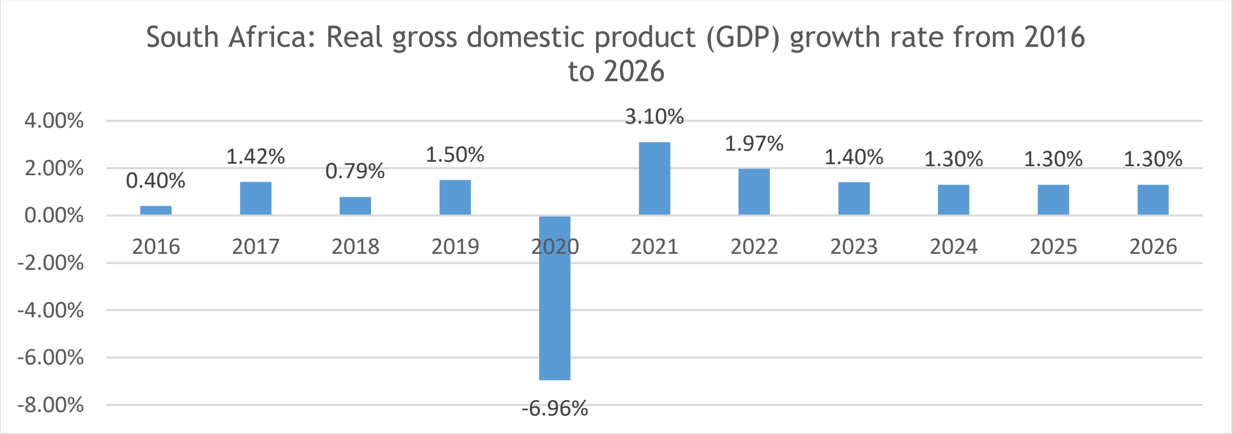

Figure 1: South Africa: Real gross domestic product (GDP) growth rate from 2016 to 2026

There is a link between corruption and political interference on the management of South African SOEs, which has led to poor performance. Further, when a political party is in power, they appoint (and remove) members of South African SOE boards along with their CEOs to unlock the value to the major shareholders and reduce the pressure from the stakeholders. This change of leadership has created a vacuum between the leaders and employees of the organisations, and this caused instability within the SOEs [2].

Change in leadership affects employee performance [3] and also plays an important role in the development and success of the organisation [4]. Change in leadership involves the introduction of different leaders with different leadership styles to the organisation, and this change can make or break the organisation, as the new leadership comes with a new vision and strategies that might affect motivation and morale of employees.

Limbo [4] argues that SOEs have the potential for good governance, efficiency and better performance. However, most SOEs are still not performing as expected. A study was conducted on the performance of the SOEs in Namibia, and the outcome confirmed that their performance was affected by how they are managed, which points back to leadership [4]. This justifies the need to investigate the impact of leadership style on the level of employee engagement and job satisfaction in the SOE to improve performance and be a contributor to the economic growth.

With the government as the majority shareholder, there have been political interferences in the operation of these SOEs, and this may be caused by change in leadership in the political parties [5]. When a president comes into power, they tend to reshuffle the ministers and appoint ministers that will support their vision for the country, which includes the operations and management of the SOEs. According to Kinanti et al [3], change in leadership is one of the reasons for the lack of performance of employees, and the organisation's leaders require an effective leadership style to improve the organisational performance [5]. In summary, leadership influences organisational behaviour; therefore, it is important for the organisation to appoint the leaders that will be able to match the organisational culture.

1.1 Background of the study

With the government as the majority shareholder, there have been political interferences in the operation of these SOEs and this may be caused by change in leadership in the political parties. When a President comes into power, they tend to reshuffle the ministers and appoint ministers that will support their vision for the country, which include the operations and management of the SOEs. Change in leadership is one of the reasons for the lack of performance of employees, and the organisation's leaders require an effective leadership style to improve the organisational performance [5].

1.2 Problem statement

Given the underperformance of the SOEs, it is of critical importance to identify the leadership style employed at an SOE, and evaluate the impact is has on employee engagement and job satisfaction.

2 LITERATURE REVIEW

2.1 Leadership defined

Leadership is the process of having a certain influence in a group and guiding it to achieve its goals through such influence [6]. Leadership as the process of social influence in which leaders seek and organise followers' participation to achieve organisational goals [7]. Leadership can also be described as the weapon of the organisation to accomplish its goals and its necessary objectives, and without it, it is impractical for the organisation to attain its main target [8]. Therefore, leadership can be summarised as the process applied by the organisation to influence an individual or a group of people in an organisation to achieve the desired output.

2.2 Leadership theories

Leadership studies employ several theories to guide their research. Contingency leadership theory was found to be the suitable lens to be used for this research, as it has the tenets and contrasts that are aligned to the overall study proposed. This theory provides the researchers an opportunity to explore a variety of leadership styles in an organisation, as leaders are not limited to their effectiveness on certain situation [9].

2.2.1 Leadership style as a contingency variable

The leadership style as the characteristic behaviours of a leader in motivating, guiding and managing the employee with the aim of making them to work effectively, and using their strength and weaknesses to optimise their output [10]. Transactional and transformational leadership styles will be explored in this research as they are considered to be the most successful management and leadership approaches in the 21st century, and it is recognised that both leadership styles has potential of increasing organisational performance depending on the situation at hand [11].

The study of the transformational and transactional leadership styles is aligned to the contingency theory.

2.2.2 Transformational leadership style

Transformational leaders are leaders who motivate their subordinates by identifying their potential and by instilling hope, trust, optimism and positive emotions [12]. Transformational leaders are confident and trusted by their employees, and their management style leads to high productivity and great performance [7]. The findings of a study into transformational and transactional leadership concurred with the definition of transformational leadership as the leader who believes in identifying, developing and mentoring their subordinates to improve the organisational performance [12]. In several studies, a multifactor leadership questionnaire (MLQ) was used to determine the relationship between transformational leadership and job satisfaction, and the results were significant and positive [13] – [15]. The same studies revealed that transformational leadership is positively related to job satisfaction during organisational change [13]. The application of the leadership style is dependent on the situation; therefore, leaders are effective to increase job satisfaction when the right leadership style is employed [16]. It is worth testing the relationship between the transformational leadership style and job satisfaction in the SOEs as the research outcome might be different.

2.2.3 Transactional leadership style

Transactional leadership involves the exchange of resources such as rewards for the benefits of both parties, and organisation leaders use the reward and punishment mechanism as a form of motivation to manage organisational performance [7]. In this case, leaders believe that personnel perform their duties successfully if they know that they will get a reward in exchange. This mechanism is not sustainable as employees tolerate it for a short duration due to the reward and punishment aspects associated with it [14]. Therefore, if it happens that the company does not pay the incentives; employees will leave the organisation for better rewards. In this leadership style, leaders set targets and delegate their power to subordinates so that they can work according to their capabilities and only intervene when required [7], [17]. A transactional leadership style is based on maintaining the status quo of the organisation and it does not promote organisational change [14]. In university guest houses in South-West Nigeria, the transactional leadership style with a contingent reward was found to have a positive but weak relationship with the satisfaction of the employee with their job [18]. De Lay et al [19] posits that MR TechnologistsThe relationship between leadership styles and job satisfaction, that is, the transformational and transactional leadership quality, had significant positive correlations with overall job satisfaction. In summary, two researchers conducted a study on the relationship between transactional leadership style and job satisfaction, and they found different outcomes, which confirm that organisations differ and leadership styles are situational.

2.3 Employee engagement as a contingency variable

Employees are the most important asset of organisations and their role includes driving the organisation’s strategies that contributes to good outcomes for an organisation. Organisations need to make an effort to ensure that they create better performance by involving the employees in their organisational activities and to make them enthusiastic in their employee engagement [18], [20]. Employee engagement influences performance and employee engagement influences the employee’s behaviour when they are doing their activities; therefore, it is important for the organisation to have effective leadership that is able to engage its employees to contribute to good outcomes for an organisation [19]. This style of leadership encourages problem-solving culture among the employees. It also opens a room for individual growth and self-development among employees.

2.3.1 Leadership style and employee engagement

Sulamuthu and Yusof [21] identified a positive relationship between leadership style and employee engagement. Transformational leadership and pragmatic leadership impacted on staff performance, and transformational leadership is one of the key factors that increases employee engagement in an organisation [21]. There are different views with regard to employee engagement; many superiors believe that it is about keeping the employees happy, whereas the engagement is about encouraging employees to perform above par in achieving the aims of the organisation [21]. In summary, leadership style is a key factor for organisations in achieving its goals and meeting targets.

Employees react to the leadership style, positive or negative, depending on how they are engaged in the implementation of the style instilled. Leadership style, employee engagement and work environment to employee performance in manufacturing companies, there is a positive influence between transactional leadership style and employee engagement [20].

Breevaart and Bakker [17] investigated the relationship between daily transformational leadership behaviour and employee work engagement, and the results showed a variation on different days, which means that the function of transformational leadership behaviour changes from day to day, and depends on the type of job demand.

In summary, there is a positive relationship between the leadership styles and employee engagement.

2.4 Job satisfaction as contingent variable

Job satisfaction is the pleasure that employees get when performing their duties. Lan et al. (2019) defined job satisfaction as the level in which an employee achieves positive results through positive attitude and effective orientation [7]. A satisfied worker is more efficient and effective in an organisation, and highly satisfied employees have a positive attitude towards their work, whereas unsatisfied workers have a negative attitude towards their work [7].

In summary, job satisfaction is based on how employees perceive their job, and the extent to which they are happy with their jobs.

2.4.1 Leadership style and job satisfaction

Studies have argued that neither transactional nor transformational leadership styles are capable of improving employee motivation and satisfaction [7] and transformational leadership is more effective in increasing employee commitment, performance and job satisfaction [23]. Transformational leadership improves employee perception and commitment towards the organisation [24], and both transactional and transformational leadership affect the satisfaction level of employees [25]. Several studies have revealed that there is a positive relationship between transactional and transformational relationships; however, the study by Long et al. [16] are in disagreement with this view, as their research revealed that not all the transformational leadership styles are positively related to the job satisfaction.

Therefore, it is important for the leadership to recognise that organisations differ, and the outcome of this research might support or oppose the positive relations between the transformational leadership style and job satisfaction in the study of the SOEs.

2.5 Conceptual framework

Figure 2 shows the conceptual framework that was used to assist the researcher in studying the relationship between the leadership styles and the employee engagement and job satisfaction as well as measuring the effect that each variable has on one another.

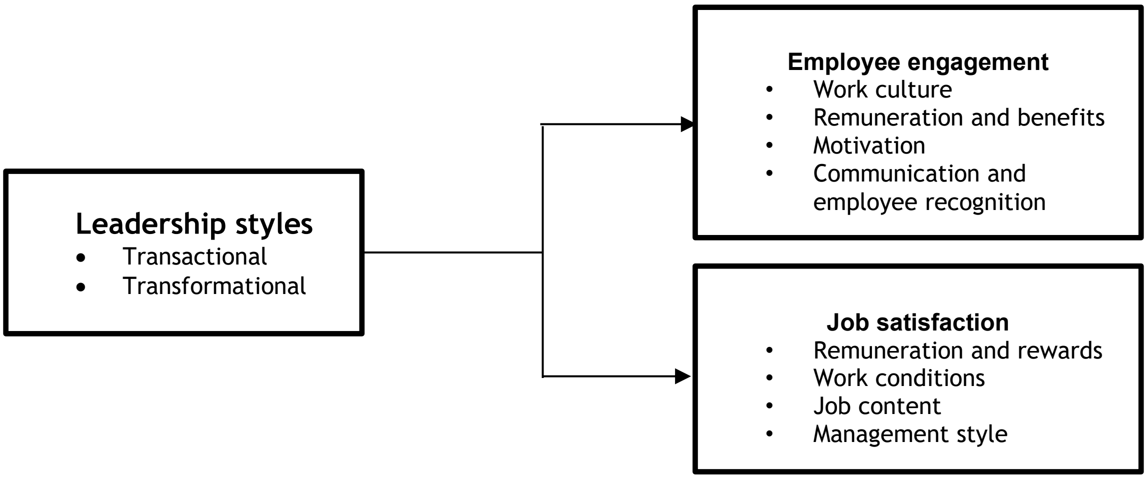

Figure 2: Conceptual framework (source: authors)

3 METHODOLOGY

For this research study, a quantitative research approach was utilised. A self-administrative online questionnaire was distributed to the respondents through an e-mailed link, to measure the impact of leadership style on the level of employee engagement and job satisfaction at an SOE. The link was sent to 135 participants as the sample method was census sampling; only 100 participants responded and the data was exported to Microsoft Excel, which was analysed by a statistician. Cronbach's alpha index was used to generate and measure the robustness and reliability of the questionnaire [26].

3.1 Quantitative research methodology

Quantitative research focus on identified variables and the relationship among them. Therefore, a quantitative research approach is adopted as it allows the researcher to test the hypotheses by gathering the required data, analysed through statistical analysis, and draw conclusions [27], [28]. In quantitative research, an analytical survey in the form of a questionnaire is used for data collection, and it provides a broad capability of providing accurate samples that can be used to make conclusions and good decision making.

3.1.1 Population and sample framework

In this study, the population consists of full time employees of the SOE. One entity is used for the purpose of this study. This organisation has a total population of 34 773 permanent employees based in nine different provinces. The researcher narrowed the population size down to cover the division of the organisation with the technical team and the supervisors, amounting to 135, as they are mainly involved in the day-to-day operations within the organisation. A non-probability sampling method in the form of a census sampling was used, and the respondents were selected based on their technical involvement in the organisation.

Purposive sampling was used for selecting participants for the sample size of 135, which is 100% of the population size in different sections of the organisation. Strydom and De Vos (1998) state that a sample population of 100 is sufficient for a 500 population size; therefore, the sample size will be fully representative of the entire population,. According to Blumberg et al. (2014), one of the studies indicates that more than 90% of the total survey error was from the non-sampling sources and only 10% or less was from the random sampling error; therefore, the sample will produce fewer errors compared to the other. Questionnaires (see Appendix A) were sent to the respondents through an e-mailed link, and the respondents were given an opportunity to consent to participate before they can proceed with the completion of the survey. The consolidated data was gathered and analysed by a statistician.

3.1.2 Data analysis methods, techniques and instruments

Data collected was analysed using statistical analysis and descriptive analysis such as mean, standard deviations, skewness and kurtosis to calculate and analyse the data. The reason for using the statistical method is to find patterns and meaning of ordinal data that can be used to relate the variables as per the research problem [28].

4 RESULTS AND DISCUSSION

4.1 Reliability and validity of data

This study used the Cronbach's alpha index generated by the SPSS to measure the robustness and reliability of the questionnaire. The reliability statistics for the study constructs are shown in table 1. The results indicate that the reliability of all the constructs was good, ranging between 0.949 (for employee engagement) to 0.958 (for job satisfaction).

Table 1: Reliability statistics

Construct	Cronbach's alpha	No. of items
Employee engagement	0.949	15
Job satisfaction	0.958	15
Organisational leadership	0.951	15

It should be noted that all the scores of the employee engagement were added to obtain or form the variable “employee engagement”; similarly, all the scores of the different items that were used to measure job satisfaction were added to form a variable labelled “job satisfaction”, and all the scores of the different items that were used to measure organisational leadership were added to form a variable labelled “organisational leadership”.

4.2 Demographic Information

4.2.1 Departmental participation

Table 2 shows the frequency distribution of departments that participated in the research. The majority of respondents came from Engineering (30%), Maintenance 25%) and Chemical services (16%).

Table 2: Name of organisation

	Frequency	Percent
Chemical services	16	16.0
Engineering	30	30.0
Maintenance	25	25.0
Operation	8	8.0
Other	21	21.0
Total	100	100.0

4.3 Inferential data analysis

4.3.1 Frequency distributions of the key study constructs

In this study, the items of employee engagement, job satisfaction and organisational leadership were measured on a 5-point Likert scale, where: strongly agree = 1, agree = 2, neutral/undecided = 3, disagree = 4 and strongly disagree = 5.

4.3.2 t-test

The t distribution was used to compare the mean scores on the Likert scale with the undecided or neutral score of 3, which was the mid-point between disagree and agree by applying the one-sample t-test.

$$T = \frac{\bar{x}-\mu}{s/\sqrt{n}}$$

Where $\bar{x}$ is the mean score, μ is the assumed mean value (in this case, it equals to 3), s is the standard deviation of the scores, x_i (where i = 1, 2, …30) and n is the sample size.

As an example, for question 1 (section B of the questionnaire: I feel involved in the future growth and direction of my organisation), the calculated mean score for the respondents is 2.95 (std. dev.= 1.226), which is lower than 3 (and t = -0.408, p-value=0.684>0.100) at the 10% level of significance. This meant that the respondents were undecided on this statement. This indicates that the p-value is statistically significant and should be considered.

The results indicate that respondents agreed with most of the statements; they were neutral on:

Employee engagement

Table 3: Employment engagement t-test results

Topic	T -value	p-value	Interpretation
I feel involved in the future growth and direction of my organisation	-0.408	0.684	The p value indicates that item is significant at the 10% level.
I feel engaged whenever there is a change in my organisation	-1.155	0.251	The p value indicates that item is significant at the 10% level.
I receive continual feedback for my contribution in the organisation	0.754	0.452	The p value indicates that item is significant at the 10% level.
I discuss my career growth with my supervisor timeously	1.130	0.261	The p value indicates that item is significant at the 10% level.
I believe that my organisational leadership team communicates honestly and timeously	0.695	0.489	The p value indicates that item is significant at the 10% level.

Job satisfaction

Given an opportunity to move to another organisation, I will still choose my organisation (t=-1.429, Prob.=0.156>0.100). The item is significant at the 10% level of significance.

Organisational leadership

Table 4: Organisational leadership t-test results

Topic	T -value	p-value	Interpretation
My manager appreciates my work efforts	1.421	0.158	The p value indicates that item is significant at the 10% level.
My manager helps me understand the strategic goals of the organisation	1.445	0.152	The p value indicates that item is significant at the 10% level.
My manager treats everyone in the team fairly	1.643	0.522	The p value indicates that item is significant at the 10% level.
My manager involves the team in the decision making	0.422	0.674	The p value indicates that item is significant at the 10% level.
Leadership of my organisation is fair and transparent	1.023	0.232	The p value indicates that item is significant at the 10% level.
My organisation encourages employees to celebrate each other's success	-1.203	0.115	The p value indicates that item is significant at the 10% level.
My organisation benefits are the key factor that retains employees	-1.590	0.115	The p value indicates that item is significant at the 10% level.
My manager demonstrates open and transparent communication	-1.461	0.187	The p value indicates that item is significant at the 10% level.
My manager creates an environment that promotes creative thinking and new ways of approaching problem solving	1.329	0.187	The p value indicates that item is significant at the 10% level.

It should be noted that the respondents were neutral on a large number of organisational leadership items. This is a cause for concern; it calls for some leadership attention, especially if you consider all the above items of employee engagement for which they were also undecided, especially, *I believe that my organisational leadership team communicates* *honestly and timeously; and that of job satisfaction, Given an opportunity to move to another organisation, I will still choose my organisation.*

4.3.3 Tests of normality

4.3.3.1 Tests of normality: Employee engagement

The results in table 5 indicate that the dependent variable, employee engagement, is normally distributed according to its skewness of 0.139 and kurtosis of -0.913, which are within the acceptable range of -3 to 3; the values are close to zero; compared to the recommended cut off point of near zero (0). The normal Q-Q plot (figure 3) and box-whisker diagram (figure 4) were also checked; and they, however, indicate the opposite.

Table 5: Employee engagement statistics

Statistic	Value	Std. Error
Mean	2.7420	0. 0906
95% CI for mean (lower bound)	2.5622	
95% CI for mean (upper bound)	2.9218	
5% Trimmed mean	2.7415	
Median	2.6000	
Variance	0.821	
Std. dev.	0.906	
Minimum	1.000	
Maximum	4.600	
Range	3.600	
Intermediate range	1.580	
Skewness	0.139	0.241
Kurtosis	-0.913	0.478

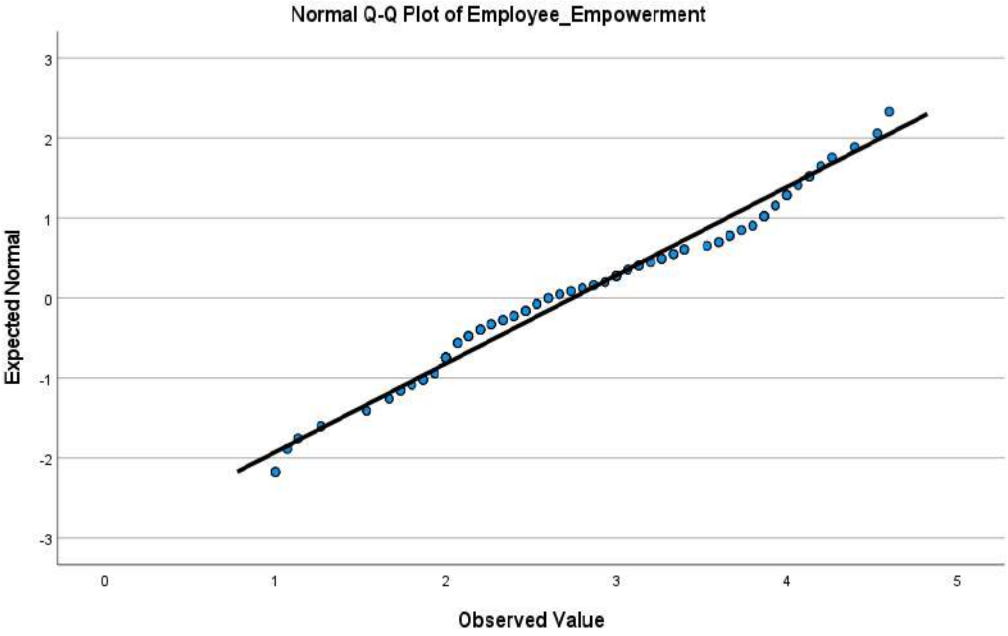

Figure 3: Normal Q-Q plot for employee engagement

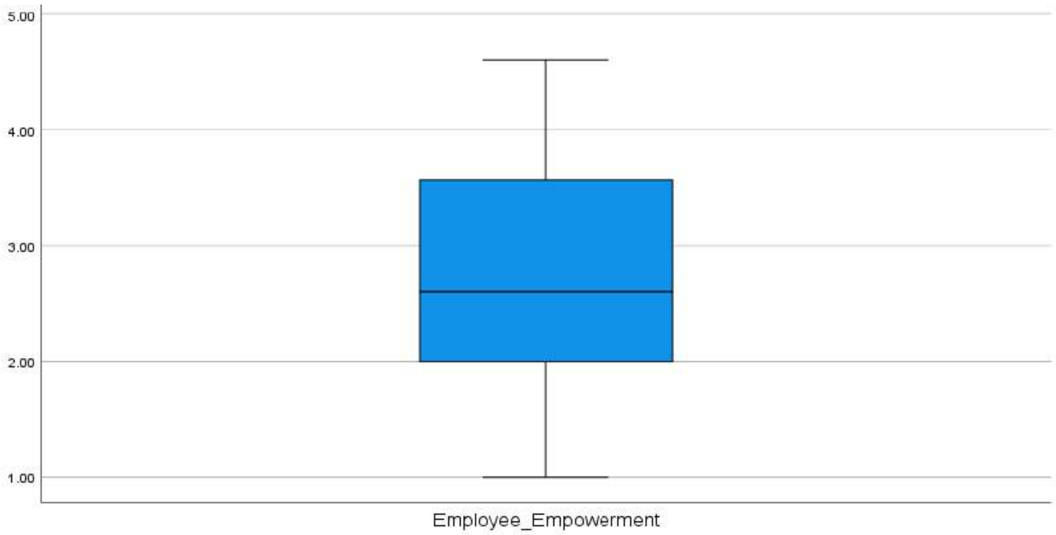

Figure 4: Box-whisker plot for employee engagement

In this case of the normal Q-Q plot and the box-whisker diagram, the distribution does not clearly approximate normality since, for example, some data points do not fall on the straight diagonal line. The following tests of normality were also done. The null hypothesis being tested is that the distribution follows the normal distribution. According to table 6, the Kolmogorov-Smirnov test (KS) and Shapiro-Wilk test were used to test if the variable followed the normal distribution. It tests how much the data differs from normality. If the deviation percentage is quite small, the probability or p-value will be high; otherwise, it will be small. So, a **large** deviation has a **low p-value**. As a rule of thumb, we reject the null hypothesis if $p < 0.05$. So, if $p < 0.05$, we do not believe that the variable follows a normal distribution in the population.

Table 6: KS and Shapiro-Wilk tests for employee engagement

Kolmogorov-Smimov			Shapiro-Wilk		
Statistic	df	p-value	Statistic	df	p-value
0.085	100	0.071	0.970	100	0.021

The results for the Kolmogorov-Smimov test show that the p-values are higher than 0.05, the level of significance; hence, we do not reject the null hypothesis that the data follows the normal distribution. However, for the Shapiro-Wilk test, the p-values are less than 0.05, which indicates that we should reject the null hypothesis and accept the alternative hypothesis that the distribution of the variable is not normally distributed. This, therefore, implies that we have to interpret the results of regression analysis with caution.

4.3.3.2 Tests of normality: Job satisfaction

The results in table 7 below indicate that the dependent variable “job satisfaction” is normally distributed according to its skewness of 0.496 and kurtosis of -0.557, which are within the acceptable range of -3 to 3; the values are close to zero; compared to the recommended cut off point of near zero (0). The normal Q-Q plot (figure 5) and box-whisker diagram (figure 6) were also checked; and they, however, indicate the opposite.

Table 7: Job satisfaction statistics

Statistic	Value	Std. error
Mean	2.619	0.09492
95% CI for mean (lower bound)	2.431	
95% CI for mean (upper bound)	2.807	
5% Trimmed mean	2.594	
Median	2.333	

Statistic	Value	Std. error
Variance	0.901	
Std. dev.	0.949	
Minimum	1.000	
Maximum	4.930	
Range	3.930	
Intermediate range	1.450	
Skewness	0.496	0.241
Kurtosis	-0.557	0.478

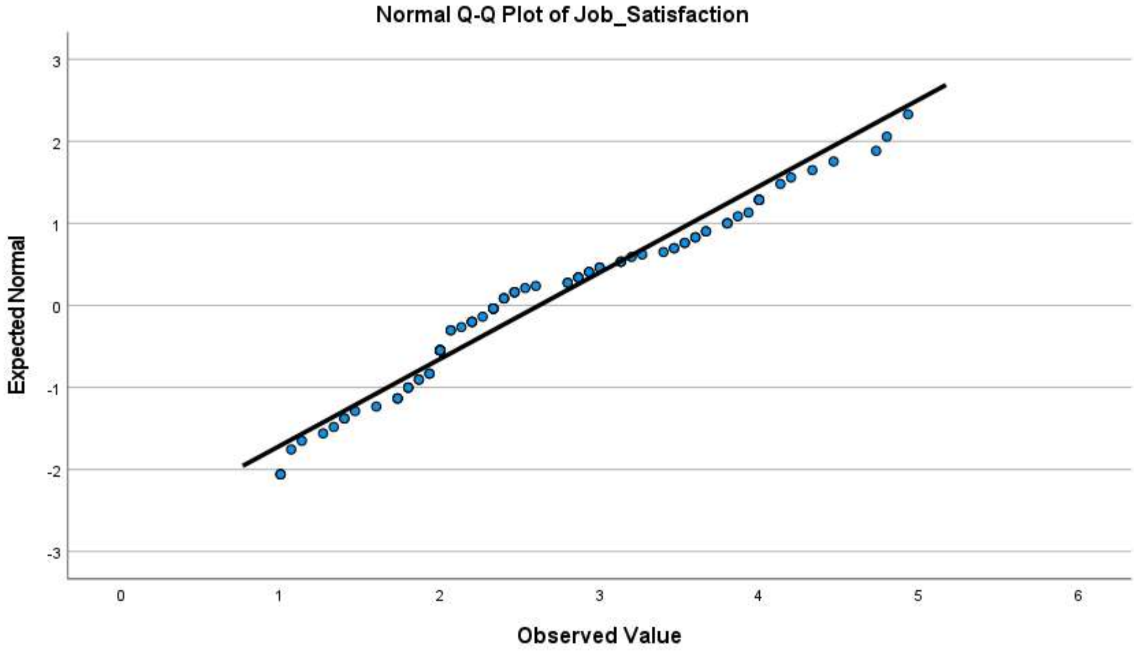

Figure 5: Normal Q-Q plot for job satisfaction

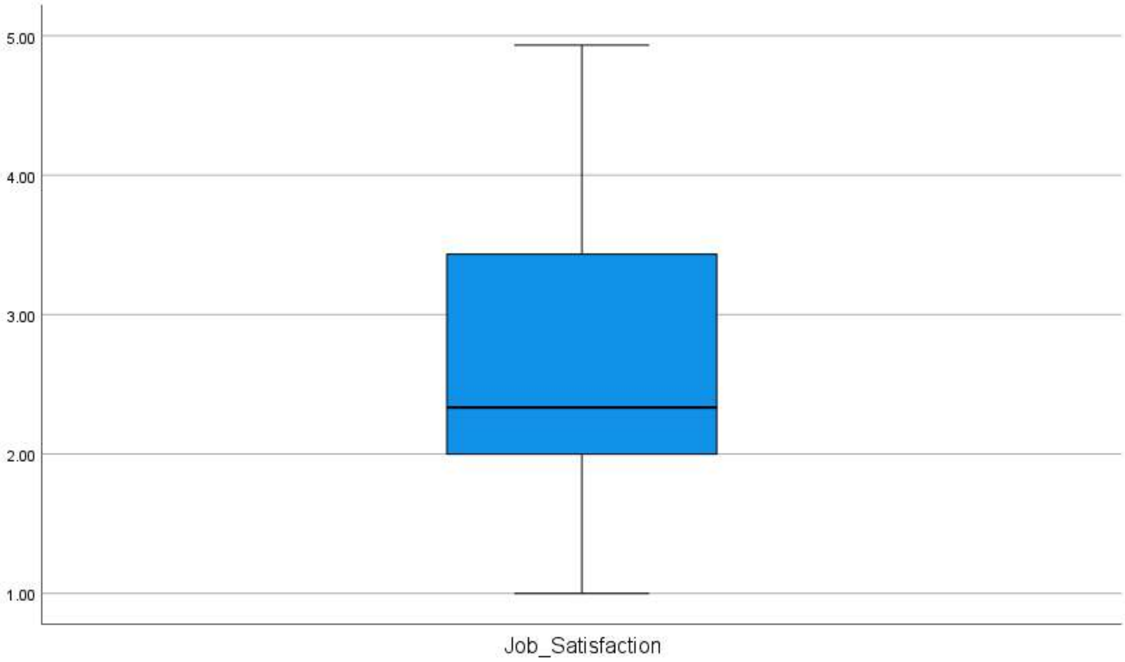

Figure 6: Box-whisker plot for job satisfaction

The results in table 8 indicate that according to the Kolmogorov-Smirnov test (KS) and Shapiro-Wilk test, we should reject the null hypothesis that the data follows the normal distribution, and accept the alternative hypothesis that the distribution of the variable is not normally distributed. This, therefore, like in the case of employee engagement, implies that we have to interpret the results of regression analysis with caution.

Table 8: KS and Shapiro-Wilk tests

Kolmogorov-Smimov			Shapiro-Wilk		
Statistic	df	p-value	Statistic	Df	p-value
0.144	100	0.000	0.950	100	0.001

For the inferential analysis, the quantitative data analysis was done using multivariate statistical analysis, more specifically correlation analysis and regression analysis.

4.3.4 Correlation

Part of table 9 shows the correlations of some of the study variables (that is, organisational leadership, employee engagement and job satisfaction) at the 1% level of significance.

Table 9: Correlation matrix

	Organisational leadership	Employee engagement	Job satisfaction
Organisational leadership	1		
Employee engagement	0.834** (0.000)	1	
Job satisfaction	0.700** (0.000)	0.803** (0.000)	1

4.3.5 Regression data analysis

Regression analysis helps us to understand how a value of the dependent variable changes when any one of the independent variables is varied, while the other independent variables are held constant. The analysis is widely used for modelling the data generating process, forecast and to understand which among the independent variables are related to the dependent variable, and to explore the forms of these relationships. It was assumed that these assumptions were not violated; otherwise, the coefficient estimates would be biased. These are sufficient conditions for the estimates to possess desirable properties, of being unbiased, consistent and efficient.

In the multiple regression models, there are p independent variables:

$$y1=\beta 1x1+\beta 2x2+\ldots Bpx1p+C1y_1 = \beta_1 x_1 + \beta_2 x_2 + \cdots Bpx_1 p + C_1$$

where x_{ij} is the i^{th} observation on the j^{th} independent variable.

The residual, $c_1 = y_i - \hat{y}_1$, is the difference between the value of the dependent variable predicted by the model, $\hat{y}_i$ and the true value of the dependent variable y_i.

The residual can be written as:

$$y_1 = \beta_1 x_1 + \beta_2 x_2 + \cdots Bpx_1 p + C_1$$

The method of estimation, ordinary least squares minimises the sum of squared residuals,

$$SSE = \sum_{t=1}^{N} e_i^2$$

These are the normal equations which are solved to yield the parameter estimators.

In matrix notation, the normal equations are written as:

$$(X^T X)\hat{\beta} = X^T Y$$

where the ***ij*** element of is x_{iJ}, the *i* element of the column vector *Y* is y_i, and the *j* element of B_i is B_J. Thus *X* is *n*×*p*, *Y* is *n*×1, and β is *p*×1. The solution is:

$$\hat{B} = (X^T X)^{-1} X^T Y$$

Once a regression model has been estimated, it is important to confirm the goodness of fit of the model by calculating the R-square and the statistical significance of the estimated parameters. Statistical significance is normally checked by an F-test of the overall fit using the ANOVA table, followed by t-tests of individual parameters.

4.3.5.1 Employee engagement

In this study, a regression model was fitted to determine the effect of organisational leadership on employee engagement. The results are shown in table 10.

Table 10: Regression model for employee engagement

Model	Sum of squares	Df	Mean squares	F	Prob.
Regression	56.553	1	56.553	224.087	0.000
Residual	24.732	98	0.252		
Total	81.286	99			

Adj. R^2= .693

Table 11: Regression model for organisational leadership

	Coeff	Std. error	Beta	t	Prob.
(Constant)	0.406	0.164		2.478	0.015
Organisational leadership	0.827	0.055	0.834	14.970	0.000

The results indicate that the model is highly significant (F=224.087, Prob.=0.000<0.010) with adjusted R^2 of 0.693, which indicates that the model explains 69.3% of the variation in the data. Organisational leadership affects employee engagement (t=2.478, Prob.=0.015<0.050) positively such that good organisational leadership will enhance employee engagement.

4.3.5.2 Job satisfaction

Another regression model was fitted to determine the effect of organisational leadership on job satisfaction, and the results are shown in table 12.

Table 12: Regression model for job satisfaction

Model	Sum of squares	Df	Mean squares	F	Prob.
Regression	43.686	1	43.686	94.077	0.000
Residual	45.508	98	0.464		
Total	89.194	99			

Adj. R^2= 0.485

Table 13: Regression model for organisational leadership

	Coeff	Std. error	Beta	t	Prob.
(Constant)	0.566	0.222		2.547	0.012
Organisational leadership	0.726	0.075	0.700	9.699	0.000

The results indicate that the model is also highly significant (F=94.077, Prob.=0.000<.01) with adjusted R^2 of 0.48.5, which indicates that the model explains 48.5% of the variation in the data. Organisational leadership affects job satisfaction (t=9.699, Prob.=.0000<.01) positively such that good organisational leadership will enhance job satisfaction.

5 CONCLUSIONS

The objective of this research question was to determine the type of leadership style that is employed at a SOE in South Africa. Identification of the leadership style is important because every situation is different and leadership style applied depend on the internal and internal situation at hand [5]. Leadership of the organisation need to identify and understand the type of leaders that they are bringing to the organisation because leadership styles are required to manage the culture to achieve the organisational objectives, by either changing the culture or re-enforcing the existing culture of an organisation [8]. In this study, transactional and transformational leadership styles were explored through the use of a questionnaire, so respondents were required to answer accordingly.

The data indicates that the respondents were neutral on a large number of organisational leadership items meaning that they were indecisive during their response. This is concerning and it calls for some leadership attention, especially when considering all the items of employee engagement for which the respondents were also undecided. In the employee engagement section, the majority of the respondents believe that their organisational leadership team communicates honestly and timeously, while regarding job satisfaction, the majority of the respondents were neutral in their answers and believe that given an opportunity to move to another organisation, they will still choose their organisation.

The data on the effect of leadership style on employee engagement indicates that the regression model is highly significant (F=224.087, Prob.=0.000<0.0100) with adjusted R^2 of 0.693, which indicates that the model explains 69.3% of the variation in the data. Organisational leadership affects employee engagement (t=2.478, Prob.=0.015<0.050) positively such that good organisational leadership will enhance employee engagement.

Regarding the effect of the leadership style on job satisfaction, the results presented indicate that the model is also highly significant (F=94.077, Prob.=0.000<0.010) with adjusted R^2 of 0.48.5, which indicates that the model explains 48.5% of the variation in the data. Organisational leadership affects job satisfaction (t=9.699, Prob.=0.000<.01) positively; thus, good organisational leadership will enhance job satisfaction.

There is no conclusion on the type of leadership currently employed at a SOE as most of the questions under organisational leadership were answered as neutral; therefore, the suitable leadership style cannot be recommended as the theory explains that both have a potential of influencing job satisfaction in a positive and negative manner.

6 RECOMMENDATIONS

- It is recommended that organisational leadership should be attended to enhance employee engagement and job satisfaction.
- It is recommended that the leadership of the organisation should do an in-depth review/survey on leadership to address issues that were highlighted in section 4 and need to be addressed. It is recommended that employee engagement as a variable addressed as the majority of the employees could not decide whether they are engaged or not.
- Perhaps another aspect of the recommendation could be to do a 360 degree review of the leadership team, which allows the organisation to give feedback on each and every leader, it could also be a valuable tool to determine which leaders style seems to be resonating with employees

7 BENEFITS OF THE STUDY

The study will serve as a source of reference for a state-owned entity in the type of leadership required to improve the employee engagement and job satisfaction.

8 LIMITATIONS OF THE STUDY

The MAIN limitation was to determine the representative sample as the chosen organisation comprises about 34 773 permanent employees based in nine provinces at various divisions.

Thus, on this limitation, the researcher narrowed the population size down to cover the division of the organisation with a total number of the technical team and the supervisors amounting to 135. These respondents are personnel mainly involved in the day-to-day operation within the organisations.

9 MANAGERIAL IMPLICATIONS

Data analysis from the study could not reveal the type of leadership style currently employed at an SOE, as the majority of the respondents were indecisive on the part that speaks to organisational leadership, which makes it difficult to draw conclusions. Therefore, it was concluded that further research should be conducted in this area.

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APPENDIX A: QUESTIONNAIRE

This survey/questionnaire serves as an integrated, holistic, organisational diagnostic addressing critical factors affected by the change in leadership styles in an organisation.

Section A: Demographic information

Please complete demographic information below and note that the information is required for reporting purpose and will be kept confidential.

What is the name of your organisation?

Which department are you working for?

What is your designation?

What is your highest qualification?

What is your gender?

Female	Male

Section B: Strategic leadership questionnaire

The following questions are comprised of employee engagement and job satisfaction. Please answer honestly and note that there is no wrong or right. The first 15 questions addresses the Employee engagement, 15 for job satisfaction and the last 15 organisational leadership. Please answer them by using the rating scale below. Rating scale: 1= strongly agree, 2= Agree, 3=Neutral, 4=Disagrees, 5= strongly disagree

Employee Engagement	
	Rating
I feel involved in the future growth and direction of my organisation.	
I feel engaged whenever there is a change in my organisation.	
I receive continual feedback for my contribution in the organisation.	
I am aware of the company strategic plan.	
I understand the strategic goals of my organisation.	

I have a good understanding of my roles and responsibilities .	
My organisation communicates the vision and vision of the organisation effectively.	
I discuss my career growth with my supervisor timeously.	
My organisation acknowledges excellence and success.	
My organisation promotes teamwork.	
My organisation create a platform to express my views and opinions with the team.	
I believe that success of the organisation is shared with its employees.	
I believe that my organisational leadership team communicates honestly and timeously.	
I am aware of the communication platforms in my organisation.	
I am aware of my organisation s expectation.	
Job Satisfaction	
	Rating
I enjoy working at my organisation.	
I understand my contribution to my organisation.	
I am satisfied with the opportunities that I am offered in my organisation to enhance skills and knowledge.	
I enjoy working with my colleagues.	
My supervisor supports my career development.	
I understand my contribution towards the organisational goals and objectives.	
I feel emotionally invested and connected to my organisation.	
My organisational leadership inspires me to be the best in everything that I do.	
My organisational culture promotes innovation.	
I understand my contribution and how it contributes to the organisational objective.	
My organisational culture allows me to adapt to the changing requirements of the organisation.	

Given an opportunity to move to another organisation, I will still choose my organisation.	
I have the required skills and knowledge to perform my job.	
I would recommend my family and friends to work for my organisation.	
I feel that I am part of a high performance team.	
Organisational leadership	
	Rating
My manager appreciates my work efforts.	
My manager helps me understand the strategic goals of the organisation.	
My manager treats everyone in the team fairly.	
My manager involves the team in the decision making.	
My organisation rewards the team for good performance.	
My organisational leadership promote team work.	
My organisational culture is the one that drives excellence.	
Leadership of my organisation is fair and transparent.	
My organisation encourages employees to celebrate each other’s success.	
My organisational benefits are the key factors that retain employees.	
My organisation develops others to enable them to perform at their best.	
My manager demonstrates open and transparent communication.	
My manager create environment that promote creative thinking and new ways of doing in approach in problem solving.	
My manager promotes high standards and does not tolerate poor performance.	
My manager understands the business processes and applies them accordingly.	

ASSESSING ORGANISATIONAL SUPPORT STRATEGIES TO REDUCE TURNOVER INTENTIONS AMONG HEALTHCARE WORKERS

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ABSTRACT

The current COVID-19 global pandemic is presenting healthcare workers with a new set of challenges, such as longer shifts, irregular routines, shortage of equipment, and increased anxiety at the workplace. This places tremendous strain and healthcare workers and increases their intention to leave organisations. A quantitative research approach was used in this study, with a cross-sectional correlation survey methodology. The target population was 178 healthcare workers, and the sample size was 120 HCWs (RNs, ENs, and ENAs) who are employed permanently or full-time at a hospital. A probability sampling method with a random sampling technique was used. The results of this study are significant to stakeholders, as they clearly show that finding solutions to the problem of essential employees leaving organisations during a time of crisis is becoming a matter of extreme urgency. Healthcare services are critical at this time, and organisations should review the processes and procedures they employ to motivate their employees.

Keywords: healthcare, employee turnover intention, quantitative, organisational support, COVID19

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1 INTRODUCTION

In early December 2019, an outbreak of coronavirus disease 2019, caused by a novel severe acute respiratory syndrome coronavirus (SARS-CoV-2), occurred in Wuhan City, Hebei Province, China. On 30 January 2020, the World Health Organisation (WHO) declared the outbreak to be a Public Health Emergency of International Concern [1]. COVID-19 pandemic has affected the way in which organisations around the world operate, the way in which people interact with each other and the way countries relate toward each other, and it has also changed the traditional way of operating private hospitals [2]. Medical staff caring for COVID-19 patients face mental stress, physical exhaustion, separation from families, stigma, and the pain of losing patients and colleagues. While COVID-19 has not changed the role of healthcare workers (HCWs) [1], it has certainly increased their responsibilities within patient care. There is an ever-growing list of healthcare workers who have been infected or who have lost their lives due to the continued rise of COVID-19 [2]. This has led to a reduction in the roaming workforce, and continues to contribute to the overloading of the remaining few – some of whom are victims too, having contracted COVID-19 themselves. Fear and anxiety and the effects of these on mental health among healthcare workers facing the pandemic must be acknowledged and addressed [2].

The pandemic has increased employee intention to leave the healthcare sector, particularly among frontline workers who are responsible for caring for and handling COVID-19 patients. This study aims to measure the impact of employee support strategies on turnover intentions among employees working with COVID-19 patients at a hospital.

1.1 Background of the study

The ongoing pandemic caused by the coronavirus has drastically transformed the professional field of healthcare workers in South Africa and all over the world [2]. Healthcare workers are at the forefront of attending to patients suffering from COVID-19. This represents an increase in their daily workload because, prior to the outbreak of the virus, healthcare workers, particularly in South Africa, already had to contend with patients suffering from other diseases [3]. According to Ayla, Caitlin, Sheldon and Lauren [3], due to the current coronavirus pandemic, healthcare workers are now confronted with a new set of challenges, such as longer shifts, irregular routines, shortage of equipment, and increased anxiety at the workplace. This places tremendous strain on healthcare workers [4] and it increases their intention to leave the organisations where they work [5].

1.2 Research question

What is the impact of organisational support strategies on the turnover intentions among health care workers affected by COVID-19 at a private hospital?

1.3 Research objectives

1.3.1 *To explore the employee support strategies for HCWs affected by COVID-19 at the Hospital.*

1.3.2 *To determine the importance of employee support strategies for HCWs affected by COVID-19 at the hospital for the organisation and its employees.*

1.3.3 *To determine the causes of employee turnover intentions among HCWs affected by COVID-19 at the hospital.*

1.4 Hypotheses for the study

The following hypotheses are defined for this study. These were derived from the literature review.

1.4.1 Hypothesis 1: There is a relationship between organisation support and turnover intention of employees.

1.4.2 Hypothesis 2: *There is a relationship between training and development at the hospital and turnover intention of employees.*

1.4.3 Hypothesis 3: *There is a relationship between the COVID-19 work environment and turnover intention of employees.*

1.4.4 Hypothesis 4: *There is a relationship between communication and turnover intention of employees.*

2 LITERATURE REVIEW

2.1 Organisational support theory

The organisational support theory suggests that employees tend to form a general perception with regards to the support that they receive from the organisation. Ahmed and Nawaz [6] define POS as employee satisfaction with the organisation’s policies and its measures of respect for employee contribution. The organisational support theory will be used in this study to develop organisational support strategies that can be implemented for HCWs affected by COVID-19 as well as ways in which the healthcare system can improve, matters that directly impact HCW retention at a hospital.

2.2 Turnover intention theory

According to Nazim [7], turnover intentions may be defined as employees’ intent to leave their company. Employee turnover leads the organisation to suffer great losses, such as an increase in the cost of hiring and training of new incumbents; it also reduces productivity and negatively affects the morale of the remaining employees or team in the organisation. This is because the workload of the remaining employees will increase as experienced and skilled employees exit the organisation.

Mobley [8] developed a model in the year 1978 that proposed a number of intermediate relationships between job satisfaction and turnover as shown in Figure 1.

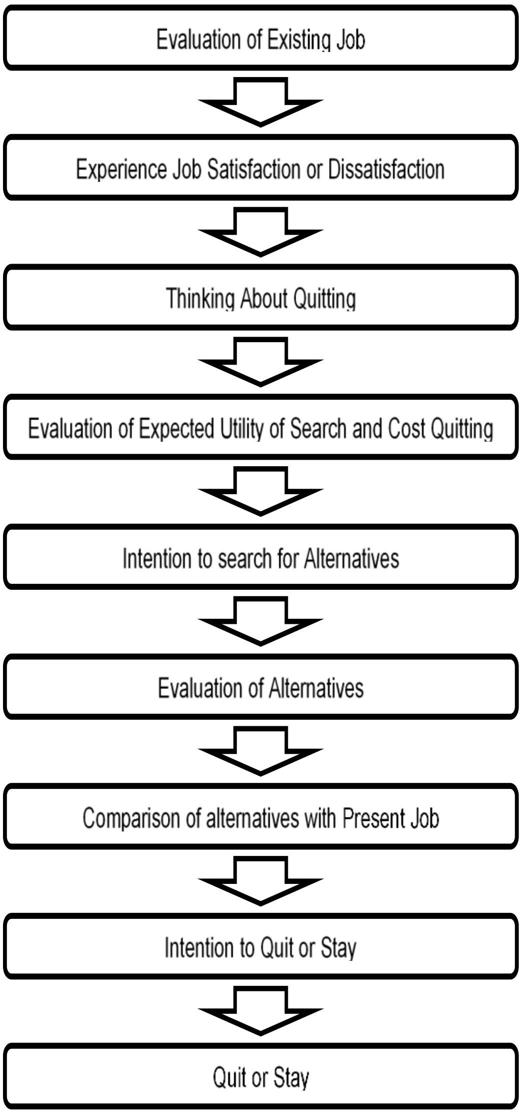

Figure 1: Mobley's Intermediate Linkage Model [8]

The model showed that, once job dissatisfaction happened, a desire to quit the job arises. As a result, when alternative opportunities arise, the employees' expectations matched the work opportunities presented, which could lead to turnover. Mobley also indicated that the biggest predictor of actual turnover is turnover intentions. This model is considered necessary because it treats turnover as a sequential process that can be stopped or blocked at any time.

2.3 Employee turnover intentions

Saengchai, Thaiprayoon and Jermsittiparsert [9] define employee turnover intentions as the process by which an employee decides to leave the employer. The issue of employee turnover has long been on the minds of businesses and organisations [10]. Turnover intentions are often an issue that affects employee desire in organisations. Employee turnover and retention research in the past has been primarily focused on the individual characteristics of the employees. The purpose of pursuing this solution is to avoid the negative effects of high turnover [11].

*2.3.1 **Hypothesis 1:** There is a relationship between organisation support and turnover intention of employees.*

2.4 Healthcare workers turnover intentions

A healthcare worker is a person who treats patients directly or indirectly, whether as a doctor or nurse, an aide, a helper, a laboratory technician, or even a medical waste handler [12]. Private hospital groups have had to act fast to deal with the COVID-19 outbreak [12]. There has been a reduction in the share price of three major private hospital groups in South Africa. A wide scope of employment opportunities for health workers in foreign countries, changes in the economy, cultural variations, educational growth, and change in technology, recruitment, and supervision strategies has also influenced the retention of nurses in South Africa [11].

2.5 Organisational and employee commitment

There are three types of employee commitment, namely.

- **Affective commitment** is defined as an employee's commitment and emotional bonding to the organisation. It also refers to how committed employees are to their organisation.
- **Continuance commitment** refers to an employee's desire to remain with the organisation. Continuance commitment is emotional, where an employee considers losing his or her or her membership in an organisation to be very costly [13].
- **Normative commitment** of an employee defines how long he or she feels he or she should remain with the organisation, with the employee deciding to reciprocate the commitment that he or she has gained from the organisation. An employee who has a normative commitment is generally inclined to stay with his or her organisation [14].

Therefore, the employee's commitment to stay with an organisation depends on the level to which the organisation commits itself to the employee. The organisation, therefore, has a huge responsibility to ensure that it proves itself through its commitment to its employees. This, in turn, will strengthen their long-term relationship and commitment toward each other. Lower organisational commitment, meanwhile, negatively affects employee commitment and/or employee turnover intentions and leads employees to look for an alternative organisation.

2.6 Reasons for turnover intentions and organisational support strategies

The shortage in supply of healthcare labour is a common phenomenon at the global level [15]. According to research presented at the World Health Organisation's third Global Forum on Human Resources for Health, the world will be short of 12.9 million healthcare workers by the year 2035, in both rich and developing countries. To address this anticipated gap, Health Report developed the Health Workforce Decade (2006–2015), emphasising the maintaining of high-quality health care personnel. Employees' turnover intentions are motivated by a variety of reasons, and more aspects of this phenomenon are still being discovered by scholars around the globe. According to Asimah [16], quality of work life, job satisfaction, organisational justice, environmental factors, job stress, and work attitudes are the most common drivers of employee voluntary turnover.

*2.6.1 **Hypothesis 2:** There is a relationship between training and development at the hospital and turnover intention of employees.*

This is important as perceived organisational support shows how an employee views the organisation's side of the transaction. The moment employees feel appreciated in the work environment and taken care of, while perceiving their employer as helpful, compassionate, and concerned about their well-being, they are likely to demonstrate favourable attitudes and behaviours, which include intention to stay [17]. Hence, it is to the benefit of the organisation to ensure that employees are satisfied and that they are thus retained in challenging environments such as COVID-19. The term "job satisfaction" describes a worker's attitude toward his or her job, taking into account organisational, social, and physical work atmosphere, as well as the compensation that he or she earns. Job satisfaction plays a major role in both attraction and retention of employees [16].

2.6.2 Hypothesis 3: There is a relationship between the COVID-19 work environment and turnover intention of employees.

2.7 Perceived organisational support for frontline healthcare workers

Given the stress and anxiety that has been part of working in healthcare since the COVID-19 outbreak in December 2019, COVID-19 has been linked with a lot of long-term stress among healthcare workers. In this light. some of the hospitals in China that were most affected by COVID-19 implemented a three-pronged approach to care for the mental health needs of staff [17]:

- *Psychological intervention* – medical teams developing online courses to manage common psychological problems.
- *Psychological assistance hotline* – team offering guidance and supervision to callers to help solve psychological problems.
- *Individual and group psychological interventions*, including activities to release stress.

However, employees were hesitant to engage with these. Interviews and communications with staff suggested that this reticence was due to a lack of immediate concern about being infected and their feeling they did not need psychological support. The employees concerned stated they needed more rest and personal protective supplies, and that they wanted mental health training or mental health staff to assist them when interacting with difficult or aggressive patients.

2.7.1 Hypothesis 4: There is a relationship between communication and turnover intention of employees.

3 METHODOLOGY

For this research study, a quantitative research approach was utilised. A self-administered online questionnaire was developed and sent to respondents.

3.1 Research paradigms

This study utilises the positivism approach, which emphasises scientific rationality by employing methods rooted in controlled measurements, systematic observations, and external controls. The positivistic view emphasises using natural science methods to study social realities. The rationale is to make predictions using measurable outcomes and to explain the predictions [18]. The study adopted the positivism approach as the philosophical method.

3.2 Cross-sectional study

In this study the researcher used a cross-sectional survey design to gain a holistic perspective of the research problem and understand how the organisational support strategies and HWC retention at a hospital are related.

3.3 Target population and sample size

3.3.1 Target population

A population can be defined as a group of people who have a common set of features. In this study, the population was 171 healthcare workers, and 120 HCWs who are permanently or fulltime employed at the Hospital. The researchers excluded managers, support services, admin staff and those HCWs on fixed-term contract employment, as well as those working through agencies.

3.3.2 Sampling procedure

The study used a probability sampling method with a random sampling technique, as the researcher did not set any-predetermined criteria for the 120 respondents selected.

3.4 Research measuring instrument

The term “measuring instrument” or “tools” refers to the different methods by which researchers acquire data from their respondents for their research project purposes [19]. A questionnaire with closed-ended questions was used as a measuring instrument in this study. The questionnaire with pre-determined answers was distributed to respondents to determine their opinions regarding topics aligned to the research objectives. The questionnaire is the instrument for the research that collects data from respondents through a sequence of questions. The questions have been derived from the literature review which was used to support the development of the questionnaire.

3.5 Pilot study

To ensure that the questionnaire was clearly and understandably written, some senior faculty from the University checked and approved the questionnaire, wherafter the researcher made minor changes in line with the quality assurance process.

3.6 Data collection management

Data collection is the systematic process of acquiring and measuring information on variables of interest to answer research questions, test hypotheses, and evaluate outcomes [19]. The literature review was conducted using the factors that influenced the developed the study. Once the factors were determined from the literature review the factors were tested through inferential statistical methods to determine the relevance and strength of the factors. This ensure the alignment to the literature review and analysis were aligned.

To ensure that the integrity of the research and data were maintained, the researcher honestly and accurately collected data. In addition, the respondents were provided with instructions for each portion of the questionnaire, which stated clearly what was required of the respondents before they completed it. Poor data collection may compromise the results of a study where the results are to be used to support recommendations for a hospital.

4 DATA ANALYSIS AND DISCUSSION

Survey questionnaires were distributed by hand to 120 respondents to collect the quantitative data, which, when analysed, produced descriptive and explanatory findings related to the demography of the respondents and the impact of organisational support strategies on the turnover intention among health care workers affected with COVID-19 at a hospital.

4.1 Demographic

The demographical information of the respondents is presented in this section.

4.1.1 Age group distribution

The age group distribution of the respondents is presented in Table 1.

Table 1: Age group distribution of respondents (*N* = 120)

	Frequency	Percentage	Cumulative percentage
18-29	14	11.7	11.7
30-39	45	37.5	49.2
40-49	39	32.5	81.7
50-59	18	15	96.7
60 & Older	4	3.3	100
Total	**120**	**100**	

Table 1 shows the age group frequency distribution. The results indicate that age groups 30-39 (37.5%) and 40-49 (32.5%) accounted for the largest numbers of respondents.

4.2 Descriptive statistics

A five-point response scale, anchored at extreme poles ("Strongly disagree" 1 to "Strongly Agree" 5) was used to score the items. A mean score of < 3 will be an indication that the respondents did not agree with the statement, while a mean score of > 3 will be an indication the respondents agree with the statement.

4.2.1 Organisation support

The descriptive statistics for organisation support are presented in Table 2.

Table 2: Descriptive statistics for Organisation Support (*N* = 120)

Items	N	Mean	Standard Error
Q1: My employer was able to help when I was infected with COVID-19.	120	2.35	1.15
Q2: I was given enough time to recover when I was infected with COVID-19.	120	2.29	1.18
Q3: I was recognised and valued for my contribution in fighting against the COVID-19 pandemic.	120	1.98	1.08
Q4: The organisation had reserved staff with certain expertise for Disaster Management protocols.	120	2.05	1.17
Q5: My company cares more about making a profit than about me.	120	3.91	1.32

The item with the lowest mean score reported was for Q3, stating: *"I was recognised and valued for my contribution in fighting against COVID-19 pandemic"* (Mean = 1.98; *SD* = 1.08), an indication that the respondents strongly disagreed with this statement. The highest mean score reported was for Q5, stating: "*My company cares more about making a profit than about me*" (Mean = 3.91; *SD* = 1.32), an indication that the respondents agreed with this statement.

4.2.2 Training and Development

The descriptive statistics for Training and Development are presented in Table 3.

Table 3: Descriptive statistics for Training and Development (*N* = 120)

Items	N	Mean	Standard Error
Q6: The organisation provided clear guidelines on the diagnosis and treatment of the patients infected with COVID-19 virus.	120	**1.86**	0.96
Q7: There was ongoing training and development to improve the understanding of care of patients with COVID-19.	120	1.73	0.84
Q8: My organisation provided enough funds for training and development of COVID-19 related initiatives.	120	1.74	0.86
Q9: My organisation gave us enough time-off to attend training-related activities.	120	1.70	0.86
Q10: Due to the ongoing training and development process to improve clinical skills, I feel that I have the necessary skills to care and expertise to care for COVID-19 patients.	120	**1.69**	0.90

The item with the lowest mean score reported was for Q10, stating: "*Due to the ongoing training and development process to improve clinical skills, I feel that I have the necessary skills to care and expertise to care for COVID-19 patients*" (Mean = 1.69; *SD* = 0.90), an indication that the respondents strongly disagreed with this statement. The highest mean score reported was for Q6 stating: "*The organisation provided clear guidelines on the diagnosis and treatment of the patients infected with COVID-19 virus*" (Mean = 1.86; *SD* = 0.96), an indication that the respondents strongly disagreed with this statement.

4.2.3 COVID-19 Work environment

The descriptive statistics for COVID-19 Work Environment are presented in Table 4.

Table 4: Descriptive statistics for COVID-19 Work Environment (*N* = 120)

Items	N	Mean	Standard Error
Q11: The organisation provided adequate Personal Protective Equipment (PPE) to protect staff, patients, doctors and visitors from cross-contamination or infection.	120	**1.68**	0.86
Q12: My organisation showed active concern for my well-being by providing the necessary tools of trade for efficient clinical outcome.	120	1.64	0.86
Q13: The organisation introduced new coping mechanisms for staff during COVID-19.	120	1.65	0.86

Q14: It was practically possible for everyone to keep the social distance amongst other nursing staff and COVID-19 infected patients	120	1.63	0.85
Q15: The work environment that was provided under COVID-19 was conducive.	120	**1.63**	0.85

The item with the lowest mean score reported was for Q15 stating: "*The work environment that was provided under COVID-19 was conducive*" (Mean = 1.63; *SD* = 0.85), an indication that the respondents strongly disagreed with this statement. The highest mean score reported was for Q11 stating: "*The organisation provided adequate Personal Protective Equipment (PPE) to protect staff, patients, doctors and visitors from cross-contamination or infection*" (Mean = 1.68; *SD* = 0.86). an indication that the respondents strongly disagreed with this statement.

4.2.4 Communication

The descriptive statistics for Communication are presented in Table 5.

Table 5: Descriptive statistics for Communication (*N* = 120)

Items	N	Mean	Standard Error
Q16: There was constant communication between management and staff.	120	1.66	0.90
Q17: My organisation kept me informed of the changes required in my working environment.	120	1.68	0.90
Q18: My organisation informed me of all COVID-19 protocol developments.	120	1.67	0.86
Q19: My manager listened attentively to my work environment issues and always responded in the way that I understood.	120	1.66	0.87
Q20: The organisation went an extra mile to ensure that employees were part of the solution to improve hospital operations.	120	1.66	0.87

The item with the lowest mean score reported was for Q16 stating: "*There was constant communication between management and staff*" (Mean = 1.66; *SD* = 0.90) an indication that the respondents strongly disagreed with this statement. The highest mean score reported was for Q18 stating: "*My organisation informed me of all COVID-19 protocol developments*" (Mean = 1.67; *SD* = 0.86), an indication that the respondents strongly disagreed with this statement.

4.2.5 Turnover Intention

The descriptive statistics for Turnover Intention are presented in Table 6.

Table 6: Descriptive statistics for Turnover Intention (*N* = 120)

Items	N	Mean	Standard Error
Q21: I have often considered leaving my job.	120	4.16	1.16
Q22: I have often become discouraged at work because I am not given the chance to achieve my personal goals.	120	4.18	1.12
Q23: I have often dreamt about finding another job that will improve my personal needs.	120	4.19	1.12
Q24: I frequently look forward to starting a new day at work.	120	2.06	1.10
Q25: I am satisfied with work in terms of meeting my personal needs.	120	**1.95**	1.08
Q26: I am likely to accept another job if it has similar pay levels as my current one if offered from another organisation.	120	**4.33**	0.94

The item with the lowest mean score reported was for Q25 stating: "*I am satisfied with work in terms of meeting my personal needs*" (Mean = 1.95; *SD* = 1.08), an indication that the respondents strongly disagreed with this statement. The highest mean score reported was for Q18 stating: "*I am likely to accept another job if it has similar pay levels as my current one if offered from another organisation*" (Mean = 4.33; *SD* = 0.94), an indication that the respondents strongly agreed with this statement.

4.3 Reliability and validity of the data

This study used the Cronbach's α generated by the SPSS to measure the robustness and reliability of the data collection tool (i.e., questionnaire) that was used in this study. The reliability statistics for the study constructs are shown in Table 7.

Table 7: Reliability statistics of the Questionnaire Scales

Construct	Cronbach's alpha index	No. of items
Organisation support	0.723	5
Training & Development	0.957	5
COVID-19 work environment	0.983	5
Communication	0.995	5
Turnover intention	0.296	6

The majority of the reported Cronbach Alpha values are above the guideline value of above 0.7, as recommended BY [20], which indicates that the resulting factors are reliable. Because the reliability of Turnover intention was low, item-total statistics were calculated to determine the item that was causing this. The results are reported in Table 8.

Table 8: Iterative reliability analysis for the Turnover intention Scale

ITEM	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Cronbach's Alpha if Item Deleted
Q21	16.71	4.612	0.7	-0.315
Q22	*16.69*	4.669	0.727	-0.319
Q23	16.67	4.759	0.697	-0.287
Q25	18.81	11.618	-0.451	0.615
Q26	18.92	13.321	-0.641	0.691
Q27	16.53	5.915	0.581	-0.068

From the results, if the item Q.26 were excluded, the Cronbach's Alpha of the Turnover intention Scale would increase to 0.691, which indicates that the Turnover intention are reliable [20].

4.4 Inferential statistics for the study

4.4.1 Correlation analysis

For the inferential analysis, correlation analysis and multiple regression analysis were conducted to give an indication of the relationships between organisation support, training and development, COVID-19 work environment and communication, and turnover intention.

Table 9: Inter-correlations matrix of the factors (*N* = 120)

	TI	OS	TD	CoWE	Coms
Turnover intention (T1)	1				
Organisation support (OS)	-.444**	1			
Training and Development (TD)	-.530**	.659**	1		
COVID-19 work environment (CoWE)	-.553**	.573**	0.852**	1	
Communication (Coms)	-.505**	.579**	0.829**	0.947**	1

A statistically significant negative correlation exists between Turnover intention and Organisation support (r = - .444); between Turnover intention and Training and Development (r = - .530); between Turnover intention and COVID-19 work environment (r = - .553); and between Turnover intention and Communication (r = - .505). The results indicate that the four variables are statistically significant and negatively correlated with between Turnover intentions. This means if the Turnover intention score of the organisation “improve” the scores for the other four factors will drop and vice versa. The largest correlation is .947, between communication and COVID-19 work environment. The correlation between communication and COVID-19 work environment is so high, which might cause a multi-collinearity problem in regression analysis. One solution for this kind of problem is to exclude one of the two variables from the regression model.

4.4.2 Regression analysis

A regression model was fitted for turnover intention to determine its factors. The results are shown in Table 10.

Table 10: Regression model of turnover intention

Model	Sum of Squares	df	Mean Squares	F	Prob.
Regression	20.933	2	10.467	28.832	.000c
Residual	42.474	117	0.363		
Total	63.407	119			

Adj. R^2 *= .319*

Table 11: Regression model of organisational support and organisational support.

Variable	Coefficient	Std. Error	Beta	t	Prob.
(Constant)	4.856	0.18		27.039	0
COVID	-0.392	0.082	-0.444	-4.813	0
Organisation support	-0.17	0.083	-0.19	**-2.053**	0.042

Table 12: Model excluding training and development and communication.

Excluded Varaibles	Beta In	t	Prob.	Partial Correlation	Collinearity Statistics
					Tolerance
Training & development	-0.115	-0.73	0.467	-0.068	0.231
Communication	0.254	1.071	0.286	0.099	0.101

The stepwise regression method was applied. The regression model is highly significant (28.832, Prob. = .000<.01), with an Adjusted R^2 of .319. This means that the model explains the variation in the data of 31.9%. Only COVID-19 and organisation support were included in the model. The effect of COVID-19 (*t* = -4.813, *Prob.* = .000 <.01) and organisation support (*t* = -2.053, *Prob.* = .042 <.05) is to discourage employees to leave as expected.

4.4.3 Hypothesis testing

In conclusion, the hypotheses of the study were tested, and the following results were obtained:

- **Hypothesis 1:** The hypothesis that there is a relationship between organisation support and turnover intention of employees has been accepted.
- **Hypothesis 2:** The hypothesis that there is a relationship between training and development of the Hospital, and turnover intention of employees needs further research.

- **Hypothesis 3:** The hypothesis that there is a relationship between COVID-19 work environment and turnover intention of employees has been accepted.
- **Hypothesis 4:** The hypothesis that there is a relationship between communication and turnover intention of employees needs further research.

5 DISCUSSION OF RESULTS

The study sought to answer the following research objectives:

5.1 Research objective 1

"To explore the employee support strategies for HCWs affected by COVID-19-19 at a hospital"

It was found that the respondents have a negative perception of their organisational support that will influence organisational performance.

Training and Development: It was found that, for Training and Development, the respondents disagreed with all the statements of the Training and Development Scale. The respondents reported that that they do not have the needed skills to care for COVID-19 patients and that the organisation did not provide clear guidelines on the diagnosis and treatment of patients infected with the COVID19 virus.

COVID-19 Work Environment: It was found that, for COVID-19 Work Environment, the respondents disagreed with all the statements of COVID-19 Work Environment Scale. The respondents perceived the work environment they work under as not conducive and that the organisation did not provide adequate Personal Protective Equipment (PPE) to protect staff, patients, doctors, and visitors from cross-contamination or infection.

Communication: It was found that, for Communication, the respondents disagreed with all the statements of the Communication Scale. The respondents reported that there was insufficient communication between management and staff and that the organisation informed the respondents of all COVID-19 protocol developments. It was found that the Registered Nurse, that yielded the lowest mean score, perceptions about the Communication that differ statistical significantly from the other to nursing categories.

Turnover Intention: It was found that, for Turnover Intention, the respondents agreed with most of the statements of Turnover Intention Scale. It was found that the work the respondents conducted does not satisfy their personal needs and that they do not look forward to a new day at work. Many of the respondents will leave their current employment if the opportunity arises.

In general, it was found that these results show that the hospital is currently experiencing a dire situation. This means that if the organisation's support, training and development, COVID-19 work environment and communication issues, all of which employees are not happy with, are not dealt with, there is a high probability that they will leave if they get a chance.

5.1.1.1 Research objective 2

"To determine the importance of employee support strategies for HCWs affected with COVID-19 at a hospital for the organisation and its employees"

It was found that the respondents have a negative perception of all the supporting functions the organisation offers. The respondents are not happy with the organisational support, training and development, communication, and their work experience. A statistically significant negative relationship was found to exist between Turnover intention and the other variables, Organisational Support, Training and Development, COVID-19 Work Environment and Communication. If the organisation is unable to improve its employee-supporting functions, it may experience employee shortages in future.

5.1.1.2 Research objective 3

'What are the causes of employee turnover intentions among HCWs affected by COVID-19 at the hospital?"

From the literature, it was found that employees' turnover intentions are motivated by a variety of reasons, and more aspects of this phenomenon are still are being discovered by scholars around the globe. Based on this finding it can be concluded that everything that influences the employee in a negative, or even a positive way within his or her work environment, or from outside the work environment, may serve as a motivation for the employee to leave his or her current job.

6 RECOMMENDATIONS

Based on this finding it is recommended that the organisation develop and adopt an organisational supporting strategies plan, which will include senior management, regional managers, line managers, team leaders and co-workers to support HCWs that are directly affected and/or working in COVID-19 units.

7 BENEFIT OF THE STUDY

In general, it was found that these results show that the Hospital is currently experiencing a dire situation. This means that if the organisation's support, training and development, COVID-19 work environment and communication issues with which employees are not happy with are not dealt with, there is a high probability that they will leave if they get a chance.

8 LIMITATIONS OF THE STUDY

One of the main limitations of the study is that it focuses on healthcare workers in a private hospital. Most of the people seeking healthcare services in South Africa go to public hospitals because the hospitals are subsidised by government, hence, most people can afford them. Thus, the findings of this study may not be applicable to public hospitals; hence its significance will be limited in this regard.

9 MANAGERIAL IMPLICATIONS

It was found that the respondents have a negative perception of all the supporting functions the organisation offers. The respondents are not happy with the organisational support, training and development, communication, and their work experience. The respondents indicated high levels of turnover intention that could have a serious impact on the bottom line of the organisation. Based on the findings, the development and effective implementation of employee support strategies for HCWs is very important for this organisation.

10 CONCLUSION

There is evidence, confirmed by the research, indicating that the organisational support towards HCWs affected by COVID-19 leads to reduction of HCWs turnover intentions and improves their retention at the organisation. The study also showed that a good working environment also improves HCW turnover. The study has indicated that the issue of HCWs affected by COVID-19 turnover is directly linked to lack of organisation support and poor working environment at the Hospital. This will provide the Hospital an opportunity to develop strategies that will focus on organisational support towards its HCWs that are affected by COVID-19 and improve their working environment which, will, in turn, will result in improving HCW turnover intentions.

The study has emphasised the fact that there is positive correlation between organisation support and the turnover intentions of HCWs affected by COVID-19. This is supported by the respondents' answers to the survey questions having ranked organisational support and working environment above the midpoint of the range. These factors are seen as obstacles to the attraction and retention of HCWs. The COVID-19 outbreak has worsened the situation as the government proactively created attractive remuneration packages for HCWs joining South African public hospitals on a permanent basis. This means that the hospital studied has lost a limited talent pool from which it could source HCWs who were previously readily available in the labour market.

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A SYSTEMIC APPROACH TO POTABLE WATER INFRASTRUCTURE MANAGEMENT IN RURAL SETTINGS – CASE STUDY MPUMALANGA PROVINCE

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ABSTRACT

In this paper, a systemic approach is used to evaluate potable water infrastructure management in the Mpumalanga province of South Africa. In supplying water over a long term, mismanagement of potable water infrastructure is the main concern in the province. The systemic approach to management of water in the province provides strategies to ensure that every community has access to potable water. Specific potable water infrastructure issues that contribute to shortage of water in the province are pointed out in order to give indication of more appropriate measures to supply potable water according to systemic approach for potable water infrastructure management. A framework on water infrastructure was developed to identify challenges of potable water supply and validate how the infrastructure contributes to access of potable water. It was observed that municipalities in the province can overcome challenges of water supply through interaction among all stakeholders in the area, water companies, industries, local authorities, government, infrastructure owners and operators while giving more attention to water quality and demand. The findings underline that systemic approach to potable water infrastructure has the potential to enable optimized water supply in the province.

Keywords: Potable Water; Infrastructure; Mpumalanga Province; Water Supply; Systemic Approach; Water Quality; Water Demand.

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1 INTRODUCTION

Access to potable water across South Africa is still a challenge especially in rural areas. Most rural areas resort to using unprotected water sources for their water needs [1]. Mpumalanga province is largely rural and large farms are in rural areas. This is where most water supply shortages are experienced. As a result, people in the province make use of self-supply water strategies for domestic and agricultural use during times of less rainfall [2, 3]. Rural areas in the province depend on community initiatives to obtain access to water supplies. There is a critical need for safe and adequate surface and groundwater sources, to sustain both domestic and agricultural activities. Self-supply water strategy improves access to water faster and is more cost-effective and sustainable than public services do [4]. The challenge faced with self-supply water is that water is used without taking into consideration water quality which can be risky to people's health. It is still known that those who currently lack access to water are people that mainly depend on agriculture and diversified livelihoods [4]. The challenges of the water supply in Mpumalanga are due to the lack of management and maintenance of potable water infrastructure to meet demand of water in communities [5, 6]. Failure of the provincial government to meet water demand due to population growth in the communities has caused some members of the communities to do illegal pipeline connections for their homes from the main supply. This has directly affected potable water infrastructure whereby water pumping systems are at risk of being damaged [7, 8]. For years municipalities have been known to mismanage resources from road maintenance to potable water infrastructure [9, 10]. Water supply networks are used to deliver drinkable water to encourage human health. Mismanagement of water supply networks compromise the quality of water. For this reason, effective management of water supply networks must be undertaken at the multiple areas within the provincial government. In practice, this is difficult to achieve because many of these water systems networks are complicated, very old and drawings are no longer existing which makes it difficult to monitor them. Water infrastructure also poses substantial financial challenges to the municipalities in the province [7, 8]. Although the local government in the province work hard to improve the access of drinkable water but they cannot keep up with the increase rate of population growth and water demand on a daily basis.

This paper addresses potable water infrastructure management, challenges and possible solutions for sustainability of potable water supply across the Mpumalanga province. This will also contribute to the management of water quality and implementation of water recycling systems that will secure water for future use. With a challenge for low access to service delivery and increasing water demand, systemic approach of interaction of stakeholders and system components in the province is adopted to plan for sustainable potable water infrastructure to meet water demand [11] . Systemic approach applies to all water supply assets and for this study focuses on potable water infrastructure across Mpumalanga province. Systemic approach will help the Mpumalanga province government to ensure that residents have access to reliable, sustainable, safe and affordable water services. This also includes the planning, development, operation and maintenance of existing potable water infrastructure for the purpose of water supply.

2 LITERATURE REVIEW

In this literature review, we discuss the challenges of potable water infrastructure management in a rural setting and identifying that the understanding of effective management of water infrastructure systems is not yet discussed through systemic approach. Systemic approach is discussed as a technique to address the challenges of water shortages in Mpumalanga province. Different aspects that have impact on the operations of water infrastructure are discussed.

2.1 Systemic Approach

Water pumping systems are complex and system thinking approach is required to analyse it. Correct approach to address systems problems seek to detect and comprehend the multiple of water system problems [12]. These techniques help to identify the main issues that contribute to shortage of potable water supply in the Mpumalanga province. In the water sector, systemic approach is hoped to increase water productivity and improve water quality. Systemic approach that are discussed in this paper is Integrated Water Resources Management (IWRM) and system dynamic approach [12].

2.2 Integrated Water Resource Management

Effective and sustainable management of water is very important because of economic and social development. Treatment of wastewater is expensive due to lack of incentives for sewage treatment facilities [13]. Integrated Water Resources Management (IWRM) is a process that brings together management of water, land and related resources. The system thinking was founded in the 1990s and it helps with encouraging global and local partnership to address issues of water supply [12]. These were mostly adopted by developed countries and is used to overcome the problem of institutions, coordination and system failure. IWRM improves management of water, resources related to water and helps water users in any sector to check if their practices in water management are within IWRM framework, see Figure 1 below.

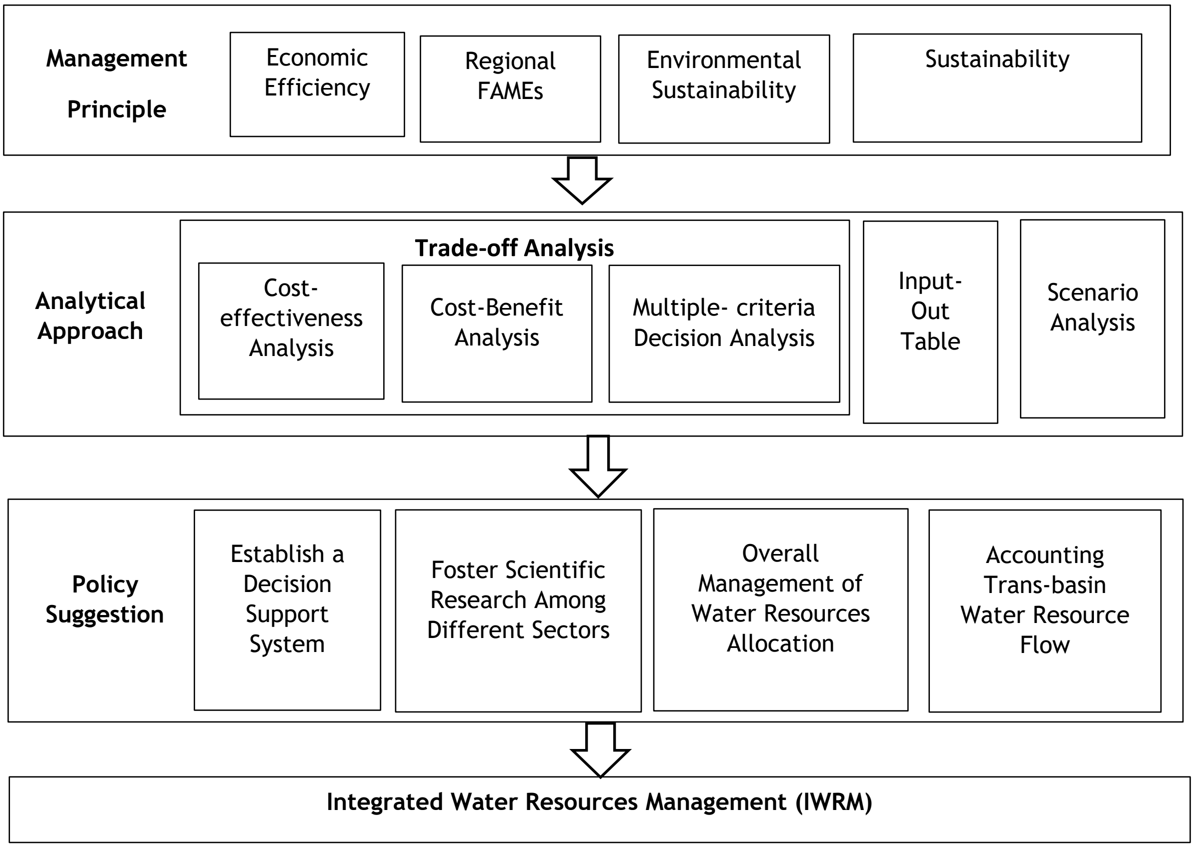


Figure 1: Framework representation of integrated water resources management [14]

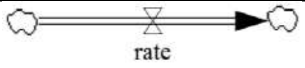
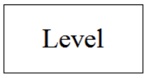
IWRM provides a broader context through which to achieve an objective of ensuring potable water is supplied and saved for future use [15, 16]. The process is mostly used in Africa, China and Mexico [17]. Although operation of IWRM is a challenge to implement because of differences between and within countries, Mazvimavi, et al. (2008) showed that it is critical to implement IWRM to increase access to potable water [17]. Contribution of different stakeholders within water sector is an efficient way of endorsing the success of IWRM [14]. Manzano-Solis, et al. (2019) used IWRM to facilitate the analysis of the water management system of Nenetzingo River Watershed based in Mexico. Structural analysis and strategic planning perspectives were employed. The results support the use of a systemic perspective for guiding water management and the implementation of IWRM [18].

2.3 System Dynamics

System dynamics approach was founded in the late 1950s as a numerical simulation technique [20, 21] .The approach outlines better understanding of water systems and how it changes overtime [20, 21]. System dynamics is used in engineering to analyse systems and it was used many times to analyse problems and identify solutions for improved water resource management[19]. It offers effective tools to analyse problems and identify solutions to improve water resource management [19]. Through system dynamics, the future condition of water supply can be predicted and develop strategic plan that will assist prevent unforeseen water problems. Systems dynamic models can be developed with focus on two scenarios; (1) measures that could have been taken with respect to the recent water scarcity and (2) water accessibility up to a definite period in the future [20, 21]. The issue of water can be analysed by building a model that includes factors related to water systems, human activities, flows of indicators sources (water catchments and population). In system dynamics model one can find the relationship between factors and flow indicators [19, 21].

Systems dynamic modelling can be used to determine the system structure between variables, feedback loops, system archetypes and delays. The model is used in a complex reality situation to test theories and process of water systems that are more complex. The use of dynamic simulation models in water management has a long tradition due to the complex nature of the problems addressed. The model also helps with testing the real world behaviour in an artificial setting [22]. Dynamic simulation helps to observe the behaviour of a modelled system and response to interventions over time. Table 3 shows the basic elements of systems dynamics models and provides a description for each system components [21].

Table 1: Components of System Dynamics Models [21].

Symbols	Names	Definitions
	Arrow	Shows a direction between two variables
Auxiliary Variable	Auxiliary Variable	Supporting variables that are constant
	Rate	Rate, also called flow variable, the cloud mark at the end or beginning of the rate represents a sink or a source.
	Stock/ Level	It represents accumulation

2.4 Literature Review Summary

The literature review suggests that systemic approaches that can be applicable to water management is Integrated Water Resources Management (IWRM) and system dynamics. The model helps with finding effective strategies that contribute significantly to management of potable water infrastructure system. IWRM is used mostly in developed countries and these pose a challenge to implement in a rural setting due to lack of services and resource. System dynamics work well in a setup where access to water supply is continuous because is easy to predict the future conditions. For these reasons, a framework is required to support the development of system dynamic model and implantation of IWRM in a rural setting. A framework on water infrastructure will be developed to identify challenges of potable water supply and validate how the infrastructure contributes to access of potable water.

3 METHODOLOGY

The challenge of integrating and managing water infrastructure system and stakeholders in charge of the system requires a systemic approach that provides a deeper understanding of the problem and its context. The aim of systemic approach is to understand the factors that contribute to the shortage of water. Therefore, in this study systemic approach is presented as a primary methodology to discourse and resolve dynamically the complex problems and challenges in potable water infrastructure management and water supply in Mpumalanga province. Systemic approach is used to investigate challenges and benefits of integrating and managing multiple infrastructure to ensure sustainability of water supply in the province. The province is experiencing challenges in accessing water services and the paper intends to investigate these challenges and implement solutions and strategies that will speed up the process of delivering potable water to communities. Various approaches were used to point out causes of water shortage in rural areas within the province. System dynamics model is introduced because Mpumalanga province water supply services require a sustainable water resources management that accounts for dynamic connections between cost of water, consumer and period effect among others [22, 23, 21]. The adopted framework of analysis follows a revisited systemic approach to help with solving water challenges by means of addressing the current challenges and integrating local water infrastructure to ensure sustainability of potable water supply across the province. Again, the study aim is to conduct ~~a~~ literature review to observe the challenges of infrastructure that has been installed by the local government in selected areas. The focus on infrastructure includes the resource development, bulk infrastructure and distribution infrastructure.

The research includes framework pointing out the infrastructure challenges, responsible stakeholders and propose solution. The tools and techniques used for water solution based on a literature review and situation in the province. The criteria for proposing or selecting possible solutions are those that have been practically applied at different capacities and produced good results in literature case studies and are related to impact assessments at the local level [24].

4 RESULTS AND DISCUSSION

4.1 Systemic Approach through System Dynamics

Development of Mpumalanga province brought changes in water systems, the rules and regulations of water resources development. These have not been successful as planned due to complexity of water supply systems. Pumping system is dynamic due to the changes within the system [12]. Under systems dynamics, the existing potable water infrastructure improves the quality and quantity of water supply. Systems dynamic model in Figure 2 represents casual loop for potable water infrastructure and shows the interaction of variables for potable water infrastructure. It can be observed that the interaction of various subsystems has complex casual relationships. Some systems affect others positively while others are affected negatively and some have no relationship. These results with understanding the integration between various systems but not pointing out specifically challenges and solutions to water supply. The focus is on existing changes and benefits of integrating the management of water catchment, water treatment works, water demand and amount of wastewater and water recycling stage. It can be observed that the amount of water catchment depends mostly on the rainfall which means during low rainfall seasons, Therefore, the framework is required to address these challenges and solutions on potable water infrastructure management to improve the current state of water supply.

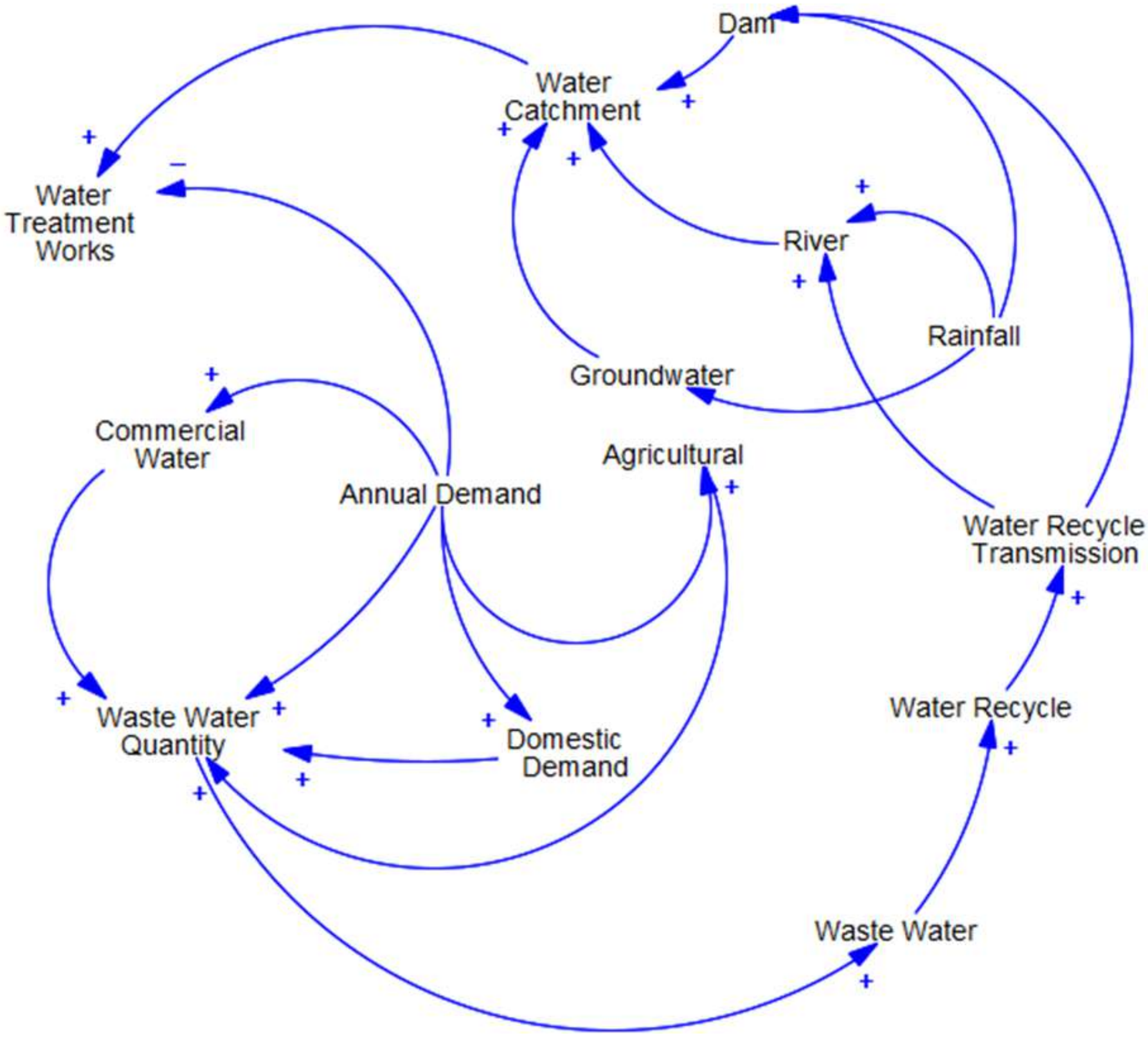


Figure 2: System approach to potable water infrastructure resources management in the Mpumalanga province. The (+) sign donates positive relationship among elements in the particular system. The (-) sign represents negative relationship.

The model has four subsystems contributing to water supply in the province area as follows: water catchment, water treatment works, wastewater quality and water recycle transmission. The contribution of the subsystem to systems dynamics is summarized in Table 2. These are four subsystems that the systems dynamics models are built on.

Table 2: Sub-Model of the Develop System Dynamics Model

Four Sub-Systems	Condition
Water Catchment	Describe the sources of water supplied to water treatment works for purification before reaches the consumes. The level of water abstracted for purification depends of the amount of rainfall, water from the dams and rivers.
Water Treatment Works	Used for purifying water and ensure that the water meets drinkable water standard.
Water Wastewater Quality	Represent used water (domestic or industrial water)
Water Recycle Transmission	Represent the recycling of used water as a way to secure and save water for future use.

4.2 Framework on Water Infrastructure

Interaction of different stakeholders is critical in management of potable water infrastructure and ensuring that water is supplied to consumers continuously. This plays a major role in service delivery in a rural setting. A framework was developed in Table 1 to identify challenges that contribute to shortage of water supply in rural areas of Mpumalanga province. The major risks that need to be managed to avoid water shortages, include climate change, mismanagement of costs and assets, water pollution, power cuts, lack of maintenance and operation cost, land use, population growth and over allocation of surface water and groundwater, other factors are outlined in Table 1. The challenge with water supply systems is that they depend on different factors in order for them to operate efficiently. Hence it is important to have storage tanks or reservoirs to store water and as a standby should there be any breakdown in the process of water supply.

Water Service Authorities (WSAs) contribute significantly to the process of water supply. It can be observed in Table 1 that a WSA is responsible for all aspects related to water in the province. Their responsibility is to ensure that there is enough water sources to abstract from, water infrastructure for treatment and distribution to the consumers. Also, cost is a major factor to all stages of the infrastructure from the water source to water treatment process and water supply stages. It means cost management strategies should be brought to attention when refurbishing, installing, communicating and operating water systems across the province. In Table 1, the list of water infrastructure and its components is presented. Each item of the water infrastructure was discussed with the focus on responsible stakeholders, challenges and their solutions. These variables were categorised according to their level of contribution towards water supply and management of potable water infrastructure in the province. It was observed that managing potable water infrastructure is a challenge due to the complexity of water pumping systems because it is made up of different components. The challenges of potable water infrastructure include climate change, mismanagement of costs and assets, water pollution, shortage of electricity to operate water treatment works, lack of maintenance and operation cost, large areas are occupied by the mines which contaminate groundwater [26, 27], population growth and over allocation of surface water and groundwater. The components of water supply influences each other such that none of them will operate efficiently without the others.

These lead to the fact that there is a need for interaction of different stakeholders responsible for different sectors of water infrastructure with the purpose of solving water challenges. Water infrastructure requires implementation of strategic planning and management to support activities that contribute to water supply. Therefore, local government, stakeholders and communities should interact with the aim of ensuring that enough potable water is supplied to the communities in the province. Climate changes in the province can be solved when the government changes from fossil fuels to renewable fuel sources. There is need to invest in renewable energy to alleviate shortage of electricity supply, improve farming, protect and restore nature to absorb more carbon dioxide. Teach the communities the risk of water pollution so it is always at the back of their minds during daily activities. Engage stakeholders, government, communities, and all people who have direct impact on potable water infrastructure management.

Table 3: Framework on water infrastructure development to identify challenges and possible solutions on potable water infrastructure management.

Water Infrastructure	Components of Water Infrastructure	Stakeholders	Responsibilities	Challenges	Solution
Water Source (Raw Water)	Rivers, Dams, Canals, Groundwater.	Water Service Authorities (WSA), Government.	Strategies, Water Policies, Risk Management, Monitoring and Evaluating the responsible stakeholders of water infrastructure	Mpumalanga Province region is dominated by the mine industries that extract and burn coals, oil and this contributes to the effect of climate changes in the province. Low % of Rainfall, Water Pollution, Cost Mismanagement, Assets Mismanagement.	• Climate changes in the province can be solved when the government changes their reliance on fossil fuels to renewable energy. • Invest in renewable energy, improve farming, protect and restore nature to absorb more carbon dioxide. • Avoid spilling of oil in drainages. • The government must invest in environmental charities. • Protect and restore nature to absorb more carbon dioxide. • Teach the communities with water pollution so that is always at the back of the mind of community members during their daily activities. • Plant more trees. • Costs can be managed through the following techniques; - Cost planning and control, - Estimation, - Cash flow forecasting, - Financial reporting and cost reporting.
Bulk Water Infrastructure (Potable Water)	Water Treatment Works (WTW), Pumping Stations, Bulk Water Pipe.	Water Service Authorities (WSA), Government, Water Companies, Infrastructure Owners, Operators.	Installation, Operation and Maintenance of Water Pumping Systems, Optimization of water systems,	Shortage of Electricity Supply. Lack of Maintenance Costs, Operation Costs, Unskilled manpower.	• Investment in renewable energy, make use of solar panel to operate the water pumping systems, install solar pumping, install solar pumps, cost management for maintenance and operation. • Provide training to equip unskilled stuff members. The municipalities should invest in training of their employees in order to fill gaps. • Create new opportunities and adopt new technologies. • Rethink workforce.
Distribution Infrastructure (Potable Water)	Reservoirs, Storage Tanks, Pipe Networks (External and Internal tap-water).	Water Service Authorities (WSA), Government, Operators, Consumers/ End Users.	Report damages of water infrastructure, vandalisms, leaks, illegal connection. Paying water service.	Vandalism, Tariff Costs, Illegal connections, Lack of service deliveries, Lack of training on water management, Lack of support from WSA, Access to contaminated water.	• Engage stakeholders, government, communities, and all people who have direct impact on the pipeline. • Report vandalism. • Management of water systems and population to which water is supplied to. • Install small water treatment package to purify water.

5 CONCLUSIONS

In this paper, systemic approach proved successful in the management of water systems in the Mpumalanga province by ensuring that every community has access to potable water. The results support the use of framework to identify challenges on potable water supply and validates how the infrastructure contributes to access of potable water. The study also supports the implementation of Integrated Water Resources Management (IWRM) and system dynamics approach. The systemic approach to potable water infrastructure has the potential to create optimized water supply in the province. It was observed that the municipalities in the province can overcome challenges of water supply through implementation of interaction among all stakeholders in the area, water companies, industries, local authorities, government, infrastructure owners and operators while giving more attention to water quality and demand. Water Service Authorities (WSAs) contributes significantly to the process of water supply and is responsible for installation, operation and maintenance of potable water infrastructure. In order to support water management planning in the Mpumalanga province, the next step will be to research and define record to know the status of water supply and the whole system. With this information, it will be easy to achieve the goal of water access to every community in the province.

6 RECOMMENDATIONS FOR FURTHER RESEARCH

This study focuses on how systemic approach improves the performance of water supply systems, also addresses the challenges and solution of water supply in rural setting. It is recommended that more studies are conducted on developing other assessment tools, which would be specifically designed to support the application of systemic approach to management of potable water infrastructure. Provincial government should invest in developing skills and relevant knowledge in their staff members as well as community members by initiating training and development on water management. In rural areas, management of resource is effective when the community members are involved. Based on the findings of this study, it is recommended that the local and district municipalities should interact and share resources for the purpose of solving water issues in the entire province.

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A SYSTEMIC APPROACH TO POTABLE WATER INFRASTRUCTURE MANAGEMENT IN RURAL SETTINGS – CASE STUDY IN LIMPOPO PROVINCE

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ABSTRACT

Lack of service delivery, growth of population and lack of maintenance of infrastructure is directly affecting standard and quality of potable water infrastructure in rural settings of Limpopo Province. A systemic approach to potable water infrastructure management in rural areas of the province involves collaboration of water companies, industries, local authorities, operators and infrastructure owners. The approach is based on managing the assets efficiently and effectively over a long-term optimization and analysis of potable water infrastructure so that the communities in the province have access to bulk potable water supply. This paper addresses potable water infrastructure management and methods of integrating local water infrastructure to ensure sustainability of potable water supply across the province. This will also contribute to the management of water quality and implementation of water recycling systems that will secure water for future use. The findings show that systemic approaches to potable water infrastructure has a potential to improve water quality, water supply and water management in the province. With the challenge from population growth and low access to service delivery and with increasing water demand, systemic approach of interaction of stakeholders in the province must be adopted to plan for sustainable potable water infrastructure to meet water demand.

Keywords: Infrastructure, Potable Water, Water Quality, Rural Water Supply, Water Recycle System, Water Demand, Systemic Approach.

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1 INTRODUCTION

Water pumping systems are part of a distribution network which is designed to distribute potable water that promotes human health [1, 2]. The efficiency of water pumping systems is determined by the load not exceeding maximum usage, which in turn should reduce the water supply below minimum [3]. The challenge faced by municipalities is that quality of water depreciates significantly with time as water is being transported to commercial and domestic users. Therefore, effective management of these resources must be taken at multiple scales [4, 5]. Mismanagement of infrastructure affects water quality and increases operational cost [6, 7]. Shortage of water is a challenge that is experienced globally. Lack of potable water contributes to high rate of poverty and illness caused by contaminated water. South Africa is amongst the countries that experience shortage of water while the available water in selected areas is not potable enough to be consumed [7, 8]. The existing water supply infrastructure are not well maintained and managed to ensure enough potable water supply to communities especially rural areas [8]. This paper focuses on the Limpopo province of South Africa, especially in the rural areas. Water shortage in the region is as a result of high hot temperatures, increase of population, change of climate, water pollution and old mines drainage that contaminate groundwater [9, 10]. Pit latrines in rural areas affect groundwater quality [11]. The existing water infrastructure is not well maintained and managed as a result, the provincial government is unable to meet demand of water supply [12, 13].

Water is key to life and therefore access to water is a concern to every organisation and organism [14]. The management of water is a responsibility of everyone and everyday practice. All stakeholders in the province should be involved to ensure access of potable water to everyone [14]. Typical examples, technicians and engineers should solve water infrastructural problems, natural scientists provide information on the quality and availability of water and regulatory matters are handled by political and social scientists [14]. The interaction of these stakeholders will therefore improve the availability and access of water supply to communities. Potable water infrastructure management and methods of integrating local water infrastructure is addressed in this paper to ensure sustainability of potable water supply across the province. With a challenge from population growth [15] and low access to service delivery and increasing water demand, systemic approach of interaction of stakeholders and system components in the province is adopted to plan for sustainable potable water infrastructure to meet water demand. Systemic approach can be used to solve issues of water supply assets and for this study focuses on potable water infrastructure across Limpopo province. A systemic approach will help the government of the Limpopo province to ensure that residences have access to reliable, sustainable, safe and affordable water services. This includes the planning, development, operation and maintenance of existing potable water infrastructure for the purpose of water supply.

2 METHODOLOGY

A multiple method approach was used to identify potential causes of water shortage in Limpopo province. A review of grey and white literature was taken on with the aim to study and identify the challenges of installation, operation and maintenance of water infrastructure in the province. Systemic approach is presented as a methodology to discourse and resolve dynamically the complex problems in potable water infrastructure management and water supply in the province. The adopted framework of analysis follows a adopted approach systemic approach to help with solving water challenges by means of interaction between stakeholders in the province and integrating local water infrastructure to ensure sustainability of potable water supply across the province.

2.1 Systemic Approach

A systemic approach is a technique used to manage and improve the management of processes in different sectors water by means of integrating different stakeholders and repeating benefits in complex interacting elements [14]. These include the environment that affects potable water infrastructure. Various municipalities' goals on water supply can be achieved as long as practical management of water are dominated by specialization and distinction [14]. Systemic approach can help local municipalities to effectively manage and maintain their potable water infrastructure. In addition, interaction of different stakeholders with the purpose of solving water issues can be achieved through the Integrated Water Resources Management (IWRM) technique. Integrated Water Resources Management (IWRM) is a systemic approach that enables different stakeholders to work together to achieve the purpose of managing water infrastructures and water resources [16, 17].

Research showed that it is critical to implement IWRM to improve access to potable water [18]. Contribution of different stakeholders within the water sector is an efficient way of endorsing the success of IWRM [18]. Manzano-Solis et al (2019), used IWRM to facilitate the analysis of water management system of Nenetzingo River Watershed based in Mexico. The results support the use of a systemic perspective for guiding water management and the implementation of IWRM [19]. The development of Optimum Integrated Water Resource Management (OP-IWRM) approach with the aim of solving the challenge of implementing IWRM in the social, economic environmental, ground and surface water resources has been achieved [21]. Results have shown that proper implantation of the OP-IWRM may lead to a sustainable national development plan [20].

2.2 Potable Water Infrastructure

The process of supplying potable water is complicated because it has different components and stages that are essential to ensure sustainable and continued water supply, see Figure 1 [21]. The stages amongst them include resource development, bulk water infrastructure and distribution infrastructure which is made of connectors and internal infrastructure [3, 21]. The complexity of potable water infrastructure has raised difficulties to municipalities to manage and maintain water supply and infrastructure [12]. An increase of population and settlements causes water demand to rise which results in a need to optimize potable water infrastructure to meet demand. In any new development, new connections, installation of pumps, operation and maintenance of water systems are not easy to perform due to complexity of the water infrastructure and lack of affordability [21].

As a result, households access water through illegal connections [15]. This causes leaks and tempering with water supply networks resulting in water losses in the process. This is a serious challenge which municipalities find difficult to manage, especially maintaining the potable water infrastructure to meet demand because of complexity of water supply systems. The solution to water supply challenges can be achieved through interaction of stakeholders that are involved in ensuring different stages are managed well to meet the needs for the next section in the schematic diagram of potable water (Figure 1). Systemic approach is suitable to ensure that the complexity and challenges of water infrastructure are identified and addressed [20]. In the following section, a framework is developed to identify the challenges and interaction between stakeholders, industries, communities and agriculture [20].

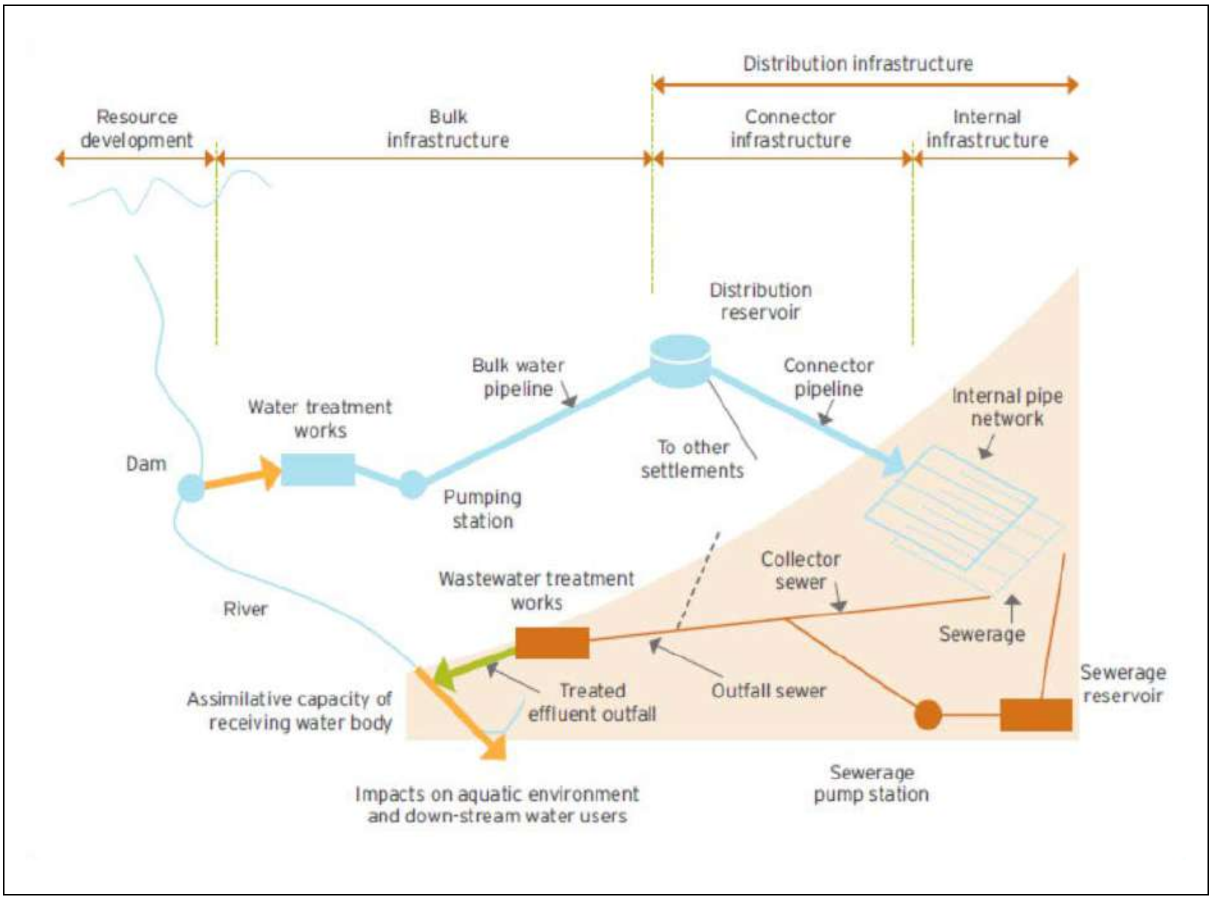

Figure 1: Components of Potable Water Infrastructure (Adopted from Mutamba & Busari, 2014)

3 SYSTEMIC APPROACH TO WATER SUPPLY INFRASTRUCTURE

Different materials are used for potable water infrastructure. The selection criteria for the materials used for water infrastructure include the strength, corrosion resistance, cost, maintainability, availability and effect on water quality. Common materials of water pipeline network are cast iron, concrete, polyvinyl chloride (PVC), polyethylene and glass reinforced polyesters [5]. Impact of water infrastructure on water supply includes water quality failures, structural failure, pump failure, hydraulic failure and appurtenance failure [5]. Systemic approach for potable water infrastructure is the interaction of different aspects that contribute significantly to water management. The management of potable water infrastructure includes the following aspects [5].

- Infrastructure data,
- Setting water service standards and monitoring water services provision,
- Setting budged and priorities investment,
- Undertaking rehabilitation,
- Setting service standard and monitoring performance,
- Planning management.

The diagram in Figure 2 shows interaction and management system of potable water infrastructure. Continued water supply follows the concept to ensure that water supply is maintained (Marlow, et al., 2014). Water Service Authorities (WSA) are responsible for management of these activities to ensure that safe drinking water is supplied to rural areas in the province.

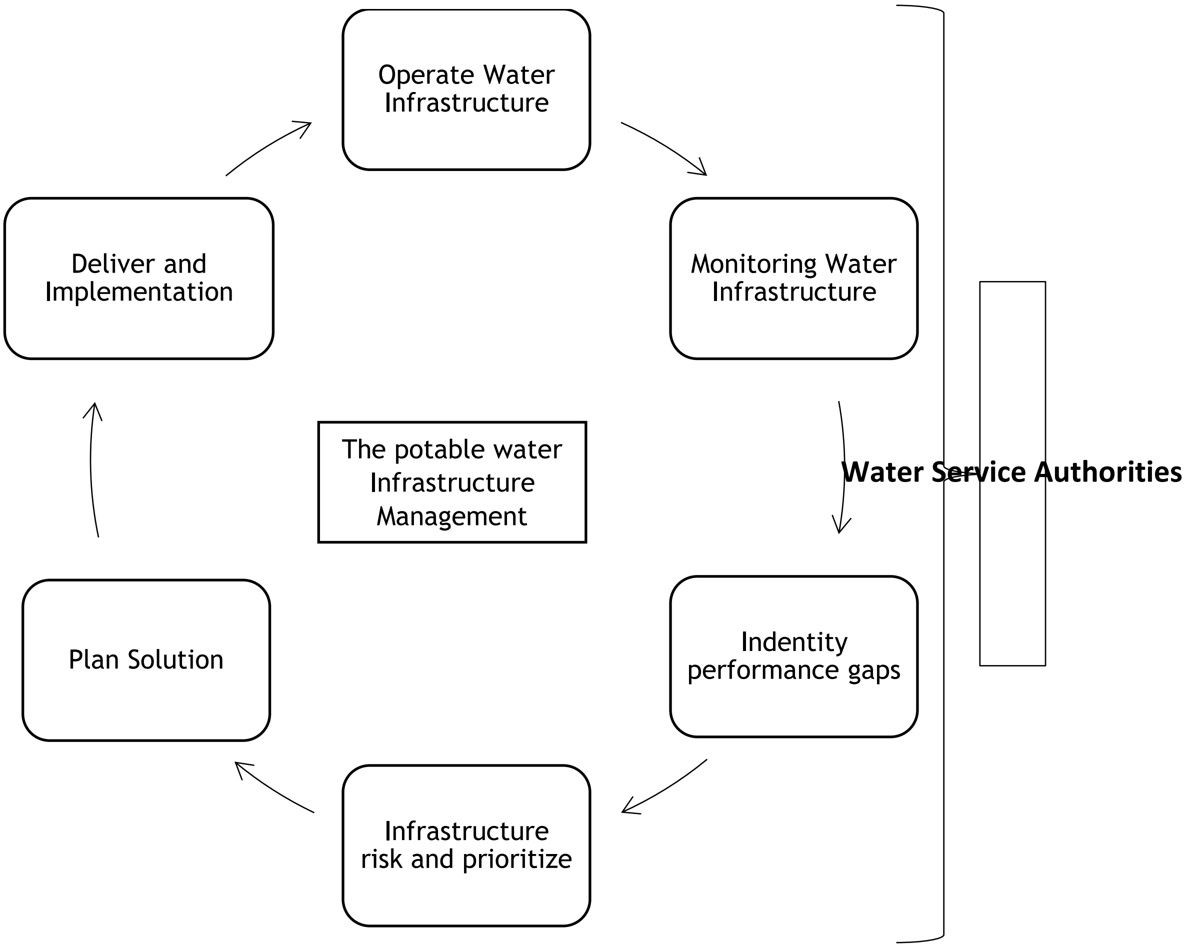

Figure 2: Interaction and Management Structure of Potable Water Infrastructure (adopted from Marlow et al, 2014).

Although the interaction and management of potable water infrastructure is effective, there is a gap that can be addressed by involving communities through training and workshops to teach them how the water infrastructure systems work. This will help the communities not to attempt illegal connection and also the management of water. There should be a practical link between the Water Service Authorities (WSAs) and rural community members leading to ensure sustainable water quality supply and reducing risk of water shortage. Interaction of the municipalities and community members will ensure that water infrastructure is protected by the community members and vandalism reduced. As a result, another concept of potable water infrastructure management is proposed in Figure 3 to ensure proper management of potable water infrastructure.

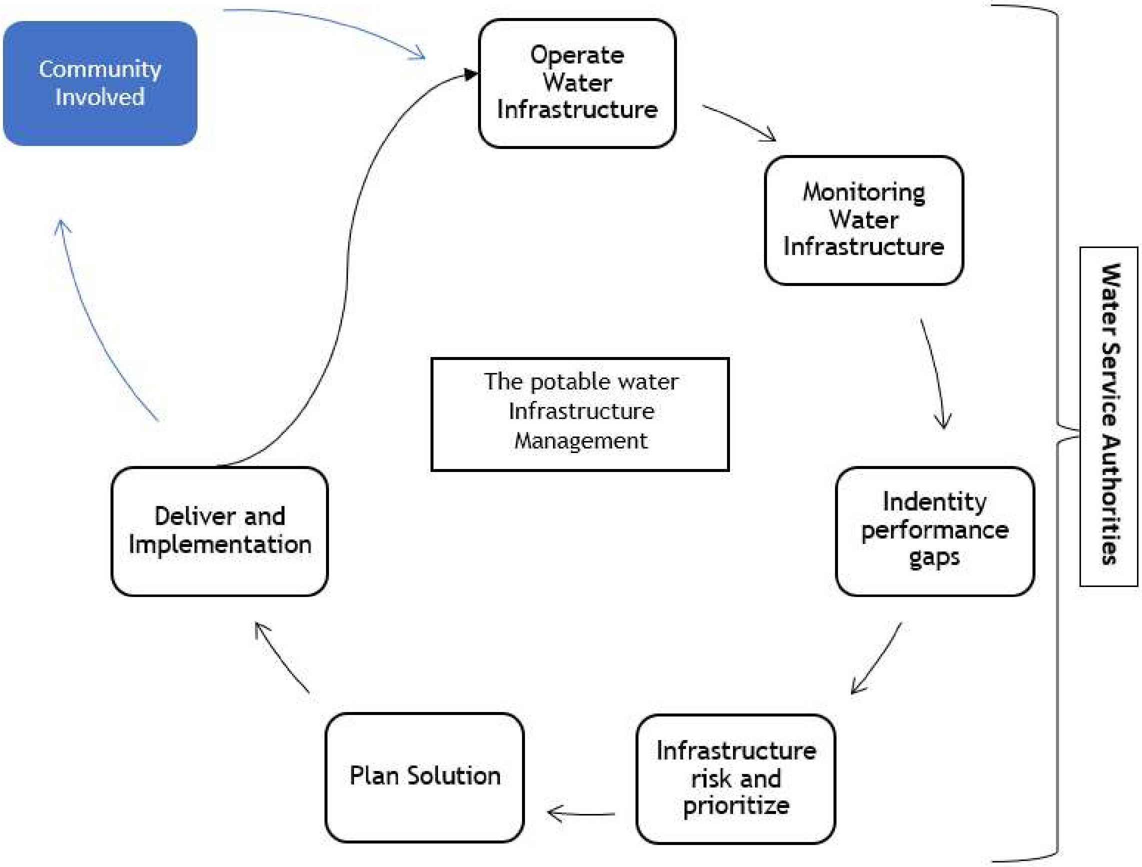

Figure 3: New Concept of Interaction and Management Structure for Potable Water Infrastructure (adopted from Marlow et al, 2014).

4 RESULTS AND DISCUSSION

In Limpopo province, the Water Service Authority is responsible for providing water services to rural area. Involving the community will mean being informed of their concerns and needs regarding water services. This will help the WSA to have a better approach to solve water problems. The results in Figure 3 showed that implementation of systemic approach in managing potable water infrastructure can be achieved through involvement of different stakeholders in the province. WSA are responsible to manage bulk water infrastructure, implement water policies, strategies, managing risk, monitoring and evaluating potable water infrastructure. Communities are responsible to report illegal connections and vandalisms of infrastructure components. The stakeholders should integrate to bring contingency plans and strategies to ensure water sustainability in the province.

These lead to the application of Integrated Water Resources Management (IWRM) technique that helps to achieve sustainable potable water infrastructure, increase potable water supply, improve water quality [22]. Although, IWRM is promoted strongly internationally, even locally it can be more applicable in local communities to meet demand of water. Amendment of water policies, strategies and plans by WSA in the province should involve local communities so that need for water supply is achieved. The balance between water demand and supply as well as water quality and capacity can also be achieved by proper management of water supply system and integration of potable water infrastructure components (bulk water infrastructure and distribution infrastructure which is made of connectors and internal infrastructure). It can be observed in Figure 2 that supply of potable water can be achieved through interaction and management of potable water infrastructure although to this end, there is still a gap because only WSA are involve hence community members should be part of the water supply plans (Figure 3) and strategies to achieve balance of water supply, water quantity and water quality.

5 CONCLUSION

The systemic approach is a technique that recognizes issues of potable water infrastructure management holistically as it engages stakeholders and multiple sectors that contribute to the supply of potable water in rural communities. It also addresses potable water infrastructure management and methods of integrating local water infrastructure to ensure sustainability of potable water supply across the Limpopo province. This contributes to the management of water quality and implementation of water recycling systems that will secure water for future use. With a challenge from population growth and low access to service delivery and with increasing water demand, systemic approach of interaction of stakeholders in the province is essential to plan for sustainable potable water infrastructure to meet water demand.

Most of potable water infrastructure are failing due to lack of interaction between WSA and consumers. Although WSA is responsible for potable water infrastructure management, there is a need to involve community members, operators, owners of infrastructures and industries as far as addressing and solution to water supply challenges are concerned. This will effectively address the issue of water management and water security. In addition, various sector goals can be achieved if scientific knowledge about practical management of water is dominated by specialization and distinction. Sustainable management of water resources can be achieved through integration of ideas and approach towards defining informed mitigation options and planning on water infrastructure. Management of water infrastructure in Limpopo province is identified as means to achieve sustainability.

6 RECOMMENDATIONS FOR FURTHER RESEARCH

The limitation of this study includes how systemic approach improves the performance of water supply systems in a rural setting. It is recommended that more studies are conducted on developing other assessment tools, which would be specifically designed to support the application of systemic approach to management of potable water infrastructure. Provincial governments should invest in developing skills and relevant knowledge in their staff members as well as community members by initiating training and development on water management. In rural areas, management of resource is effective when community members are involved. Based on the findings of this study, it is recommended that local and district municipalities should interact and share resources for the purpose of solving water issues in the entire province.

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SYSTEMS THINKING AND DECISION MAKING IN HIGHLY DYNAMIC AND COMPLEX ENVIRONMENTS

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ABSTRACT

Rapidly increasing digitization and the resulting emergence of disruptive technologies are forcing companies to make decisions – and react to market changes – at an ever-increasing speed. Moreover, the success of any business is highly dependent on how fast and how well it is able to make decisions and implement them. Therefore, decision making is one of the most important skills required by companies to remain competitive in highly complex market environments. Based on existing literature, this paper investigates a holistic systems thinking approach to address the complexity of decision-making processes in highly dynamic environments. The objective of the paper is to propose a systems-thinking approach that enables companies to enhance the quality of their decisions, and to optimize the time required for taking such decisions.

Keywords: decision making, strategy, systems thinking, system dynamics

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1 INTRODUCTION

Rapid technological change, caused by disruptive technologies or increasing digitization, radically changes the fundamentals of decision processes.

For example, the automotive industry is facing its biggest transformation in its history – the transformation from combustion engines to electrically driven vehicles. According to McKinsey [1], by 2030, 75% of all new cars sold will be driven electrically. This does not only affect the automotive industry itself, but also the entire supply chain of the automotive sector.

Furthermore, in 2020 the corona pandemic hit the entire world: its economies, its industries and its people. Supply chains in all industries were damaged and do not function as before. As if this was not enough, the situation was worsened by a big fire in 2021 in a Japanese factory that manufactures electronic chips for the automotive industry. And currently the world faces Ukraine war, shaking the energy markets and global energy geopolitics. As a result, oil and gas prices rose to its highest levels in ten years.

This leads to an even more complex and dynamic environment within which organizations must cope. To survive, companies need to continuously develop and offer new products to the markets, and continuously adapt to new, unforeseen environmental conditions. As a result, decisions must be taken at an ever-increasing speed that severely increases the burden on decision makers.

Many scholars researched the enhancement of decision-making processes and improving the robustness of decisions. Vincente [2] added dynamics to the traditional decision approaches to cope with complex environments, using ecological interface design while Doukas & Nikas [3] introduced a multi-criteria model to support decision making in climate policy. Schmidt and Gary [4] showed that system dynamics (SD) can be successfully applied to the automotive supplier industry to improve decision making. Maani and Maharaj [5] concluded that systems thinking can lead to a better performance in complex decision making while Thomson and Bank [6], Macmillan, Davies, Shrubsole, Luxford, May, Chiu, Trutnevyte, Bobrova and Chalabi [7] and Fong, Matsumoto and Lun [8] used system dynamics to improve decision making in building design to adapt to unforeseen external events such as terrorism, future policy changes or stricter future targets for carbon dioxide emissions. In the energy industry, Mwanza and Ulgen [9] developed a model to predict future energy mixes using multicriteria decision-making and system dynamics. Currie, Smith and Jagals [10] illustrated, that SD modeling has the potential to enable decision makers to understand complex environmental health topics.

Although much research has been done regarding decision making, none of them deals with SD modeling and adapting to deep uncertainty. This article aims to close this gap by developing a conceptual SD model that will be able to deliver robust decisions and strategies. However, this model is part of further studies regarding strategy definition and execution processes in highly dynamic and complex environments, in which the authors are involved as well. It continues analysing the decision making process of the conceptual model for strategy definition and implementation [11] to cope with deep uncertainties.

The next section reflects on some relevant literature to derive the model. In section 3 the underlying research method is explained while Section 4 focuses on developing the conceptual model before the conclusion is provided in section 5.

2 LITERATURE REVIEW

2.1 Value Creation Model

By nature, every system or organism aims to survive and secure its existence. According to Schaveling and Bryan Schaveling and Bryan [12], the only way a system can achieve this, is to create additional value for its environment. Without such creation of value, there will be no interactions or transactions – the system would miss additional input and will eventually fail.Van der Heijden's ground-breaking research [13] forms the basis for a value creation model. The idea behind it is that distinctive competencies will result in additional value for customers or for a system. This can be illustrated by a reinforcing feedback loop (R).

Figure 1 explains on the simple example of births and deaths how a reinforcing feedback loop works: Increasing births will increase the population and an increasing population will increase the birth rate (R). Further, on the right hand loop, an increasing population will increase the death rate and an increasing death rate will decrease the population, which leads into a balancing feedback loop (B) [14].

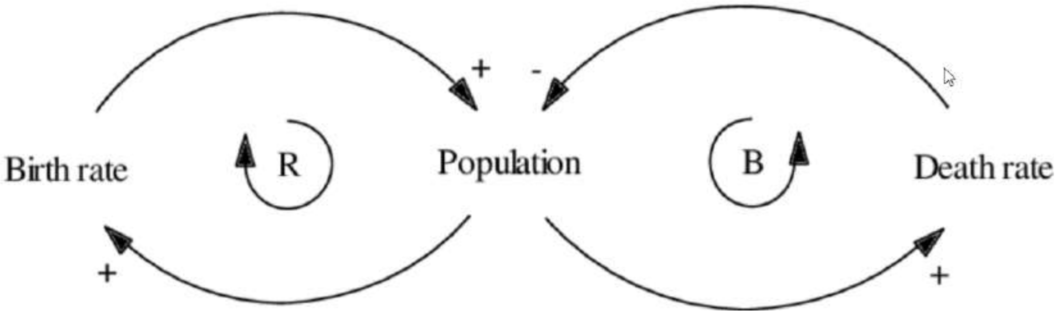


Figure 1 Reinforcing (R) and balancing loops (B) adapted from Sterman 2000 [14]

Systems and organisations adapt to and react continuously to recurring external and internal events. Therefore, the value creation model consists of two different loops – one at the top, adapting to outside developments and one at the bottom, adapting to developments within the organisation. The model itself contains of the following elements: [13]

- Distinctive competencies that ensure differentiation from the competitors
- Set of activities: the services and products of the organisation interact with the market demand or social needs
- A competitive advantage (unique selling point)
- Customer interaction that creates additional value or transaction: creating additional value for both the organisation and its environment through meeting a market demand with a specific set of activities and distinctive competencies
- Results: increased revenue, increased market share and increased knowledge
- Investment: financials needed to safeguard and further develop the distinctive competencies

The Value Creation Model provides benefit by asking the following three questions of Sinek [15] regarding an organisation: Why? What? and How? As shown in Figure 2, the bottom loop defines in which field an organisation invests its resources to best meet its strategic targets. It could aim on increasing its market share, on further developing its distinctive competencies, or on intensifying its competitive advantage. The creation of value starts with understanding a societal need and finding a solution to satisfy such a need. Thus, an organization must develop distinctive competencies to improve its competitive advantage. The development of specific distinctive competencies means that organisations sometimes develop niche markets with limited possibilities. So, it is of great importance for organisations to decide where and in what to invest. In general, organisations have four different options to select from: Improvement and further specialisation, aim for higher market share, improve the quality or extend competences. [12]

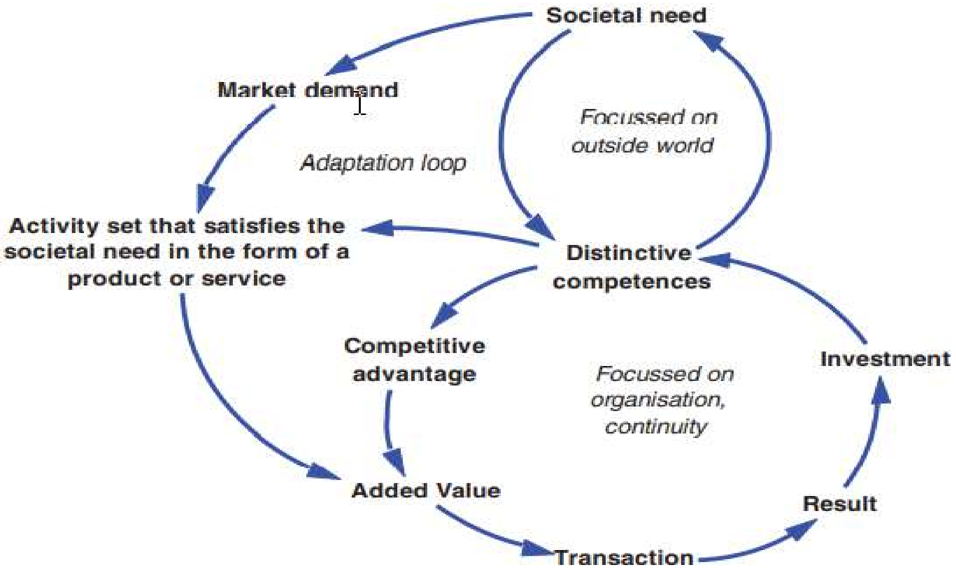


Figure 2 The Value Creation Model [12]

2.2 Decision Making under Deep Uncertainty (DMDU)

According to Sterman [14], decision-makers operate between two extremes – perfect rationality (homo economicus) and mindless, emotional behavior. This means that, under time pressure, no perfect decision will be obtained. This can be vital for organisations.Decision-making for the future necessitates being willing to deal with change. This can be extremely difficult when trying to align short-term and long-term decisions [16].

Uncertainties, caused by unprecedented environmental and socio-economic changes such as pandemics, wars or disruptive technological changes, can neither be eliminated nor quantified. Usually, these changes are combined with a huge lack of knowledge about the outcome or results of the changes [17] [18]. Lempert, Popper, and Bankes [19] define these uncertainties as “deep uncertainties”, where it is hard to recognize the key driving forces of change and their relationships in the long term.

Walker, Marchau and Kwakkel [18] introduced five levels if uncertainty. They defined level 4 and 5 as “deep uncertainty”:

- Level 1: An adequate, obvious and sensitive future that can be described by a single system model.
- Level 2: Alternate futures with definable probabilities for their occurrence, which can be described by a single model with probabilistic parameterization.
- Level 3: Alternate futures with defined rankings, that can be described by several system models, one of which is most likely to occur.
- Level 4: A multiplicity of plausible unrankable futures, that can be described with several system models consisting of different structures.
- Level 5: Unknown future, that cannot be described with a known system model – we know that we do not know.

To adapt decision-making with deep uncertainty , Walker, Marchau and Kwakkel [18], as well as Marchau, Walker, Bloemen and Popper [16] describe several DMDU approaches. These are approaches that generate robust decisions for a wide range of possible expectable futures, or that can cope with changing conditions.

The following approaches were mentioned:

- **Robust Decision Making (RDM)**: RDM consist of a set of processes, concepts and tools that are based on calculation [19]. It applies multiple futures to identify a path that can best meet the future targets in a variety of possible futures and suggests a set of reasonable solutions to achieve robustness. It also provides an iterative vulnerability-and-response-option analysis framework, which helps to prevent situations where it might fail to hit decision-makers' expectations [20]. Additionally, RDM should also consider the level of risk aversion – the value that needs to be achieved by the decision maker, considering the overall objective [21]. RDM can address vulnerabilities and initiate hedging actions [20] [22].
- **Dynamic Adaptive Planning (DAP)**: In a first step, DAP aims to implement a basic plan that can be adjusted over time if the plan is not on track [23]. Generally, it is split into two phases, the design phase, in which the dynamic plan and the monitoring approach are created, and the implementation phase in which the implementation of the actions defined in phase one will be implemented and contingency actions will be executed [16]. Contingent actions contain mitigation, shaping, (re)seizing and hedging actions [18]. Triggers or signposts are formulated with a predefined threshold, beyond which actions will be taken [24]. All in all, it is based on prediction of potential vulnerabilities that forces decision makers to make decisions and continuously adapt the plan [25].
- **Dynamic Adaptive Policy Pathways (DAPP)**: DAPP combines two approaches, which overlap in some parts and complement each other: DAP and Adaption Pathways (AP) [26]. AP is about prediction of vulnerabilities to initiate possible actions to limit negative impacts over time. The identification of Adaption Tipping Points (ATP) is crucial to find alternative paths. An ATP is the point where the system cannot be stopped from failing, regardless of any action you take [27]. Compared to DAP, DAPP highlights system analysis significantly to identify impossible paths, vulnerabilities and objectives [26]. DAPP defines scenarios to visualize challenges, opportunities and possible actions for mitigation and utilization. When an action reaches a tipping point, triggers and contingency actions need to be defined to anticipate a reaction. A further goal is to keep possible pathways open, if possible. The pathways are illustrated graphically in a pathway map. Based on this map, planners can assess the opportunities and identify pathways that are no-regret options, meaning that no more options are available once a tipping point is reached. Alternatively, pathways are lock-ins, meaning that they still offer further options when a tipping point is reached. Finally, decision-makers have to choose the preferred pathways and to include contingencies into their planning to strengthen the robustness of the chosen pathways [28]. One step further, it is also possible to enhance the DAPP approach with institutional and socio-cultural conditions as an enabler for preferred adaption pathways [29]. DAPP monitors the execution of the plan continuously to initiate contingency actions when necessary. DAPP also assesses uncertainties and objectives if more significant adaptions to the plan need to be applied in a dynamic process [28].
- **Info-Gap Decision Theory (IG)**: IG is based on analyzing information gaps, which are basically the difference between what you know today and what you would need to know in the future in order to make sustainable and responsible decisions [16]. It determines options that work quite well for a variety of conditions and aims more for robustness than for optimality (robust-satisfying) [30]. A strategy is satisfyingly robust when it fulfills the minimum performance requirements for a broad spectrum of potential scenarios, even if the future results vary from the best estimate [31]. To define the info-gap, it is necessary to identify the uncertainties. The next step is to estimate the results of alternative decisions, which are exogenously available. Decision makers obtain trade-off curves that are used to rate the defined strategies as robust or opportune strategies [32]. In this context, robustness is the greatest horizon of

uncertainty for which an alternative solution meets the critical outcome requirements. On the other hand, opportuneness is the lowest horizon of uncertainty that enables the aspired outcome [33].

- **Engineering Options Analysis (EOA)**: EAO is based on the idea of allocating economic value to technical flexibility. It provides tools and processes to calculate the value of optional approaches (e.g., flexibility in timing, location of changes, size) about additional value that would result from the options. Furthermore, it makes these benefits available for decision makers as extreme possibilities, average expectations, or initial capital expenses (Capex). Decision makers can decide whether or not to monetize these values [34].

Generally, planners make decisions in a multi-layered context. As illustrated in Figure 3, a decision maker belongs to an organisation that forms part of an institution. However, these layers influence and shape each other in deciding on or rating of options. Whether an option or decision is feasible for an decision maker depends highly on their institutional context (sociocultural, historical, economical, political) [28]. A given set of institutional conditions will facilitate certain options while impeding others [29].

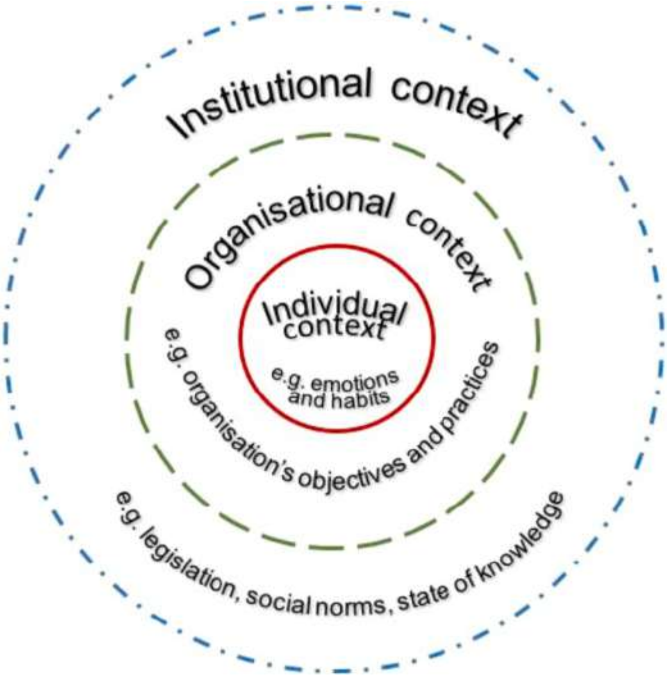


Figure 3 Relationships of Institutions, organisations and individuals [28] [35]

The success of applying DMDU approaches depends highly on organisational conditions. If an approach is not well considered and coordinated with organisational conditions, such as political and social acceptance or resources, the successful implementation will most likely fail [36]. Moreover, if the benefits of a solution are not in line with expectations of an actor or an organisation, it will not be successful. [37] On the other hand, institutional frameworks can influence organizations regarding to norms, values or processes [38].

2.3 Strategic decisions and systems in complex socio-technical environments

Driven by the growing speed of technological and social change, society changed significantly over the last 30 years. As a result, global interconnectivity and social complexity increased [39].Developments in socio-technical change, such as the method discussed next, can help to understand change in complex systems. The method introduced by Nieminen and Hyytinen [40], consists of three main components:

1. **Regime level**: The Regime level collects self-evident action patterns and structures as well as institutionalized practices. It is the conservative element in the model that consists of five sub-levels:
    a. deployed technologies available
    b. scientific institutions and paradigms
    c. and politics and administration
    d. socio-cultural values and symbols
    e. actors and markets.
2. **Landscape level**: The landscape level is the socio-technical context and embeds the Regime Level. It combines fluctuations of the economy, political changes, general sociocultural values and norms of the society and the infrastructure of the society. The status quo is reached if compatibility is reached between the landscape and the regime level.
3. **Niche innovations**: Niche innovations occur and develop outside of the regime. They are powerful enough to transform or even to reform the existing regime.

The model assumes that change must interact through all three levels. Depending on the situation, the levels are weighted differently. The effort required to achieve compatibility between the regime and the landscape level can be high. The most radical situation occurs when it is impossible to achieve compatibility, and consequently, niche innovations will transform the whole regime [39].

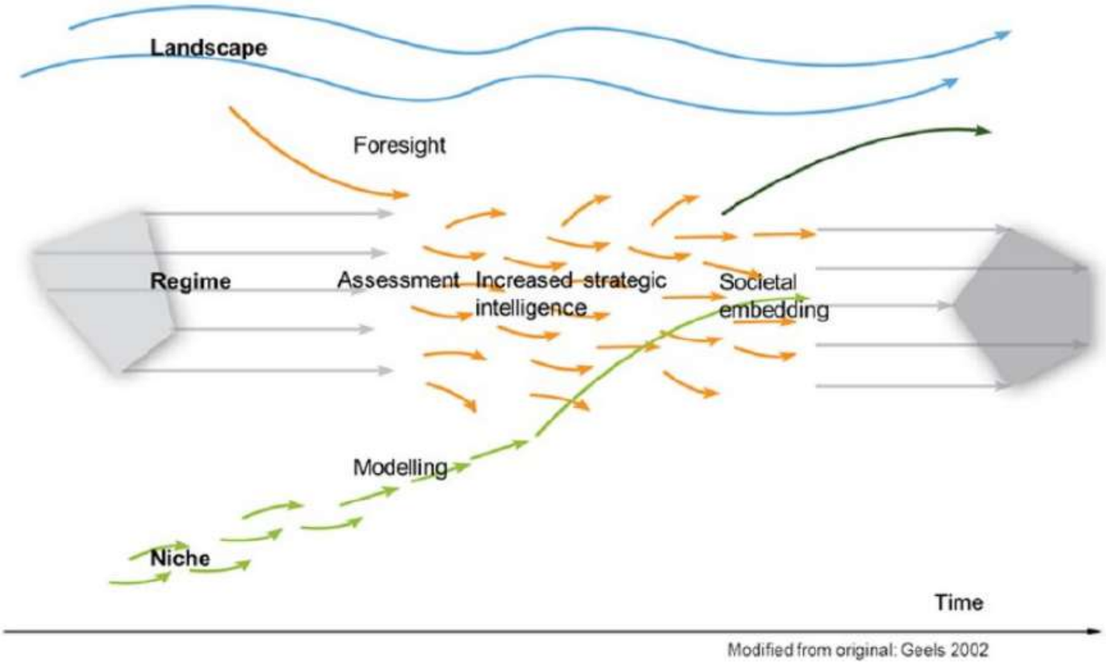


Figure 4 Methodological multi-level framework approach [39]

The next section explains the research method.

3 RESEARCH METHODOLOGY

As explained in section 1, this article aims on formulating dynamic hypotheses and deriving a first conceptual model for decision making in highly dynamic and complex environments. It forms part of a wider research project on strategy definition and strategy implementation in such environments. This project follows a modified version of Forrester's six-stages approach, suggested by Martinez-Moyano and Richardson [41]. The first two stages suggested in the wider model are problem identification and definition, and system conceptualization. The next step, which is not part of this study, focuses on designing the model, including the structure, the variables, and the interdependencies. This article follows the proposed research design of Cooper and Schindler [42] and the preferred design for this. Future research includes an exploratory multiple-case study. As the research aims at finally gaining in-depth information about current processes and practices to simulate and evaluate the SD model, an explorative qualitative approach will be followed.

Section 4 aims at formulating dynamic hypotheses to derive a conceptual model for decision making in highly complex and dynamic environments.

4 SYSTEM DYNAMICS MODEL

The fundamental elements of SD modeling are causal loops [43] based on reinforcing and balancing loops, as mentioned in section 2.

As emphasised by Sterman [14], arrows and their polarity (+/-) build positive and negative causal relationships in SD causal loop diagrams (e.g.Figure 6). The short arrow in the middle indicates the direction (clockwise / counter clockwise) and shows if the feedback loop is reinforcing or balancing. Dynamic hypotheses are represented in a Dynamic Model by a pair of variables, which are linked by an arrow with a positive or negative sign. The reading direction of these dynamic hypotheses is in the direction of the arrows. For example, in Figure 6, more and greater "Uncertainties" lead to more "Analyzed vulnerabilities and opportunities". In this article we will not handle dynamic hypotheses as classical hypotheses as is commonly done in statistical testing. In contrast, we will treat dynamic hypothesises, as well as typical system dynamic testing and validation approaches as suggested by Sterman [40].

Stanton & Roelich [28] compared the results of different DMDU approaches regarding the robustness of the resulting decisions under deep uncertainty. They analysed 37 case studies, 53% of which used RDM, 26% used AP and 13% used DAPP. As a key finding they emphasized that several individual, organisational and institutional factors are missing in the application of the DMDU methods but are crucial for an effective decision making under deep uncertainty. Kwakkel, Haasnoot and Walker [44] compared RDM and DAPP using a hypothetical case and highlighted the following insights for decision making:

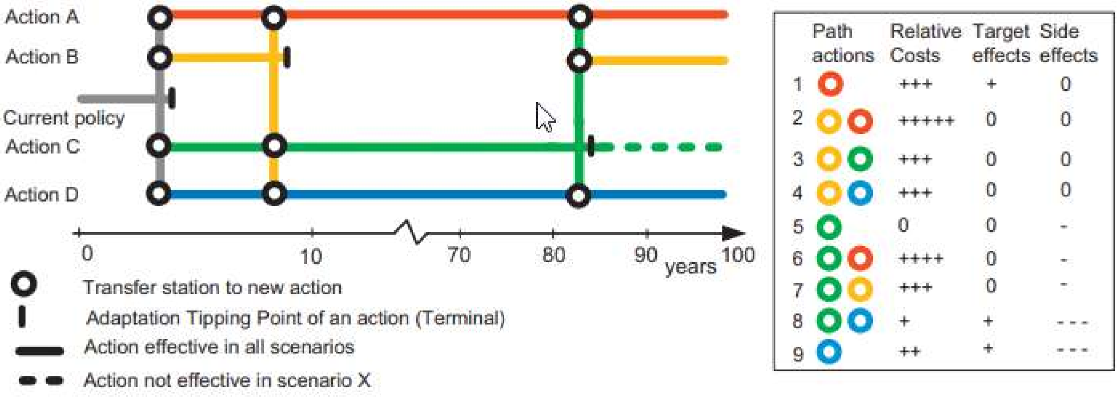
- RDM requires less computational resources than DAPP
- RDM cannot guarantee the optimally robustness for the resulting solution or a set of solutions
- RDM produces an adaptive plan, whereas DAPP offers several potential pathways, from which short-term and long-term actions are specified
- DAPP can be illustrated as a more dynamic systems approach, resulting in adaptive plans

Considering these results, we follow the DAPP approach, to develop the conceptual model in this article.The DAPP approach consists of the following seven steps:

1. Decision Context: Definition of the objectives and description of the system.
2. Assess weaknesses and opportunities: Identification of adaption tipping points of current status and evaluation of scenarios for potentially occurring tipping points.
3. Determine and assess actions: Rating of efficiency of potential actions with respect to tipping points and timing.
4. Develop and evaluate adaption pathways: Exploration of pathways, as well as generation and evalution of pathways map.

5. Design adaptive plan: Selection of preferred short-term actions and long-term strategies, as well as identifaction of triggers and signposts.
6. Implement the plan: Implementation of actions.
7. Monitor: Further implementation of actions if a tipping point is reached and of adjustments of signposts if necessary.

Step 4 develops potential pathways, resulting in a pathways map, from where decision makers choose their preferred path. Their selection is supported by a pathways scorecard, as can be seen in Figure 5 [26].



	Path actions	Relative Costs	Target effects	Side effects
1	🔴	+++	+	0
2	🟡 🔴	+++++	0	0
3	🟡 🟢	+++	0	0
4	🟡 🔵	+++	0	0
5	🟢	0	0	-
6	🟢 🔴	++++	0	-
7	🟢 🟡	+++	0	-
8	🟢 🔵	+	+	- - -
9	🔵	++	+	- - -

Adaptation Pathways Map

Scorecard pathways

Figure 5 Example for a pathways map and a scorecard for rating [26]

Generally, it is possible to illustrate the DAPP approach in a SD model. Given this, the seven steps define a balancing feedback loop around:

- “Describe current situation, system, objectives & Uncertainties,”
- “Analyse the problem, vulnerabilities & opportunities using transient scenarios,”
- “Identify actions,”
- “Assess efficacy sell-by date of actions with transient scenarios,”
- “Develop adaption pathways and map,”
- “Select preferred pathway(s),”
- “Determine contingency actions and triggers,”
- ”Specify a dynamic adaptive plan,”
- “Implement the plan” and
- “Monitor”

as shown in Figure 6.

Additionally, we developed a second reinforcing feedback loop around “identify actions,” “Reassess vulnerabilities / opportunities” and “Develop adaption pathways map.”

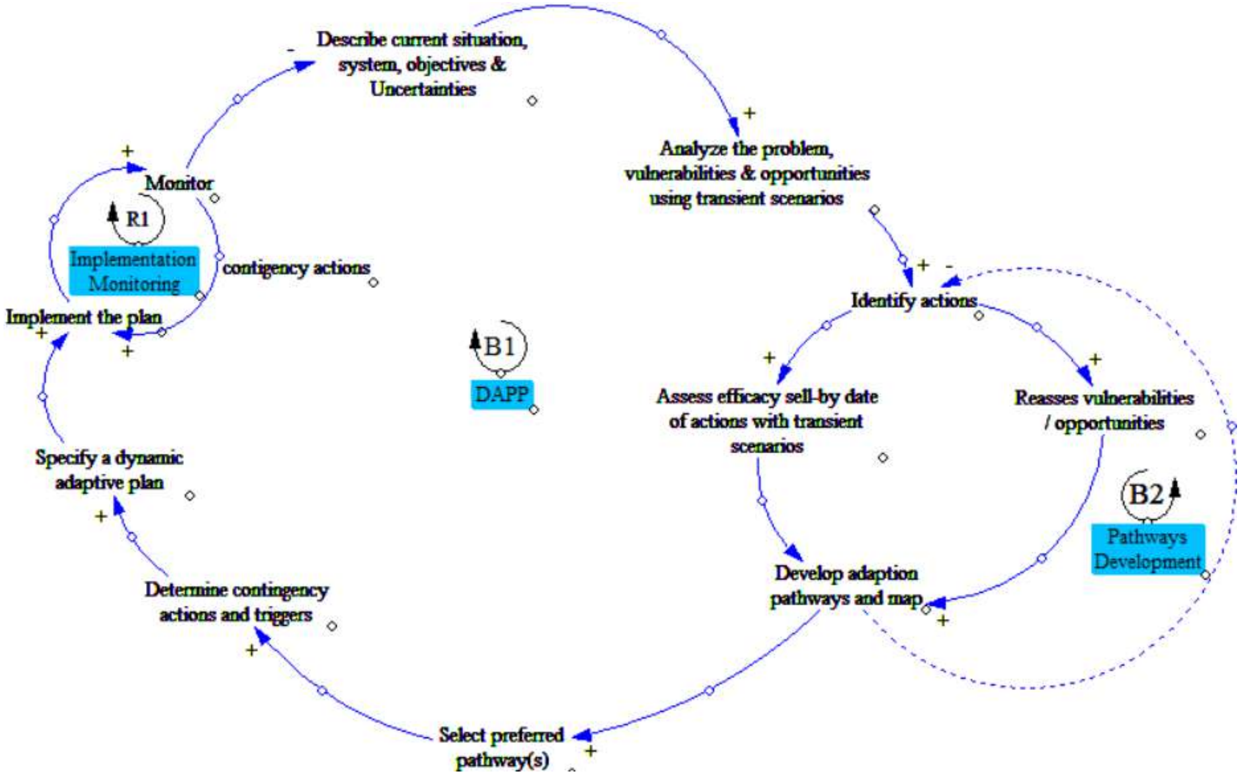


Figure 6 DAPP Feedback loop adapted from Haasnoot, Kwakkel, Walker, and ter Maat [26]

According to Brugge and Rossjen [29], institutional and socio-cultural dimensions are not adequately addressed in the DAPP approach. However, socio-cultural conditions, like individual conditions such as beliefs, habits and emotions, or institutional conditions such as social norms, legislation and state of knowledge, have a considerable influence on fostering some adaption measures while harming others. Therefore, as illustrated in Figure 7, we enhanced the model in Figure 3 accordingly with institutional, organisational, and individual contexts.

Once a preferred plan is implemented, we must evaluate the chosen strategy. This can be done by using the value creation model. If the strategy was successful, we have met the targets and created value for the organisation and the environment. In case it failed, we need to reassess the environment, its vulnerabilities and its opportunities again and choose another set of pathways.

Auvinen Ruutu, Tuominen, Ahlqvist and Oksanen [45] pointed out that a multi-level framework approach contributes in positive way to decision making and facilitates the development of practical strategies using SD modeling. Hence, combining the model so far developed with the value creation model shown in Figure 2 and, taking the findings from Auvinen Ruutu, Tuominen, Ahlqvist and Oksanen [45] into account, we define the final conceptual model, illustrated in Figure 8. Fundamentally, we derived this conceptual causal feedback loop model from a systems-thinking point of view by initially combining different views in literature as described above and shown in Table 1.

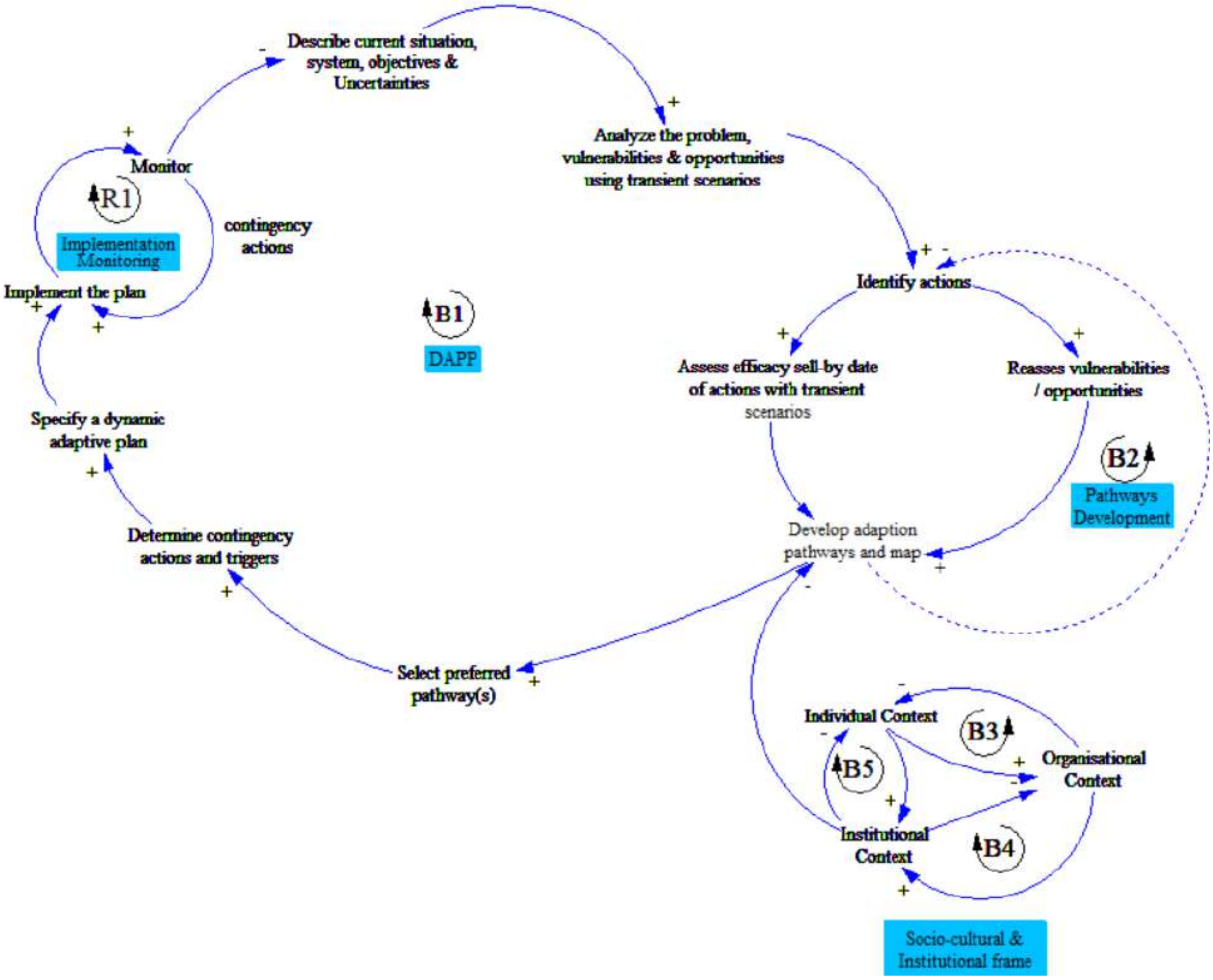


Figure 7 DAPP Feedback loop adapted from Haasnoot, Kwakkel, Walker, and ter Maat [26] and Stanton & Roelich [28]

Table 1: Literature views used for the conceptual SD model shown in Figure 8

Relation	Source
The value creation model visualizes the growth of a dynamic system using distinctive competences. This can be used to assess whether a decision was successful or not. The more sustainable the growth of the system is the more robust were the decisions.	Schaveling and Bryan [12]
DAPP provides transient scenarios evaluating various uncertainties and their development over time in a dynamic approach.	Haasnoot, Kwakkel, Walker, and ter Maat [26]
DAPP points at generating a pathway map that contains different possible pathways and their impacts. Stakeholders will use this result as a basis for their discussions and decisions.	Kwakkel, Haasnoot and Walker [44]

Institutional, organisational and individual contexts have a huge impact on the development and the evalution of adaption pathways.	Cuppen, Kwakkel and Quist [35]
As long as the regime and landscape level in complex socio-technical environments are in balance the status-quo is maintained. Once compatibility between the two levels is lacking, the regime will reform itself or be transformed by niche players.	Nieminen and Hyytinen [39]
Decision making benefits from a multi-level framework approach in complex socio-technical environments using SD modeling. In this context, SD modeling fosters the generation of alternative future scenarios and illustrates the impacts of chosen pathways.	Auvinen Ruutu, Tuominen, Ahlqvist and Oksanen [45]

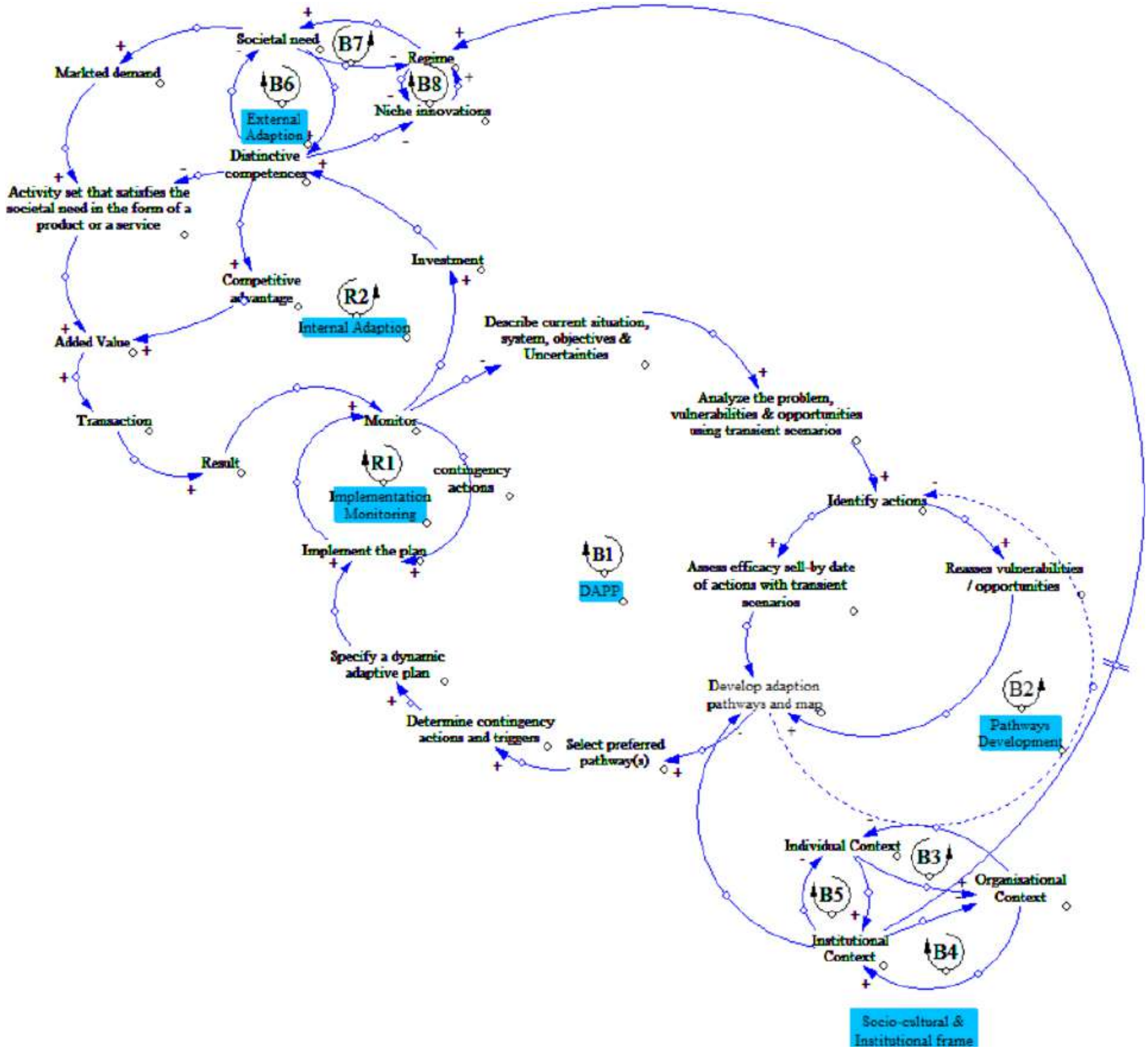


Figure 8 DAPP Feedback loop adapted from Haasnoot, Kwakkel, Walker, and ter Maat [26] and Stanton & Roelich [28] and Schaveling & Brayn [12] and Nieminen & Hyytinen [39]

5 CONCLUSION

This article examined decision-making processes in a highly dynamic and complex environment. Organisations must cope with unpredictable external events as well as with rapidly changing environmental conditions. Therefore, one question was how an organisation can obtain robust decisions in a rapidly-changing environment under deep uncertainty by following a structured approach. We conducted a literature study, which we split into two parts, viz. value creation and decision-making. Although, we identified several DMDU methods, which all deliver useful results [28], to support decision makers. Nevertheless, we followed the DAPP approach as it promises high compatibility with dynamic approaches while offering robust and best results [44]. By using system dynamic tools, this resulted in the formulation of the final dynamic causal feedback loop illustrated in Figure 8. Table 1 shows the main relations of the outcomes of the literature review ("the value creation model", "DAPP", "institutional, organisational and individual contexts" and "decision making in complex socio-technical environments") and the final derived SD model. One of the key findings in this study is that it is crucial for the success of organisations to make robust decisions while adapting to exogenous impacts. We also found that socio-cultural and institutional conditions have a significant impact on decision making and implementing pathways. The beliefs and habits of individuals are the fundamentals of their decisions and shape their behaviour. From an institutional perspective, multiple stakeholders can harm or impede adaption actions and the successful implementation of plans [28].

Although, we attempted to address all the objectives of this paper, some limitations exist. For instance, the paper addressed only the first two stages of the modified version of the six-stages system dynamics modeling approach suggested by Martinez-Moyano and Richardson [41] (viz. problem identification and formulation; system conceptualization; model formulation; model testing and evaluation; model use, implementation and dissemination; design of learning strategy/infrastructure). This resulted in a preliminary causal loop diagram. However, it is of great importance to undertake further research, as this paper did not go far enough to obtain a fully competent system dynamics simulation model. Once such a model has been developed, it can be validated and adjusted, using quantitative data to test the dynamic hypotheses, as proposed by Luna-Reyes and Andersen [45]. Nevertheless, the authors of this paper are currently involved in further studies focused on system dynamics modeling of strategy formulation and definition processes in complex and highly dynamic environments, which may address these limitations. Further studies may also focus on time delays in the decision process and on further impact of individual, organisational and institutional characteristics, as well as on positive feedback loops (ripple effects), that may harm the robustness of preferred pathways especially regarding the already derived initial conceptual SD model for strategy execution and implementation processes [11].

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AN INVESTIGATION INTO STOCK CAPACITY UTILIZATION OF A MANUFACTURING LINE AT A CATALYST MANUFACTURER

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ABSTRACT

Bottlenecks in a manufacturing line are the fundamental reason that obstructs productivity. Accurately and effectively recognizing bottleneck areas, can improve the use of limited assembling resources, increment the framework throughput, and limit the complete expense of production. This article focuses on improving the throughput of a manufacturing line in an automotive component supplier plant. The project aims to develop a solution to increase the capacity of the production system by following an adapted design thinking method to approach the problem. The first step in the process is to Underline (Emphasize), followed by Define, Research, Analyse, Ideate, and Conclude with Testing and Verification. Tools used in this project are Process mapping, Genchi Gembutsu, Time studies, Ishikawa diagrams (Root cause analysis), and five why analysis. Insight was gained in the Emphasize phase using Gemba walks and observation.

Keywords: root cause analysis, productivity, efficiency

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1 INTRODUCTION

This project was conducted at the powder manufacturing unit of an automotive catalyst manufacturer that supplies high-value catalysts to the industry. Although the organisation's fundamental goal is to produce catalysts, the powder manufacturing unit directly impacts the finished good products and ultimately the company's profit margins. The automotive industry is exceptionally competitive; therefore, an increase in capacity output and meeting customer demand whilst also building a satisfactory buffer/ safety stock variation will benefit the company. The powder manufacturing line is accountable for manufacturing approximately 25 different types of powders in different batch quantities, this process forms part of a five-step process to achieve the finished good. Therefore, whilst trying to increase the capacity output of the powder manufacturing line by looking at the process capacities, the project strives to maintain the high-quality standards that the company instils not only into its products but also in each member of the company and upholds the company ethos.

1.1 Background to Study

This project involves mapping, evaluating, and analyzing the current process of the company’s Powder manufacturing system. The Powder system meets the demand with additional labour hours as the system capacity is balanced with demand without taking unplanned events into account. Powder short supply does occur very rarely however the production plan has to then immediately be changed to counteract any potential line stoppage. Multiple powder models are planned for the week depending on the production plan. These plans must be adjusted to not create a capacity constraint on the line. These adjustments result in some weeks having to run a seven-day, three-shift operation which places a major constraint on equipment. The powder manufacturing process has a four-step process: a wet powder(slurry), a microwave process, a calcination oven, and milling.

1.2 Research Problem Statement

Company ABC’s powder production demand is not consistently met by the company’s powder manufacturing line capacity. This leads to the need for additional production planning and amendments to the original plan during a production week, thus increasing costs (material and labour costs).

1.3 Research Aim

This study aims to develop a solution to meet customer demand whilst keeping adequate safety stock levels by increasing powder capacity output and improving profit margin.

1.4 Research Objectives

The objectives to achieve the project aim have been defined as:

- To determine the main contributors to capacity constraints by conducting a root cause analysis.
- Determine improvement methods for the powder production system.
- Design an improved manufacturing system.
- Establish the new system’s impact on the production system.

1.5 Research Questions

Considering the research objectives described above, this research seeks to address three research questions stated below:

- What strategies can be used for the improvement of low-capacity manufacturing volumes at company ABC?

- What best-suited strategy and performance measures will improve the throughput of capacity as well as customer order satisfaction?
- Can an agent-based inventory management model mimic and unveil the execution of the selected integrated-inventory management strategy to be proposed in this study for company ABC?

2 METHODOLOGY

Figure 1 outlines the adjusted planned thinking that was followed to move towards approaching the problem. This strategy will be clarified extensively in this part.

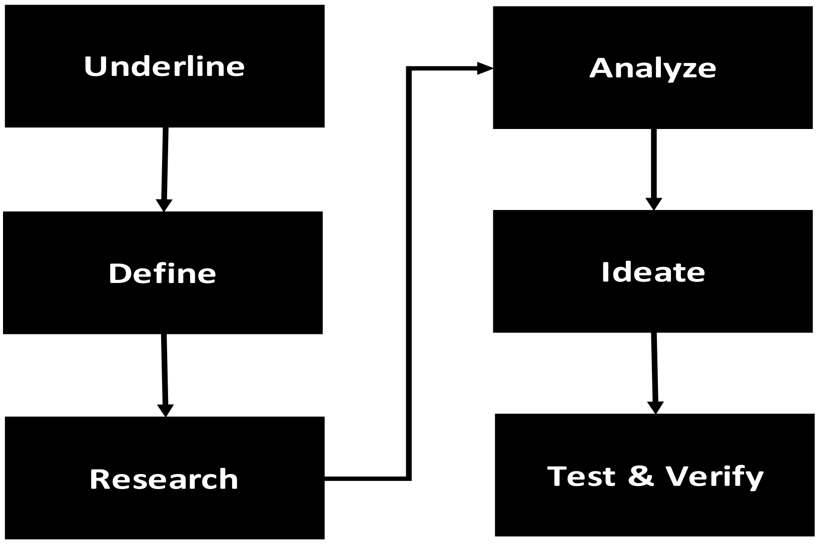


Figure 1: Method Followed to address the problem

In the underline stage, knowledge was acquired about the organization and its tasks through Gemba strolls and observation of the line. Key factors were additionally recognized during this stage.

During the Define phase, the powder system process was mapped by using a process flow diagram. A needs analysis was conducted during this phase to define the company's system requirements, which resulted in the identification of the manufacturing capacity not fully utilized.

In the Research stage, a writing study was directed on the problem statement, on subjects that emerged from this undertaking, and on different writers that have considered or tackled comparable issues, the problem of the manufacturing line not being fully utilized and creating bottlenecks in the overall production process at company ABC can relate to a Theory of constraint issue.

In the Analyse stage, the speculation that the Powder production was not effective was tried by investigating various factors such as overtime required each week. Referring to company ABC's historical production data that the Powder line was not effectively productive as it was initially designed to be, a present status examination was finished, and the main investigation was directed by joining two designing instruments, an Ishikawa graph and a 5 Why examination.

In the Ideate stage, a limit adjusting technique was picked to foster further developed system idea plans. The upgraded configuration intends to improve the system's limits, thus reducing additional mistakes in the system and less time worked.

In the Testing and Verification phase, the final design was tested to ensure that the system was improved. The system was tested by running a simulation multiple times with the new system design and comparing the improved system results to the old system results as well as historical data.

3 LITERATURE REVIEW

Different philosophies and strategies were considered and discussed with the problem encountered within this project, by conducting this literature review we will attempt to discover the gaps within previous research conducted on the issue and put forward possible problem-solving approaches.

3.1 Strategies to improve manufacturing capacity

In the journey to further develop production execution, various extensive ways of thinking have been proposed in research and are being carried out practically. It is broadly held that the fruitful execution of these methods of reasoning requires system thinking in which one sees things holistically, including the many variations of relationships between the diverse elements of a complex system. Functional integration in which supplier processes meet the requirements of customer processes in terms of cost, availability, and time, and lastly, we consider flatter organizational structures which elevate each employee's tasks within the plant and eliminate excess management layers to improve coordination and communication [1]. We can now delve further into the philosophies applicable to the problem being addressed in this project.

3.1.1 Theory of Constraints

The Theory of Constraints (TOC) is a moderately new administrative way of thinking that has been consistently advancing since the mid-1980s. This framework-based way to deal with management, principally credited to Eliyahu M. Goldratt, looks to comprehend the basic cause-and-effect connections that are liable for an association's performance [2]. Utilizing the five-step measure that Goldratt introduced, the TOC way to deal with limitations of management will be utilized as a system to direct the improvement of the system as company ABC look to make their association more receptive to client requests in a serious and dynamic commercial sector. The five stages look to:

- Recognize the system constraint.
- Exploit the constraint.
- subordinate the non - constraints.
- Elevate the constraint.
- Return to step 1

3.1.2 Total Quality Management

One technique for “extending quality is through Total Quality Organization (TQM). “TQM is detailed organizational thinking that relies on guidelines and practices that lead to further development of business execution [3]. Many situation-oriented surveys or surveys provide evidence that maintains TQM achievements in terms of money-related results, job execution, and customer and worker satisfaction. TQM execution redesigns an association's image and further creates delegate satisfaction and quality care. Similarly offered some evidence for a productive result of TQM practices on market course and organization quality in the Malaysian production industry [3]. [4] found that three TQM factors (supplier quality organization, measuring the board and quality data, and uncovering) add to achieving the practical goals. Therefore, by utilizing TQM standards there can be a potential increase in productivity on the Powder line.

3.1.3 *Queueing theory*

Queueing hypothesis is a high-level numerical displaying strategy that can appraise holding up occasions [5]. As a rule, a queueing framework has two primary parts: clients and workers. On the off chance that a client should stand by in line, it is alluded to as a line. A queueing model can be utilized to decipher the appearance examples and preparing times to appraise significant framework execution measures, for example, the normal client holding up occasions and the probability of an irregular client experiencing zero deferrals, for quite a few workers [5].

3.1.4 *Lean Manufacturing Philosophy*

According to [6] reported that the Lean Philosophy which originated in Japan has become a worldwide marvel, because of its authoritative advantages for persistent improvement. This brilliant philosophy continued to grow from inception and the conventional term lean manufacturing was promoted by its significant advocates, the Lean way of thinking is portrayed as being founded on five key standards [7], in particular:

1. Define Value – characterized according to the client's point of view.
2. Map the value stream – map the arrangement of activities needed to make items or administrations.
3. Create Flow – After removing wastes from the VSA, ensure the remaining steps run smoothly.
4. Pull – utilize a drawing framework.
5. Chase Perfection – consistently make progress toward the paragon of the item/administration.

3.1.5 *Six Sigma*

All through the development of Six Sigma in industry, according to [8], there have been numerous ways by which Six Sigma has been made sense, nonetheless, for the setting of this paper, we will sum up the definitions and decide how is "Six Sigma" valuable to this project.

Firstly, Six Sigma is a set of statistical tools adopted within the quality management dynamics to build a system for process improvement. The goal is to upgrade the Six Sigma level of performance measures referred to as the critical to quality (CTQ) which mirrors the client prerequisites through a group of tools for the investigation of the information [9]. Measurable tools recognize the major quality indicators which are the Parts Per Million (PPM) of non-adjusting items. Achieving a Six Sigma level means having a process that creates yields with < 3.4 defective PPM.

Secondly, Six Sigma is an operational philosophy of management that can be shared beneficially by clients, investors, representatives, and providers. Thanks to its adaptability, the Six Sigma application isn't restricted exclusively to assembling and can be rolled out to the entire inventory network which incorporates the arrangement of services. It is helpful to implement a more focused approach towards production network undertakings to thoroughly characterize and execute them more [10]. Six Sigma is likewise characterized as a diverse, client-situated, organized tool that accelerates the deliveries of goods and diminishes overall costs.

3.1.6 *Value Stream Mapping (VSM)*

As per [11], value stream mapping (VSM) achieves the likelihood to distinguish value-adding exercises. At the end of the day, VSM continually seeks the goal of waste reduction intending to increase the value [12]. Likewise, by applying VSM, which could assist with recognizing functional misfortunes, associations will want to dispose of functional misfortunes and advance toward more worth creation for the client [13]. This is the very issue that the current examination endeavours to review and answer in practice [14]. VSM is one of the most valuable and instrumental strategies [15]. VSM is characterized as movements of every kind and occasion (both value-added, and non-value added) that an item or service goes through on its way from provider to client [16]. In organization ABC, these exercises incorporate delivery, waiting, (in stock, in a line to be handled), packaging, examination, revision, and both manual and robotized handling [17]. VSM can't be utilized straightforwardly for exceptionally complex assembling processes with merging flows [18].

3.1.7 Statistical Process Control (SPC)

The control “graph method is viewed as one of the significant apparatuses in factual quality control [19]. A primary goal of control graphing is to distinguish any crumbling in quality so the remedial move can be made before delivering a huge number of nonconforming things. The idea of the control diagram was first presented by [19]. Shewhart control diagrams are more productive in identifying huge changes in measure boundaries, as they rely just upon the data in the last example perception. Therefore, these charts are imperative to prevent problems before they occur, its flexible enough to be used on any process line.

3.2 Performance Measurements

The current powder manufacturing processes within the company are audited by their performance effectiveness, therefore in this section, we will discuss the various applicable Key Performance Indicators [20].

3.2.1 Throughput

According to [21], it is observed globally, that delivery lead time and reliable delivery are of critical importance to a manufacturing industry's capacity to compete more effectively in both the domestic and export markets. Industries are reputed to have a poor delivery performance record, but very little research has been performed to ascertain the causes of this problem. However, [22] states research has been reported on the possibilities of using various heuristic priority rules to sequence batches through a job shop. The SPT (Shortest Priority Time) heuristic, or modifications to it, has been proven useful in many studies. The simulation model has been utilized to test the impact of notable priority rules of delivering groups into the shop arranged by diminishing expected throughput time. The significant impact of this "phase release" of batches is to build the level of batches conveyed in completed parts on time, especially for the situation where priority rules were being used which could somehow have brought about unfortunate conveyance. This has significant repercussions for the executives because it implies that by "phased" release of batches in the manner discussed, a large proportion of batches will be delivered on time whatever priority rule is in operation in the shop.

3.2.2 Change Over Time

Accomplishing "production greatness" is fundamental for the endurance and monetary development of any country in this period of globalization. The "mechanical age" of the last century has offered a way to the "data age" which in assembling terms upgrades capacity and lessens item process durations, thus changing Cycle Times (CTs). The advancement of innovation, complex high-creation frameworks, and mechanical production systems has introduced another period in assembling [23], notwithstanding To contend in this ceaselessly evolving climate, these organizations should search out new strategies permitting them to stay serious and adaptable and, all the while, empowering their organizations to react quickly to new requests [23] accordingly single minute exchange of die (SMED) is a significant lean instrument to decrease squander and further develop adaptability in assembling measures and assembling stream enhancements. single minute exchange of die (SMED) lessens the non-useful time by smoothing out and normalizing the activities for trade instruments, utilizing basic procedures and simple applications. We can see that In the single-minute exchange of die (SMED) technique, arrangement exercises are partitioned into inward and outside exercises.

Outside exercises can be done during the ordinary activity of the machine, when it is yet running, for instance, preparing the hardware for the arrangement activity should be possible before the machine is closed. Inside exercises can be performed just when the machine is closed, for instance, appending or eliminating the dies. The interior and outer arrangement exercises contain various activities like planning, after-measure change, checking of materials, mounting, and eliminating devices, settings and alignments, estimations, preliminary attempts, changes, and so on [24]. A few techniques can be applied to diminish the length of exercises. A few alternatives like utilizing useful cinches, executing equal tasks, lessening acclimations to least, and planning successful instruments are recommended [24] however theoretically the change over time is inversely proportional to the problem of capacity utilization of the Powder manufacturing line.

3.2.3 Planned Maintenance

According to [25], It is imperial to support capacity, and in this manner with regards to the upkeep that companies have developed. The far and wide motorization and mechanization have decreased the quantity of manufacturing staff and expanded the capital utilized in the manufacturing gear and designs. In processing plants, for example, it's anything but extraordinary that the upkeep and activities divisions are the biggest, and each contains 30% of the all-out labour. Moreover, close to the energy costs, upkeep expenses can be the biggest piece of any functional spending plan. However, the primary connection looked at by management, regardless of whether its yield is positive, is its commitment to organization benefits.

3.2.4 Overall Equipment Effectiveness

Producers give superb dependability and nature of their equipment at cutthroat costs. “To have exceptionally dependable machines to make smooth assembling measures certain, numerous associations have executed absolute useful upkeep (TPM) as the empowering device to augment the viability of hardware [26]. Upkeep and its administration have moved from being considered a "means to an end" to being of key significance for the most serious associations throughout the planet [27]. Quite possibly the most pivotal and broad applied devices of execution estimation in the assembling business are in general gear viability [53]. OEE is the critical proportion of both TPM and lean upkeep [28]. The OEE uncovers the secret expenses related to the effectiveness of the hardware. OEE is characterized as a proportion of complete gear execution, that is, how much the hardware is doing what it should do [29].

3.2.5 Capacity Utilization

This concept is an idea firmly connected with the thoughts of usefulness and effectiveness. [72] states that "capacity utilization (CU)" in the industry is a much-ignored area and members are still familiar with the sustainable benefits of capacity and effective utilization. Research shows that the estimation of capacity can only be carried out by management in the workplace. To conquer such issues and expand the huge consciousness of the CU idea, the novelty of the current work is to investigate the CU discernment through practicality via the current project outcomes. Research shows the situation with CU across the world and its job in the improvement of efficiency and quality inside the enterprises. Besides, the difficulties looked at in a CU assessment are featured for propelling the industrialist and specialists. CU is directly related to the production level of a production line. CU is a latent ability to perform and produce output without increasing input variables according to [25]. The CU as output could be increased with the full use of all input variables under normal conditions like extending the working hours and considering regular holidays and machine maintenance [25].

3.3 Techniques & Problem-Solving approaches

3.3.1 Total Quality Management (TQM)

TQM decides the general intent to augment the processing plant's execution pointers dependent on the distinguishing proof of production bottlenecks and apparatus [26]. For many quality circles, there has been a struggle, because total quality management has been something to “get around to one day” and continuous improvement has just been another expression for total quality management. As indicated by [27] there is no widespread agreement meaning of TQM, and various gatherings including academicians, researchers, experts, designers, and others have thought of different definitions. For example, [28] characterized TQM as a business cycle zeroing in on working on hierarchical viability, proficiency, and responsiveness to client needs by effectively affecting individuals in process improvement exercises. According to [29] past researchers have shown that TQM is an administrative practice that can work on the nature of an item or administration. It is in this critical manner to find and distinguish a specific quality and its suggestion. Quality can be characterized distinctively since individuals could see quality comparable to contrasting rules considering their singular jobs in the production chain, based on broad surveying of the TQM writing [30]. It has also been observed that there are seven significant classifications of practices estimated in past examinations, to be specific administration, key preparation, client concentration, data and examination, human resource management (HRM), and supplier management [31]. These practices, excluding supplier management, are consistent with the criteria that are used in TQM [32].

3.3.2 Simulation Approach

Simulation is defined as the process of model designing of a system as well as the conduction of experiments using this model to 1) understand the system behaviour and 2) evaluate different strategies for system operation. The behaviour of the model should be consistent with the response behaviour of the system in reaction to the event happening over a period according to [2]. It was elucidated by [32] that simulation models are flexible, although a closed form of solutions (e.g., queuing) is not provided. The goal of simulation includes the retrieving of supplementary information on the performance of the models that are proposed [32]. A simulation was used by several researchers to analyse waiting time [33], test the scheduling heuristics performance, and compare the performance of simple scheduling rules within a system [34]. The implementation of simulation optimization offers improvements, however small the impact is.

3.4 Implementing the Improvement

Based on certain restrictions from higher management at company ABC, only two possibilities for improvement were allowed to be put forward, one being advancing the current equipment and the second being installing new machinery, the possibility that will be chosen for implementation would ultimately be based on reducing the low volume capacity that the powder manufacturing line is currently experiencing.

3.4.1 Advancing Current Equipment

By redesigning the equipment, the bottleneck could be decreased, bringing about higher throughput, which will empower the interaction to satisfy reliability. This conceivable arrangement will be generally moderate as no foundation changes will be required except if the upgrades are done outside of working hours.

3.4.2 Adding New Equipment

By adding new equipment, factors such as equipment installation time as well as cost factors will have to be greatly scrutinized, although changes will happen within the plant’s layout, the bottleneck constraints will be enormously relieved.

The two above-mentioned improvement possibilities were used as the foundation for further design and improvement concepts and investigations in the further part of the project.

3.5 Literature Review Conclusion

In this literature review, the work of other authors that have solved or researched similar problems was analysed. By using the lean philosophy, Six Sigma, and the Theory of Constraints, strategies for system enhancements were identified. It was observed that integrated philosophies eliminate unnecessary limitations that may lead to a plateau and the depletion of resources in the long term. Different approaches were identified to optimize the entire feed production process. These approaches include the Theory of Constraints and the Simulation approach. The TOC is divided into bottleneck and non-bottleneck machinery. The bottleneck can be elevated by either replacing machinery, adding machinery, or upgrading existing machinery, these restrictions being determined by higher management at company ABC. The concepts in this section will be used as a basis for alternative designs that could solve the problem, as stated in the problem statement.

4 DESIGN INTRODUCTION

This section of the article examines a proposed answer for the problem as far as a calculated plan. The theoretical structure whereupon the arrangement is based, is examined. Potential answers for the customer's necessities as electronic frameworks used to carry out the interaction for observation. Furthermore, whether it is smarter to buy or foster such frameworks in-house is examined. The part is then closed and the importance of the writing concerning the task is examined.

4.1 Design Requirements

The design requirements are based on root-cause analysis. The design requirements should be met for the task to be effective. The design requirements are:

a) The powder interaction should have an overabundance ability to represent changeability.

b) Production yield deficit should be insignificant.

c) Maximum limit increment for the most reduced venture.

d) The final plan should be monetarily achievable for the business.

Figure 2, depicts the Fishbone diagram, followed by Table 1, which is a scoring matrix of all the main causes identified that could be generating the effect. The main causes that are identified, were finalized by company ABC’s Engineering department and higher management.

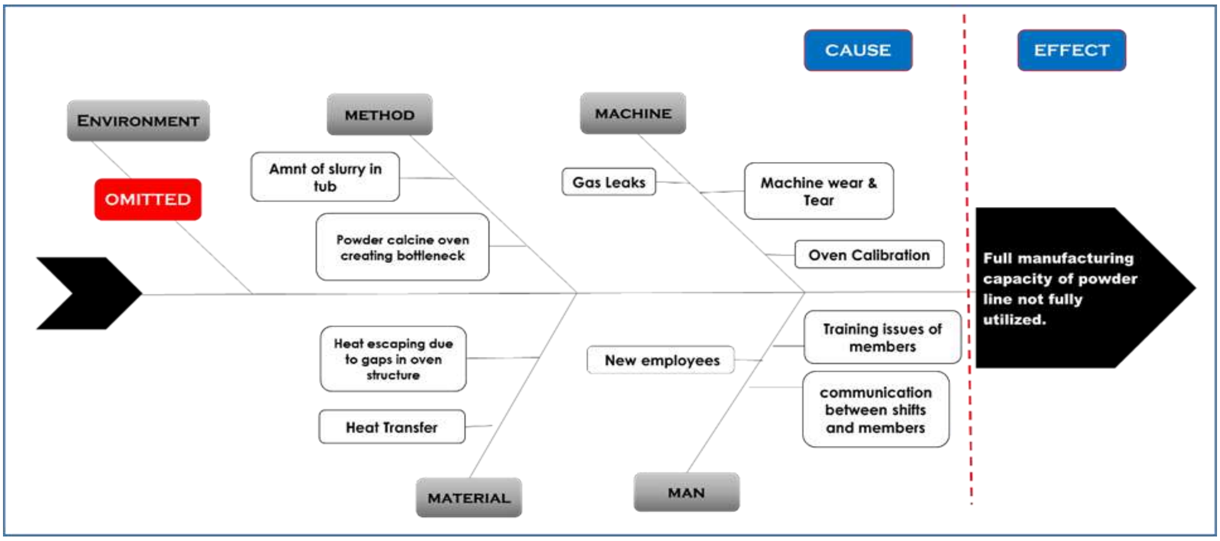


Figure 2: Ishikawa diagram (Root-cause analysis)

Table 1 Scoring matrix of the Ishikawa diagram's main cause

Score Rating: > 0 - (Not likely) ⟷ 5 - (Very Likely)		**Full manufacturing capacity of powder line not fully utilized.**			
4M + E Factor	**Cause**	**Does this problem impact the "EFFECT"**	**Possibility of achieving positive outcomes once countermeasure is developed?**	**Risk of creating a line stoppage**	**Score**
Man	Training issues of members	**1**	**0**	**0**	**1**
Machine	Oven Calibration	**1**	**1**	**1**	**3**
Machine	Gas Leaks	**1**	**1**	**1**	**3**
Material	Heat escaping due to gaps in oven structure	**0**	**3**	**1**	**4**
Method	Powder calcine oven rack not effectively utilized	**5**	**5**	**1**	**11**

4.2 Design Decision Criteria

The design criteria are based on the current state and the root cause analysis. The design will be utilized to guarantee that the main system is tended to and that the issue, as characterized in the issue articulation, is settled. The models that will be utilized to assess every idea configuration are:

a) Cost-Effectiveness Short Term

b) Cost-Effectiveness Long Term

c) Investment Short term

d) Investment Long Term

e) Production Increase

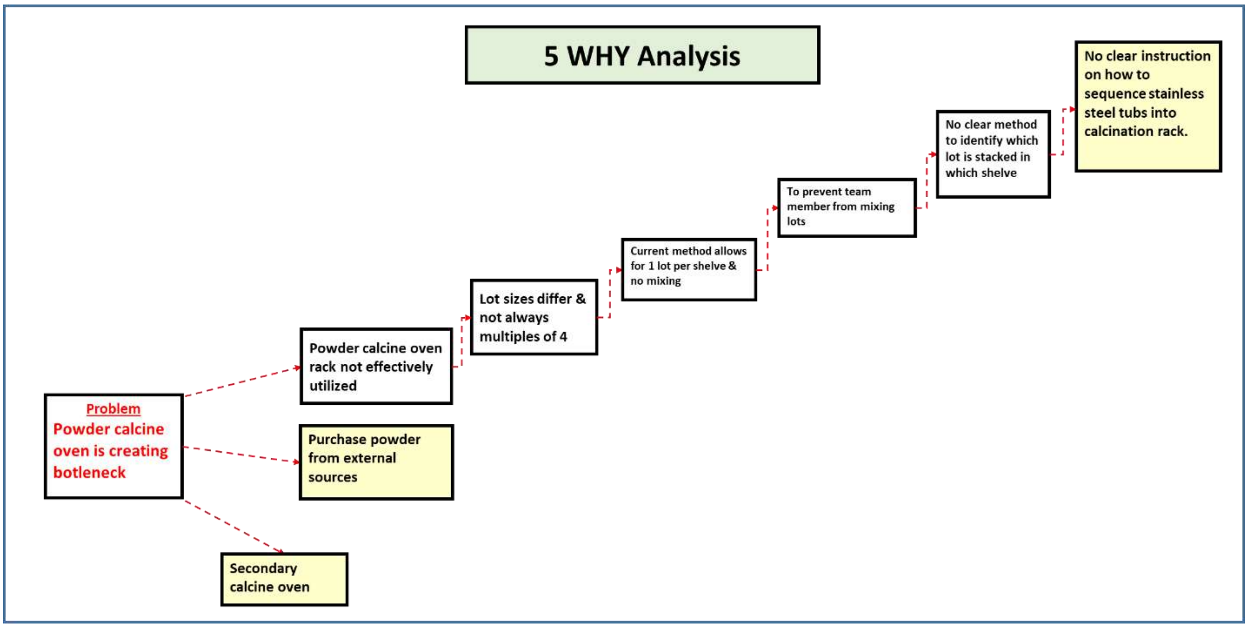


Figure 3: 5 WHY Analysis

Figure 3 represents the 5 WHY analysis that was conducted after the Ishikawa (Fishbone analysis) was completed. Higher management together with engineers at Company ABC determined the constraints of improvement, based on restrictions from company ABC's headquarters in Japan.

4.3 Factors to consider when developing the final countermeasure

4.3.1 Variables

The variables in the process will result in variation in daily powder production but will not influence weekly production to the same extent. Different powder quantities will cause variation as the microwave timings have different durations from the calcine oven. Also, some powders must be calcined twice, and this may impact the overall capacity output. The variables that we are being considered, are based on the potential countermeasures developed from the 5 WHY analysis. They are stated below as follows:

4.3.1.1 Purchasing of Powder from an external source

Purchasing of powder from the companies' headquarters would alleviate major pressure off from the production line, Powder would be ordered as per customer order and in line with the in-house production sequencing plan. There are however a few negatives to this solution, since the powder will be of high monetary value, importing into the country would pose a few safety hazards, as well as potential contamination of powder as most of the powders, would be shipped rather than arrive via airfreight.

4.3.1.2 Improved oven racking system concept design

An improved oven racking system could be the result of the enhanced bottleneck processing time or because of the improvement of a combination of the bottlenecks in the system. A simulation using excel graphs was developed to allow the various parties concerned, to visually see what the potential improvement could be like. The simulation delivered the current system capacity based on six days with three 6-hour shifts 24-hour cycle workday. The concept design was weighed against the final design requirement.

4.3.1.3 Implementing secondary microwave and calcination oven

A secondary microwave oven could be possibly installed, this would alleviate strain from different powder models having to go through the microwave process, this aids with the theory of constraints theorem with regards to current conditions. Various discussions were held with management as well as the company's headquarters in Japan, a green light was received if this would be the option that best suits the current problem.

4.4 Decision Tree analysis

Decision trees are graphical, simple-to-develop portrayals of the different decision ways inside a task. At their most fundamental level, decision trees can be utilized as a straightforward device to put together groupings of occasions or decisions.

Based on different variables that were developed from the Ishikawa diagram, the 5 WHY analysis was then conducted to produce possible countermeasures, and a decision tree analysis was conducted afterwards. Figure 4 reflects the various factors, their probabilities, and possible monetary values per powder batch.

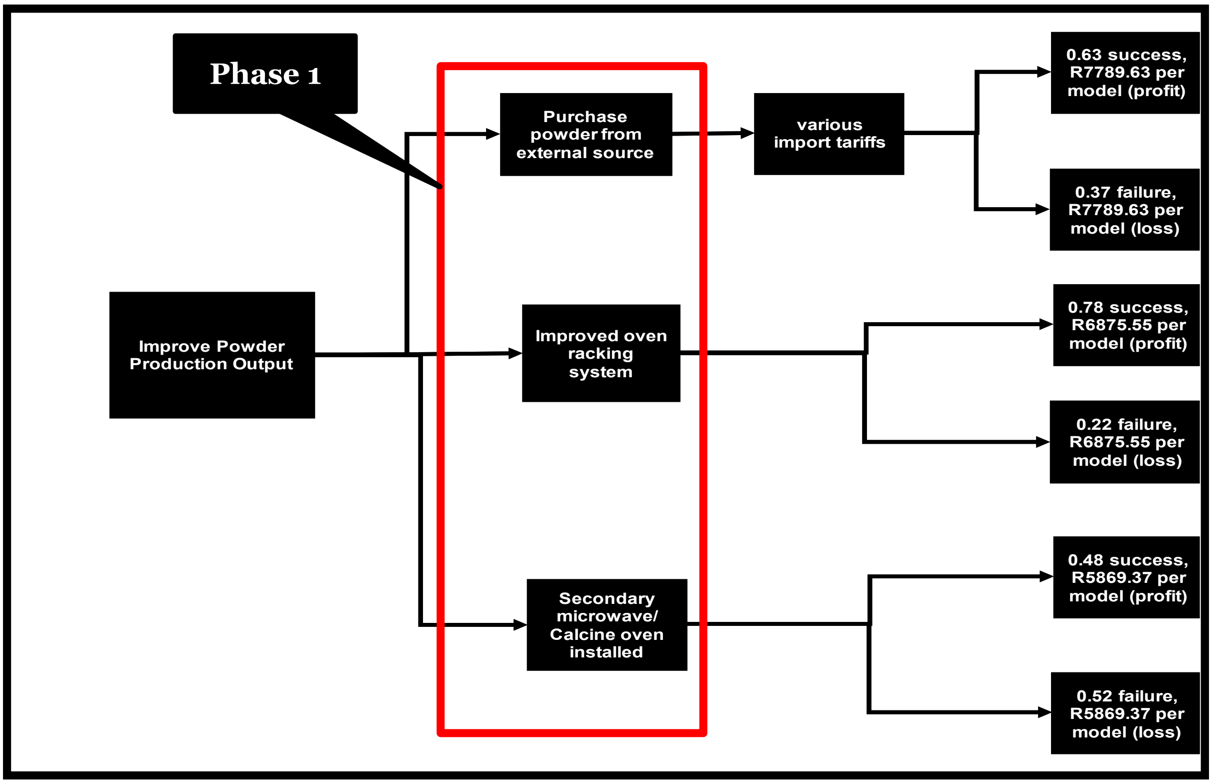


Figure 4: Decision Tree analysis of 3 possibilities

After conducting the tree analysis, the blocks in phase 1 of the analysis demonstrate the possible improvements that could be, and the blocks in phase 3 demonstrate the monetary values regarding one batch of powder as well as the probability factor of success or failure. Phase 3 would indicate the most economical criteria to choose from.

Table 2: Feasibility options

	External Purchase	**Improved Racking System**	**Secondary Microwave and oven**
Success	R4 907.47	R5 362.93	R2 817.30
Failure	-2882.1631	-1512.621	-3052.0724
	R2 025.30	**R3 850.31**	**-R234.77**

Table 2 reflects the calculation conducted, the green cells, highlights option 2 as the more applicable countermeasure to implement.

Option 2, being the "Improved Racking System" reflects the highest theoretical profit gain based on model costs over a period of 12 months. This will direct the project in developing an efficient and cost-effective mechanism that takes into consideration the ergonomics of members working on the line. The design will need to be easy as well as yield positive feedback from the members who will utilize the improvement in their everyday work.

4.5 Section conclusion

After weighing the 3 different options as stated in the decision tree analysis, the best analysis would be to improve the stacking matrix of the calcination rack combined with a user interface to get the best output from the calcination oven, this would allow for capacity to meet demand more conveniently allowing for flexibility on the line and reduce bottleneck at the PGM Powder area.

5 FINAL DESIGN

The best alternate decision will now be discussed, the improvement will meet the project aim, resulting in an improved stacking matrix, this will also be regarded as the final deliverable of the project and will be a practice of Industrial Engineering improvement tools.

5.1 Improved calcination stacking

The final design entails a new matrix of how production members stack the calcination oven rack, this allows for more tubs to be placed on the rack and ultimately increases capacity output. The sequence stacking will be broken up into horizontal and vertical stacking compared to only vertical stacking methods of the calcination rack. The figure below reflects both horizontal and vertical stacking based on the powder manufacturing method and quantity of tubs.

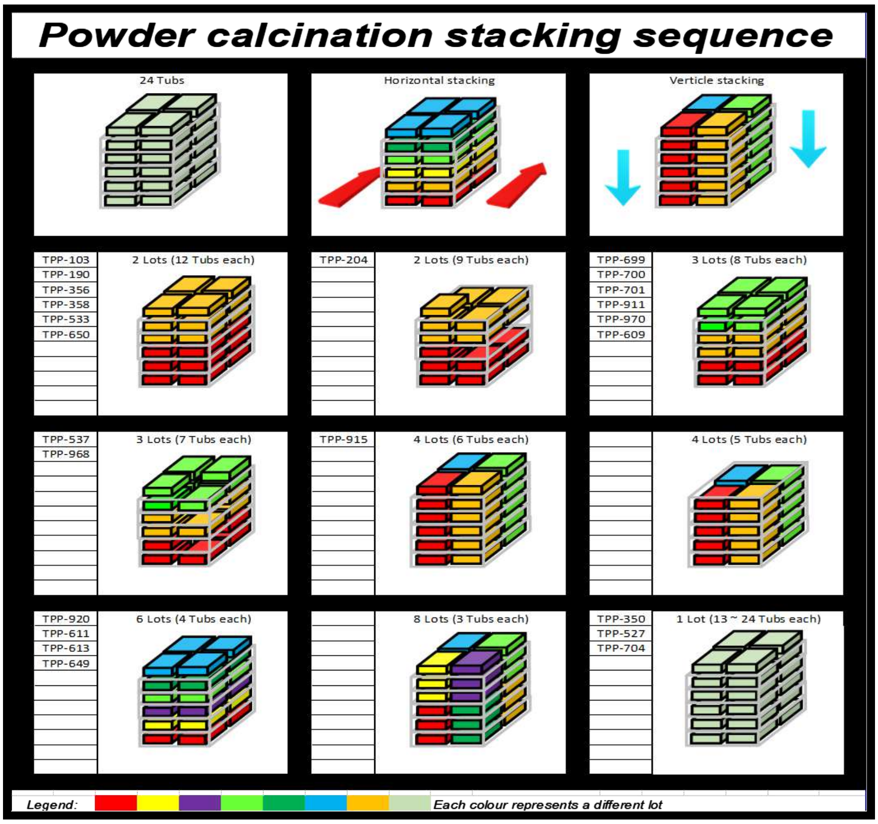
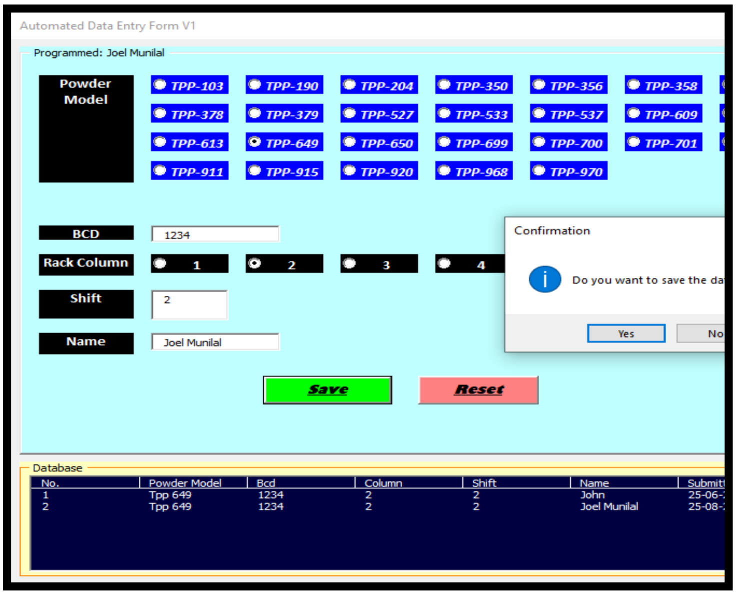


Figure 5: Horizontal & Vertical stacking methods.

5.2 Graphical User Interface development

Using the 4IR thinking, a graphical user interface (Figure 6) will run parallel to the stacking sequence, the member will make use of keyboards and scanners to load data onto the system as he or she loads the powder batch into the oven, the data will be stored and easily accessible to management for traceability purposes as well as eliminating the factor of batch mixing which can lead to contamination and ultimately loss in company profit margins.



Automated Data Entry Form V1

Programmed: Joel Munilal

BCD: 1234

Rack Column: 2

Shift: 2

Name: Joel Munilal

Confirmation

Do you want to save the da

Database

No.	Powder Model	Bcd	Column	Shift	Name	Submit
1	Tpp 649	1234	2	2	John	25-06-
2	Tpp 649	1234	2	2	Joel Munilal	25-08-

Figure 6:Example of UI (Final Stage)

5.3 Design conclusion

This section concludes with the improved stacking sequence and the graphical user interface that runs parallel to the stacking matrix.

5.4 Evaluation Conclusion

This final design meets the final design requirements. The deliverable of this project is the recommendations as to what areas in the system must be given attention. The recommendation of improving the stacking of the powder oven rack is accompanied by possible tools (stacking matrix chart and user interface) to be used to reach the designed capacities. Company ABC's management was happy with the final design and agreed that it could solve the problem.

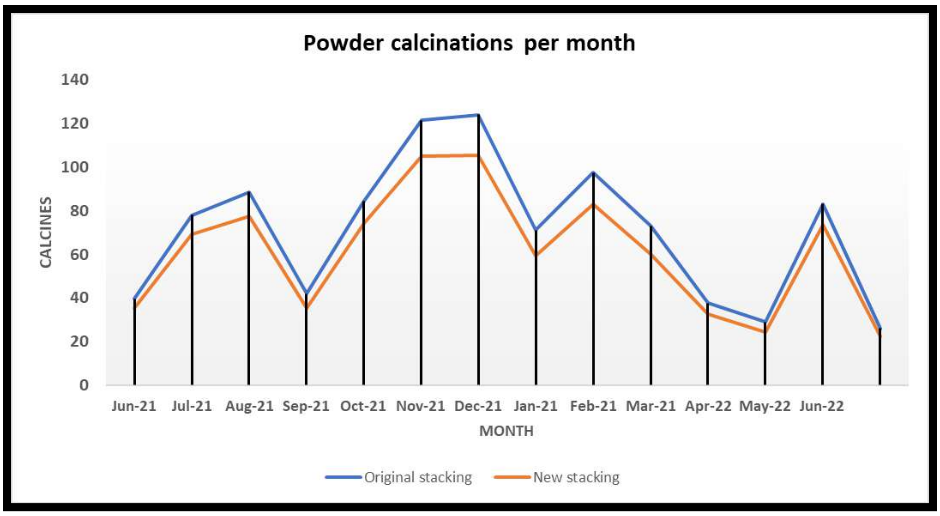


Figure 7: Original vs Improved stacking

Figure 7 reflects the originally planned calcination between June 2021 to June 2022, this datum is reflected on the blue line. The improved calculations are reflected on the orange line, the is an evident gap between the blue and green lines, thus reflecting an improvement in the calcination oven and proving the improved stacking method to be true. Before further approval from management was received, extensive trial tests had to be conducted using different analysis methods from production, after weeks of running trials on different powder models, the results returned positive and the green light was given from production, Figure 8 reflects data on one of the powder models at company ABC, the powder model is called (TPP – 920) that had been run on a trial to determine if the improved stacking method of the calcine rack affects the integrity of the powder. It is evident that the results fall within the tolerance range, thus maintaining the integrity and quality of the powder.

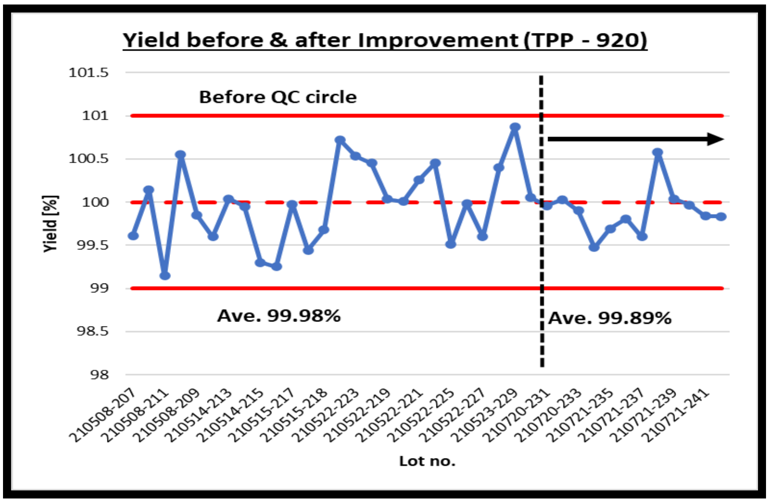


Figure 8: Trial analysis for TPP - 920

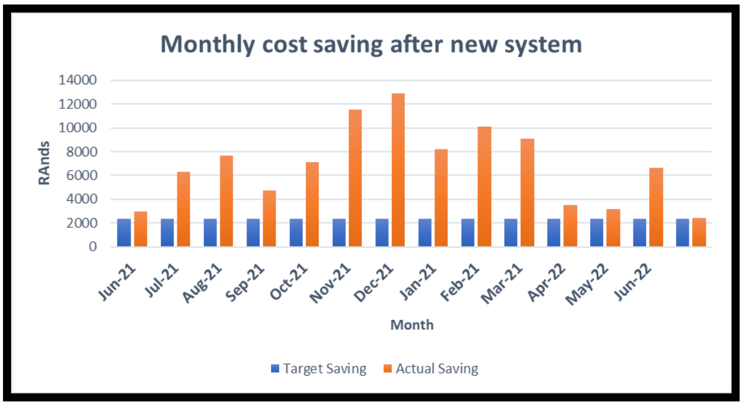


Figure 9: Cost Saving of improvement

Figure 9 reflects the theoretical cost-saving improvement that will be achieved after the new sequence method., the target saving was based on the average calculations that can be done on the line, however, based on different model runs, the orange bar reflects the actual savings to be achieved.

6 CONCLUSION

The final system design results were compared to both the current state simulation and the current state data from the past. This comparison displayed an immense increase in system capacity, resulting in a much larger system capacity than there is a demand in the current system. The final design and recommendations were delivered and were accompanied by a high-level implementation plan. The project aim and objectives were delivered on time. The problem statement is addressed, and the required deliverables are delivered.

7 RECOMMENDATIONS FOR THE SYSTEM

The powder production system does not group the same powder models to increase production efficiency. Implementing a new stacking matrix to increase volume going into the oven to improve production efficiency is highly recommended. Also, implement 2D barcode labels for each stainless-steel tub going into the oven, this allows for better traceability and not mixing lot numbers up.

7.1 Recommendations for Future Studies

Develop new universal stacking matrix methods to accommodate for instances such as the problem stated in this project. As well as develop a universal method for planning production based on a pull-forward method.

Understanding how to improve the greenhouse effect, based on reducing gas consumption in the automotive industry.

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BLOCKCHAIN SUITABILITY ASSESSMENT AND HIGH-LEVEL DESIGN: A SYSTEMATIC REVIEW

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ABSTRACT

Blockchain is a nascent technology with the potential to disrupt the foundations of several industries and is consequently gaining major attention. Blockchain is a digital ledger of cryptographically linked asset transactions that are duplicated and distributed across a network of computer systems that ultimately form the blockchain network. This architecture enables characteristics to a degree never experienced before, such as transparency, immutability, decentralization, and security. Blockchain's architecture, coupled with its unique characteristics, has triggered major interest. Blockchain is, however, a complex information system and there are multiple configurations addressing a variety of needs. As such, analysing blockchain as a potential information system solution within an organization is far from straightforward, proven by the fact that majority of blockchain projects have failed. This article presents a high-level assessment framework for analysing the suitability of blockchain and identifying a high-level design swiftly and inexpensively, while providing a strong base for future iterations.

Keywords: blockchain, assessment, suitability, capability, blockchain design, decision aid

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1 LITERATURE REVIEW

Technology is evolving exponentially, and organizations continuously find themselves at the forefront of this evolution. Technology can be used to enhance the competitiveness and productivity of organizations and it is thus becoming more crucial to remain in front of the adoption curve [1]. The benefits of these novel technologies are often only realized through implementation and often require that multiple organizations implement them in order to maximize value through network effects [1]. There is plenty of literature available to help with the assessment and subsequent implementation of a variety of technologies, along with professional expertise to help with this process. The problem lies where disruptive novel technologies, with the capacity to change the foundation on which many organizations operate, enter the market.

Enter the novel blockchain technology. Blockchain is an emerging technology with the potential to disrupt the foundations of organizations within a variety of industries [2], [3]. Often an immediate connection is made between blockchain and Bitcoin, because Bitcoin was the first and is the most well-known application of blockchain [4]. Blockchain, however, is not limited to the financial industry and has potential in multiple industries ranging from government to energy to food [5] – [9]. The copious beneficial characteristics of blockchain have attracted many supporters and enticed them to take the risk of investing in blockchain projects, but many have learned it is more situational than previously expected.

A narrow technical understanding of blockchain is required to understand how the characteristics of it are materialized. Blockchain is a type of distributed digital ledger that usually operates without a central authority or central repository [10], which it accomplishes by using one of a wide variety of consensus mechanisms. Blockchain has many definitions without a universally agreed upon definition, which may be due to blockchain being new and hence not fully understood. However, assessing the different uses of blockchain and its key elements, an all-encompassing definition is proposed by [12]:

> *"Blockchain is a decentralized database containing sequential, cryptographically linked blocks of digitally signed asset transactions, governed by a consensus model"* – Sultan [12], p. 54

A block in a blockchain can be conceptualized as a mechanism for storing a group of transactions that occur at the same time instant and are chronologically chained to other blocks to form an immutable digital ledger [13]. Each block in a blockchain typically consists of the block header and the block body [10], [14], [15]. The block header contains information on the block version, block hash, parent block hash, and timestamp, while the block body will contain the transactions the blockchain records as well as any other necessities. An illustration of these block components in a typical blockchain is shown in Figure 1.

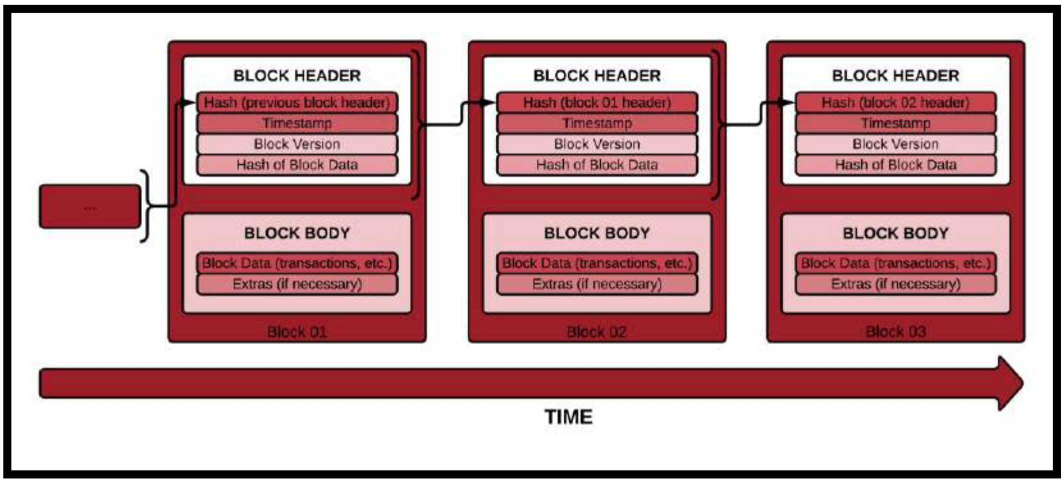

Figure 1: Blockchain Block Components

Only the key components of the block need to be understood to understand blockchain's benefits. The hash is a 64-character hexadecimal string that is generated based on the data in the block and any change in the block data, even spacing between characters, will produce a completely new hash value [10].

Forming part of the block data, with which the hash value is generated, is the hash of the parent block (the block before the current block). This is the mechanism by which blocks in a blockchain are linked, because any change in the parent block data will change its hash value and in turn the hash value of the next block will have to change, as well as every block's hash value after the altered block.

Hashing, while appearing complicated, is a trivial task for modern day computers and thus consensus mechanisms are used to ensure that a newly appended block cannot be altered without immense resources, and that the block data correlates with previous blockchain data in an environment without trust [15]. [16] describes consensus mechanisms as "the process in which a majority (or in some cases all) of the network validators come to agreement on the state of a ledger. It is a set of rules and procedures that allows maintaining a coherent set of facts between multiple participating nodes." There are many consensus mechanisms with differing characteristics and the selection of a suitable one is far from straight-forward.

One may begin to understand how hashing and consensus mechanisms are used to make blockchains more secure, but a third characteristic that elevates it to a new level is its shared and distributed nature. The full history or ledger of transactions of a blockchain is shared among the participants of the blockchain, enabling unforeseen transparency among users [10]. The users with access to the blockchain depends on the type of permissions the blockchain is developed with, being either permissioned, permissionless, private, or public [17]. Furthermore, the nodes of a blockchain are often distributed and thus allow anyone to join from anywhere with an internet connection, thus creating a system in which there is no single point of failure.

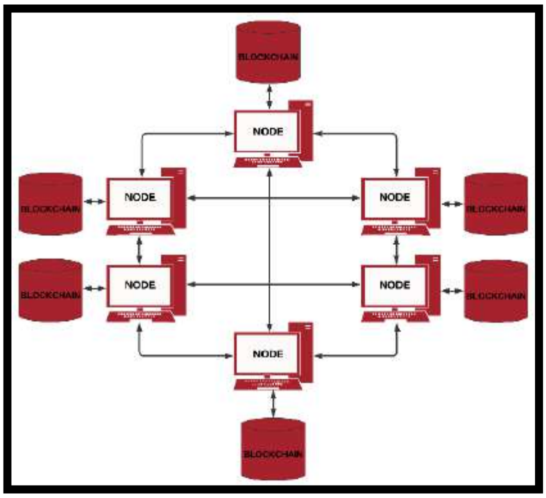

Figure 2: Distributed Blockchain Network

With this basic understanding of blockchain's fundamentals, one can begin to understand the benefits that employing a blockchain solution may have. Firstly, blockchains are near immutable because of the vast number of resources required to tamper with an existing block [10]. However vast and unreasonable the amount of effort and resources needed, blockchain is still vulnerable to certain attacks, where a common blockchain security breach is a 51% attack. The more nodes in the network, and the further back the transaction block, the more difficult such an attack will be because the number of resources one would need, and the amount of data one would have to change, increases as the blockchain grows [18].

Distrusting parties would usually have to rely on mutually trusted intermediary parties to facilitate transactions before the introduction of blockchain. This gives the control of transactions to one party, who will in turn charge for their services and could potentially be subject to fraudulent activities. Perhaps the greatest benefit of blockchain is its ability to reduce reliance on an intermediary party to create trust between two distrusting parties [17]. This trust is facilitated through its distributed nature and the use of a consensus mechanism to validate new additions to the blockchain by verifying that the new data correlates with existing data. Therefore, blockchain requires users to trust the mechanism with which it operates, rather than having to trust other parties that may have different interests, and thus allows these parties to interact in a meaningful way without the need for an intermediary.

Furthermore, the shared and distributed nature of blockchain allows an elevated level of transparency by allowing anyone on the blockchain with the necessary permissions to have access to the entire history of transactions. The transparency and immutability of blockchain allows transaction auditing to be completed extremely effectively because transactions can be traced back to their origin and no data can be manipulated without immense effort or the knowledge and approval of the network users [15].

Unfortunately, even with these benefits, blockchain still has its drawbacks and is certainly not suitable for all industry scenarios, with some sources claiming blockchain project failure rates as high as 92% [19]. Blockchain has been hyped up to a point where expectations are far exceeding the capabilities of it, leading to projects where blockchain is neither beneficial nor necessary. This tends to occur with nascent technologies that are not fully understood, where misconceptions are born out of excessive fanfare and the fear of missing out pushes forward projects that would never succeed, thus leading to high project failure rates [10].

Researchers have realized the value of blockchain and subsequently sought to address the general misunderstanding of it. Consequently, a library of resources has accumulated since the inception of blockchain highlighting the potential of this technology. There are various topics that have been addressed with varying depth, from general blockchain overviews to comprehensive research on one element.

To address the high project failure rates, a decent portion of blockchain research has gone into various assessment approaches to assess multiple different aspects of blockchain. However, blockchain is a complex technology and assessing it is a challenging and involved undertaking, with the potential subsequent adoption being equally, if not more, challenging [20], [21]. Consequently, blockchain assessment studies have focused on specific use cases rather than attempting to create generic assessments. A generic blockchain assessment framework stands to produce more value than concentrating on specific use cases because of the number of organizations that can gain insight from the use of such a framework, as opposed to just a handful of specific organizations.

There have been multiple attempts at various aspects of blockchain assessment. A particularly common assessment is a high-level technical suitability assessment, where the suitability of blockchain is determined from its functionality and characteristics and how they suit a particular use case. These assessment methods are scattered throughout literature, and they often neglect certain aspects addressed elsewhere.

Blockchain design is another assessment aspect that is found in literature but is even more scattered. Many studies fail to encompass certain design decisions and the effect they have on one another, or they neglect certain criteria that could affect the decisions made. Furthermore, these design decisions are often left up to the subjective views and biases of the user, rather than attempting to make it as objective as possible.

Studies in blockchain literature rarely address both aspects well, making it challenging and time-consuming for organizations to utilize these approaches to assess blockchain for their specific use case. These insights highlight the opportunity within the current blockchain assessment academic domain, enabling the definition of this study's main objective.

Main Objective

Create a generic blockchain assessment framework to assess technical suitability and recommend a high-level blockchain design for an organization and their specific use case.

2 METHODOLOGY

The research of this study is based on a systematic review of blockchain literature, with a focus on blockchain assessment approaches. Blockchain assessment literature is scattered and thus the systematic review allows common threads to be found between multiple studies and ultimately enables the combination and distillation of these studies into the work presented. Only academic articles and theses in English and focused on blockchain or blockchain assessment are considered for the systematic review.

3 BLOCKCHAIN ASSESSMENT FRAMEWORK

3.1 Overview

As stated in Section 1, the main objective of the blockchain assessment framework is to determine whether blockchain is technically suitable for a specific organization's use case and what a high-level blockchain solution might look like if blockchain is suitable. The blockchain assessment framework assesses the suitability of blockchain for an organization using three different groups of factors: critical, organizational, and process factors. The high-level blockchain design has two design features, blockchain type and consensus mechanism, which are weighted based on a chosen use case.

3.2 Suitability Factors

3.2.1 *Critical Factors*

The critical factors are those which are important for the successful implementation of blockchain within an organization's process. If the use case requirements do not align with the critical factors, there may be a more sensible solution than blockchain. Many studies have identified critical factors for successful blockchain implementation [9], [10], [22] – [29]. The combination and distillation of these factors is presented in Table 1, along with the associated questions that are used to evaluate each factor. Figure 3 shows how the critical factors are used to assess blockchain suitability at a high level.

Table 1: Critical Factors

Critical Factor	Evaluation Question
Data Store/Exchange*	Do you need to store or exchange data?*
Multiple Distributed Parties*	Are there multiple parties inputting, updating, and reading information from distributed locations?*
Validated Transactional Data*	Are exchanges/transactions involved in the process or is data transactional and must these transactions be validated?*
Lack of Trust	Is there a lack of trust or conflicting interests among involved parties?
Lack of a Trusted Intermediary	Is there a lack of a trusted intermediary or a need/want to remove them?
Consistent Set of Rules	Can a consistent set of rules help achieve the process outcome?
Consistent Governing Rules	Will the governing rules be consistent over time?
Interrelated Transaction History	Is transaction history required and are transactions dependent or interrelated?
Mapping Parties Transactions	Must parties be mapped to their transactions or do transactions have increased value when claimed by a participant?
Transparency Importance	Is transparency of the transactions a beneficial feature?
Immutability and Auditability Importance	Is an immutable, auditable record of transactions beneficial?
Censorship or Attack Reduction	Can a distributed infrastructure reduce the risk of censorship or attack?

*essential for blockchain suitability

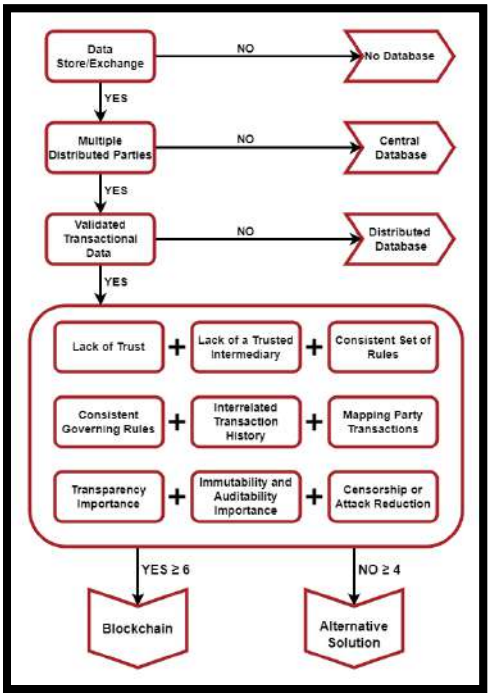

Figure 3: Blockchain Critical Assessment

While an affirmative answer is not required for every factor, the case for blockchain implementation becomes weaker with a greater the number of negative answers. Four or more negative answers indicate that blockchain is not suitable and it is required for the first three factors to be satisfied for blockchain suitability.

3.2.2 Organizational Factors

Organizational factors are those which affect how well suited the organization is for the successful implementation of blockchain. A variety of authors have identified organizational factors in some form [9], [10], [28], [30], [31]. The combination and distillation of these factors into relevant domains is presented in Table 3, along with an evaluation question or statement and the relevant answer that indicates the threshold between blockchain being suitable and not being suitable. Lastly, the importance of each factor is rated on a scale of 0-1, with the importance ratings and corresponding ranges shown in Table 2.

Table 2: Importance Value Ranges

Importance	Value Range
Not important	0 – 0.25
Mildly important	0.26 – 0.50
Important	0.51 – 0.75
Very important	0.76 – 1.0

Table 3: Organizational Factors

Organizational Factor		Evaluation Question/Statement	Threshold Answer	Importance
Critical	Administrative Authority Support	The administrative authority supports blockchain experimentation.	*61*	*1.0*
	Financial Support	The financial means are available for blockchain experimentation and implementation.	*61*	*1.0*
	Legal/Regulatory Framework	The legal/regulatory framework allows for blockchain experimentation and implementation within this industry/organization.	*61*	*1.0*
Core Expertise	Managerial Capabilities	The managerial capabilities are available for blockchain experimentation and implementation.	*51*	*0.75*
	Blockchain Complexity	The organization comprehends blockchain's complexity.	*51*	*0.35*
	Risk Aversity	The organization is risk averse with IT innovation experimentation and implementation.	*51*	*0.6*
	IT Capabilities	The organization has the IT capabilities or the ability to outsource for blockchain experimentation and implementation.	*61*	*0.8*
	Blockchain Enthusiast	Is there a blockchain enthusiast within the organization that understands blockchains and is willing to experiment with and implement it?	*Maybe*	*0.4*
	Technological Uncertainty	The organization is capable of handling technological uncertainty linked with blockchain applications.	*51*	*0.8*
Operation	Interoperability	The organization does not use a particular set of data in multiple different information systems.	*51*	*0.3*
	Decentralized Characteristics	The organization is willing to decentralize data storage.	*51*	*0.6*
Willingness	Top-management Dedication	The organization's top-management is dedicated to blockchain experimentation and implementation.	*51*	*0.8*
	Collaborating Parties Willingness	Potential stakeholders are willing to participate in blockchain experimentation and implementation that is led by the organization.	*51*	*0.8*
	Inter-organizational Trust	Potential stakeholders trust the organization to facilitate data exchange/registration.	*51*	*0.2*

Organizational Factor		Evaluation Question/Statement	Threshold Answer	Importance
	External Influence to Adopt	There are external influences on the organization to adopt blockchain (pressure, incentives, penalties, etc.)	*51*	*0.2*
Industry	Similar Use Cases in the Market	Are there existing use cases similar to the one being explored?	*Maybe*	*0.45*
	Collaborating Parties Competencies	Potential stakeholders are competent to experiment with and implement blockchain.	*51*	*0.8*
	Fraud Prevalence	Is fraud prevalent in your industry or organization?	*Maybe*	*0.3*

All questions are simple yes/no/maybe answers, whereas the statements are answered on a scale of 0–100, with Table 4 indicating the answer and relevant ranges. The user will answer each question/statement indicating their preference or reality.

Table 4: Answer Value Ranges

Answer	Value Range
Very false	0 – 20
False	21 – 40
Partially false	41 – 50
Partially true	51 – 60
True	61 – 80
Very true	81 - 100

An **Organizational Fit Score** can be determined by using the fuzzy weighted average method proposed by [40] as presented in Equation 1 below.

$$Organizational\ Fit\ Score = \frac{\sum_{n}^{i=1} w_i \cdot x_i}{\sum_{n}^{i=1} w_i} \tag{1}$$

Where w_i = importance, x_i = factor answers, and n = number of factors. This formula is used to determine the user's organizational fit score based on their respective factor answers, where "*yes*" is a score of 75, "maybe" is a score of 50, and "*no*" is a score of 25. This formula can now be used in conjunction with the threshold values from Table 3 to determine the threshold score which will indicate the organizational fit score at which point a blockchain solution becomes suited for an organization. **The threshold value is 54.30.** Thus, the user's Organizational Fit Score will need to be greater than this to indicate blockchain suitability for their organization.

3.2.3 *Process Factors*

Process factors are those which determine how well a particular process is suited for blockchain. Once again, various authors have identified process factors in some form [9], [23], [28], [31]. The combination and distillation of these factors into relevant domains is presented in Table 5, along with evaluation questions, an answer range and threshold value (indicated in bold). Lastly, the importance of each factor is rated using the same importance range as the organizational factors.

Table 5: Process Factors

Process Factors		Evaluation Question	Answer Range & Threshold Value	Importance
Users	Predictable Actor Behaviour	How predictable is the data input and behaviour of potential actors in the network?	*Predictability (0-100):* ***61***	*0.8*
	Limited Trust in Current Process	Do current actors lack trust in the current process?	*Lack of Trust (0-100):* ***50***	*0.4*
	Desired User Control Over Data	Will potential stakeholders want to store their data locally for better control in the process?	*Desired Control (0-100):* ***50***	*0.7*

Process Factors		Evaluation Question	Answer Range & Threshold Value	Importance
	High Importance of User Experience	What is the level of importance for the user's experience and ease of use in the process?	*UX Importance (0-100):* ***50***	*0.3*
	Transparency Required	Is it required for transparent data to exist between potential stakeholders involved in the network?	*Transparency (0-100):* ***61***	*0.7*
Process Facilitation	Peer-to-Peer Potential	Is there potential for the process to be facilitated by peer-to-peer interactions?	***Yes****/No/Maybe*	*0.8*
	Low Interest of Organization Being Intermediary	Is there a low interest of the organization being the intermediary in this process?	*Yes/No/***Maybe***	*0.3*
	High Availability of Bandwidth	Does the network have enough available bandwidth and computing power for the required specifications?	*Availability (0-100):* ***50***	*0.8*
	Low Throughput of Data	What is the frequency of transactions experienced?	*High (>2000tps) /* ***Medium*** */ Low (<100tps)*	*0.6*
	Current Laborious Human Facilitations	Is human labour required to facilitate the process?	*Yes/No/***Maybe***	*0.3*
	Workflow Simplification	Will distributed ledger technology help simplify the workflow of the process?	*Simplification (0-100):* ***50***	*0.9*
Hardware/ Software	Legacy Systems in Place	What is the level of the legacy systems that are currently in place?	***Brownfield*** */ Greenfield*	*0.3*
	Interface Differentiation	Do all involved parties have their own interfaces for the process or are all interfaces standardized?	***Single*** */ Multiple*	*0.55*
Control	Low Institutionalized Environment	Is there a lack of bureaucracy in place for this process?	*Lack of Bureaucracy (0-100):* ***50***	*0.9*
	Network Ability to Implement Technology Standards	Do the potential stakeholders adapt well to new technology standards?	*Yes/No/***Maybe***	*0.7*
	Importance of Control Over the Infrastructure	How reasonable is it to have a lack of control over the infrastructure of the network?	*Infrastructure Control (0-100):* ***50***	*0.4*
Data	Data Complexity	Are there multiple data formats involved in the process?	***Single*** */ Multiple*	*0.55*
	Low Trust in Current Data Storage	Is there a lack of trust or information asymmetry in the data storage in the current system?	*Yes/No/***Maybe***	*0.4*
	Traceability Required	Is it required to be able to trace who has accessed and created data in the network?	*Traceability (0-100):* ***61***	*0.5*
	Data Integrity	What level of data integrity is required for the process?	*Data Integrity (0-100):* ***50***	*0.6*
	Interoperability Possibility	Is the data from the current process involved in other processes? Is there one or many different uses of the data?	***Single*** */ Multiple*	*0.55*
	Inter-organizational Information Exchange	Is there data exchange between multiple organizations or distributed branches of the same organization?	***Yes****/No/Maybe*	*1.0*
Data	Transaction Dependency	Are there interactions between the transactions created by the potential stakeholders of the network?	*Yes/No/***Maybe***	*0.75*
	Asset Digitization Potential	How much potential is there for assets involved in the transactions/exchanges to be digitized?	*Potential (0-100):* ***50***	*0.8*
	Privacy of Sensitive Data	Is there process information that is privacy sensitive?	*Privacy Importance (0-100):* ***50***	*0.4*

The questions that utilize a range are answered in a level of agreement with the question. The ranges for each level of agreement in shown in Table 6.

Table 6: Question Answer Range

Answer (level of agreement)	Value Range
Very low	0 - 20
Low	21 – 40
Medium	41 – 60
High	61 – 80
Very high	81 - 100

Like the Organizational Fit Score, a **Process Fit Score** can be determined using the fuzzy weighted average method proposed by [40] as presented in Equation 2 below.

$$Process\ Fit\ Score = \frac{\sum_{n}^{i=1} w_i \cdot x_i}{\sum_{n}^{i=1} w_i} \tag{2}$$

Where w_i = importance, x_i = factor score, and n = number of factors. This formula is used to determine the process fit score using the factor answers as inputs, where the qualitative answers are scored as follows:

Table 7: Qualitative Answer Values

Qualitative Answer	Value		Qualitative Answer	Value
Yes	75		Brownfield	75
Maybe	50		Greenfield	25
No	25		Low	75
Single	75		Medium	50
Multiple	25		High	25

Using the threshold values and importance ratings of Table 5 in conjunction with Table 7 to convert non-numerical answers into numerical values, Equation 2 can be used to calculate the threshold value. **The threshold value is 57.72.** Therefore, the user's Process Fit Score will need to be greater than this to indicate blockchain suitability for their process.

3.3 Consensus Mechanisms

Consensus mechanisms are used to ensure that the ledgers on the distributed nodes of the blockchain agree with one another [15]. It is the protocol which determines how transactions will be validated [9]. The basic concept of consensus mechanisms is to perform secure and frequent updates of the distributed ledger, resulting in a shared state throughout the blockchain network [32]. If a node publishes a block and all other nodes agree with it, the block is then added to each node's respective blockchain [20]. [33] presented a formal definition of consensus mechanisms:

> "*A consensus mechanism is the way in which the majority (or, in some mechanisms, all) of the network members agree on the value of a piece of data or a proposed transaction, which then updates the ledger*" – Seibold [33], p. 3

There are many different consensus mechanisms, however, this study will only consider the most relevant in today's blockchain ecosystem because of the practical experience and subsequent deductions that have been and can be made on them. A brief definition of each mechanism, along with a comparison of them, is presented below.

1. **Proof-of-Work (PoW):** a node earns the right to verify and append the newest block by being the first to solve a computationally intensive puzzle, where the puzzle is taken as "proof" that the node has performed work and is subsequently rewarded for its effort [10].

2. **Proof-of-Stake (PoS):** a node is randomly chosen to verify and append the newest block and is rewarded for it, where the chance of selection is proportional to the number of digital tokens the node has staked in the system [10].

3. **Delegated-Proof-of-Stake (dPoS):** a node is voted by the network to be one of a few limited publishing nodes which get randomly selected to verify and append the newest block and rewarded thereafter [10]. Nodes have voting power proportional to their stake of digital tokens in the network and receive rewards proportional to this stake if the node they voted for verifies and appends a block [10], [34].
4. **Proof-of-Elapsed-Time (PoET):** specialised hardware and software are used to generate random wait-times for the network's nodes, whereby a node gets the chance to verify and append a block and be rewarded for it once their wait-time has elapsed and no other node's wait-time has finished [10], [35].
5. **Practical Byzantine Fault Tolerance (pBFT):** a group of validating nodes select a leader node (which can change each round) to validate and group transactions into a new block after a predefined number of transactions or time interval is reached [36], [37]. Once the block has been broadcast to the validating nodes, three stages commence: the pre-prepare phase, prepare phase, and commit phase [35]. These stages ensure the block is valid and that there is consensus among nodes and will broadcast the validated block to all non-validating nodes in the last phase [35].

3.4 Blockchain Type

Blockchain solutions can be broadly categorized based on two properties: data access and consensus participation. Data access is either made public or private, where public access allows anyone to transact and view transaction history, whereas private access restricts access to a select number of participants who may transact and view transaction history [38]. Consensus participation can either be permissioned or permissionless, where permissioned only allows a predefined group of nodes to participate in validating and appending blocks, while permissionless allows anyone to participate in the consensus process [38]. These categorizations enable the identification of four main blockchain types: public permissionless blockchains, public permissioned blockchains, private permissioned blockchains, and private permissionless blockchains. Due to contradicting properties, private permissionless blockchains have no current use cases [9], [39].

3.5 Design Features Comparison

The design features of blockchain can be compared to one another using select criteria enabling an effective direct comparison of these different features. Table 8 on the next page presents this comparison, where the definitions for the process criteria are presented in Table 9.

Table 8: Design Feature Comparison

Comparison Criteria	Proof-of-Work	Proof-of-Stake	Delegated-Proof-of-Stake	Proof-of-Elapsed-Time	Practical Byzantine Fault Tolerance	Public Permissionless	Public Permissioned	Private Permissioned
Energy Efficiency	--	+	+	++	++	-	-	+
Latency Performance	-	+	+	+	++	-	+	+
Throughput Performance	-	o	++	+	++	-	+	+
Hardware Dependence	--	-	o	--	o			
Centralization	--	o	+	o	+			
Scalability (validating nodes)	+	++	+	++	--	-	+	+
Scalability (client nodes)	+	++	++	++	++	-	+	+
Fault Tolerance	-	++	++	-	+			

Comparison Criteria	Proof-of-Work	Proof-of-Stake	Delegated-Proof-of-Stake	Proof-of-Elapsed-Time	Practical Byzantine Fault Tolerance	Public Permissionless	Public Permissioned	Private Permissioned
Settlement Finality	Probabilistic	Probabilistic	Probabilistic	Probabilistic	Deterministic			
Incentivization	Yes	Yes	Yes	Yes	No			
Organization Control						--	-	+
External Transparency						++	++	--
Immutability						++	++	o
Consensus Participation						Permissionless	Permissioned	Permissioned
Data Accessibility (read)						Public	Public	Private
Data Accessibility (write)						Public	Public	Private
Actor Identities (clients)						Unknown	Unknown	Known
Actor Identities (validators)						Unknown	Known	Known

(++ = very good, + = good, o = average, - = poor, -- = very poor)

3.6 High-Level Blockchain Design Element

With the comparison criteria identified in Table 8, a description and answer range for each criterion is presented in Table 9. Each criterion has an answer range to gauge the user's preferences and is linked with a score from 1-5. As shown in Table 9, each score is linked with one of the elements of Table 8's key.

Table 9: Comparison Criteria

Comparison Criteria	Description	Answer Range				
		1 (--)	2 (-)	3 (o)	4 (+)	5 (++)
Energy Efficiency	The ability of the solution to operate while producing minimal resource waste and cost.	Minimal	Low	Average	High	Maximal
Latency Performance	The amount of time it takes from the initiation of a transaction to the commitment.	Very high (>10s)	High (10 - 6s)	Average (6 - 4s)	Low (4 - 1s)	Very low (<1s)
Throughput Performance	The amount of read or write operations that can be performed per unit time (usually transactions per second, tps).	Very low (<100tps)	Low (100 - 500tps)	Average (500 - 1000tps)	High (1000 - 2000tps)	Very high (>2000tps)
Hardware Dependence	The solution's dependence on hardware to be implemented and operate.	Full	Above average	Average	Slight	None
Centralization	The amount by which the implementation of a specific solution promotes centralization.	None	Low control	Average control	High control	Full
Scalability (validating nodes)	The ability of the solution to scale up the number of validating nodes in the network.	Not	Minimal	Average	High	Maximal
Scalability (client nodes)	The ability of the solution to scale up the number of client nodes in the network.					
Fault Tolerance	The solution's ability to handle faults or security breaches.	None	Minimal	Average	High	Maximal
Settlement Finality	The finality of a transaction, which can either be		Probabilistic		Deterministic	

Comparison Criteria	**Description**	**Answer Range**				
		1 (--)	**2 (-)**	**3 (o)**	**4 (+)**	**5 (++)**
	deterministic (immediate) or probabilistic (subject to change).					
Incentivization	The ability of the solution to incentivize the validation mechanism.		Yes		No	
Organization Control	The control that the organization issuing the network will have over the other network parties.	Very low	Low	Average	High	Very high
External Transparency	The transparency of data to those not within the system.	None	High Control	Average control	Low control	Full
Immutability	The inability of users of the solution to tamper with data.	None	High control	Average control	Low control	Full
Consensus Participation	The permissions of nodes able to participate in the consensus process.		Permiss-ionless		Permissi-oned	
Data Accessibility (read)	The ability of the public to read data on the network.		Public		Private	
Data Accessibility (write)	The ability of the public to write data to the network.					
Actor Identities (clients)	The transparency of the identities of clients to actors of the systems.		Unknown		Known	
Actor Identities (validators)	The transparency of the identities of validators to actors of the system.					

Table 9 is used to identify the scores for the user's preference for each process criterion based on the range presented and answer selected. The user should also identify the importance of each criterion to their use case, again using Table 2 to identify the relevant importance ranges. The user's preferences and importance ratings can be used to identify the most suitable blockchain solution for their particular use case. This element of the assessment must proceed as presented in Figure 4 below.

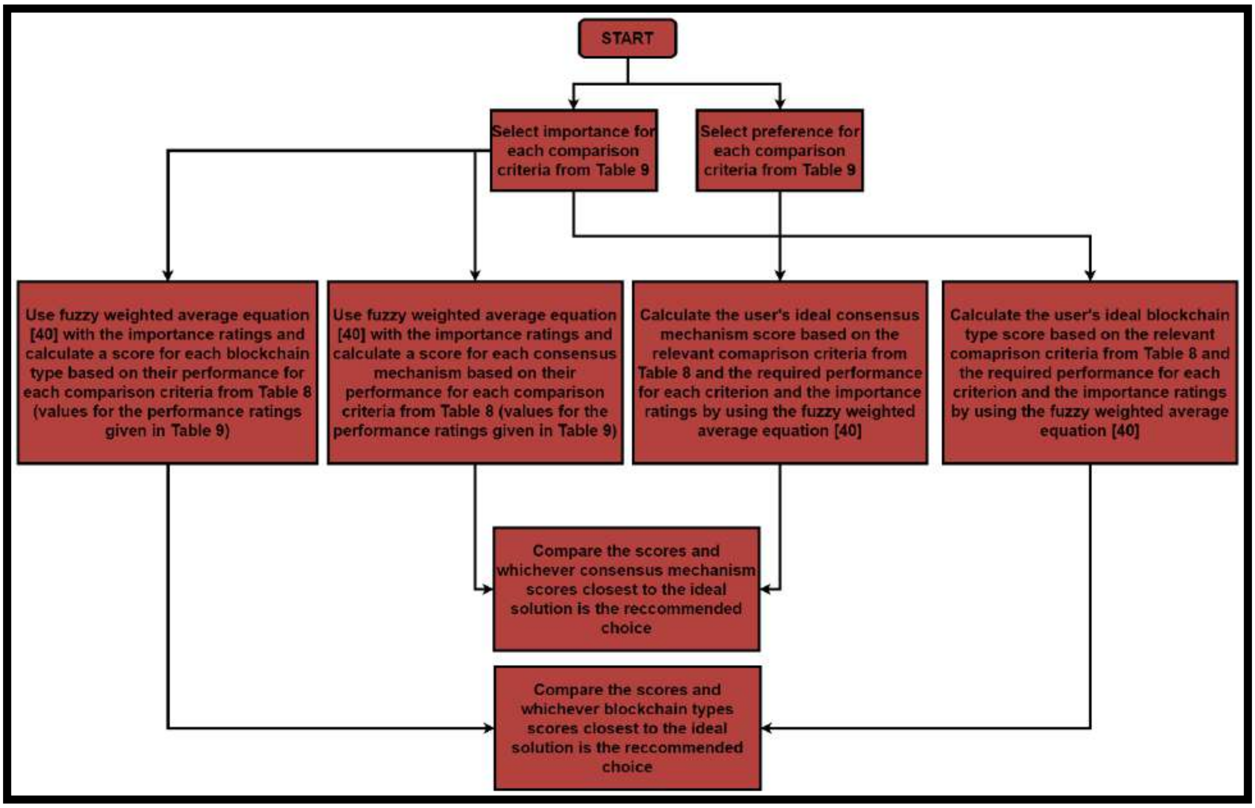

Figure 4: High-Level Blockchain Design Process

3.7 Overall Framework

The overall assessment framework is presented in Figure 5 below. The Pre-Assessment Critical Analysis is used to determine blockchain suitability at a high level, with a threshold score of 8. The Blockchain Suitability Analysis is used to determine the organizational fit score and process fit score, which are then plotted on a graph to identify the region where the user falls, where a marginal outcome indicates that the choice to continue is up to the user's discretion. Finally, Blockchain High-Level Design is used to determine the design features for the blockchain solution.

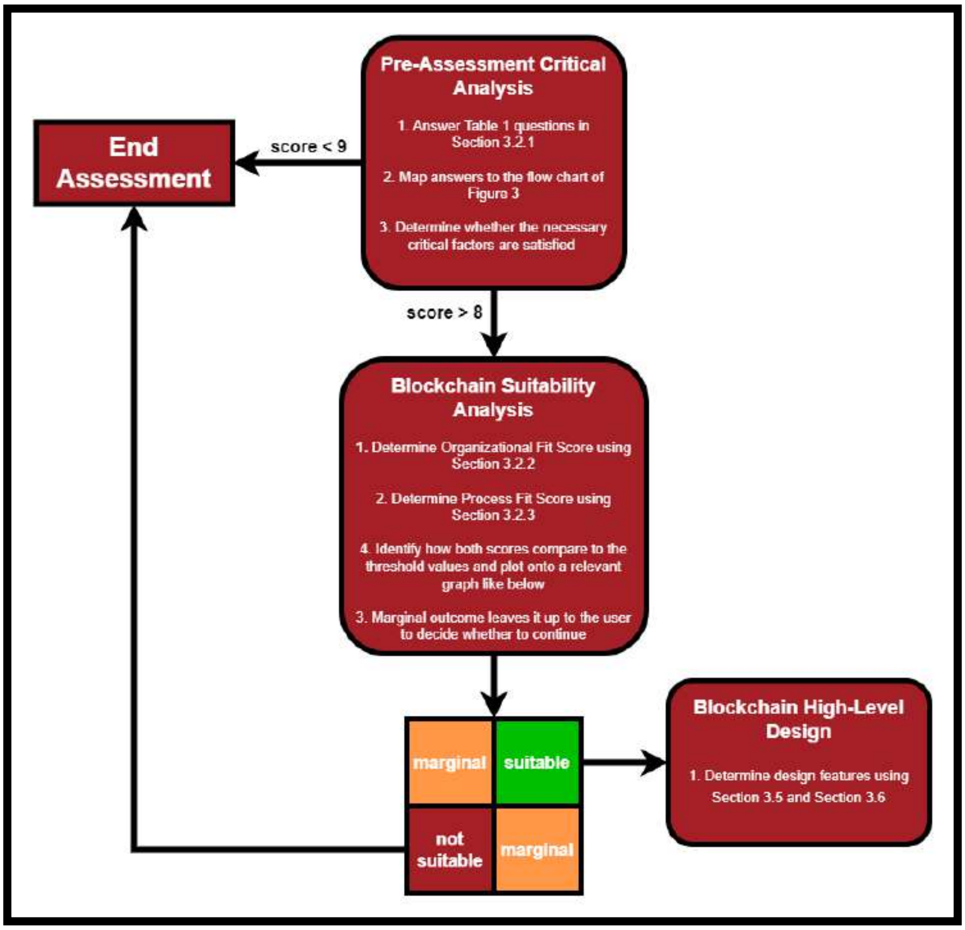

Figure 5: Blockchain Assessment Framework

4 CONCLUSION

Blockchain is an extremely complex technology and determining the suitability of a blockchain solution for any particular use case is a nontrivial endeavour. This article presented a Blockchain Assessment Framework that can be used to determine the suitability of blockchain for a specific process within an organization, as well as presenting a high-level blockchain solution for this process by identifying a suitable consensus mechanism, as well as a suitable blockchain type. The framework is limited by only providing a high-level overview of blockchain suitability and a subsequent solution design. A further limitation is the lack of research and available data in the academic blockchain domain because of its novelty. Future research could focus on including more design features to allow a more detailed design and using more filters to truly identify what the user requires, such as determining the use case and associated requirements of such a use case. Furthermore, the framework could be tested in a variety of different case studies to ensure that results are consistent and provide insight to the users. Lastly, gathering quantitative data on the performance of different blockchain configurations would help immensely with investigating the effects of certain design decisions.

Ongoing research is being conducted by the authors to further improve the Blockchain Assessment Framework by including a blockchain adoption strategy, a blockchain value analysis, and making it more dynamic by responding to user's answers and narrowing the potential options. Current research is aimed at proving the efficacy of the framework by using it in an enterprise asset management case study. This article has allowed the intricacies of the assessment framework to be identified and presented, and future work will focus on enhancing and expanding the framework.

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BUSINESS PROCESS REENGINEERING CONCEPTUAL FRAMEWORK IN THE SOUTH AFRICAN MINING INDUSTRY

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ABSTRACT

South African Mining Industry (SAMI) mines, beneficiates and trades various mining minerals and commodities (coal, platinum group metals, diamonds, gold, copper, lead, zinc, and cobalt). SAMI contributes approximately 18% to the gross domestic product (GDP) of South Africa, 60% exports, over 500,000 direct jobs, and over 800,000 indirect jobs in the country, PwC [8]. However, many businesses process reengineering (BPR) concepts used in the industry are not improving inefficiencies (EXPENSES-EBIT-RATIO ~ 6:4). Hammer [3] categorically advocates BPR philosophies to improve operational efficacy. The study reported in this paper investigated the root causes of BPR incapacity at SAMI. The qualitative method was utilized to garner data from a stratified-convenient-sample of top ten mining firms at SAMI, which contribute ~ 85% to SAMI revenue. Research data were meticulously collected, scientifically analyzed into informative results that facilitated the orchestration of a BPR conceptual framework with the aim of improving BPR efficacy at SAMI.

Keywords: business process reengineering, root causes analysis, goal-alignment culture, value engineering management, continuous quality improvement, sustainable lean production

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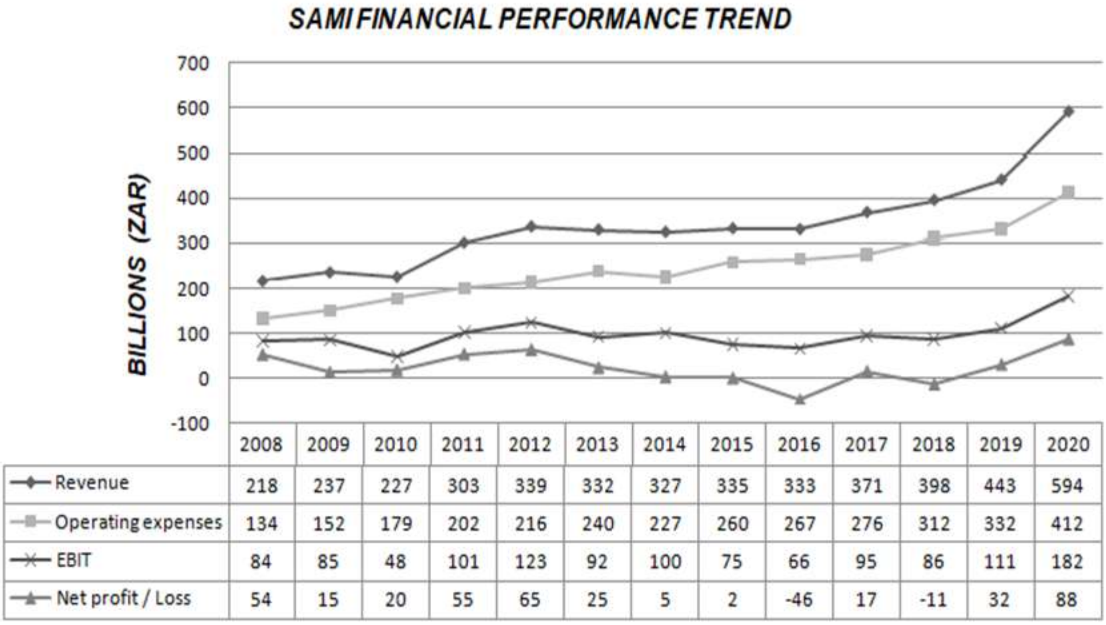
1 INTRODUCTION

SAMI is currently ranked fifth (5th) internationally in terms of mining contribution to GDP, and South Africa (RSA) is ranked within top ten countries globally in terms of production of PGMs, gold, iron ore, coal, vanadium, ferrochrome, alumino-silicates, vermiculite, zirconium, titanium minerals, manganese ore and antimony, ferro-silicon, silicon metal and fluorspar. Statistics from the South African Department of Mineral Resources (RSA DMR) and the U.S. Geological Survey highlight that South Africa has ore reserves amounting to an approximate value of more than US$2.5 trillion, with 16 various commodities ranked in the top ten internationally, PwC [8].

PwC [8] furthermore mentions that RSA has largest reserves of platinum group metals (PGMs), manganese, chromite and gold reserves in the world. RSA is ranked second in titanium minerals, zirconium (25%), vanadium, vermiculite, and fluorspar. Moreover, RSA contains 17% of the world's antimony reserves and excessively in abundance of a variety of natural minerals. SAMI also produces the top five major commodities (diamond, gold, PGMs, coal, and iron) plus the base metals along with other various minerals such as manganese, chromium, copper, uranium, silver, beryllium, titanium etc.

SAMI remains the country's most significantly important industry, contributing approximately 18% to the GDP of RSA, 60% of RSA exports, over 500,000 direct jobs in RSA, and more than 800,000 indirect jobs in the country. SAMI pays approximately twenty (20) cents for every Rand invested in public infrastructure and social development programs through taxes and other benefits. Despite the sustainably prevalent demand for natural mineral resources, the SAMI is continuously experiencing a performance decline in human capital deployment, production volumes and efficiencies, as depicted in Figure 1.



	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Revenue	218	237	227	303	339	332	327	335	333	371	398	443	594
Operating expenses	134	152	179	202	216	240	227	260	267	276	312	332	412
EBIT	84	85	48	101	123	92	100	75	66	95	86	111	182
Net profit / Loss	54	15	20	55	65	25	5	2	-46	17	-11	32	88

Figure 1: Financial performance of SAMI for the past twelve years [8]. Data source: PWC yearly mining performance reports.

In fact, local gold production has collapsed from 605 tons in 1994 to 133 tons in 2014, despite a 218% boom in the gold price, and RSA gold reserves still ranked first internationally by value of R 2285bn. In 1994, gold mines accounted for 392 227 jobs, and by 2014, jobs had fallen to 119 075, a loss of 273 152 jobs in just 20 years. There is still emphasis on the prospective potential of gold mining as an employer, despite a collapse in output, and in 2014, the gold mining sector was in employment of 30% of the 1994 job quantities, PwC [8].

A table in Figure 1 depicts a twelve-year summary showing SAMI's revenue and profitability after the financial crisis of 2008. However, the economic distress has implicated a severe decrease in revenue and profitability. Net profit has been at their lowest levels since 2016, and total assets decreased as of 2013 for the first time. Figure 2 succinctly presents a diagrammatical demonstration that reveals yearly revenue make-up regarding operating expenses, and EBITs of the SAMI from 2008 to 2020. In this paper, the main hypothetical reason for the collapse of SAMI (the margin squeeze) is as a result of BPR & IE concepts inefficacy in the industry. Additionally, the operating costs have significantly escalated because the country's operational research, innovative system and technology engineering, which historically expanded the limits of knowledge and skills in mining techniques, have been allowed to decay and wither

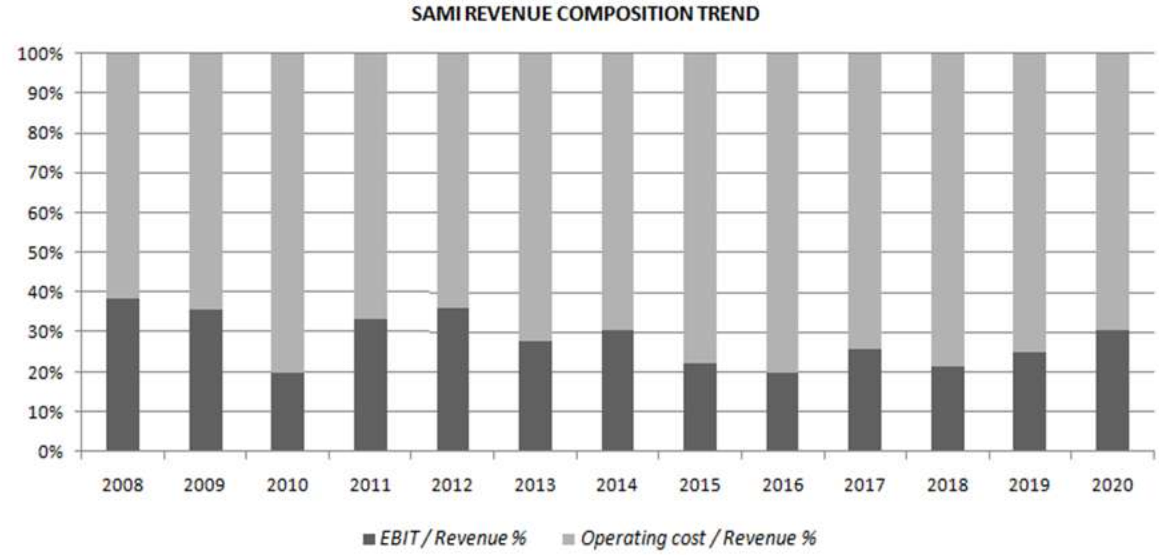


Figure 2: SAMI revenue composition. Data source: PWC yearly mining performance reports.

The top ten companies (Anglo American Platinum, Kumba Iron Ore, AngloGold Ashanti, Gold Fields Limited, Sibanye-Stillwater, Exxaro Resources, Assore Limited, Impala Platinum Limited, Northam Platinum, and African Rainbow Minerals) in the SAMI, Over the past three years, have continued to account for approximately 85% of the SAMI annual revenue. Figure 2 shows revenue increased by R36 billion, and operating expenses increased by R28 billion in 2014. In that scenario, the top ten companies accounted for 81% (R29 billion) of the revenue increase.

2 LITERATURE REVIEW

Operational excellence depends on a regular cyclical process of reengineering performance to ramp-up operational volumes, reduce the operating cost, maximize safety and the operation of more environmentally friendly processes in a system as well as positioning the operation for future products and services. Operational excellence is achieved through continual business process reengineering practice, innovations in processes, technology adoption, improved understanding of customer needs and other factors. Savvy operational management steadfastly focuses on BPR approaches and concepts to implement operational process reengineering that eventually adds superior value to the processes and consequently to customers and sustainability of the operation.

2.1 Operations Management

According to Pycraft [9], operations management is an area of management accountable for management production efficacy and process improvement or reengineering with the intention of continuously satisfying the customers or clients. Operations management are involved to ensure that business operations are effective and efficient, thus perform as required, using as limited resources as required by processes to deliver products and services that meet customer requirements. Business process reengineering is a system approach to thrust an organization with capacity to optimize business processes to achieve more efficacious production, according to Guastello [2]. The author [2] states that BPR has purportedly reduced process cost and cycle time by 90% while improving quality of process and products by over 60% in the past.

Professionals maintain that the best approach in assembling the most efficient and effective business system requires continuously incorporating both approaches: Six Sigma and Lean principles. Lean Six Sigma concentrates on eliminating defects. In essence, Lean Six Sigma is a management approach where Lean and Six Sigma complement each other. Lean Manufacturing focuses on waste elimination, while Six Sigma intellectually strives to reduce waste. The Lean and Six Sigma approach engages a plan: do, check, and act (PDCA) cycle, coined by Edward Deming.

Rummler and Brache [10] broadly highlighted business process reengineering as a fundamental obligation at an executive leadership and management level. Management of companies are fundamental pillars of BPR engagement and prosperity, thus to ensure efficacy of the BPR drive within an organization. The management should commit to ensure that the BPR is fully utilized and continuously succeeding by offering resources, guaranteeing goal-alignment processes through personal engagement and visibility as well as also guaranteeing that along with every BPR initiative, the following items exist:

a) a logically clear statement of why the change is necessary;
b) a clear vision of how the organization will be different after changes;
c) authentic researched scenario, and comprehensive recommendations;
d) a sound implementation strategy and plan;
e) adequate provision of proficient resources that are process required;
f) communication of plans, roles and responsibilities, benefits, progress, resolutions;
g) willingness (passion) of stakeholders to drive or support proposed changes; and
h) effectively management and execution of BPR implementation.

Business leaders should formulate authentic business strategies, create feasibility business strategic plans (including innovative plans created during the strategic planning process) and match meticulously appropriate resources to their strategies to gear up the organization's capacity for success. The benefits of a cross-functional team approach to BPR also play a momentous role, Rummler and Brache [10]. In operations where human beings are involved, the human factor significantly plays a substantial role and should be considered as well as genuinely be engineered as a productive input into a process. Guastello [2] intensively advocates that the human factor is a result of integration of three main components into a human employment life, as presented in Figure 3.

Krotov [5] briefly advocates that process performance must be aligned to business goals. An organization's strategic goals should guide the key direction for any BPR exercise. For instance, in Six Sigma deployment, identification of projects can be done based on how the projects fit into the Balanced Scorecard agenda of the organization. Wilson [12] claims that cause-and-effect diagrams, when applied appropriately, can reveal key relationships among various variables, and the consequence thereof, as well as that the possible causes provide additional insight into the process or system behavior. Root causes (flaw instigators) of a process defect can be traced back from a related process error by using a collaboration of cause-and-effect diagrams and five (5) Whys technique.

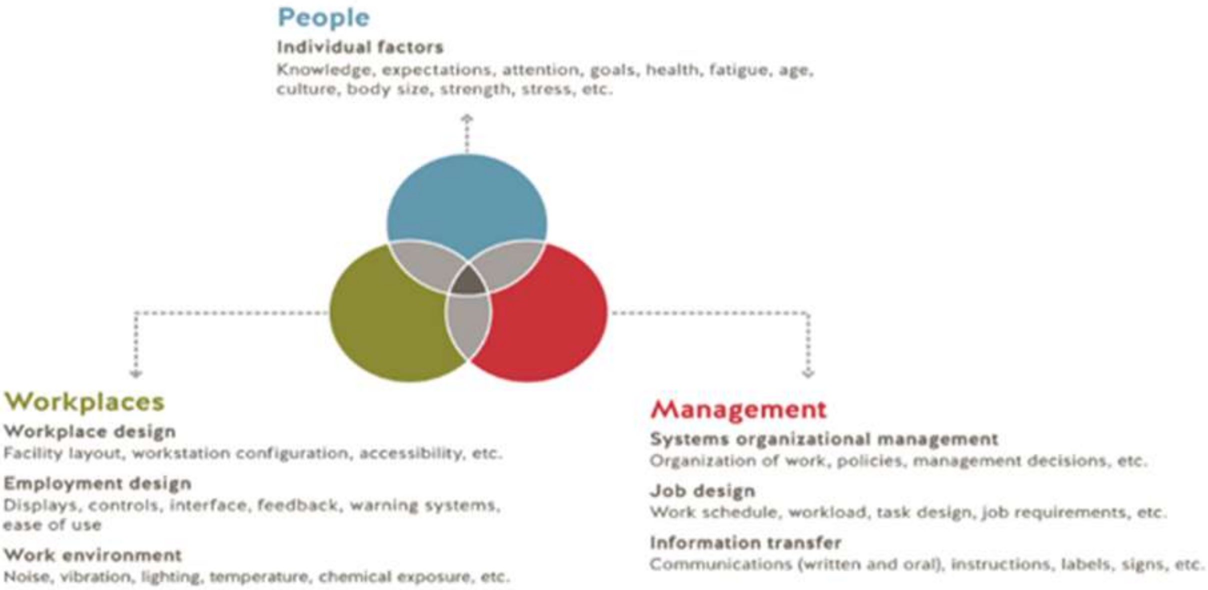


Figure 3: Contributory elements to Human factors of Employees [2]

Pycraft [9] suggests an Ishikawa diagram (the Fishbone diagram as presented in Figure 4) as a causal diagram created by Kaoru Ishikawa in order to show the potential causes of an event. Figure 4, presents the Fishbone diagram was developed for technological analysis to identify causes that result in a process defect.

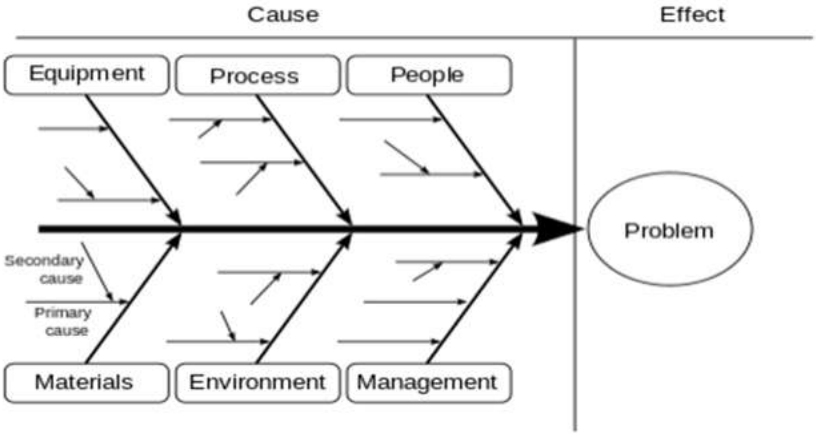


Figure 4: Ishikawa diagram [4]

After noting a process error (problem) and identification of a cause, then "five (5) whys" may then be innovatively applied to dig deeper into establishing an actual root cause to a prevailing process error. Once a root cause to a process error has been identified, then process personnel conceptually comprehend the prevailing situation and thereafter consult relevant literatures, or process experts, thereby orchestrating and implementing an appropriate solution to resolve the process error.

In essence, dealing a process error or defect, other than resolving a root-cause to a process error, tantamount to nursing the process error, thus learning to live with a process error, whereas rectifying a root cause to a process error, guarantees a complete eradication of the process error, thus rendering a process flawless with regards to a process error at hand. It's quite pivotal to comprehend a conceptual context with regards to root-causes to process defects or errors, when it comes to process error resolution.

3 CONCEPTUAL CONTEXT

After scrutinizing the SAMI background and meticulously reviewing relevant theories, a conceptual context was obviously revealed and comprehended. The research contextual profile calls for an appropriately suited research methodology in order to arrive at a possible solution that can address a process defect (research problem). The research conceptual stature specified, or mandatorily dictated, an appropriate research methodology to order to authentically identify the real root causes, which also further facilitated an orchestration of an appropriately relevant solution to address the research problem. Figure 5, presents a conceptual contextual framework of the prevailing scenario (SAMI environment) that was reflected after reviewing relevant theories and the operational background of the SAMI.

Figure 5: Conceptual integrated structure of operational system

The SAMI conceptual structure served as a system edifice that dictated the research methodology of this paper. The conceptual background facilitated and aligned the research expedition to promptly and precisely reach a research destination, thus a research resolution. In this paper, a stratified sampling was utilized as a sampling technique based on the SAMI conceptual contextual structure, as depicted by the structure presented in Figure 5, thereafter a qualitative research method was conducted to unveil the root-causes to the research problem.

3.1 Research Problem

The research problem was that SAMI performance, in the past twelve (12) years, indicated that SAMI was continuously experiencing high operational expenditures that exceed earnings before interest and tax (EBIT) amid the presence of Industrial Engineers (process experts) and IE field concepts such as BPR, Totally Quality Management (TQM), Continuous Improvement (CI), Just-in-Time (JIT), Six Sigma (δ), Theory of Constraints (TOC), Front-End-Loading (FEL), etc. In order to address the research problem, research methodology became research guiding framework that covers all the research objectives that need to be embraced, in order to efficaciously bring the research into completion.

3.2 The Aim and Objective of the research study

The main notion that motivated the research study was to improve the deteriorating economy of the country (RSA), as SAMI has a major economic contribution to South African gross domestic product (GDP) and gross national product (GNP). The main objective was to investigate factors that bring about BPR inefficacy and unsustainability in the SAMI, thereby orchestrating a business process reengineering framework to improve BPR performance in the industry. The qualitative study was conducted on field experts in the top ten mining companies and on a convenient sample of other SAMI mines convenient to the researcher. An exploratory pilot study was conducted to discover the root causes of the problem thereby authenticating the research hypotheses through understanding the actual scenario, perceptions, challenges, frustrations and successes around the BPR phenomenon in the SAMI.

3.3 Hypotheses for this study

The research hypotheses were as follows:

H0: BPR system and IE concepts are directly proportional to SAMI performance.

H1: BPR system and IE concepts are indirectly proportional to SAMI performance.

3.4 Population

The research methodology was executed in the study population that consisted of the top ten mining companies in the SAMI (through market capitalization) and other convenient firms in the industry. The study sample was purposively extracted from the following fields of expertise (of the top ten mining firms): management, finance, engineering, marketing, business process reengineering field, and supply chain management.

4 RESEARCH METHODOLOGY

An exploratory study is a preferred strategy when “what” questions are being posed, when the investigator has little control over events and when the focus is on a contemporary phenomenon within some real-life context. In essence, “what” questions are more exploratory and mostly used in exploratory studies as a preferred research technique, Yin [13]. The rationale for choosing the exploratory case study technique was that the technique was characterized by “what” questions in a single specific domain (South African mining industry).

These exploratory questions facilitated the researcher in identification of a list of root causes for BPR inefficacy and unsustainability at SAMI. An explanatory research methodology and case study strategy was utilized to collect data for this research. Both qualitative and secondary data analysis methods were applied to solicit data from intended research samples as appropriate data sources. With regard to the qualitative method, data was garnered online (Skype and Microsoft Teams) and through personal interactions, while for the secondary data, published documents were reviewed to gather relevant data thus secondary data analysis.

4.1 Research Sample

In this research study, a stratified sampling technique was used, as the size of the research population was too large that it was impossible to include the whole of research population into the study. The sampling technique facilitated the expedition of the study by virtue of narrowing down the whole population - dividing the population into small sample unit which represented the characteristics of the research population without any bias towards a particular attribute. The research sampling technique utilized was a combination of stratified and convenient purposive sampling method. Convenient purposive sampling a technique under which individual from target population is chosen on the basis of their intended sample characters, accessibility, availability and willingness to take part in survey while stratified sampling technique divides the population into strata.

The targeted research sample was eighteen (18) sample units with the following characteristics: more than ten (10) years of experience at SAMI (top-ten mining companies) supply chain and from the targeted areas of expertise (finance, marketing and engineering), with experience on the mining policies, processes and BPR phenomenon in the SAMI, was acquired. A pilot study was conducted through a qualitative study method on purposefully selected the sample units from the sample frame. The sample frame comprised 80:20 proportions, thus 80% of the research sample was from the top-ten mining firms in the SAMI, while 20% of the research sample was from convenient samples from other mining firms, exclusive of the top-ten mining firms. The reliability and validity of the results mainly depended on overlapping themes from the qualitative method, the secondary data analysis and researchers' experience in the SAMI.

4.2 The research method

According to Krotov [5], cause and effect analysis is a technique which organizes the analyst's knowledge into a cause and effect. For every effect, there is a cause. Sometimes there is a fairly long chain of relationships between the root cause and its effect. The Ishikawa diagram shows the causes of effects. Each root cause of an error is a source of variation, Wilson [12]. Actually, if the lowest cause (root cause) on the chain is addressed, the problem is completely resolved - there would be no recurrence of the problem. A root cause is an initiating cause in a causal chain which results in an outcome or effect.

In this study, the Fishbone diagram and Five (5) Whys techniques were used in combination to uncover the root causes regarding the research problem. Latino and Latino [6] affirm that root cause analysis (RCA) aims to arrive at key contributing elements that contribute to the problem being examined. These elements are then targeted for Five (5) Whys techniques in order to establish the actual source of the process error. Following data collection, qualitative data content analysis was carried out, and common views (by participants) were then clustered into themes relevant to the appropriate Fishbone diagram components. In essence, scientific attempts such as the Root-Cause-Analysis strategy were used to identify the root causes for BPR inefficacy in the SAMI.

The research questions were focused on identifying the causes for BPR inefficacy at the SAMI, then followed by five (5) "whys" to deeply uncover the actual root causes that bring about the challenges. The integrity and validity of answers to the research questions were guaranteed by duplicating the various questions, thus asking different questions for one answer. For instance, should two different questions be posed and two different answers be given, then transaction loses value and integrity and those answers are rendered invalid.

4.3 The rationale or value of the research study

The study contributes to knowledge building, thus theory building. The study has findings to establish the SAMI profile vis-à-vis application of BPR in the industry and also the root causes for BPR inefficacy and unsustainability in the SAMI.

editorial adjustments without consulting

5 FINDINGS

The qualitative data was obtained from interviewing stratified and purposefully selected participants of the population sample. All interviews were textually recorded for content analysis to be conducted at a later stage. Content analysis was conducted by counting the occurrence of certain keywords, followed by interpreting the underlying context. The counts were converted into percentages based on the number of participants interviewed. The common views were identified, integrated and summarized into themes, as presented in Table 1, and the themes posted into Pereto Chart to conclusively arrive at the main areas of improvement focus (80:20 rule) with regards to addressing BPR inefficacy at the SAMI.

5.1 Integration of Results

The process of data analysis and integration was carried out in two steps. Step one involved eliminating irrelevant factors that did not connect with the contributing elements to BPR failure at the SAMI, whereas step two involved clustering relating factors (with common views that insinuate similar meanings) into themes. Theme were then sketched into a Pareto chart. In essence, the chart is often used to narrow down contributing factors to visually depicts the situations of more significant, in this case main root-cause for BPR and IE concepts inefficacy in the SAMI.

Table 1: Fishbone diagram components, Themes and Correlation Percentage

FISHBONE DIAGRAM COMPONENTS	THEMES	CORRELATION PERCENTAGE
PEOPLE	*Human factor (HF) – employees are change-resistant due to job insecurity, and their state of being power lose sensitive.	99% reported that the SAMI workforce was power loss and job security sensitive and impassionate about the implementation of BPR initiatives (changes) to entrench quality improvement concepts and philosophies in their respective fields.
MANAGEMENT	*Management is not really into promoting BPR philosophies and quality improvement concepts. *Management performance from top to bottom is not measured on the BPR performance in their respective fields of expertise.	95% reported that management key performance indexes (KPIs) do not include process improvement (KPIs); thus, management personnel do not feel obligated to implement process reengineering ideas and entrench BPR concepts and philosophies into operating systems.
PROCESS	*Mining processes at SAMI have remained antique and slowly improving in a snail's pace. *Seniority prevails – only management preferred BPR initiatives get speedily implemented – no process drive mentality.	100% of the reported operations in the SAMI are seniority driven other than being process-driven, and HFE to build passion within the workforce is just disregarded & motivations are more streamlined to safety - No equivalent priority given to other components of SHEQ system & ideology.
ENVIRONMENT (Mining environment regarding BPR phenomenon)	*The main constraint in the SAMI environment, BPR stakeholders are impassionate about BPR philosophies & concepts. *Not process-driven but highly seniority driven.	99% reported that the SAMI workforce is high power loss, job security sensitive and not passionate about successful implementation of BPR initiatives and entrenching quality improvement concepts and philosophies in their respective fields of expertise.

FISHBONE DIAGRAM COMPONENTS	THEMES	CORRELATION PERCENTAGE
EQUIPMENT (Industrial Engineering concepts)	*BPR equipment more than the word available, and the investment are highly available for resources acquaintance regarding BPR implementation.	100% reported that “Inadequate competence, knowledge and skills of BPRT team” was a root cause for BPR failure at SAMI.
MATERIAL (BPRT)	*Industrial engineers (IE) are many in the country and yearly produced by tertiary institutions in the country. *At SAMI, IEs are utilised for other extraneous jobs such as admin work, etc. not for the core activities of IE profession.	95% reported the existence of finger-pointing and blame shifting among the SAMI employees and the inappropriate utilisation of IE resources at SAMI.

The lack of change management, the reluctance to change, failure to understand the BPR phenomenon, a lack of BPR consistent methodology, a lack of effective communication, and aesthetic BPR initiatives (initiatives not directly connected to the business constraints) and duplication of efforts (lack of process integration) were also mentioned as challenges faced by the workforce in the SAMI.

6 CONCLUSION AND RECOMMENDATIONS

After research data analysis and literature reviews, the research conclusion was reached as to what elements are the root causes for business process reengineering inefficacy and unsustainability in the South African Mining Industry.

6.1 Conclusion

In conclusion, the hypothesis is accepted, that the BPR system and IE concept efficacies are directly proportional to SAMI performance. SAMI is not cost effective because BPR and IE Concepts are not effectively utilized. The human factor was highlighted as a major constraint that impedes the BPE efficacy (to deliver splendid business process reengineering results) in the industry. In that regard, in the processes where human beings are involved, the human factor should be considered as an input into the process and also be introduced into the estimating calculations. For instance, calculations for earned value, pragmatic efficacy, and probability of process sustainability, all where human beings are involved, the human factor needs to be factored into equations and formulas as demonstrated by following equations (1), (2) and (3).

6.1.1 Value earned and pragmatic efficacy

The human factor should be scientifically estimated and numerically presented in a percentage format. Human Factor ranges from negative zone to zero (-100% to 0) and from zero to positive zone (0 to 100%). Where negative human factor has negative consequences into the process, zero human factor has neutral (zero) effects into the process, whereas positive human factor has positive consequences into the process.

$$\pm f(\wp) = \pm Human\ factored$$

- $Minimum\ value\ for\ the\ Human\ factored\ = -1\ (-100\%)$
- $-ve\ Human\ factored\ \leq\ 0$

- $+ve\ Human\ factored\ \geq\ 0$
- $Maximum\ value\ for\ the\ Human\ factored\ =\ 1\ (100\%)$

$$Commisioned\ efficacy\ (system\ designed\ efficacy) =\ E(c) = \left\{\frac{REVENUE - COSTS}{n}\right\}$$

$$E(c) = \{\frac{EBIT}{n}\}$$

$$Human\ Factored\ Efficacy = E(\wp) =\ \text{ʃ}(\wp)\ \left\{\frac{EBIT}{n}\right\}$$

$$\therefore\ Pragmatic\ Efficacy =\ \frac{E(\wp)}{E(c)}\ x\ 100\% \qquad \textbf{\textit{(1)}}$$

A human factor ranges from a negative to positive scale depending on the integrative composition of three (3) factors, as depicted in Figure 3. Figure 6 demonstrates a conceptual model of underlying concepts in edifice and profile of the human factor in a work environment. The model goes as follows: A positively engineered human factor metamorphoses into passion, and when integrating with passion-factored practice, then results in a competency and a spirit of oomph that delivers high-quality performance when properly aligned. Regarding an ignored human factor Engineering (HFE), a negative human factor prevails and culminates into a dismal performance, regardless of any interventions by the organizations' management. The scenario between positive and negative human factors implies an unpredictable and erratic performance.

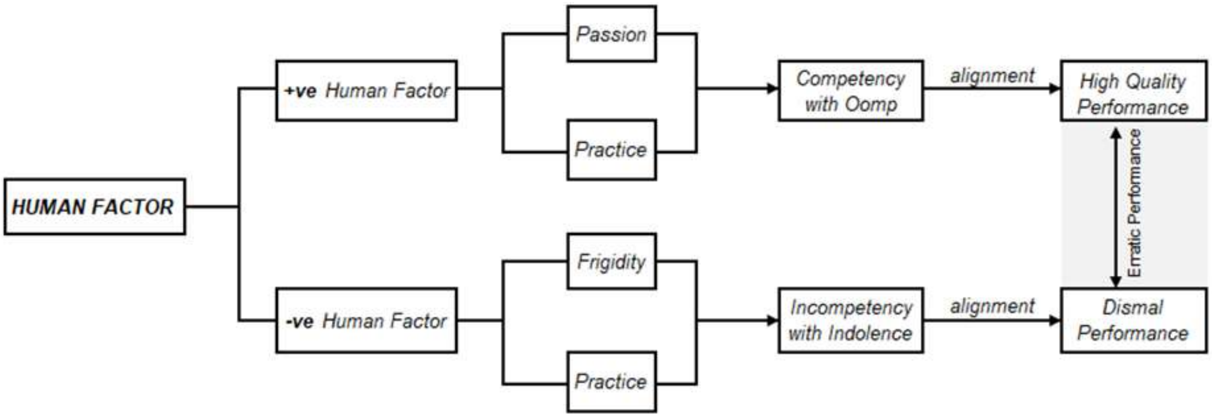


Figure 6: Human factor diversity

A package of a passion and a passion factored practice (eager to learn and practice, continuous development & actual technical performance) represents a formative element of adequate skills, and adequate skills as a summative unit. Where each component of the equation is measured percentage-wise up to the maximum of 100%, then an average package of goal aligned "passion and a passion factored practice" gives 100% of required skills to ensure 100% customer satisfaction:

$$(0.5x)((Passion)\ +\ f_{passion}(Practice)) = (x)(Skills)$$

$$x\ representing\ the\ level\ of\ specific\ goal\ alignment\ and\ depth\ (intensity)$$

$$(0.5x)\sum((Passion)\ +\ f_{passion}(Practice)) = (x)(Skills)$$

On the basis of the fact that all firms are being in existence to accomplish their vision, all factors (in the equation) are assumed to be highly specific goal aligned in an intensified manner. (x) is absolutely high (~100%) thus $x = 1$ throughout all components of the equation, then:

$$(0.5)\sum((Passion) + f_{passion}(Practice)) = Skills \qquad \textbf{\textit{(2)}}$$

For illustration purposes, if say, passion = 85% and the Practice = 95% and to estimate skill level using equation 2, then in this case, skill level would be:

$$Skill\ level = (0.5)\sum(0.85 + (0.85)(0.95))$$

$$= 83\%$$

Or if, passion = 100% and the Practice = 100% then skill level, in this case, using equation 2, would be:7

$$Skill\ level = (0.5)\sum(1 + (1)(1))$$

$$= 100\%$$

NB: The condition on equation 2 is that the passion level (expressed in percentages (%)) could only be equal or above the skill level (%) thus skill level can never exceed passion level. When the summation of passion and passion-factored-practice exceeds the average, extraordinary skills come to effect, which is an unnecessary business asset (business waste), however, when properly aligned, extraordinary skills may somehow attribute to a customer confidence that results in remarkable customer retention.

6.2 Recommendations and proposed future research

Succinctly, in this research, human factor was established as the main factor that greatly contributes to the impediment vis-à-vis BPR prosperity (and other IE concepts and principles) at the SAMI. Figure 7, was then orchestrated to present a conceptual framework that could mitigate the negative effects connected to BPR inefficacy.

The conceptual framework should be executed in a projectized fashion to quickly identify gaps (the areas of incremental improvement) during the process of implementation. Furthermore, with regard to human resources engagement, only appropriately suitable human resources should be engaged into the system; individuals should be priory tested with a stringent application of equation 2.

An essential paradigm shift has been long knocking at the door vis-à-vis moving from silo mentality into a “system thinking” mentality. Silo mentality should be developed into a “system thinking” mentality in a sense where all components that play roles in the system are relatively considered. Based on the comprehended SAMI profile and the root causes from the study, the researcher constructed a pragmatically tailor-made conceptual framework (as depicted in Figure 7) to guarantee sustainably productive operations in terms of effectiveness and efficiency with cyclical reengineering approaches at the SAMI, all through revitalization of BPR efficacy.

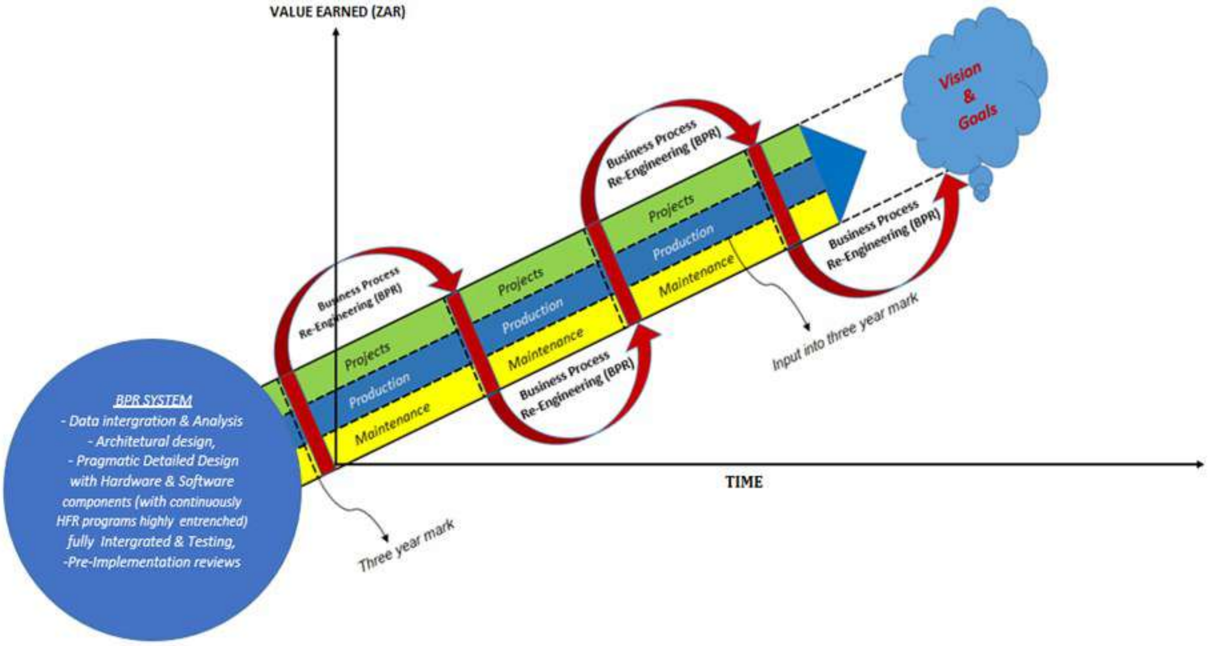


Figure 7: Business Process Reengineering Conceptual Framework

In this regard, there should a systematic integration of hardware (proposed conceptual framework, depicted in Figure 7, and software (human factor engineering drive where the human factor is engineered into passion). The conceptual framework in Figure 7 should be implemented in an integrated approach with an entrenched human factor engineering practice into the operating system. Moreover, systematically entrenched document management capabilities vis-à-vis process performance, BPR implementation, quality management, process reengineering concepts and philosophies are a pivotally and essential to be implemented along the conceptual framework.

Once again, BPR initiatives need to be implemented in a projectized fashion and in between the stage points of BPR, totally Quality Management systems, continuous process improvement techniques such as Kaizen and quality circles should be systematically executed to de-bottlenecking BPR constraints, fixing the gaps between BPR plans and actual results as well as crucially attributing operation's information into a subsequent BPR drive.

(a) Kaizen

Kaizen is small increments regarding process reengineering tasks carried out by an employee on a daily and weekly basis. It is a continuous and gradual improvement, performed in small incremental steps, with minimum or no disruption to an organization, but only through encouraging the innovative participation of each individual in a company unlike BPR which is a radical adventure. Kaizen is a highly employee-friendly approach and incrementally ensures continuous process improvement in quality, productivity, safety, and environment, as declared by Kaizen [4]. At SAMI, a collaboration of Kaizen, quality circles and BPR approaches should be implemented as a system with Kaizen technique exercised on a daily basis and/or weekly bases, at an operational level.

(b) Quality Circles (QC)

The quality circle (QC) is a continuous quality improvement cycle (CQIC), a platform where a cross-functional group of work colleagues meet voluntarily on a regular basis under their process improvement leadership to identify, analyze, and solve work-related problems and recommend solutions for process improvement. Where possible, it is recommended that at the SAMI, QC members should implement the solutions themselves, should be exercised QC adventure on a monthly basis and at a technical level of a mining organization. A continuous quality improvement cycle (CQIC), is an integrated organizational approach with the core objective of the customer's satisfaction by continuously meeting customer expectations with an appropriate economically problem-solving methodology that de-bottlenecks flow-constraints to render an operation productive, defect-free and sustainable.

(c) Business Process Reengineering circles (BPR Circles)

According to a remarkable BPR proponent, Thomas H. Davenport (1990), a business process is a set of logically related innovative tasks performed to achieve a defined business process reengineering outcome. Reengineering emphasized a holistic focus on business objectives and, encouraging full-scale, radical recreation of business processes, rather than incremental and continuous optimization of business processes and sub-processes.

At SAMI, perceptive progress has been made with regards to BPR dynamic forces, although a challenge such as human factor has rendered the BPR exploitation unnoticeable. There is a definite requirement for effective BPR practices that would optimistically influence critical success factors of business processes, such as expenditures, cycle times, volumes, speed of innovation, price, and profitability. In that regard, BPR at SAMI should be a yearly or three (3) yearly adventure that proceeds from the collection of information and resources by monthly quality circles. Should the Business Process Reengineering Conceptual Framework be implemented in the fashion as stated above then a percentage of the effectiveness, efficiency and sustainability of the mining operations would be outstandingly increased. An operation shouldn't exceed a three-year-mark without execution of BPR adventure – a thoroughly reviewing business mission against business vision and the execution of a corrective project (BPR adventure).

6.3 Sustainable Operation

Satisfying the requirements for Safety (S), Health (H), Environment (E), and quality (Q) on a continuous basis is an essential practice for an operation to continuously exist and thrive, thus ensuring business effectiveness, efficiency and sustainability. As mentioned earlier, when people are involved in a process then the human factor should be factored into the process and into related formula or equation.

$$S(\wp) = f(\wp)\left\{\frac{\sum SHEQ\%}{4}\right\} = Human\, factored\, sustainability$$

NB: Sum of SHEQ% divided by four (4) expresses the average summation of SHEQ components (Safety, Health, Environment and Quality) and an average sum of SHEQ is equal to 1 (100%) when there no safety incidents (Si), no Health Incidents Hi), no Environmental damaging incidents (Ei) and no poor-quality incident (Qi), thus:

$$S = \left\{\frac{\sum(1-Si)\% + (1-Hi)\% + (1-Ei)\% + (1-Qi)\%}{4}\right\}$$

$$Then, Human\, Factored\, Sustainability$$

$$S(\wp) = f(\wp)\left\{\frac{\sum(1-Si)\% + (1-Hi)\% + (1-Ei)\% + (1-Qi)\%}{4}\right\}$$

$$= f(\wp)\left\{\frac{(4-\sum(Si+Hi+Ei+Qi))}{4}\right\} \quad \& \quad \text{IF} \quad \Theta = \sum(Si+Hi+Ei+Qi)$$

$$then$$

$$Human\, Factored\, Sustainability = S(\wp) = f(\wp)\left\{\frac{(4-\Theta)}{4}\right\}) \qquad \textbf{(3)}$$

6.4 Future research study

Future research studies, should look at mutually exclusive criteria relevant to every component of the equation (2) i.e. passion, practice and skills. The relevant sub-elements should be scientifically determined and be used as a dip-stick tool to precisely estimate the level of each component on a measured candidate. In essence, a following paper (further study) will investigate, develop and presentation of criteria (measuring sub-elements) for measuring (to conduct a dip-stick technique) in the components of equation 2.

6.5 Summary

In summary, the research was the exploratory research conducted through qualitative method on the research sample from research population (top-ten mining company, through market capitalization, at the SAMI). The research elements (samples) were characterised by the number of more than ten (10) year of experience at SAMI with significant exposure into mining policies, mining operating processes and BPR as well as process reengineering concepts in the SAMI. The research themes were plotted in the Pereto Chart, and Human factor reflected as the primary element that mainly impedes sustainably BPR and IE concept efficacy in the SAMI. In that regard, the conceptual framework was developed to mitigate the effect. In essence, the research hypothesis was accepted – BPR system and IE concepts efficacy are directly proportional to SAMI performance. Moreover, human factor should be considered as an input into operational process of all SAMI operation where human being are involved.

Furthermore, Human Factor Engineering should be reckoned as an enticing investment where the human factor is engineered into business goal aligned passion. An average package of passion and passion-factored practise constitutes 100% skills where 100% skills refer to the skill level that results in 100% customer satisfaction. Moreover, future studies should empirically look into establishing a scientific criteria or sub-elements to be consider when estimating a passion level (human factor). The human factor would then be factored into calculations when working out the skill level via equation 2 as well as when working out earned value, pragmatic efficacy and probability of process sustainability.

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A REVIEW OF RENEWABLE ENERGY TECHNOLOGIES FOR SUSTAINABLE DEVELOPMENT: CASE STUDY-SOUTH AFRICA

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ABSTRACT

The judicious use of energy in South Africa is a key to sustainable development however the rising demand of energy has started to affect the existing power generation plants. South Africa must move towards a more sustainable energy future, addressing the imminent energy crisis in the country, also to mitigate issues of carbon dioxide emissions and climate change by providing clean energy to the society. Unfortunately, South Africa is lagging in the adoption of new energy technologies. Population growth versus energy use has become a problem and the societies have started to overwhelm the existing energy sources resulting in lack of energy hence poor sustainable development. This paper chronicles renewable energy technologies in South Africa and investigates the barriers to the implementation. The article will provide a detailed analysis of the existing energy sector in South Africa and a forecast for demand growth in other renewable energy technologies. An extensive review is presented which addresses current energy use and feasibility of new energy technologies. A review of some articles was also used to find the links between local economic development and employment creation through renewable energy resources provision.

Keywords: energy, sustainability, development,

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1 INTRODUCTION

South Africa is currently dealing with a multidimensional energy crisis that is affecting all sectors of the economy, since energy costs have been gradually rising for several years. Factors such as the increasing and unsustainable electricity prices, the urgent need for energy security, and the goal to minimize carbon emissions all add to the complexity of the current energy situation and push the development of renewable energy systems [1]. Renewable energy technology is becoming increasingly necessary in order to keep people's lives going, reduce carbon emissions, and slow the depletion of finite energy supplies. Renewable energy resources are frequently viewed as a means of addressing climate change and energy insecurity, and they have the potential to play a significant role in the development of a sustainable society [2]. This article aims to review the present potential renewable energy for the achievement of sustainable development in South Africa. Moreover, challenges of renewable energy development are examined and sorts to stipulate the role of renewable energy and explores the viability of renewable energy programs.

1.1 Background and Problem

Energy resources can be non-renewable or renewable; however, currently, the world is dominated by the usage of non-renewable energy such as fossil fuels but these are unsatisfactory because of their depletion and environmental concerns. The President of South Africa [3] acknowledges that energy is the lifeblood of the South African economy, and it is an important sector that generates jobs and value by extracting, transforming, and distributing energy goods and services throughout the economy. However, the electricity crisis in South Africa is one of the most serious threats to the country's economic and social progress.

Andreoni et al. [4] estimated that due to the ageing of most of its coal-fired power facilities, South Africa has had unpredictable electricity supply, resulting in frequent load shedding. This has prepared the door for a more thorough examination of renewable energy sources as power generation alternatives in South Africa's energy mix. Improvements in renewable energy and energy-efficient technology are especially important in achieving sustainable development.Thus, this study aims to review the current and potential of renewable energy for the achievement of sustainable development in South Africa. Moreover, challenges of renewable energy development are examined.

South Africa is been faced with erratic power supply, resulting in persistent load shedding due to ageing in most of its coal-fired power plants. Associated with generating electricity from fossil fuel are environmental consequences such as greenhouse emissions and climate change [3, 5]. Load shedding continues to have a significant impact on all South Africans' lives, interrupting business and putting further strain on families and communities. The country faces a 4,000 MW electricity gap due to outdated power plants, inadequate maintenance, policy mistakes, and the devastating impacts of state takeover [6]

Salah [7] argued that renewable energy and energy-efficient advanced technologies are especially crucial for attaining sustainable development. As a result, the aim of this research is to examine the current renewable energy potential in South Africa in order to achieve sustainable development.

2 OVERVIEW OF ENERGY IN SOUTH AFRICA

Energy plays a crucial role in the development of any nations economy [8] .The electricity crisis is one of the greatest threats to economic and social progress. Load shedding continues to have a huge impact on the lives of all South Africans, disrupting business activities, and placing additional strains on families and communities as per the presidents state of the nation address in February 2022 [3, 9].

Oryani et al. [10] stated that renewable energy technology is a pre-requisite for economy and sustainable development therefore there is much work to be done interms of research on the feasibility of renewable patterns in South Africa. M. Akinbami et al. [11] puts forward the view that overuse of coal, a limited and hostile resource, can be significantly reduced by the use of renewable energy sources as an alternative energy source.

The National Development Plan (NDP) envisages that by 2030 South Africa will have an energy sector that promotes economic growth and development through adequate investment in energy infrastructure [12]. The plan also envisages that by 2030 South Africa will have an adequate supply of electricity and liquid fuels to ensure that economic activities and welfare are not disrupted, and that at least 95% of the population will have access to grid or off-grid electricity [13].

In 1998, a government document called the White Paper on Energy [14] was published which aims on forecasting on the longer term of energy in South Africa.Subsequent to this the white paper also encourages investment within the renewable energy sector in South African economy and highlights the necessity to abide by sustainable development principles for economic development.

In line with [15] who finds that new energy technologies in the Republic of South Afrca are not well-investigated or reviewed hence there is need to analyse the feasibility and application of various renewable energy sources in the country, such as wind, solar, biomass, wood and hydro.Policies are more important in the new development of renewable energy and its sustainability The Department of Mineral Resources and Energy is mandated the task of ensuring that the energy resources are available to the society in a reasonable affordable, reliable and sustainable way, hence minimizing the associated negative environmental impacts [16].

3 REVIEW ON RENEWABLE ENERGY IN SOUTH AFRICA

There is no dispute about the importance of speeding up the development, spread, and implementation of renewable energy technologies. Nations that embrace the value of reinforcing renewables infrastructures will achieve competitive advantages in the worldwide marketplace however, one needs insight into the elements that make renewable energy development and diffusion move slowly [8, 17].

3.1 Current Energy Scenario

The White Paper on Energy Policy was created to clarify government policy for the coming decade in terms of energy supply and use [14]. It was designed to address as many aspects of the energy sector as possible. The White Paper examines the energy sector's contribution to GDP, employment, taxes, and the balance of payments in South Africa. It comes to the conclusion that the renewable energy industry can make a significant contribution to a successful and long-term national growth and development strategy [18].

It is clear that all South African households require access to a basic level of energy services.Achieving a sustainable level of energy security for low-income households can play a centralrole in the reduction of poverty, the fostering of households' livelihoods and an improved quality of life.

According to [16] [12] the National Development Plan (NDP) 2030 for South Africa is a long-term strategy for the country. It identifies an ideal state in which inequality and unemployment are decreased and poverty is eradicated, allowing all South Africans to live well. One of the most important components of a decent standard of living is electricity.

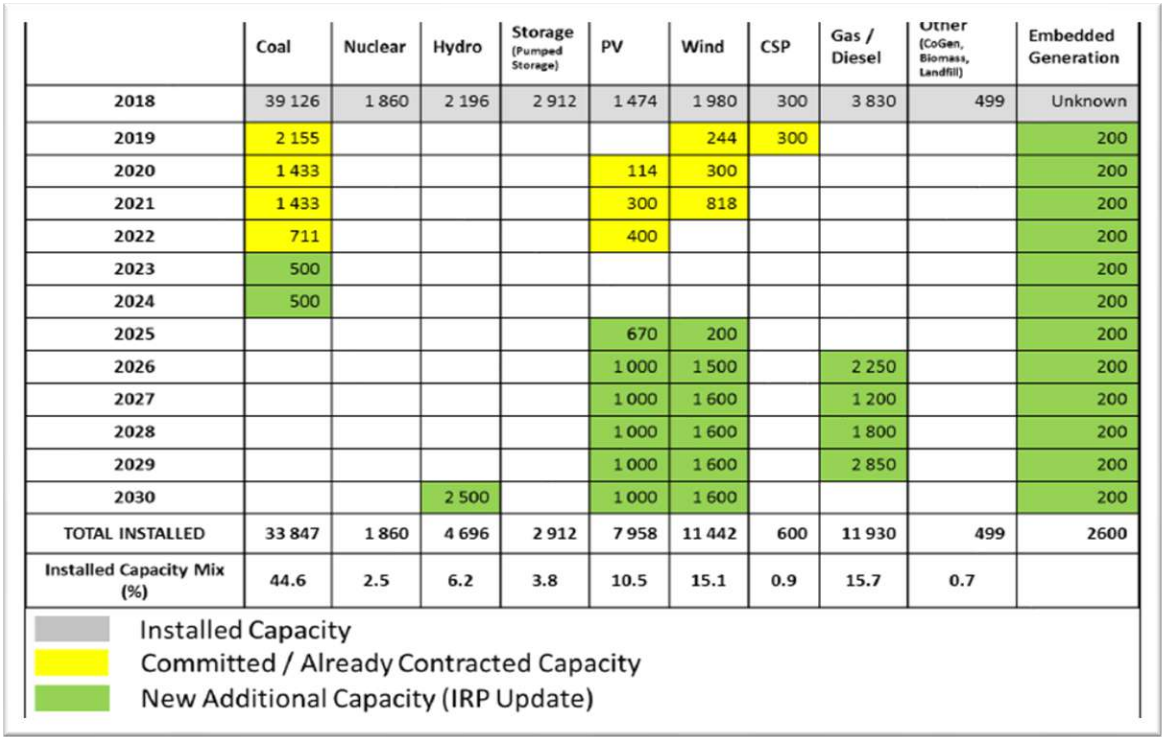
According to the National Development Plan,since the promulgated IRP 2010–2030, the following capacity developments have taken place [12, 13, 16]:

- A total 6 422 MW under the Renewable Energy Independent Power Producers Programme (REIPPP) has been procured, with 3 876 MW operational and made available to the grid.

- In addition IPPs have commissioned 1 005 MW from two Open Cycle Gas Turbine (OCGT) peaking plants.
- Under the Eskom build programme, the following capacity has been commissioned: 1 332 MW of Ingula pumped storage, 1 588 MW of Medupi, 800 MW of Kusile and 100 MW of Sere Wind Farm.
- In total, 18 000MW of new generation capacity has been committed to.

The South African Energy Sector Report 2021 [16] supplements that 'Government support for the development, demonstration and implementation of renewable energy sources for both small and large-scale applications'.As stated by [19] South Africa is committed to diversifying its energy mix and reducing its reliance on a single or a few basic energy sources as shown below.

Table 1: Energy Mix in South Africa adapted from [20]



	Coal	Nuclear	Hydro	Storage (Pumped Storage)	PV	Wind	CSP	Gas / Diesel	Other (CoGen, Biomass, Landfill)	Embedded Generation
2018	39 126	1 860	2 196	2 912	1 474	1 980	300	3 830	499	Unknown
2019	2 155					244	300			200
2020	1 433				114	300				200
2021	1 433				300	818				200
2022	711				400					200
2023	500									200
2024	500									200
2025					670	200				200
2026					1 000	1 500		2 250		200
2027					1 000	1 600		1 200		200
2028					1 000	1 600		1 800		200
2029					1 000	1 600		2 850		200
2030			2 500		1 000	1 600				200
TOTAL INSTALLED	33 847	1 860	4 696	2 912	7 958	11 442	600	11 930	499	2600
Installed Capacity Mix (%)	44.6	2.5	6.2	3.8	10.5	15.1	0.9	15.7	0.7	

▨ Installed Capacity
🟨 Committed / Already Contracted Capacity
🟩 New Additional Capacity (IRP Update)

South Africa is a major coal producer, but its usage as a source of energy is unpopular due to its impact on the environment, health concerns, and climate change [21]. South Africa's use of coal-fired power contributes significantly to greenhouse gas emissions. This is in direct opposition to the Paris Agreement of 2015, which aims to reduce global carbon emissions. The table above depicts the current energy output capacity from various sources and the projected capacity upto 2030 .

The latest IRP [12] that has been tabled above outlines the plan of new energy technologies of new installed energy capacity to 2030 will include:

- 1,000MW coal;
- 2,500MW hydro (imported);
- 5,600MW wind;
- 8,100MW solar PV; and
- 8,100MW of gas.

Energy supply and consumption are now the most important factors influencing economic growth because all economic activity require some kind of energy to run. The South African government is promoting research into renewable energy in an effort to meet the nation's growing need for electricity as well as to combat climate change and greenhouse gas emissions [6] . In order to address the issue of energy consumption, higher education institutions are also involved in a variety of renewable energy initiatives developed by provincial governments and private businesses.

3.2 Energy Supply in South Africa

With South Africa's growing population and increasing need for energy, the Department of Energy is continuously working towards ensuring energy security, achieving universal access, transforming the energy sector and ensuring the optimal use of energy resources [2, 22].South Africa's energy is dominated by coal, which is abundant and inexpensive, and ranks among the world's cheapest energy sources interms of energy cost [20]. Apart from coal, which contributes around 69% to the total primary energy supply, South Africa gets energy locally from biomass, such as wood and dung, natural gas, hydro-power, nuclear power, solar power and wind as shown by the chart below.

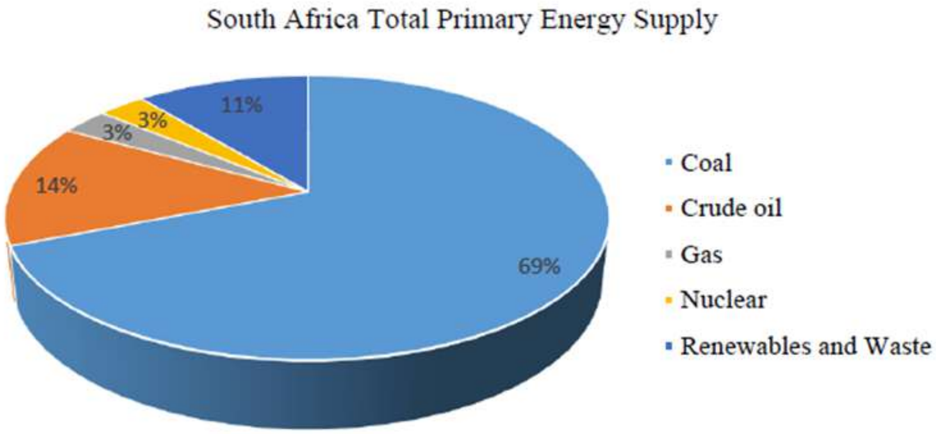


Figure 1: South Africa Energy Supplies adapted from [6]

Coal dominates South Africa's energy supply, accounting for 69 percent of primary energy This is because of its abundance and cheapness, which is regarded in the world as one of the lowest in terms of energy cost.

It is important to maintain demand and supply of power in South Africa through, demand side management measures and electricity capacity expansions in order to enhance electricity security and prevent additional blackouts. The promotion of renewable energy technology through a focus on the nations' Research and Experimental Development is one of the most obvious strategies for closing the gap and this will promote new technology advancements and the development of infrastructure and renewable energy supply-side technologies [4, 10].

4 RENEWABLE ENERGY POTENTIAL IN SOUTH AFRICA

South Africa , like other developing countries, is attempting to achieve renewable energy development by pursuing various methods of assuring inexpensive and accessible energy supply to its socioeconomic and political sectors [23]. Renewable energy is referred to as an alternative energy source because it is environmentally beneficial and helps to secure inexpensive and accessible electricity in the country [24]. Renewable energy resources are the best alternative for replacing non-renewable energy sources in order to maintain a sufficient, efficient, ecologically friendly, and long-term energy supply [25].

In 2015, the United Nations General Assembly adopted the Sustainable Development Goals, which aim to alleviate poverty, protect the environment, and ensure that all people live in peace and prosperity [15]. There are 17 goals and 169 targets in this vision and one of the sustainable development goals is for everyone to have access to reliable, affordable, sustainable, and contemporary energy [26]. As the world's population grows, so does the demand for energy and the existing population is reliant on fossil fuels, which is causing significant climate change [27].

4.1 Renewable Energy Programmes in South Africa

The government of South Africa introduced the Renewable Energy Independent Power Producer's Programme (REIPPP) established in 2011 to lure private investment into the country's energy transition. The REIPPP aims to add more megawatts to the country's electrical grid by attracting private sector investment in wind, biomass, and small hydropower, among other things [5, 16].

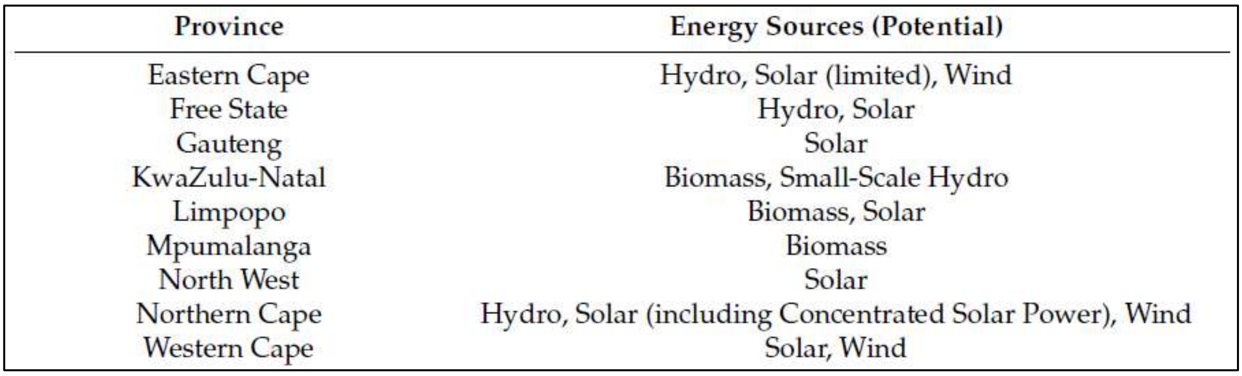
It is a renewable energy auction-based initiative aimed at increasing power generation from renewable energy sources at the lowest possible cost. In order to promote the use of renewable energy technology while supporting independent power providers, the South African government has created a number of programs and laws for renewable energy investments [4, 22].

The Renewable Energy Independent Power Producers Procurement Programme (REIPPPP) has so far attracted R209.7 billion in investment (equity and debt), with R41.8 billion (20%) coming from international investors [28]. Given that all economic activities require some form of energy to function, energy supply and consumption have emerged as the most important factors influencing economic growth. V.Ndlovu et al. [29] argues that there is a strong correlation between economic growth and energy consumption. Given the advancements made in recent years in the production and low-cost installation of renewable electricity generators, renewable energy technologies are an option to address the energy problem in South Africa.

Solar, wind, biomass, geothermal, hydropower, waste to energy, and tidal (wave) energy are all viable renewable energy options in South Africa. Their potential varies depending on the province . With the exception of KwaZulu-Natal and Mpumalanga, which have the largest biomass potential, the other seven provinces have the highest solar energy potential [23]. In the three Cape provinces, wind has the second-highest potential, biomass has the second-highest potential in Limpopo, and hydro has the second-highest potential in the Free State [30].

In summary, the resource mapping in the provinces by the Department of Energy [16] and also Baker [31] indicates the type of the renewable energy potentially endowed in each province as presented below:

Table 2:Summary of resource mapping per province ,adapted from [31]



Province	Energy Sources (Potential)
Eastern Cape	Hydro, Solar (limited), Wind
Free State	Hydro, Solar
Gauteng	Solar
KwaZulu-Natal	Biomass, Small-Scale Hydro
Limpopo	Biomass, Solar
Mpumalanga	Biomass
North West	Solar
Northern Cape	Hydro, Solar (including Concentrated Solar Power), Wind
Western Cape	Solar, Wind

Table 3:Primary energy supply in South Africa [32]

Technology	Power Capacity (MW)
Coal	1860
Nuclear	39126
Hydro	2196
Pumped Hydro	2912
PV	1474
Wind	1980

5 BENEFITS OF RENEWABLE ENERGY TECHNOLOGY IN SOUTH AFRICA

Renewable energy is a critical resource for electricity generation in South Africa and throughout Africa. Considering that only a small percentage of Africa's population has access to electricity, alternative energy has the potential to improve the lives of millions of people.

L. Kitzing et al. [33] gives the summary of different Renewable Energy technology contribution from 2016 to 2021, he observed that the fraction of renewable energy contributed increased steadily from 2016 to 2021, this shows the Renewable Energy geared programme has been very effective in line in its objective of enhancing energy capacity.

There is little doubt that these Renewable Energy-focused initiatives have aided South Africa's economic progress. In addition, the programs attracted 56 billion Rand (4 billion USD) in FDI in renewable energy technology in 2018, as well as 141 billion Rand (11 billion USD) in domestic sources across 92 projects [32]. An influx of large-scale energy project developers from all over the world, as well as a variety of local and international investors, are eager to help shape a new investment frontier, not to mention the construction of the country's first commercially viable large-scale energy project initiatives that are based on renewable energy [16, 18].

By expanding the amount of renewables in South Africa's energy mix, the country may dramatically increase employment because between 2018 and 2030, employment is predicted to grow by 40%, resulting in about 580,000 jobs [34]. Renewable energy generation jobs are primarily found in the service, construction, and manufacturing industries. Despite job losses in coal mining, employment possibilities are provided in practically all sectors, including the mining sector, which sees a net rise in employment [12].

South Africa has a one-of-a-kind renewable energy procurement strategy in the world. It also focuses on projects mostly in rural communities, which are often referred to as "marginalized populations." In terms of socioeconomic development and enterprise development, these marginalized groups can increase profit. Until 2050, more than 3000 local firms in marginalized communities can be supported. In the same amount of time, 10,000 local jobs can be produced in underserved areas [15]. These changes may have an impact on schooling as well: Access to education-related programs could assist up to 30 000 people in marginalized communities [35].

Clean energy is becoming more global. A roll-out of sustainable energy initiatives in the global South is supporting a global energy transformation following the COP21 UN Climate Change Conference in 2021 [9]. Air pollution, particularly from coal-fired power stations, is one of the major impacts of the energy sector on the environment and human health in South Africa [33]. These contaminants have a variety of deleterious consequences, the most serious of which are heart disease, lung cancer, stroke, and chronic obstructive pulmonary disease [36]. Coal power stations pollute the air in South Africa, affecting up to 44 million people. Coal-related health expenditures will peak in 2023, costing up to R45 billion in that year alone. As many as 2080 people may be born prematurely [2].

The provision of jobs, resource efficiency, and the environment are all significantly impacted by the energy industry on the sustainability of the economies. The resilience and sustainability of the entire economy, from job creation to resource efficiency, are significantly influenced by the energy sector [29] . Additionally, the expansion of the renewable energy industry in the nation has the potential to expand employment opportunities, strengthening the South African economy.

To summarize, not only would a transition to a low-carbon economy benefit South Africa, but it would also benefit the rest of the world. Vietnam, Turkey, Mexico, and India have all conducted similar investigations [18]. With favorable consequences by 2050, the renewable energy sector in India might employ more than 3.2 million people [26]. By 2050, the renewable energy sector might employ five times as many people as India's total fossil-fuel economy. In certain rural and distant places of Vietnam, electricity is still unavailable. Renewable energy in the form of off-grid technology is a low-cost solution to offer electricity to those locations. Investments in renewables not only assist achieve climate targets, but they also have a significant impact on health, jobs, and local economies around the world, according to the Fotio et al. [37].

6 CONCLUSION

This study provides a comprehensive review into the current situation of energy sector and renewable energy in South Africa. South Africa has a variety of renewable energy sources that are plentiful and potentially viable. Through off-grid connections, renewable energy can meet South Africa's high energy demand, particularly for families without power, and offer a sustainable and affordable transition to decarbonization of the current coal-dependent energy system. The abundance and strong reliance on coal, which has dominated the energy market in South Africa for decades, has clouded the development of renewable energy possibilities.The review showed that South Africa has great potential to develop more renewable energy projects for sustainable development.

To ensure timely and sustainable exploitation of available resources, the government, in collaboration with other renewable energy stakeholders, should supplement existing policies and strategies to address concerns linked to renewable energy development. There is also a need to establish a stable business and investment climate for local and international investors willing to participate in renewable energy technology and development.In a nutshell public education and training on how to invest in and use renewable energy should be made available.

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CULTURAL DIFFERENCE AND IT PROJECT SUCCESS, A FALLACY OR REALITY ON THE SOUTH AFRICAN ICT SECTOR

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ABSTRACT

With high incidences of IT project failure in South Africa and globally. The paper aims to raise awareness of the impacts that cultural differences can have on IT project success, if not appropriately incorporated in project risk planning for practitioners and academics. Data was collected through semi-structured interviews on 15 IT project managers. The research demonstrates that most IT project managers do not regard cultural differences as a risk to project success, and do not regard the impacts that cultural differences of project stakeholders could have on a project as necessary for inclusion in project risk planning. The paper suggests that IT project managers and project team members should be culturally aware and sensitive and that one of the ways to address the impacts of cultural differences in IT projects is to promote trust, collectivism with a team identity in multicultural project settings thereby enhancing project success.

Keywords: IT Project, Multicultural Project Setting, Project Success

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1 INTRODUCTION

1.1 Background

The information age in which we live in has heralded a new change in which Information Technology (IT) has become indispensable for the way organisations conduct business. Fast always connected 5G internet, smart connected devices, cheaper and smaller mobile processors, and cheap storage means that computers can be accessed anywhere and at any time. The by-product of this is that IT can generate vast amounts of data from which valuable information can be gleaned. Data mined from multiple sources, including social networking activity can be used to build models to predict and interpret customer behaviour thereby enabling businesses to provide customers with uniquely tailored experiences, in the process, giving them more value.

IT is therefore an integral component in an organisation's long-term strategic set of tools and an enabler of unlocking value. It is against this backdrop of IT strategic importance that the high incidence of IT project failure gives a cause for concern. According to Portman [1] failure rates of IT projects stand at 69% within the United States of America. From an African perspective, the picture is also gloomy. In a study where IT projects comprised 73% of the sample, Teklemariam [2] found that 71% of IT projects failed due to time constraints while 40% of IT projects exceeded their allocated budgets. South Africa's IT project success rate is higher than the US figures at just above 40% (Khoza and Marnewick [3] Sonnekus & Labuschagne [4]. In South Africa, there have been notable IT project failures such as the Administrative Adjudication of Road Traffic Offences (Aarto) and eNATIS systems (Nicola [5] Comins [6]. Other failures include the Gauteng IT tender project which was R25 Million over budget [7].

Given these alarming figures of IT project failure, what then are the criteria for project success? The most common definition of IT project success is what is commonly known as the 'Iron Triangle' (Mkoba & Marnewick [8]. According to this definition, a project is deemed successful if it meets the criteria of scheduling, budgeting, and quality. That is, a project is successful if it is delivered on time, within budget and meeting stakeholder requirements. Harwardt's [9] definition is slightly different in that IT project success is defined according to four high-level dimensions, which are planning success, implementation success, perception success and result success.

Lehtinen's et al., [10] view of the causes of software projects failure includes issues with people, methods, tasks and the environment, people-centric issues such as social interaction, the project team composition, cooperation, organisational structures. In addition, Nyasiro et al., [11] established the top six causes of IT project failure as inadequate system requirements engineering, inadequate project management, missing or incomplete features, inadequate project planning, integration failure and insufficient top management support. These issues touch on organisational behaviour and may have an impact on project success.

1.2 Problem Statement

According to Eberlein [12], despite IT projects continually taking on a global nature, empirical research on culture and project management continues to be limited and that most research with regards to the field is mostly concerned with tools, techniques, and processes. Henrie and Sousa-poza [13] state that several research has been done on outsourcing, global virtual teams, and international culture, with little being done on integrating these three aspects of the IT industry. According to Chipulu et al., [14], ignoring cultural complexity limits the ability to manage it. They further claim that the inconsistencies in IT project delivery and successes can be blamed on complexities related to culture. According to Avram [15], working on global projects presents cultural problems which may also present communication problems. Poor communication has been cited as one of the causes of IT project failure Ebad [16]. According to Mdontsane et al., [17], the way conflict is managed in a multicultural IT project can have an impact on project success. Mdontsane et al., [17] stress that some conflict can stimulate work while others can derail it, and that this should be managed accordingly.

Venter [18] points out that different cultures may have different perceptions of time and therefore manage time differently. Some cultures prefer to have more space. For some cultures performance of the individuals is more important than that of the collective. While for others, for example, most African cultures, collectivism is the norm. Certain project methods or methodologies may not be applicable to them. Mistrust across cultures can cause cultural distances which can hamper performance. Hofstede et al., [19] mentions that different cultures have different predilections towards uncertainty, which he terms uncertainty avoidance and could have impact on IT project success. Culture can lead to differences in perceptions of risky outcomes (Chipulu et al., [14], which could be impactful in the context of IT project. Given that culture has different elements as outlined above, this study aims to establish if cultural differences impact on IT project success.

2 LITERATURE REVIEW

2.1 Organisational Culture

Organisational culture is a social construct [19] [20] based on the observation that organisations mirror societies: they are characterised by a relatively coherent and bounded system, display various social structures and norms, members undergo socialisation processes and there is the possibility of dispensing sanctions Jung et al., [21]. It is the key driver of organisational effectiveness and performance Trompenaars and Hampden-turner [20] and a source of sustained competitive advantage Barney [22].

2.2 Culture and Leadership

The culture within an organisation flows from the values, aspirations, and mission of its leaders. According to Grobler [23] through the process of attraction-selection-attrition and as explained by P-O theory, people are then attracted to an organisation because they also wish to be associated with that leader or with the positive attributes of the organisation [24] [23]. Over time, these values, beliefs, and practices are aggregated.

Organisational climates are comprised of psychological contracts between employees and their employers. When these psychological contracts are breached, it can lead to a negative climate in the organisation, the psychological contract is broken and there is no Person-Environment (P-O) fit [24]. As stated earlier, climate is the subjective, experiential observed culture. There is a causal relationship that runs from culture to climate. The prevailing culture also affects the behaviour of management. It affects the way they make decisions, how they solve problems and how they formulate strategy [25].

2.3 Culture and IT Projects

Globalisation and the breaking down of economic barriers mean that business organisations are no longer confined to their geographic locations. This results in different expatriate national cultures being imported into a country, bringing with them their unique way of doing business, that is, their (business and organisational) cultures [26].

2.4 Impact of Culture on Project Success

The criteria generally used to evaluate IT project success is the triple constraint of project management, which is time, cost, and quality [26]. Project success means different things to different stakeholders [27] [28]. For example, other definitions also add meeting project requirements as set by stakeholders and before project commencement. According to Bannerman [29], a project can be a success if it meets set criteria beforehand in terms of process, project management, product, business, and strategic factors. “This approach enables success to be determined and periodically re-determined as benefits accrue from the project over time. It also enables stakeholders to progressively map success to perceptions of higher derived value from the project as benefits accrue" [29]. Gomes and Romão [30] state that an IT project is said to be a success if it achieves predefined business objectives and if it leads to both stakeholder and customer satisfaction. Gomes and Romão [30] indicate that predefined critical success factors (CSF) and project success factors (PSFs) together drive business change. Gomes and Romão [30] contend that there are enablers to those CSFs including proper training, which we can argue should include intercultural training, and managing these CSF can improve PSFs.

According to Gomes and Romão [30] the application of a benefits management process on the pre-identified critical success factors such as ensuring harmonious relationships in multicultural settings can improve project management practices and guarantee an effective impact on a project success. However, the chances of project success are diminished because according to Louw & Rwelamila [26], most curricula are too technically focused and ignore the "soft aspects" of project management such working in a changing, multicultural environment as well as social, political aspects in a project and organisational settings. De Carvalho et al., [31] indicate that, how project management is practised including making provision for environmental factors and culture, can have an impact on project success.

2.5 Cultural Impact on Project Success – Selected Studies

Research by Wiewiora and Coffey [32], on project-based organisations (PBOs) in Australia, shows that culture can have an impact on knowledge sharing in projects. Knowledge transfer and project requirements elicitation from users can be affected by a reluctance to operate from organisational subcultures. Wiewiora and Coffey [32] further suggest that depending on the project environment, different organisational cultures may require different knowledge management strategies. A study in India by Sharma & Gupta [33] states that the emphasis on technical aspects at the expense of soft issues impacts projects. The work of Sharma & Gupta [33] reveals that in project management the trend is to focus on the technical issues of the project including the timeline, the project plan, the resources, and the budget. Also in most instances, possible project pitfalls lie in leadership, lack of teamwork, and in other "soft" or cultural issues [33]. According to Sharma & Gupta [33], organisational culture has an impact on the motivation, job satisfaction and overall performance of the software developers and on a project's outcome.

In a study published in MIS Quarterly conducted on offshore IT projects involving an Indian IT vendor and using social embeddedness (how individuals relate to elements of their environment including social relationships and culture etc.) rather than agency theory as a basis, Rai et al., [34] found a relationship between cultural differences at the organizational and team level, and offshore IT project success. Some of the revelations by Rai et al. [34] are that when people have a vested interest in a project, they become more willing participants and information is exchanged more readily. This is also evidenced by Lückmann and Färber [35] who state that in IT projects, cultural factors in projects can lead to lack of stakeholder engagement because of lack of trust in an intercultural setting and insufficient communication which is also echoed by Bizjak and Faganel [36]. Lückmann and Färber [35] have revealed that cultural differences can have an impact on stakeholder engagement and that these impacts can be caused by differences between cultures in areas of trust, competitive behaviour, context related issues, perceptions of vertical relationships and philosophical differences.

A study by Chipulu et al., [14] which utilised success/failure indicators (PSFIs) measured using Hofstede's et al., [19] cultural dimensions, found that these (cultural dimensions) can have an impact on project success and can reduce/increase project success/failure factors (PSFFs). To support the importance of the need to take culture seriously as having an impact on projects, Ika [37] indicates that one of the reasons that projects have failed in Africa, has been the failure to tailor projects to African cultures. The outcomes of research by Mayer et al., [38] on intercultural collaboration between Chinese and Tanzanian IT projects and the perceptions of the cultures, revealed that there are differences between the way the two cultures view their organisations. Mayer et al. [38] found that the two groups' stereotypes of one another persisted through time while at the same time both cultures views on the self were favourable. Mayer et al., [38] also established that perceptions of cultures regarding their own organisations in intercultural settings can impede progress in projects especially if negative. This is an example of environmental factors and the context in which a project occurs being critical to success [39].

In South Africa and other parts of Africa, Aranda-Jan et al., [40] established that sociocultural factors have a role to play in IT mobile health (mHealth) projects and may lead the intended users of technologies not accepting them thereby affecting project successes. In such socio technology transfer projects Lin and Berg [41] note that culture may have a role in the impeding the technology transfer taking place. Lending credence to this is a study by Leidner et al., [42], which found that there can even be conflicts between culture and information technology known as system conflict. It is a conflict that emerges between the implementation of a system and the perceived violation of the culture of a people.

3 RESEARCH METHODOLOGY

3.1 Research design

An interpretivism philosophy in the form of a qualitative research approach was used in the study. The was based on what Creswell and Creswell [43] indicates as the goal of qualitative research, which is to understand things and further knowledge about a subject, bring attention to things, spark debate, and to change how reality is perceived. The researchers desired to understand the phenomena from the perspective of the subject, wished to raise awareness and to explore new territory.

3.2 Study Population and Sampling

This research focused on 15 out of a possible 200 ICT certified project managers (PMSA, PMP®, PgMP®, PfMP®, CAPM®, PMI-PBA®, PMI-ACP®, Prince2® Foundation, Prince2® Professional, Prince2® Agile, Professional Scrum Master™, Professional Scrum Product Owner™, APM etc.) based mainly in South Africa who had been purposely targeted using various methods including referrals, introductions and business social media platforms such as LinkedIn. This was aligned to Cooper and Schindler [44] who recommend a sample size of between four and 15 respondents for exploratory qualitative studies.

3.3 Data Collection and Analysis

Data was collected through structured interviews conducted either face to face, telephonically or with the aid of commercial video conferencing tools WhatsApp, Microsoft Skype / Teams, or Apple FaceTime and Google Hangouts. The interviews were recorded after which the data was transcribed verbatim. Data was thematically analysed through the six-phase framework promulgated by Braun and Clarke [45] and further explained through a step-by-step approach by Maguire and Delahunt [46]. This process allowed for themes and patterns to be established from the data, interpreted, and helped to address the research [46].

4 FINDINGS

Having carried out thematic analysis the following themes were established with results presented in the table:

- Organisational function
- Cultural diversity
- Communication
- Project competencies.

Table 1: Theme, Category and Findings

Theme	Category	Findings
1. Organisational functions	Internal departments; External departments; Project planning challenges; Training	a. Participants mentioned getting consensus during project planning when working on IT projects that sometimes-involved functions such as finance, human resources, sales, and other organisational functions is a challenge. b. IT departments were often compartmentalised and that projects drew different members from those compartments e.g., business analysts, developers, testers, and quality assurers. These kinds of teams usually operate autonomously with their own leadership structures and have their own cultures which impacts on project planning. c. Resources from outside an organisation would bring their own different culture and sometimes even different national cultures, thereby impacting on IT project planning. d. Participants stated that they were challenged on IT project planning due to different cultures and that they had difficulty expressing themselves creatively in new settings. e. Most participants mentioned that they received no training at all on dealing with different cultures. f. Most participants agree that cultural differences, diversity, and cultural sensitivity awareness should be part of project management training and not project planning.
2. Cultural diversity	Cultural differences; Positivity; Opportunity; Lessons learnt reports; Leadership, Cultural accommodation	a. Most participants mentioned that cultural differences alone will not make an IT project fail, however, an accommodative positive attitude will make an IT project success inevitable. b. Participants indicated that diversity of cultures in IT projects has assisted by bringing a diversity of ideas. c. Diversity of people “brought positive competition to the project, with each group of people attempting to prove its greatness”. d. View cultural differences as opportunities to widen one’s perspective and broaden minds to what is possible in an IT project. e. Most participants indicated that they document lessons learnt when closing IT projects which is helpful for future project’s success”, that is, they can reap rewards whilst organisational and generative learning are enhanced. f. Participants stated that project managers who tended to micro-manage, hamper project success, as the project team gets “frustrated throughout the project”. g. Avoiding uncertainty by over controlling resources stifles the creativity and innovation of project team members.

		h. Lack of cultural accommodation as project team members tend to group themselves into camps, thus clinging to familiarity.
3. Communication	Project requirements; Productivity; Projects environment, Project risk	a. Communication problems make the task of eliciting IT project requirements from people very difficult (resulting in failure to understand the project requirements) which in turn affects project deliverables. b. Miscommunication resulting in the recipient interpreting the information incorrectly, causing some deliverables not to function as intended. c. Participants indicated that they were not effective at the beginning of culturally diverse projects but became more productive and thrived as the project progressed. d. Most participants indicated that they were concerned about the nature of the work and outcomes rather than their environment. e. Incorrect interpretation of IT project requirements due to misconception of the IT project. f. Project leaders are interested in those aspects that are risky to an IT project and this forms part of project risk management, but they are not specifically interested in cultural differences.
4. Project Competencies	Project methodology; Conflict management	a. Difference in project methodology influence management of diversity on international projects. b. Varying degrees of knowledge, competency levels, talent, and experience influence the degree of project success. c. Conflict arising in terms of the role one would play in the project, as the project was dominated by the SCRUM approach. d. Different team members interpreting project objectives differently.

5 DISCUSSION

5.1 Theme 1: Organisational Functions

Organisational functions hamper the consideration of culture during project planning. Cultural training is not undertaken, in preparation for IT projects thus project stakeholders are exposed to cultural shock that lies ahead. This is supported by Low et al., [25] who state that the global technology market tends to be client driven and very competitive thus to please clients, providers must react quickly through IT product development projects and thus often not leaving enough time for cultural preparations.

Another cultural issue which emerged in the research results which could impact on success is, participant’s perception of having to raise their game in unfamiliar environments, “to make an impression” on other team members of different cultures”. This could point to a latent problem of fear of being stereotyped as pointed out by Hofstede et al., [19]. Davis (2014) further adds that mistrust means there is less confidence in another’s goodwill, integrity, and another’s ability and credibility and that cultural clashes usually stem from the fact that neither party has the comprehensive management capability needed to complete the project individually. Even though trust links to psychological safety required by all project team, these findings provide further context in that even project stakeholders from all cultures are confident in one another's competencies and abilities and appreciate the different perspectives and skill sets each brings to the table.

5.2 Theme 2: Cultural Diversity

The study established that cultural differences have little to no effect on project success with most participants indicating that "cultural differences alone will not make an IT project fail".

The study uncovered that there is also limited documentation of encounters or incidences related to multiculturism, that very few participants stated ever documenting their experiences in the lessons learnt repository. This finding reveals that culture and its possible impact on project success is still an ignored subject in the IT project management practice. These results are in consonance with what De Carvalho et al., [31] established in that cultural difference impacts in IT project management are receiving little attention in academic studies and surveys as well as being poorly managed in practice. In addition, this implies that organisations are not learning anything from the experience and that the same mistakes are likely to be repeated in the future.

5.3 Theme 3: Communication

Although miscommunication has many causes, this study established that it can occur resulting in the incorrect interpretation of requirements, and stakeholders also need to take cognisance of nonverbal communication. These findings are in line with what is stated by Hofstede et al., [19] as well as findings by Bizjak and Faganel [36] who state that understanding cultures and how they communicate including nonverbal communication before interaction can make a difference. This study established that most IT projects do not establish a communications strategy during the planning phase of the project, which is devoid of good project management practices.

5.4 Theme 4: Project Competencies

Participants mentioned different factions interpreting project objectives differently. This could be due to stakeholders not agreeing to objectives at the start of the project. It could also be due to not involving all stakeholders during project planning and but only in the middle of the project. As good project management practice and what this study established, there is need for agreeing to project objectives at the start of the IT project to reduce conflicts and misunderstandings in multicultural settings. Mayer et al., [38] posit that such an approach also increases performance during the project. To aid IT project successes, it is imperative to have collective agreement on the project plan and to also have clearly defined goals.

Although most participants stated there is little differences in project management competencies between cultures, they mentioned some organisations with which they have collaborated having preferences for certain project management methodologies. Most literature on the subject seems to suggest that different cultures interpret project management methodologies differently Lückmann and Färber [35]. This implies that teams from different from cultural backgrounds may struggle with one another's project methodology unless a deliberate effort is made to find a mediating solution such as finding a middle ground such as establishing standards from the onset or adopting the standards and practices of one of the parties.

6 MANAGERIAL IMPLICATIONS AND RECOMENDATIONS

Project Executives, and Project Managers can make use of the following recommendations are generated from this study:

- Proper documentation of any cultural issues that are noted or experienced in the projects that "lessons learned" document and project management information system as part of organisational learning.

- Cultural awareness and cultural sensitivity training should be included in project management certification courses.
- The inclusion of cultural awareness and cultural sensitivity components in university and tertiary level project management curricula.
- Dealing with the issue of cultural differences proactively by making the necessary preparations and having contingency measures such ways to solve disputes and ways to discipline intolerant behaviour.
- Increase collectivism in IT projects, that is, create a culture where everyone is working for the team. Have the team practice Ubuntu and empathy in a project management context.
- In line with good project management practices is the need for establishment of proper communication channels, conflict resolution measures before the initiation of the project to address miscommunications and misunderstanding between stakeholders from different cultural backgrounds.

7 LIMITATIONS OF THE STUDY

The study limitations included the following:

- Due to the availability of participants that fit the criteria particular to this study, participants did not all originate from the same organization.
- The researchers had no qualifications in anthropology, cultural anthropology or any qualifications specifically related to the study of cultures. This study only related to how culture affects software projects and was not a study about culture itself.

8 CONCLUSION

The study concludes that cultural differences though minimally impacting on IT projects, can be further magnified by the duration of the project and environmental factors. This however does not negate the fact that IT project managers and project team members should be culturally aware and sensitive. In addition, this study supports the view that promoting trust and collectivism with a team identity in multicultural project setting assist in addressing the impacts of cultural differences in IT projects thereby enhancing project success.

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EFFECTIVE RISK MANAGEMENT PRACTICE AND PROJECT SUCCESS, THE CASE OF A WATER UTILITY'S CONSTRUCTION PROJECTS

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ABSTRACT

Failure to complete projects can significantly put an organisation's competitive advantage, its strategic position, and competitive survival in jeopardy. The study sought to establish the effectiveness of applying project risk management tools and techniques at Rand Water, a state-owned entity. A quantitative approach with a survey research strategy was used in this study and 63 of the total population of 69 responded to the questionnaire that was issued. The Rand Water case study findings suggest that, in order to reduce project failure, one of the tools being utilized in managing projects is effective project risk management. In addition, the findings indicate that executive management must continue to apply project risk management tools and techniques coupled with regular project team training.

Keywords: Construction Projects, Project Risk Management, Project Success

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1 CONTEXT

1.1 Background

Rand Water is the largest bulk water utility in Africa and is one of the largest water utilities in the world, providing bulk potable water by operating thirteen tertiary pumping stations, enclosed reservoirs, secondary booster stations and multi-billion rand regional pipeline network. It is imperative for Rand water to maintain a global reputation for providing high-quality water that ranks among the best in the world. Project management is critical for Rand Water to consistently met national standards and international guidelines on water quality. Kerzner [1] notes that project management has evolved from a set of processes that were once considered "nice to have" to a structured methodology that is considered mandatory for the survival of every organisation. He further mentions that many organisations are now relying on project management which is assisting them to sustain and grow their businesses. This is supported by Hadjinicolaou et al. [2] who establish that projects have increasingly become organisations' strategic initiatives to implement changes and improve organisational performance. It can, therefore, be deduced that many organisations that are embarking on projects to implement capital investment. One such organisation is Rand Water, whose competitive advantage is dependent on successful completion of these projects. On the contrary, failure to complete such projects can significantly put an organisation's competitive advantage, its strategic position, and competitive survival in jeopardy.

1.2 Problem Statement

One notable aspect from the forgoing is that implementing strategy through projects is becoming the key for competitiveness. One notable aspect that comes with this is the management of project risk which is considered crucial once project success criteria has been agreed upon by all stakeholders [3]. Hence the effective application of project risk management is a possible significant contributor towards project success. It is against this background that the aim of this case study was to investigate the influence of project risk management on construction project success at Rand Water through a descriptive study.

2 LITERATURE REVIEW

2.1 Project Success

One irrefutable fact coming from literature review is that there is no consensus regarding the definition of project success. This was asserted by Carvalho et al. [4] who established that project success can be measured on different (i) projects, (ii) perspectives and (iii) stages. Thus, different project stakeholders understand project success differently [5]. Ramos and Mota [6] affirmed this by indicating that different stakeholders held deferent view regarding project success on the same project. For instance, senior management might view project success when it has achieved certain aspects, which might be contrary to end-user's viewpoint. Similarly, the same can happen between the project manager and end-users.

The definition of project success comprises of project success factors, project success criteria Masrom et al. [7], project success measures Satankar and Jain [8], project success metrics and project success outcome evaluations. Furthermore, Lech [9] established that the presence of project success factors increases the probability of project success. Due to the multidimensional nature of the definition of project success, Samset [10], Shenhar and Dvir [11] different stakeholders explore different perceptions. Samset (1998) indicates five success criteria of efficiency, effectiveness, impact of project on society, relevance to real need of society and sustainability. Shenhar and Dvir [11] puts forward five dimensions of project efficiency, impact on the customer, impact on the team, business and direct success and preparation for the future. Carvalho and Rabechini Junior [12] add the sustainability dimension which is linked to social and environmental aspects of projects.

The decision to classify a project success and failure is a subjective process [13]. Müller and Jugdev [14] describe project success as “predominately in the eyes of beholder”, meaning different individual perspectives on the same project. Therefore, Joslin and Müller [15] state that this element of bias when evaluating project success, should be eliminated through stakeholder alignment on project success criteria and its adoption.

2.2 Project Risk Management

Project risk management is an organized means of identifying, measuring, developing, selecting, and managing options for handling project risk [1]. It encourages considering the future, anticipating what could go wrong and then developing contingency strategies to mitigate the risks established [1].

Szymański [16] outlines the following process of risk management throughout the project cycle:

- risk identification – identification of risks and determination of their sources
- risk analysis – risk assessment in terms of hazards and their consequences
- responding to risk - number of measures and mechanisms affecting the risk level
- risk monitoring – on-going assessment and information about the risk.

All these processes are equally important and need to be carried out continuously from initiation through to project close out stage [16]. This is supported by Thamhain [17] who indicate that project risk management is an iterative, on-going review process during the life of a project. In addition, Banaitiene and Banaitis [18] echo the same in that project risk management is a valuable iterative process to organisations when it is applied consistently during the lifecycle of the project [18]. The application of project risk management practice entails learning from past experiences and implementing them in future. Whilst is it the responsibility of the project manager, project teams to assist in this regard. The project team needs to agree on the appropriate tools and techniques to be used in managing project risks [1].

The above is consistent with findings by Willumsen et al. [19] who asserts that project risk management is a common and widely adopted project practice. In addition, Kerzner [1] found that for project-driven multinational organisations, risk management is of paramount importance. However, not all organisations, understand project risk management or its importance as it is sometimes viewed as an over-management expense on a project.

2.3 Project Risk Management Practices in Construction Projects

Asaad [20] defines construction project as a collaborative teamwork process wherein stakeholders have different interests, functions and objectives although they share the common goal of a successful project. Success of projects in the construction industry depends on the level of risk [21]. Construction project risk management is seen as being a comprehensive and methodical technique of identifying, analysing, and responding to risks to achieve the objectives of the project [22]. Serpella et al. [23] assert that for decades, the approach to managing risk in construction projects seems to have not produced favourable results. For instance, one common risk management practice in the construction industry is through the application contingencies (money) or floats (time) to manage risks. The latter practice has its own flaws and is not one size fits all for projects. In order to improve project risk management Serpella et al. [23] established that, it is necessary to use tried and tested, appropriate and systematic techniques [23]. The construction industry seems to present more unavoidable risks which require effective management throughout the project life cycle than any other project management industry [24][22]. Given that unpredictability in construction projects is unavoidable, it is imperative to effectively manage risks in construction projects if an organisation is to achieve its set objectives [25].

According to Choudhry and Iqbal [26], project risk management within the construction industry practice is responsive, semi-permanent, casual, and unstructured, resulting in a lack of capacity to effectively manage risks. The main barriers that were found include lack of formality of the process and lack of comprehensive methods applying project risk management [26]. In addition, Fan et al. [27] noticed that the same precision and urgency which is afforded to other knowledge areas of project management is not afforded to project risk management on construction projects.

2.4 Benefits of Applying Project Risk Management to Construction Industry

Asaad [20] identifies advantages of construction project risk management as follows:

- assisting achievement of projects objectives
- reducing capital cost of the project
- mitigating ambiguities
- Mitigating loss of time
- increasing stakeholders' reliability

Additional benefits from effective application of project risk management include financial savings, and greater productivity, improved success rates of new projects and better decision-making [25]. This implies that the construction industry should integrate the application of effective project risk management into their organisational culture. This would make it easier for employees to acquire appropriate skills and practice this knowledge subset [23].

2.5 Project Risk Management and Project Success

Project risk management has been found to have positive impact on project success [28]. However, not managing risk throughout the project lifecycle, can result in project failure [29]. As such, it is important to use project management tools and techniques to avoid project failures [33]. Effective risk assessment adds value through enhancing the probability of project success [30][31][32].

The construction process is a complex, nonlinear and dynamic phenomenon that may sometimes exist on the edge of chaos, hence the construction projects are rich in plan failure, delays, and cost overruns more than in successes [34]. However, Ortega [35] discovered that despite large project failure percentage, managers avoid discussing failure cases due to among others, the fear of harming the reputation of the parties involved. Besner and Hobbs [32] indicated that project failure is a sensitive issue which can impact the reputation of both the organisation and the team who worked on the project.

3 RESEARCH METHODOLOGY

3.1 Methodology

A positivist philosophy in the form of a quantitative descriptive study was adopted using a single case study on a water utility organisation. The study premise was based on Leavy [36] who indicate that deductive approaches are aimed at proving, disproving, or lending credence to existing theories. Considering a limited population of 69 project managers and project team members that Rand Water has, a census was adopted for this study in which all project managers and project team members (engineers, technicians, project planners) voluntary participated in this study. This meant that all Rand Water project managers and project team members had equal chance of being selected for participation in the study, which ensured unbiased and objective outcome. Ultimately, 63 of the 69 participated giving a 90% high response rate.

The unit of analysis was Rand Water's project managers, project team members. 15 (24%) had project management experience of between 2 - 10 years; 41 (65%) had experience of between

11 – 20 years while 7 (11%) had more than 20 years' experience. This case study of Rand Water made use of a questionnaire as data collection instrument, using a Five-Point Likert scale. Data was analysed using SPSS (Statistical Package for Social Sciences).

Cronbach's alpha was used to measure the consistency of responses across a set of questions (scale items shown in Appendix A) designed together to measure a particular concept (scale). The guidelines proposed by Saunders et al. [37] wherein Cronbach alpha ≥ 0.9 is excellent; ≥ 0.7 is good and ≥ 0.6 is acceptable were used.

Table 1: Research objectives and reliability coefficient

Objective	Number of Items	Cronbach's Alpha
To establish the relationship between project risk management and projects success in water utility projects.	6	0.62
To establish how project failures can be mitigated in the construction industry's water utility projects.	5	0.83
To establish the impact of effective project risk management in the construction industry's water utility projects.	8	0.81

3.2 Case Description

The case organisation herein referred to as Rand Water operates under the parameters of the Water Services Act no. 108 of 1997 and it is mandated to supply potable water in bulk to municipalities within its operational area [38]. The primary function of Rand Water is to use its infrastructure to extract raw undrinkable water from a river/dam, purify it to drinkable standard and then distribute through its infrastructure to municipal clients and private entities such as mines [38].

Rand Water's has a vast network of pipes spanning over 3 056 kilometers, over 58 reservoirs, purification plants that are all over Gauteng, Free State, North West and Mapumalanga provinces [38]. The case organisation has embarked on an investment programme comprising of more than 23 major projects running concurrently. The strategic intent is to increase the capacity of the raw water supply system from the Vaal Dam to the Zuikerbosch Water Purification and Pumping Station (the construction site of these 23 concurrently projects in Vereeniging) [23]. Successful completion of these projects will result in a potential revenue increase of 25% [38].

4 RESULTS

4.1 To establish the relationship between project risk management and projects success in water utility projects

Spearman-Brown Adjustment Split-half correlation is 0.71 suggesting a 71% confidence on the extent to which all the questions measure the relationship between project risk management and project success. The Cronbach's Alpha (CA) was used to determine the correlation between questions on project risk management and project success, thus checking the consistency of responses. In this case, a CA of 0.62 indicates an acceptable correlation and consistency.

Table 2: Statistical summary of reliability tests

Number of questions	6
Subjects	63
Cronbach's Alpha	0.62
Split-Half (odd-even) Correlation	0.54
Split-Half with Spearman-Brown Adjustment	0.71
Mean for Test	23.69
Standard Deviation for Test	4.59

The statistical summary is presented in Table 2. The null hypothesis is that all classification levels of opinion on the relationship between project risk management and project success has the same frequency while the alternative hypothesis is that there is a significant difference between the two at 1% (0.01) significant level. From the Chi-squared test, the calculated P-value of 2.56E-4 is smaller than the 0.01 level of significance. This implies that there are statistically significant differences between the frequencies of opinions with regards to the relationship between project risk management and project success. The null hypothesis is therefore rejected, and alternative hypothesis is accepted.

Table 3: Statistical summary of relationship between project risk management and project success

	Project Risk Management and Project Success								
	Strongly agree	**Agree**	**Neutral**	**Strongly disagree**	**Disagree**	**n**	**Mean**	**Stdev**	**P-value**
Frequency	45	136	102	68	27	378	2.7	1.20	2.56E-4
Percentage	12%	36%	27%	18%	6%				
Likert scale: 1 Strongly agree; 2 - Agree; 3 - Neutral; 4 - Strongly disagree; 5 – Disagree level of significance p <1% (2- Tailed)									

Table 3 represents the overall results on project risk management and project success. The mean value of 2.7 is between 2 and 3 on the Likert scale. The results indicate that, 36% and 27% of the participants had a neutral and agree opinion about the relationship between project risk management and project success.

4.2 To establish how project failures can be mitigated in the construction industry's water utility projects

Spearman-Brown Adjustment Split-half correlation of 0.79 was found, suggesting that there is a 79% confidence on the extent to which all the questions measure project failure mitigation. The Cronbach's Alpha of 0.83 indicates a good correlation and consistency.

Table 4: Statistical summary of reliability tests for project failure mitigation

Number of questions	5
Subjects	63
Cronbach's Alpha	0.83
Split-Half (odd-even) Correlation	0.63
Split-Half with Spearman-Brown Adjustment	0.79
Mean for Test	14.18
Standard Deviation for Test	3.48

The null hypothesis is that all project failures cannot be mitigated while the alternative hypothesis is that they can at 1% (0.01) significant level. From the Chi-squared test, the calculated P-value of 4.44E-7 is smaller than the 0.01 level of significant. This implies that project failures can be mitigated. The null hypothesis is therefore rejected, and alternative hypothesis is accepted.

Table 5: Statistical summary of frequency distribution for responses to questions on project failure mitigation

	Strongly agree	Agree	Neutral	Strongly disagree	Disagree	n	Mean	Stdev	P-value
Frequency	13	123	126	19	34	315	2.72	1.01	4.44E-7
Percentage	4%	39%	40%	6%	11%				
Likert scale: 1 Strongly agree; 2 - Agree; 3 - Neutral; 4 - Strongly disagree; 5 – Disagree Level of significance p <1% (2- tailed)									

Table 5 represents the overall results on project failure mitigation. The mean value of 2.72 is between 2 and 3 on the Likert scale. Results indicate that 40% and 39% of the participants had a neutral and agree opinion respectively about project failure mitigation.

4.3 To establish the impact of effective project risk management in the construction industry’s water utility projects

As shown in Table 6, Spearman-Brown Adjustment Split-half correlation is 0.72, suggesting that there is a 72% confidence on the extent to which all the questions measure effective project risk management. The Cronbach's Alpha of 0.81 indicates a good correlation and consistency.

Table 6: Statistical summary of reliability tests for responses to questions on effective project risk management

Number of questions	8
Subjects	100
Cronbach's Alpha	0.81
Split-Half (odd-even) Correlation	0.54
Split-Half with Spearman-Brown Adjustment	0.72
Mean for Test	23.62
Standard Deviation for Test	4.59

Table 7: Statistical summary of frequency distribution for responses to questions on effective project risk management

	Strongly agree	Agree	Neutral	Strongly disagree	Disagree	n	Mean	Stdev	P-value
Frequency	30	176	172	30	96	504	2.88	1.17	1.86E-7
Percentage	6%	35%	34%	6%	18%				
Likert scale: 1 Strongly agree; 2 - Agree; 3 - Neutral; 4 - Strongly disagree; 5 – Disagree									
level of significance p <1% (2- Tailed)									

Table 7 represents the overall results on effective project risk management. The mean value of 2.88 is between 2 and 3 on the Likert scale. Results indicate that 35% and 34% of the participants had a neutral and agree opinion on effective project risk management. From the Chi-squared test, the calculated P-value of 1.86E-7 is smaller than the 0.01 level of significant. This implies that effective project risk management has positive implications for construction projects. The null hypothesis is therefore rejected, and alternative hypothesis is accepted.

5 DISCUSSION

The case study findings were able to proffer the significant positive relationship between project risk management and projects success at Rand Water. This implies that, the more effective project risk management is applied, the more likely that the project will succeed. This assertion corroborates with findings from literature in that:

- Project risk management practises are found to have a positive impact on project success [28].
- The effective project risk assessment is critical for the success of the construction projects and the risk assessment is a vital part of the risk management [30].

The case study also established that construction project failures can be prevented with proper project risk management practices in place. However, the converse is true when there are no project risk management practices in place. This is supported by findings from Hwang et al. [29] who established that projects could result in the failure if risk is not managed throughout the project lifecycle. Pimchangthong and Boonjing [28] provided insights that applying effective project risk management would allow organisations to have a control of possible future risks whilst allowing them to proactively devise plans to manage these risks. This action can empower similar organisations to mitigate possible project failures through application of effective project risk management practices.

In addition, the case study results established that effective project risk management has positive implications for construction projects. This is in line with findings from Choudhry and Iqbal [26] who established that, application of effective project risk management practices enhanced the probability of project success. It can be concluded from this case study that application of effective project risk management translates into effective project management with enhanced possibility of project success in Rand Water’s construction projects.

6 MANAGERIAL IMPLICATIONS

These aspects below concerning project risk management have implications for organisational management teams, workers, engineers, partners, and other stakeholders. As established through the case study, placing project risk management at the centre of all project operations enhancing the chances of project success, which in turn results in a competitive edge. The following recommendations and implications for change are generated from this case study:

- Organisations should make it compulsory for all its Project Managers, Project Engineers and Project Teams to possess project risk management knowledge and attendance of regular refresher courses to keep them abreast of developments in the area.
- Organisations should ensure effective application of project risk management processes and practices. This can be made compulsory through enhanced organisational policies and procedures. In addition, there is need for regular project reporting to include project risk reporting.
- Organisations should ensure that effective implementation of project risk management systems/processes becomes part of organisational culture.
- Organisations should make it mandatory to archive project risk management reports for future referral use. Similarly, that, during project initiation or planning, previously archived project risk management reports must be part of the key inputs.
- Executive management should drive a culture of project risk management across all project teams, which improves risk mitigation and enhance project success.

7 LIMITATIONS OF THE STUDY

This case study was confined to Rand Water construction projects, its information, and participants. The following organisations are excluded:

- The rest of the construction projects executed by other organisations other than Rand Water.
- Any organisation from any other sector other than the construction industry within South Africa.

The case study focus was on the effect of project risk management on project management on project success. The impact of other factors on project success was not considered in this case study. This case study focused on project risk management and did not address other areas that affect project management within organisations, for instance, finance, operations, and executive management, among others.

8 CONCLUSION

The research results demonstrated that there were statistically significant differences between the opinions of the project managers with regards to the relationship between project risk management and project success. The conclusion based on the case study is that there is a significant and positive relationship between project risk management and projects success in Rand Water projects. This implies that effective project risk management can enhance project success. Furthermore, effective project risk management can assist in mitigating failure in water utility projects.

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Appendix A: Questionnaire

To what extent do you agree or disagree with each of the following. 1 = Strongly Disagree (SD); 5 = Strongly Agree (SA)

To establish the relationship between project risk management and projects success in water utility projects

	SD	D	N	A	SA
1. In our organisation, project risk management has impact in attaining project success.					
2. In our organisation, tools for managing knowledge on project risk management assist in attainment of project success.					
3. In our organisation, databases containing information on project risk management assist in attainment of project success.					
4. In our organisation, knowledge sharing on project risk management increases the chances of project success.					
5. In our organisation, client involvement in project risk management results in project success.					
6. Knowledge sharing on risk management in IT projects accelerates the relationship between project clients and project team.					

To establish how project failures can be mitigated in the construction industry's water utility projects

	SD	D	N	A	SA
7. In our organisation, project risk management practices assist in minimising project failures.					
8. In our organisation, information on project risks from previous projects is used to manage future projects.					
9. In our organisation, we respond to identified risks mitigation planning.					
10. In our organisation, we perform regular project team training n project risk management.					
11. In our organisation we hold meetings to review active, occurred or retired risks.					

To establish the impact of effective project risk management in the construction industry’s water utility projects

	SD	D	N	A	SA
12. In our organisation, at the commencement of each project, a full project risk assessment is done.					
13. In our organisation, project risk management is practiced on every project.					
14. In our organisation, different tools and techniques are used to identify project risks.					
15. In our organisation, risk prioritisation is linked to project objectives.					
16. In our organisation, knowledge pertaining to project risk management is managed centrally.					
17. In our organisation, information on project risks is analysed to support the decision-making process during project implementation.					
18. In our organisation, project risk management on projects is done internally.					
19. In our organisation continuous communication on project risk management enable better project management.					

MAINTENANCE MANAGEMENT AND IMPACT ON ORGANISATIONAL PERFORMANCE, A POWER UTILITY PERSPECTIVE

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ABSTRACT

Increased plant availability, equipment reliability and safety and health of the personnel have become the significant aspect of the maintenance function within power generation. This paper positions maintenance functions and their impact on organizational performance from a power utility perspective. Research data was collected based on semi-structured interviews on thirteen maintenance engineering management personnel. The findings indicate that the challenges facing maintenance teams in executing maintenance activities include, ageing plant, staff shortage, lack of skills and knowledge and low employee morale. The paper recommended adoption of world class maintenance framework, for maintenance to achieve greater operational performance.

Keywords: Maintenance management, Organisational performance, Plant availability

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1 CONTEXT

1.1 Background

A combination of increased electricity demand coupled with deficit in power supply has resulted in the power utility organisation to focus more on plant maintenance. Power plants are deteriorating thus power stations are not operating at the required capacity resulting in almost half of the current power outages Baker and Phillips [1] Motepe et al., [2]. This implies that more maintenance work and financial assistance is required to keep them online. Additionally, is the need to increase power plant maintenance to minimize the risk of unreliable and unsatisfactory plant performance Velayutham and Ismail [3]. As such, the power utility must reduce downtime and increase plant availability to ensure sustainable economic growth. This is aligned to the global move concerning asset management aimed at improving power plant equipment reliability, availability, and maintainability Motepe et al., [2] Global Forum on Maintenance and Asset Management [4].

Velayutham and Ismail [3] stated that internal effectiveness of an organisation is influenced by the maintenance role and impacting on areas such as production, quality, production cost, working environment, work in progress and tied up capital. Foon and Terziovski [5] have also discussed the importance of the maintenance function in keeping and improving asset availability, performance efficiency and product quality. Therefore, the maintenance function plays a critical role on the ability of the organization to minimise loss, financial or otherwise Global Forum on Maintenance and Asset Management [4]. The foregoing indicates that, if maintenance is effectively executed an organisation will compete based on costs, quality, and service delivery performance resulting in enhanced productivity and profitability Velayutham and Ismail [3]. This implies that improvement in maintenance functions can have positive impact on the achievement of optimised production output.

1.2 Problem Statement

Velayutham and Ismail [3] states that, to sustain power plant operations such as, plant efficiency and availability, safety of employees, environmental safety, and high-quality production, it is generally depends on how organizations effectively co-ordinate and manage the maintenance function. Therefore, it is required to establish maintenance related issues, before developing and implementing an improved system Parida and Kumar [6] Maletič et al., [7]. Unplanned capability loss factor (UCLF) measures the unplanned pant breakdowns Motepe et al., [2]. The UCLF was around 80% in 2019, compared to 20% in 2010 against a best practise of 10% Motepe et al., [2]. The foregoing indicates that generation performance due to unreliable plant and poor maintenance performance is deteriorating and requires attention to improve plant performance. The aim of this research is to investigate challenges facing maintenance management and the resulting impact on the power utility’s performance. Lastly the study provides recommendations on how to improve maintenance management.

2 LITERATURE REVIEW

2.1 Maintenance and the Maintenance Function

Maintenance has been defined as combination of all technical and administrative actions, including supervisory actions, intended to retain an item in, or restore it to, a state in which it can perform a required function ISO 14244:2016 [8]. If equipment and machines are poorly maintained, Velayutham and Dhingira [9] indicate that random breakdowns resulting in unavailability for production or service become the order of the day. On the other hand, Idoniboyeobu and Ojeleye [10] states that if maintenance is effectively executed, it will assist to improve the availability of production facilities, production rate, quality of the service, operation costs, and safety of the operation. These factors will in turn determine the profitability of the enterprise. For this study, maintenance can therefore be summarized as a combination of technical and administrative activities required to retain the equipment to its original state, in a cost-effective manner, considering the safety, health of the personnel and plant, to ensure the availability and reliability of the plant.

Maintenance function is defined by Maletič et al., [7] as the business decisions and corresponding activities required for the optimization of the production system or machine, for the attainment of desired performance. This function includes formulation of a maintenance vision, strategies, policies, and standards, as well as planning and execution of activities in a way that meets the prescribed technical condition, plant availability, safety of the personnel requirements, environmental requirements, warrants the quality of delivered products and services, and secures the expected service life of individual devices [4] [5] [9].

Juxtaposing maintenance definition and the maintenance function above implies that the maintenance service must be delivered at an agreed service level – i.e., response time, quality of work and costs. This will ensure achievement of required plant availability, ability to guarantee quality of the products, compliance to safety standards and regulations concerning people and environment, and desired equipment durability Foon and Terziovski [5]. This implies that maintenance work must be identified, planned, scheduled, resources assigned (people, tools, material, spare parts, procedures, policies, permit to work, etc.), executed, and, finally, evaluated Velayutham and Dhingira [9]. It can be deduced from above discussion that maintenance department play a vital role within the organization and the critical part of the successful operation of the maintenance function relies on their inter-departmental relations. It is also important for the maintenance function to be reliable and trustworthy as the basis for building inter-departmental relationships.

2.2 Maintenance Challenges

There are numerous reasons why maintenance cannot meet or sustain world-class performance. The most common reasons are insufficient budget, not enough time, lack of support from management and poor maintenance management Foon and Terziovski [5] and poor contract management Greenhalgh [11]. There are also non maintenance activities which take on average between 30% and 40% of the maintenance budget Palmer [12]. Such non-maintenance activities are expected to be executed by the department. Further, Sighn [13] indicated that organizations encounter many obstacles in implementing effective maintenance management resulting in poor plant availability, as such, management must formulate action plans to overcome these challenges.

Furthermore, poor control of inventory can lead to high stock levels and the unavailability of spares Urissa [14] which ultimately hinder maintenance management work. In addition, poor contract management which according to Greenhalgh [11] is hinged on corruption has riddled procurement departments. As such, optimal management of spares inventory and contacts is crucial for effective execution of maintenance activities Foon and Terziovski [5].

Although some have been mentioned earlier, Ntshangase [15] studied maintenance practices of different organisations and established the following challenges:

- Ineffective spares and inventory management
- Lack of production and maintenance technician technical competence
- Ageing equipment and machinery
- Insufficient maintenance budget
- Poor leadership skills.

Apart from the above, staff shortage is another challenge as alluded to by Cheema and Asrar-ul-Haq [16]. The authors indicated that staff shortages result in increased responsibilities and workload for current employees resulting in burnout and other shortcomings which impact on employee's performance and eventually organisational performance. Such organisational staff shortages have been established by Pembi [17] to be caused by business financial constraints and workforce issues.

2.3 Maintenance Benefits

Foon and Terziovski [5] [4] states that maintenance effectiveness adds value towards the availability and reliability of the plant, improves production efficiency and profit margins of the organization. Maletič et al., [7] further emphasises that effective maintenance increases the competitiveness of the organization and its profit margins. Furthermore, Palmer [12] summarised the benefits as minimisation of downtime, improvement in total availability of the system, safety of personnel and extended useful life of the equipment. To reap these benefits, an organisation must build on core competences. Tayauova [18] states that core competence can be thought of as group of qualities that a business holds of which in return will allow the business to achieve competitive advantage. This is achieved through training which Tismal et al., [19] generally considers as means of enhancing person's skills, knowledge, and capabilities which empowers them to understand business aspects.

2.4 Maintenance Strategies

Each organization has defined maintenance needs due the different types of machinery and equipment requiring different methods of maintenance. This implies that maintenance management and engineering personnel must came up with proper maintenance strategies to be used for different types of machinery and equipment Rani et al., [20]. Based on an organization's budget, number of resources, level of combined experience, and maintenance goals, one or more maintenance strategies are used. Maintenance strategies generally included two approaches namely corrective and preventative maintenance Bakri et al., [21]. Palmer [12] describes preventative maintenance (PM) as the care and servicing of the equipment as per the approved maintenance strategies, to keep equipment in satisfactory operational state by conducting regular inspections, identification, and correction of emerging failures either prior to their occurrence or prior to their development into major failure. Thus, PM is carried out to reduce the probability of failure whilst mitigating degradation [4]. PM system is centred on recommendations made by the equipment original manufacturers, taking history of the equipment and system environment into account Rani et al., [20] and form asset maintenance plan although it requires more money upfront [4]. Seddiqe et al., [22] define corrective maintenance (CM) as a maintenance task performed to identify, isolate, and rectify a fault so that the failed equipment, machine, or system can be restored to an operational condition within the required tolerances or limits. CM is also known as repair and replacement, run-to-failure, failure-based maintenance, fire-fighting maintenance, or breakdown maintenance Rani et al., [20]. Depending on the criticality, severity, or impact of the equipment failure on the functioning of the system, maintenance can be done immediately, which is referred to emergent work, or can be deferred, which will become planned corrective maintenance [20]. Some of the limitation of this maintenance strategy include higher long terms costs and increased unplanned downtime [20].

2.5 World Class Maintenance Strategies

Imam et al., [23] defines world-class maintenance (WCM) as a complete system that is created when organizations integrate clear visionary leadership with well-defined processes and supportive culture to ensure that the vision and ownership of proper maintenance procedures infiltrates the organization. Further, Goyal and Maheshwari [24] further define world class maintenance as a relationship between maintenance and production organizations to enhance the quality of the product, reduce waste, decrease manufacturing cost, increase availability of the equipment, and improve the organization's overall state of maintenance. As such, the main goal is to take advantage of performance to gain meaningful advantage over opponents [25].

Several world class maintenance frameworks are abuzz and choosing a particular framework from several frameworks reported in the literature might not be an easy task for the maintenance manager. Felice et al., [26] taking into consideration the different frameworks identified ten management pillars for a maintenance framework namely: safety and health; cost deployment; focused improvement; autonomous activities; professional maintenance; quality control; logistics; early equipment management; people development and environment.

A more optimised world class maintenance management framework adopted by this study was introduced by the Global Forum on Maintenance and Asset Management [4] which contains nine subject groups namely: business requirements and organisational context; asset creation and acquisition; maintenance tactics and task types; asset maintenance strategy development; human and material resource management; maintenance work management; asset performance and condition; maintenance data and information management and maintenance programme management. Implementation of such a world class maintenance framework is of critical importance to improve the maintenance status of the organization to world class standard.

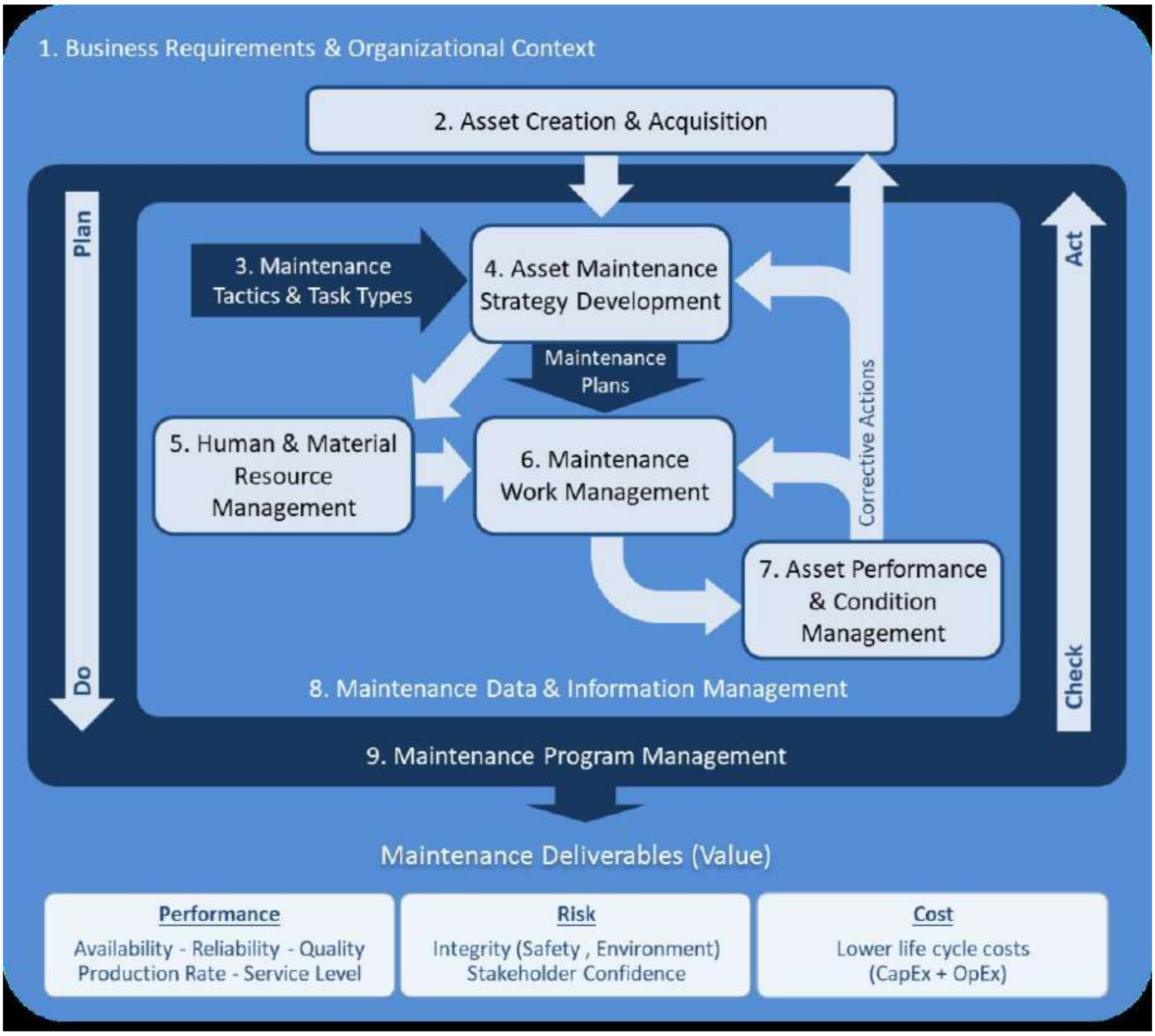

Figure 1: World Class Maintenance Framework, adapted from Global Forum on Maintenance and Asset Management [4]

3 RESEARCH METHODOLOGY

To satisfy the objectives of the study, a qualitative research approach with an interpretivism philosophy was adopted. This allowed the researcher to understand the real-life situations within the organisation [27]. This research focused on 13 out of a total of 150 personnel in the Power utility's Maintenance Engineering department. This was aligned to Cooper & Schindler [28] who recommend a sample size of between four and 15 participants for exploratory qualitative studies.

The 13 consisted of 1 Executive,1 Senior Manager, 2 Managers, 3 engineers, 3 Technicians, 3 Artisans 15. 5(39%) had maintenance management and engineering experience of between 2 - 10 years; 6 (46%) had experience between 11 – 20 years while 2 (15%) had more than 20 years.

Data was collected through semi-structured interviews conducted face to face, or telephonically. Semi-structured interviews yielded rich data, as participants were able to raise their views without the influence of the researcher. Data was recorded to ensure that all the interview discussions were properly apprehended and correctly captured. Data analysis ensured using the six-phase thematic analysis framework format [29]. This allowed for the research questions to be addressed as themes and patterns were established from the data and interpreted [30].

4 FINDINGS

Thirteen participants took part in this study, analysis of the interviews was done according to the thematic analysis process and the following themes and categories were created:

Table 1: Themes, Categories and Findings

Themes	**Categories**	**Findings**
Spares Management	Process Deficiencies	Spares management was identified to be major challenge facing maintenance, which hinders the effectiveness of maintenance task execution. *"Unavailability of spare parts is an issue due to the incorrect spares delivered. This is impacted by the source where it comes from"* *"Maintenance is not effective; the plant is more often than not available nor reliable due to defects that cannot be attended to because of unavailability of spares"* *"Procurement process has too much red tape"* *"Due to open tender process end-users are not allowed to go to original equipment manufacturer (OEM)"*
	Spares contracting	Spares management was identified as a challenge. *"Spares availability and accuracy of stock is one of our monsters in maintenance, you find nothing at stores, more than 40% of contracts expire and are not renewed on-time"* *"Reasons for the unavailability of spares are the delays on the procurement process due to lack of*

Themes	Categories	Findings
		resources. The buyers are on contract basis, sometimes their contract expire and is not renewed on time. This result in delays of getting the spares"
Outsourcing	Contract Management	Outsourcing was also identified as one of the major challenges in maintenance. *"Service providers are profit driven, whereas the power utility is production driven. The more there is plant failures, the more they gain. As a result, they do not come up with long term solutions, to gain more profit"* *"Power utility employees lack technical skills and experience to manage the contracts". "Outsourcing is not a problem if the power utility employees must be upskilled to manage contractors better"*
	Contract structuring and governance	Irregularities and inconsistencies in governance and managing of contract were cited as challenges. *"Contractors are not held accountable when they are not performing as per contractual agreement, because staff have conflicting relationship with contractors"* *"Some contractors take time to resolve plant maintenance related issues"*
Training	Lack of experience and technical expertise	Training was established aa a pain for the power utility *"Challenge in maintenance is lack of skills and competencies"* *"One of maintenance challenges is poor workmanship due to lack of skills. There are artisans, who were hired with recognition prior learning process, fact remains that those artisans did not go through the complete training for the artisans' programme"* *"Engineers are inexperienced to draft maintenance strategies, instead they use history and what was done by the previous engineers"*

Themes	Categories	Findings
Human Resource	Understaffing and Recognition	The study identified staff shortages as a contributing factor to maintenance challenges. *“We have lot of preventative maintenance to be done but fewer resources, as a result we are not able to execute all the maintenance tasks diligently and effectively, and this affects our performance”* *“There is no encouragement or motivation for employees to lift up their morale”* *“There is low employee morale due to 0% salary increase and no performance bonus and that has a negative bearing on performance”*
Business Performance	Plant performance Quality	Ageing plant and obsolete equipment poses some of the challenges in maintenance. *“Ageing plant requires more maintenance; thus, spares are required more often than normal, and more people are required to maintain the plant and attend to breakdowns. That results in more overtime requirements due to breakdown caused by ageing plant and staff burnout”* *“Not all maintenance tasks have documented quality control plans, meaning that there are minimal checks on the quality of work done”*

5 DISCUSSION

Theme 1: Spares Management

Non-delivery and delayed deliveries of spares was identified as the most common problem in spare parts management, which leads to unavailability of spares for the execution of maintenance tasks. The reasons cited by the participants was that these challenges were because of unsuitable suppliers, the unavailability of spare parts in the local market and current government policies that supports the local suppliers and not the OEM. The study also revealed that the current procurement procedures and processes are not effective in ensuring the selection of suitable suppliers.

Management and monitoring of stock levels and proper cataloguing of spares at stores, was also identified as one of the challenges in spare parts management. These findings are aligned to what Urissa [14] established in that poor control of inventory can lead to high unnecessary stock levels and unavailability of spares. Foon and Terziovski [5] further states that it is very critical for an organization to ensure optimal management of spares inventory as that will provide assurance to the effective execution of maintenance activities. The study also revealed that spare management challenges were because of poor management of spares contracts and or not having spares contracts in place. In addition, delays in procurement process are impacted by lack of personnel in procurement and material management.

Theme 2: Outsourcing

The study revealed that the business model of outsourcing maintenance activities is not appropriate and brings forth a lot of challenges. This notion was supported by several participants who stated that outsourcing is a suitable business model due to the following:

- In outsourcing, contracts are replaced for a certain period, when the period expires, they are renewed or changed to another supplier. This results in loss of skills and the business also losses its competitive advantage.
- The business is unable to build long-term relationships with the service providers due to the short-term contracts.

The above responses are in line with the literature, which stipulates that the need for core competency to be maintained internally, and that those other activities that are not deemed core to the business, need to be considered for outsourcing [18].

The study also identified concerns about the skills of the employees provided by the service providers. In addition to that, the service providers do not provide training (technical and on job training) to their employees and that there is no succession planning in place. Tayauova [18] established that the disadvantages associated with the inability to control outsourced activities originate from the fact that managing of external resources requires special skills which entails a combination of contract management, power to negotiate, people's skills and process management. In addition, participants raised concerns and frustrations mainly on challenges regarding the application of the processes and procedures, for managing contractor performance. Other challenges cited include cases being reported and investigated with no corrective action being taken, inconsistencies in handling and concluding misconduct investigations and the lack of consequent management for non-compliance with the contract management processes.

Other participants cited personal interest and relationship with suppliers as a contributory factor, which results into intentional failure in effective contract management due to other interests. According to Greenhalgh [11] one of the contributory causes of poor contract management is the corruption that has dominated the procurement department. As a result, awarding of contracts is influenced by some members of the tender awarding committee, evaluation committee, and procurement officers. This has resulted in contractor failures given that the technical ability was not assesses when the contract was awarded [11]).

Theme 3: Training

In coherence with the literature by Ntshangase [15] the study revealed that maintenance personnel are lacking technical experience, knowledge, and skills as a result they cannot effectively execute maintenance activities. The plant is suffering as they are failing to meet the expectations of resolving plant issues make informed business decisions. In addition, the organisation is not empowering employees to make decisions, influence, and effect changes to maintenance programmes.

The study established the high turnover of experienced engineers, leaving engineers in training to carry out the duties. It was highlighted that one of the engineer's roles is to support maintenance personnel in resolving plant issues and to also compile maintenance strategies. This requires experienced engineers with extensive technical skills. Contrary to this, inexperienced engineers are allocated plant systems and expected to perform optimally.

It was also identified that the focus on technical training to enhance employee skills, and to be in synch with new technology has been neglected by the organisation and that there is no provision for formal or proper on job training for inexperienced employees. Tismal et al. [19] generally considers training as a means of enhancing a person's skills, knowledge, and capabilities and to empower them to understand business aspects. If training and alignment to new technology is not happening, the maintenance function will be crippled.

Theme 4: Human Resource

It is evident from participants that staff shortage is prevalent, the impact is aligned to views by Cheema and Asrar-ul-Haq [16]) who stated that shortage of staff increases responsibilities and workload for the current employees, resulting in burnout and other shortcomings which impacts on employee's performance and ultimately organisational performance. Such organisational staff shortages have been established by Pembi [17] to be caused by business financial constraints and workforce issues.

Participants shared their views and concerns on employee recognition. Due to the organisational financial position, all the other incentives or the processes have been put on hold including a moratorium on payment of bonuses, salary increases and external positions. This has a negative bearing as work force issues such as staff shortages, morale, employee engagement, staff-centred factors such as participation, morale, and staff shortages are not only inseparable, but are critical in the performance and effectiveness of an organization [16].

Theme 5: Business Performance

Most equipment has reached its end of life, because of ageing plant and equipment obsolescence which has led to:

- Frequent plant breakdown which requires more maintenance activities and resources
- Spares no longer available in the market
- Skills to maintain the equipment are no longer available resulting in plant breakdown taking longer to repair due to trial and error.

The prolonged plant downtime and shortage of skills impacts negatively on plant availability. Plant breakdown due to ageing requires regular maintenance and more resources. The above statements are in line with findings from Rani et al., [20] and Velayutham and Dhingira [9] and ultimately impact on maintenance management and the financial status of the power utility in general.

Other issues include quality of work execution within maintenance. Quality issues included unavailability of quality control plan and inconsistent quality control on the execution of maintenance activities. The shortage of resources and lack of discipline from the employees were cited as a reason of not monitoring quality control in maintenance. In addition, poor planning of maintenance activities was also identified as one of issues within maintenance. Furthermore, the participants indicated that poor planning results in re-work on maintenance activities, decrease in production due to increase of unplanned and unscheduled repair work and expensive shutdowns, or costly repairs.

6 MANAGERIAL IMPLICATIONS AND RECOMENDATIONS

Leadership, and management of the Power utility can make use of the following recommendations are generated from this study:

World Class Maintenance

The power utility is recommend adopting the world class maintenance framework with nine subject groups and propagated by the Global Forum on Maintenance and Asset Management [4]. The proposed framework will be beneficial for the maintenance function as they strive to be the best in the global scenario. Further, this framework must be implemented and monitored following the seven-step approach highlighted by Arsovski et al., [27].

Outsourcing

It is recommended that the business must evaluate the benefits and reputational risk of outsourcing of maintenance works balancing with the effectiveness and efficiency of managing maintenance functions. This must be done with the understanding that core functions relating to turbo generator maintenance should not be outsourced.

Human Resource Strategy - Manpower and Skills

- To close the skills gap, the power utility must conduct skills audits and training needs assessments within maintenance teams and maintenance training standards. These documents will provide a clear guideline and opportunity for the maintenance employees to be trained with appropriate skills, qualifications, and experience to manage and execute maintenance work optimally. Skilled maintenance personnel will assist in proper issue diagnosis, the planning maintenance intervention, and the effective and efficient execution of activities.
- Institute an organisational design model for optimal maintenance department structure and the requisite capacity planning for its optimal resourcing.
- Explore and make use of the modern technology e.g., computerised maintenance management systems for the execution of maintenance task to address the issues of staff shortages.

Spares Management

- Greater inventory control should be implemented and strict measures to be put in place to address the performance issues at stores as it will result in better procurement and management of spare parts.
- Identify the list of spares to be on contract and establish spares contract to minimise errors and delays on tendering process. Ensure a balance between material resource requirements held as inventory on site or elsewhere through the using of different stoking methodologies considering cost effectiveness and performance.
- To purchase spares from the original equipment manufacturers where possible, to reduce cost and build a better and more cohesive supply chain. Proper storage of spare parts would be considered as damaged spares compromises plant availability and reliability

Contract Management

- Review existing systems, policies and procedures related to contract management and its governance to identify any potential failures or deficiencies. In addition to that (a) preserve an ethical tone and in still a culture of honesty throughout the contract management process and the organisation at large; b) provide fraud prevention systems, processes, and training and (c) ethics training for employees in positions that are subjected to corruption which can be extended to all employees and (d) conduct regular effective contract management process evaluations and audits.
- Conduct an assessment on the existing contract to establish the duplicated resources, and thereafter devise a plan of integrating the contract to eliminate such duplications.

Plant performance

- Quality management system should be enhanced by ensuring the appropriate identification of critical activities, quality controls for such activities to be in place and close monitoring of quality control implementation be in place. The organisation is ISO 9001: 2015 certified and should adhere to the different provisions of the standard in ensuring an optimised quality management system.
- The plant modifications and projects should be initiated and or fast tracked to ensure the plant is aligned to current technologies thereby enhancing ease of maintenance. Interlinked to this is the need for data driven decision making which are however dependent on the organisation’s ability to institute and manage a data management

system. Such maintenance data must be managed real time and converted to knowledge after which it will be used in the management of maintenance activities.

- There must be incentives for performance and sanctions for non-performance in the maintenance department.
- Maintenance audits and benchmarking must be mandated and driven as part of continuous improvement in maintenance function, and lessons learnt should be shared across the whole power utility.

7 CONCLUSION

The study concludes that the challenges facing the power utility relate to the following: process deficiencies, spares contacting, contact management, contract structuring and governance, lack of technical expertise, understaffing challenges, ageing plant, and obsolescence of equipment. In addition, the study confirm that effective maintenance execution enhances performance of the organisation. Recommendations have been made relating to the human resources strategy, spares management, contract management and plat performance for improved ad optimised maintenance management department to ensure the organisation drives towards maintenance excellence.

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ASSESSING THE IMPACT OF LEAN MANUFACTURING PRACTICES ON OPERATIONS AT A SOUTH AFRICAN RAIL ORGANISATION: TOWARDS IMPROVING PERFORMANCE

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ABSTRACT

This paper reports on a study to assess the impact of lean manufacturing practices on operations to improve organisational performance at a sub-division of a rail organisation. The study pursued three objectives; to review current lean manufacturing practices, to assess the impact of lean manufacturing practices on operations performance and to make recommendations to improve performance. The study adopted a quantitative research approach using a questionnaire. Probability sampling was used with a sample of 100 employees. Descriptive and correlation analyses were conducted. The findings revealed that management training, employee involvement, and waste reduction leads to efficient lean manufacturing practices. This paper succeeds in assessing the impact of lean manufacturing practices on operations towards achieving improved performance. The recommendations address the upskilling of managers to train employees and the importance of implementing lean manufacturing practices to improve the effectiveness of the operational processes. As further research, a qualitative study is envisaged.

Keywords: Lean manufacturing, effectiveness, operational processes, and performance improvement.

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1 INTRODUCTION

Rapidly evolving consumer needs, intense competition, and technical innovation brought on by the 4th Industrial Revolution (4IR) are both motivating factors for companies to implement more advanced production and maintenance methods, and lean manufacturing best practices are one of the primary enablers to enhance its market processes and operating efficiencies [1]. Seeking and introducing strategies to increase process effectiveness and performance, as well as cost effectiveness, is the aim of lean manufacturing. The key is to be mindful of what is going on, where bottlenecks can exist, and to be open to removing bottlenecks to increase business efficiency [2].

Lean refers to making the most use of existing services by eliminating non-value added (NVA) operations. Panwar, et al. [3] define lean manufacturing as a set of activities that operate together synergistically to build a coordinated, high-quality method that delivers finished goods at the speed of consumer demand. Toyota developed a revolutionary production process now known as lean manufacturing. This highly successful method for reducing waste, improving flow, and increasing production began as a method to compete with Western automakers and soon became a revolutionary production mentality the world over. Although lean manufacturing practices have been embraced globally, the South African environment is unique and different from the Japanese environment. Hence, for the successful implementation of lean practices, difference must be considered [4].

Many projects and works in South Africa are marred by delays, resource wastes and overrun of costs [5]. A study by Pieterse, et al. [4] showed that lean manufacturing practices have not been fully adopted in the South African context and the phenomenon is widespread in the public sector and state-owned enterprises. This justifies the need to assess the impact of lean manufacturing practices on performance in the South African public sector.

For the purposes of anonymity, the organisation is referred to as “Company A”. Company A is a division of the holding company which is responsible for manufacturing, refurbishing, and maintaining rolling stock machinery and facilities for Botswana Railways, the South African Passenger Rail Agency (PRASA), and other cross-border railways. The holding company is a state-owned transport organisation that operates at various terminals in South Africa [6]. The research was conducted at the engineering division of Company A, which concentrates on railway capital; production, upgrading, and maintenance. Locomotives and wagons are used in the rolling stock machinery and equipment. Company A has maintenance depots all over the country to ensure that their machinery and equipment are stored near their operations.

The essential contribution of this paper was to assess the impact of lean manufacturing practices on operations at Company A towards improving performance. As such, this paper will aid Company A to understand and develop the best lean manufacturing practices used to achieve higher performance.

2 PROBLEM INVESTIGATED AND THE RESEARCH OBJECTIVES

2.1 Problem investigated

It is common knowledge that an organisation with well implemented lean manufacturing practices performs well in operations. Company A is facing increased competition because of globalisation, and demanding customers and clients. It has also decided to increase production and the quality of finished products to improve their performance and maintain their market share. Various interventions were pursued, but due to the massive capital expenditure involved, incorrect identification, introduction and execution of such initiatives could have catastrophic implications on Company A’s operations and revenues. Lean management and improved production are two examples of methods that are used to minimise waste and thereby improve staff productivity, service efficiency, throughput, and the cost effectiveness of finished products. The organisation is faced with poor performance by way of decreased sales, loss of customers, customer dissatisfaction and inadequate number of products being delivered to its customers. Company A also delivers products late which results in dissatisfied customers. Company A has not met their customers demand for the past 12 months, and this has resulted in a negative effect on the customer-supplier relationship and its revenues. The organisation is operating at a 30% loss due to the low deliveries [6]. Poorly implemented lean manufacturing systems seriously affect an organisation’s viability.

2.2 Research objectives

The research aims to assess the impact that lean manufacturing has on the performance of Company A and to make recommendations for lean manufacturing to improve operational performance. To solve the above problem and achieve the aim of this study, the following research objectives are proposed:

a) To determine the lean manufacturing practices that are currently used at Company A.

b) To determine the factors that impact lean manufacturing practices at Company A.

c) To assess the impact of lean manufacturing practices on operations performance at Company A.

d) To make recommendations for best lean manufacturing principles to improve operational performance at Company A.

3 LITERATURE REVIEW

The literature review topics consisted of the lean manufacturing, operations management, and performance management. These main constructs made up the theoretical framework for the study and was used as indicators for the compilation of the research instrument (questionnaire).

3.1 Lean manufacturing

Lean manufacturing is a technique which is used to reduce waste without compromising on productivity and performance [7]. Lean manufacturing is also termed the “Toyota Way” after it was developed by the organisation [8]. According to [9], lean manufacturing is based on the principles of value, perfection, flow, pull and value stream mapping. The application of lean techniques, concepts, and tools to the creation and production of physical goods is referred to as lean manufacturing. In a fast-paced, dynamic, and ever-changing global economy, many firms are using lean manufacturing concepts to remove waste, improve processes, decrease costs, increase innovation, and shorten time to market [10].

Many businesses experienced changes which enabled them to substantially increase competitiveness within their sectors by boosting value and decreasing the amount of labour needed to complete activities [11]. The elimination of waste within an operation is a key concept in lean methodology and waste is one of the most significant drains on profitability in any organisation. Time and material wastage and excessive labour usage are all examples of lean waste. However, it may also be linked to a lack of skill set use and inadequate planning. In lean manufacturing, waste refers to any expenditure or effort that does not result in the transformation of raw materials into a product that customers are willing to pay for. Only real value is created at each stage of manufacturing by improving process processes and reducing waste [11].

The lean manufacturing model identifies eight kinds of waste in an operation: seven, when the Toyota Production System was initially developed, and an eighth, after lean methodology was embraced in the Western World. These are: defects, overproduction, waiting, non-utilised potential, transport, inventory, motion, and extra processing. Seven of the eight wastes are linked to the manufacturing process, while the eighth is directly related to management's capacity to use people [12].

3.2 Lean philosophy

Jacobs, Chase and Aquilano [13] posit that the lean philosophy or concept was derived from Toyota's Just-In-Time (JIT) manufacturing methods, which were popularised in the 1990s to emphasise the objective of methodically reducing waste across the supply chain. The lean concept was developed as waste aversion measure owing to resource scarcity and lack of space in Japan [11]. This lean philosophy aims to reduce the waste on the shop floor and improve productivity, not forgetting customers' requirements.

As a management philosophy, lean emphasises continuous improvement through detecting and reducing waste across the whole value chain of a product, thus taking a holistic approach [14]. The types of wastes which lean aims to eliminate are over-production, excess motion, excess inventory holding, defects and long production and distribution lead times [15]. For lean to be achieved, there is need for reinforcement of organisational practices which include total quality production, human resources management, and supplier vetting and integrated information sharing through modern technologies [16]. Lean is based on the premise that resources and input should be available when they are needed in line with the JIT philosophy [17]. As a systematic way to increase efficiency and better please customers, lean principles run counter to traditional mass-production practices. Yet, they allow small and medium businesses to consistently increase quality while decreasing costs.

3.3 Lean Principles

Lean manufacturing principles refer to the guidelines that an organisation can adopt to improve efficiency [18]. Lean principles are derived from lean thinking which aims at minimising wastes and improving efficiency. The five key principles of lean thinking are: value, value-stream, flow, pull and perfection.

3.4 Lean implementation

Lean implementation is a transformative process that requires both process improvement and organisational growth. A risk-based approach can be devised for determining which lean tools are most suited to a particular organisational context [19]. When lean approaches are implemented, it is necessary to understand how the current methods can communicate with the actual job environment and the existing social structure. However, if there is a misalignment between the technological and social subsystems, lean approaches may be difficult to introduce and enforce, and the promised economic benefits may not materialise.

Panwar, et al., [3] are firm in their belief that a theory must be in place for people to look critically at what they do on a regular basis and improve it, a concept established by [12]. Employees must participate actively in the lean transition process, according to [20], or the proposed change will be resisted. Employees must feel free to share their suggestions for change in a learning atmosphere created by management. By having this setting, a metric will be generated as part of the balanced scorecard, allowing workers to be evaluated based on their feedback for quality progress [21]. According to [22], the task for top management is to successfully incorporate lean and Total Quality Management (TQM) approaches in a population that is resistant to reform because it perceives employing less workers to achieve better as a detrimental and a long-term danger to job security. The introduction of lean manufacturing, like every other quality growth program, is thought to be fraught with challenges [23]. Effective corporate strategies, such as lean management, should be carefully prepared before execution, [20].

3.5 Operations Management

Operations management (OM) is a management process that oversees staff, equipment, technology, records, and all other tools needed to deliver goods and services. The central core function of an organisation is OM [24]. OM is the administrative function in charge of managing goods, service production and delivery. All the materials needed to produce an organisation's goods and services must be prepared, arranged, scheduled, and supervised [24]. Since it comprises the action of managing resources to create and transfer products and services, operations management is a critical aspect of an organisation's success [25]. The operations function is the component of the firm that oversees managing operations and it implies that every business has an operations function because they all create a product or provide a service for the end user [25]. This is true regardless of the organisation's scale, industry, production, or service, for-profit or non-profit position, or whether it is for profit or not.

The three main components of OM are inputs, transformation processes, and outputs. The systematic direction and control of processes that change resources (inputs) into completed goods or services for consumers or clients is known as OM (outputs), [26]. This fundamental transformation paradigm is applicable to manufacturing and service organisations, as well as commercial and non-profit organisations. Operations administration is a corporate branch concerned with the management of business operations to boost an organisation's competitiveness. It involves planning, organising, and overseeing the activities of the organisation in order to maximise operating benefit while matching revenue and costs [27]. An operations manager oversees ensuring that the organisation's resources, such as materials, equipment, and technology, are turned into outputs as quickly as possible [12].

3.6 Performance management

Performance management is a comprehensive approach to improving and sustaining employee performance, which leads to greater business efficiency. Managers will concentrate on employee development and balance corporate expectations with team and individual goals and provide a work environment that encourages all employees and businesses to excel [28]. A structure is developed within an organisation to assess and enhance the efficiency of its employees, according to the concept of performance management. In reality, success management entails management's ongoing efforts to improve their staff, set concrete targets, and provide timely guidance during the year. In contrast to other ways of measuring employee success, such as yearly performance appraisals, employee performance measurement is a much more nuanced and involved process with better outcomes [29]. Company A has established goal-setting seminars for business units and departments, [30].

3.7 Implementation of lean manufacturing at Company A

Company A is still in the early stages of implementing lean management, and it is seen as a sensitive problem, especially on the shopfloor [30]. In accordance with Company A's five-year turnaround plan, the rail division has developed its own strategy to increase efficiency by improving throughput through process change and waste reduction across all its business units [31]. This approach centered on implementing lean management through the division's various business divisions. Prior to implementing the plan, visits to General Electric in the United States of America (USA) were made to gain greater knowledge about the procedures and advantages of doing so, as well as to benchmark against a branch of a first-world organisation [32]. Company A adopts a lean six sigma approach. As part of the Business Units introduction, this approach was applied to freight rail at the start of the 2012/2013 financial year [5]. The aim of the Operations Development and Efficiency (ODP) department is to enhance the freight rail's performance across the board, ensure cost-effective decision making, and achieve scheduled railway to satisfy customer demands by providing an efficient and consistent service [5].

The approach is aligned with the organisation's Market Demand Strategy, which aims to accelerate volume development, increased transparency, governance, and organisational efficiencies through quality improvement and problem-solving methodologies like Lean Six Sigma. These methodologies will also aid in the implementation of the country's road-to-rail plan, which seeks to improve the country's economy while also pushing carbon-reduction efforts towards a greener South Africa [31]. Company A uses Lean Six Sigma to eliminate waste and reduce uncertainty to maintain continuity in our results and provide a more predictable experience to its customers [5]. Some of the challenges faced when implementing lean manufacturing practices include lack of training and management support, lack of interest, financial constraints, lack of change management and dependency on traditional ways of working.

4 RESEARCH METHODOLOGY

4.1 The research design and instrument

The research design consisted of a quantitative approach which was used to gather data, which enabled the researcher to come to conclusions and to make recommendations regarding the impact of lean manufacturing practices on operations at Company A. Data collection consisted of a questionnaire survey. This questionnaire survey was found to be the most appropriate survey method as the respondents could easily be accessed. Due to the Coronavirus (COVID-19) pandemic, where face to face interactions were limited, A self-administered questionnaire procedure was applied for the study. Permission to gather data was obtained from Company A prior to collection. The participants were contacted via telephone to participate in the research. The questionnaire was forwarded to participants via email. The online approach is appropriate, as surveys enable researchers to generalise their findings, [33].

4.2 The population and sampling in the study

The target population of the study reported in this paper comprised six hundred (600) employees in Company A's engineering division. Probability sampling was used to select the sample for the study. For the purposes of this study, a sample was drawn from approximately 100 employees who are responsible for lean manufacturing practices and improvement. Ninety-five (95) respondents submitted their questionnaires via email. Three questionnaires were found to be incomplete submissions, realising a total of ninety-two (92) questionnaires. The response rate was 92% and found to be acceptable for the purposes of this study.

4.3 Data collection and analysis

Data was collected by means of a questionnaire. The questionnaire was utilised to elicit responses as to the impact of lean manufacturing practices on operations at Company A. The questionnaire was pilot tested with participants from an identified sample of ten employees. The collected data was analysed using the Minitab software, which analyses data and shows the relationship between variables. Descriptive and inferential statistical analysis were used to examine the results. The association between lean manufacturing methods in the development chain and increased efficiency was investigated using correlation and regression analysis. Graphs and other visual aids were used to present some of the material.

5 FINDINGS AND RESULTS

5.1 Presentation of analysis and findings

The findings and results are aligned to the objectives and the three main constructs of this study.

5.1.1 Lean manufacturing practices:

The first objective of the research study was to determine the lean manufacturing practices currently used at Company A.

The responses from the participants with regards to lean manufacturing practices were ranked according to the scores from the Likert scale. The use of the median was used to infer the rating on the Likert scale. The median in the Likert scale shows the skewness of the data which helped in the analysis of interval data. The respondents were asked to indicate the lean manufacturing practices which are currently being used at Company A.

Table 1: Lean manufacturing practices currently used

	Kaizen	Just Do It	Lean	Six Sigma	TQM
Mean	2,63	2,36	3,84	3,05	3,17
Median	3	2	4	3	3
Total options	460	460	460	460	460
Total score:	**242**	**217**	**353**	**281**	**292**
Percentage	52.61%	47.17%	76.74%	61.09%	63.48%
Observations	92	92	92	92	92
Ranking:	**4**	**5**	**1**	**3**	**2**

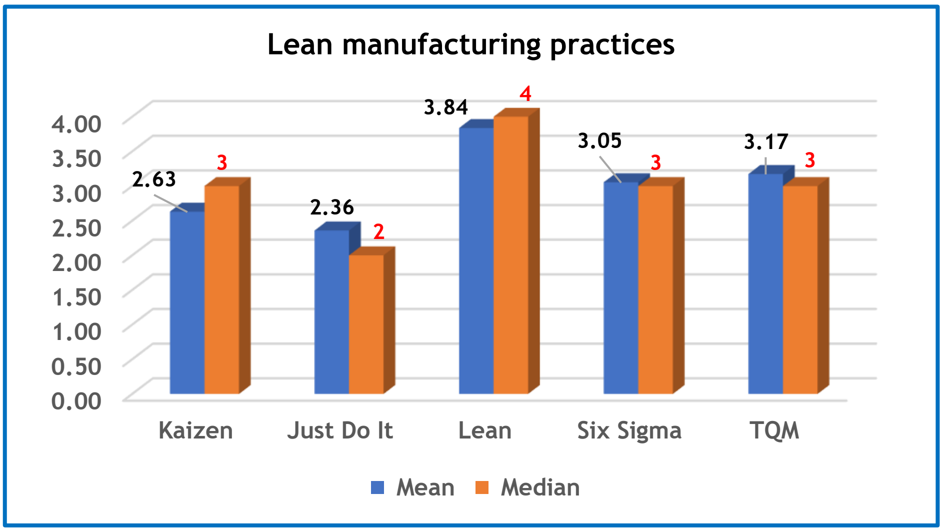

Figure 1: Lean manufacturing practices

The results from Table 1 and Figure 1 indicate that the median of 4 (76.74%) for lean shows that the majority of the respondents agree that lean six sigma is the manufacturing practice that is currently used. Lean manufacturing was adopted in the 2012/2013 financial year and is applied to all units of Company A. The study results support the notion by [5]. However, Gupta and Jain [34] noted that the lean manufacturing practices overlap each other such that a distinction between them can sometimes be difficult to make.

5.1.2 *Factors which impact lean manufacturing practices:*

The second objective of the research study was to determine the factors that impact lean manufacturing practices at Company A.

The major benefits of the lean manufacturing are to reduce waste and ensure that the production process uses few resources to produce output [11]. Earley [7] concluded that the primary objective of adopting lean manufacturing practices is to reduce waste and promote efficiency although other secondary benefits such as improvement in the product quality and customer satisfaction are realised. Tsikgas [35] acknowledges that lean manufacturing improves product quality through solving production issues and eliminating defects. The study results support the views by [11]. Tsigkas [35] and Earley [7] that noted lean manufacturing reduce wastes and enhance efficiency which are the primary goals of the practice. According to Coetzee et al. [5], Company A adopted the lean sigma with the mandate of eliminating waste and enhancing efficiency to improve market competitiveness. The study results are in line with the mandate of adopting lean six sigma by Company A.

Table 2: Impact of lean manufacturing practices

	Enhancing efficiency	Improving product quality	Reduces wastes	Value stream mapping	Demand based pull system
Mean	3.206522	3.728261	3.695652	2.021739	1.836957
Median	3	4	4	2	2
Total options	460	460	460	460	460
Total score:	**295**	**343**	**340**	**186**	**169**
Percentage	64.13%	74.57%	73.91%	40.43%	36.74%
Observations	92	92	92	92	92
Ranking:	**3**	**1**	**2**	**4**	**5**

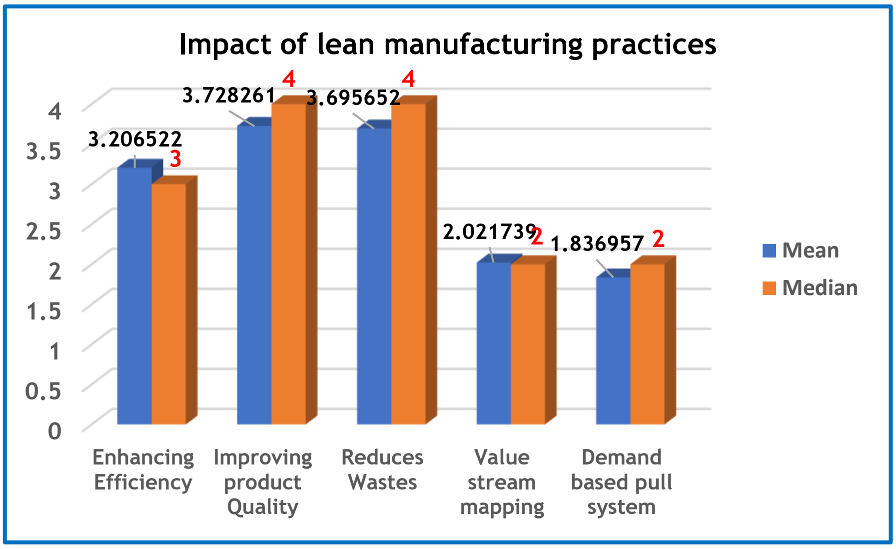

Figure 2: Impact of lean manufacturing practices

The results from Table 2 and Figure 2 indicate that improving product quality (74.57%) is top ranked followed very closely by reducing wastes (73.91%), enhancing efficiency and value stream mapping. Demand based pull system was ranked the lowest out of the five listed impact of lean manufacturing.

5.1.3 *Challenges in implementing lean manufacturing practices:*

The third objective of the research study was to assess the impact of lean manufacturing practices on operations performance at Company A.

A study by Ortiz [36] showed that the challenge “resistance to change" is high in public owned enterprises as they are risk averse and laggards in adopting innovation. The SA government is the majority shareholder in Company A and based on [36], this may be a possible link to the dependency on traditional ways of working. Mwacharo [37] stated that lean manufacturing is a continuous process where employees should be technically equipped to apply it. Furthermore, Mwacharo [37] acknowledged that most lean manufacturing practices are imposed on workers, who are closely monitored and with little autonomy, hence there are no necessary conditions in place for empowerment leading to limited participation. The study results support the view by [37] in that lack of training is a challenge in the implementation of lean manufacturing practices.

Table 3: Challenges faced in implementing lean manufacturing practices

	Lack of training	Lack of support from management	Lack of interest	Financial constraints	Lack of Change management	Dependency on traditional ways of working
Mean	3,423913	2,73913	2,380435	2,836957	2,5	3,521739
Median	4	3	2	3	2	4
Total options	460	460	460	460	460	Total options
Total score:	**315**	**252**	**219**	**261**	**230**	**324**
Percentage	68.48%	54.78%	47.61%	56.73%	50.00%	70.43%
Observations	92	92	92	92	92	92
Ranking:	**2**	**4**	**6**	**3**	**5**	**1**

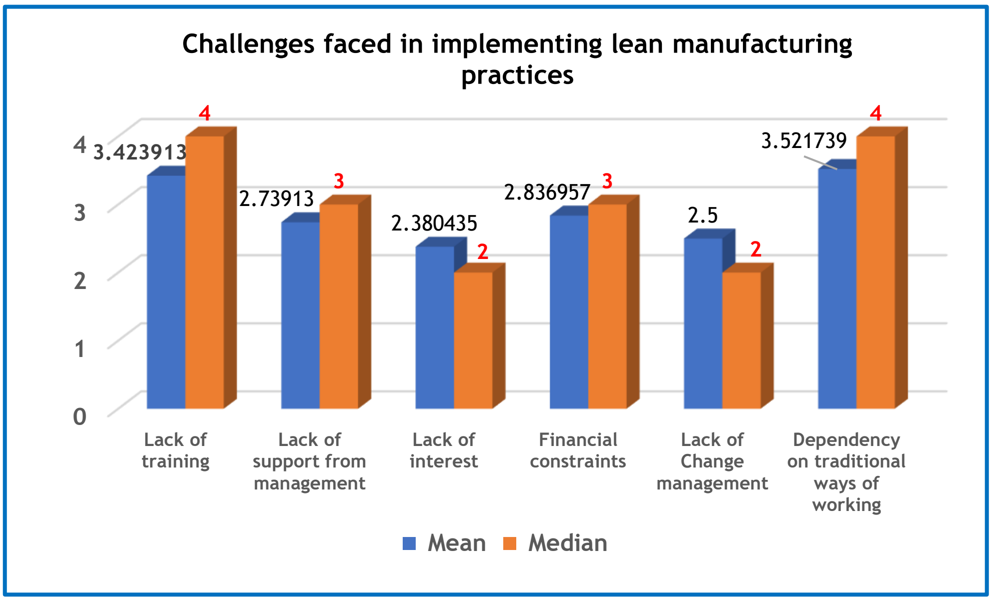

Figure 3: Challenges faced in implementing lean manufacturing practices

Table 3 and Figure 3 shows that based on the mean, the main challenge in the implementation of lean manufacturing practices is the dependency on traditional ways of working (70.43%), followed by lack of training, financial constraints, lack of support from management, lack of change management and lack of interest. Furthermore, the results show that based on the mean, most respondents agreed that dependency on traditional ways of working and lack of training are the challenges faced in the implementation of lean manufacturing practices and were undecided whether financial constraints and lack of support from management were challenges.

5.2 Regression analysis

Regression analysis aided this study to determine/achieve the significant strength between the variables, lean manufacturing practices, operations management, and performance measures in Company A. The p-value is used to determine the significance of the impact of lean manufacturing practices on the performance of Company A. The variables are considered significant when $\alpha<0.05$.

Table 4: Regression analysis

Regression Statistics						
Multiple R	0,1005					
R Square	0,0101					
Adjusted R Square	-0,00089					
Standard Error	3,1097					
Observations	92					
ANOVA	***df***	***SS***	***MS***	***F***	***Significance F***	
Regression	1	8,8814	8,8814	0,9184	0,3404	
Residual	90	870,3359	9,6703			
Total	91	879,2173				
	Coefficients	**Standard Error**	**t Stat**	**P-value**	**Lower 95%**	**Upper 95%**
Intercept	9,36867	0,9006	10,40177	4,19531	7,5792	11,15797
Performance measurement	0,0821	0,0857	0,9583	4,19531	7,5792	11,15797

Table 4 represents the regression analysis to determine if lean manufacturing practices influences the performance of an organisation. The hypothesis test is accepted, and because the p-value is greater than $\alpha=0.05$, there is a linear relationship between lean manufacturing practices and the performance of Company A. The results are interpreted by the regression equation $y=9,36867+ 0,0821Q1$. It is evident that Company A's performance has a relationship with the lean manufacturing practices that are implemented in the organisation.

5.3 Correlation analysis

Correlation in the broadest sense is a measure of an association between variables, [38]. In correlated data, the change in the magnitude of 1 variable is associated with a change in the magnitude of another variable [38]. They further state that most often, the tern correlation is used in the context of a linear relationship between 2 continuous variables and expressed as Pearson product-moment correlation. The Pearson correlation coefficient is designed to range between -1 to +1.

Table 5: Correlation analysis

		Lean Manufacturing Practices	Company A	Operations Management	Performance Measures
Lean manufacturing practices	Pearson correlation	1	.0414”	.1149”	.07”
	Sig.(2-tailed)		.000	.000	.000
	N	92	92	92	92
Company A	Pearson correlation	.0414”	1	.0485”	.0654”
	Sig.(2-tailed)	.000		.000	.000
	N	92	92	92	92
Operations Management	Pearson correlation	.1149”	.04854”	1	.2370”
	Sig.(2-tailed)	.000	.000		.000
	N	92	92	92	92
Performance measures	Pearson correlation	.0699”	.06536”	.2370”	1
	Sig.(2-tailed)	.000	.000	.000	
	N	92	92	92	92

Table 5 depicts the correlation analysis of the impact of lean manufacturing practices on the operations management in Company A. From the analysis a positive correlation is shown between the variables. Operations management and performance measures shows a stronger positive correlation of 0.2370 ($r>+0.2$, $p<0.01$) while the other variable shown a medium positive correlation ($0.04<r<0.06$; $p<0.01$).

6 LIMITATIONS OF THE RESEARCH

As with all research, this study was not without limitations and the typical limitations of quantitative research apply. One of the potential limitations of this study was that the study was restricted to only one department at Company A. As further research, a qualitative study which captures the non-quantifiable aspects of lean management practices could be conducted. This study could be also extended to the other departments within Company A.

7 MANAGEMENT IMPLICATIONS

The outcomes from the objectives of the study will encourage Company A's managers to adopt proper lean production practices to gain greater efficiency and a competitive edge. Apart from the lean manufacturing interventions implemented by by Company A, management should look into implementing lean manufacturing practices such as Kaizen, Just Do It, Lean, Six Sigma and TQM. The achievement of the study objectives and the implementation of recommendations highlighted above will assist management of Company A in different ways, by upskilling workers, reduce operational cost, improve efficiency, getting a buy-in from the executives or the relevant stakeholders when executing lean manufacturing projects and streamlined processes.

8 CONCLUSIONS AND RECOMMENDATIONS

The conclusions of this study are based on the research findings in line with the objectives of the study. The following noteworthy conclusions were drawn from the primary research:

The first objective of the research study was to determine the lean manufacturing practices currently used at Company A. The research established that the lean manufacturing practices are not properly followed by the workers and they do not understand the importance of practicing lean manufacturing principles. This harms the effectiveness of the processes and resulted in an increase in losses in terms of revenue. The quantitative approach applied in this research presented the need for an organisation that fully practices lean manufacturing. It is recommended that management of Company A ensure that workers are provided with the necessary training to equip them with the prerequisite skills necessary for effective lean manufacturing implementation. It is also recommended that Company A to fully implement lean manufacturing to reduce wastes and enhance efficiency. There was a lack of resources and poor management skills that led to the poor performance at Company A. The literature review revealed that there is a need to implement lean manufacturing fully to prevent revenue losses and increase performance. It is recommended that Company A ensure that talented human resources are attracted and retained. It is also recommended that the production/operational processes are efficiently implemented to improve the performance of the organisation.

The second objective of the research study was to determine the factors that impact lean manufacturing practices at Company A. Processes at Company A are not streamlined which affects the performance of an organisation. The poor performance was the result of poor-quality work produced by the workers at Company A, lack of training and wastes that are within the processes. It is recommended that to improve the performance of Company A, lean manufacturing practices must be improved. The organisation needs to promote a culture of lean manufacturing and involve all key stakeholders to reduce resistance to change. Management must revise and implement processes to align lean manufacturing practices to assist in the reduction of loss of revenue and to streamline the processes.

The third objective of the research study was to assess the impact of lean manufacturing practices on operations performance at Company A. The negative impact of lean manufacturing resulted in low performance are low productivity, lack of critical skills and poor quality. The literature review revealed that the elimination of waste within an operation is a key concept in lean methodology and waste is one of the most significant drains on profitability in any organisation [39].

The analyses revealed that the main challenge in the implementation of lean manufacturing practices was the dependency on traditional ways of working. It is recommended that management use training interventions to inform employees of the value of new tools and techniques which would assist Company A to eliminate the dependency on traditional ways of working. It is recommended that quality should be improved by reducing the number of reworks which will improve productivity and employees should also be trained to ensure that they understand the processes. It is also recommended that waste should be eliminated by conducting process observations to identify the eight types of waste and develop an implementation plan to improve on the identified sources of wastes.

The aim of the study was to assess the impact of lean manufacturing practices on operations at Company A towards improving performance. Improper implementation of lean manufacturing affects the performance of Company A and has resulted in revenue losses. The recommendations will assist the organisation in improving the production/operational processes and assist in reducing the negative impact that affects the implementation of lean manufacturing. Furthermore, the recommendations will improve the performance of Company A.

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EVALUATING THE EFFECTIVENESS OF LOGISTICS MANAGEMENT PRACTICES TO ENHANCE SERVICE DELIVERY AT A SOUTH AFRICAN PRINTING ORGANISATION

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ABSTRACT

This paper reports on a study to evaluate the effectiveness of logistics management practices in enhancing the quality-of-service delivery at a printing organisation. The study pursued four objectives; to evaluate the effectiveness of logistics management practices, determine factors affecting the efficiency, assess the impact on quality service delivery and provide recommendations to improve the efficiency of logistics practices. The study adopted a qualitative research approach using interviews. Convenience sampling was utilised with a sample of ten participants after which a thematic analysis was conducted. The findings revealed that improving the effectiveness of the logistics management practices and processes will improve the quality of service delivery. This paper succeeds in evaluating the effectiveness of logistics management practices in enhancing the quality-of-service delivery. The recommendations address an improvement in the use of information and communication technology, training, customer surveys and effective communication to enhance service delivery.

Keywords: Printing, logistics management process, efficiency, service delivery.

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1 INTRODUCTION:

Owing to the current dynamic environment and growing competition globally, the role of effective logistics management in enhancing the competitiveness of an organisation is increasingly being recognised. Wirtz and Lovelock [1] mentioned that the logistics activities within an organisation attempts to satisfy customers through achieving the time and location-related market challenges and through the cost and quality of the services provided, taking into consideration customer needs, and purchasing power. Hence, the management of these organisations is being forced to seek and implement innovative strategies with which to advance their company's competitive advantage as well as their profitability. According to Fugate, Mentzer and Stank [2], logistics management, as a function within the supply chain of an organisation, plays a crucial role in the delivery of quality products and services to customers. There is a huge potential for significant cost reductions as well the delivery of quality goods and services at the right time and place through the effective management of logistic management practices that include inventory management, order processing, warehousing, and transport management among others [3].

The current dynamic changes taking place in the business environment are increasingly challenging organisations to realise the importance of continuing and strategically re-looking at their business processes to remain competitive [4]. Managers are therefore constantly searching for strategies to minimise operational costs and increase returns. In particular, logistics practices have emerged to possess a huge potential to enhance supply chain and organisational performance. In their efforts to meet customers' needs and achieve sustainable competitive advantage, organisations perform various logistical functions [5]. logistics management as a component of supply chain management whose aim is to meet customer requirements through planning, controlling, and implementing effective movement and storage of goods and services as well as related information from the point of origin to the point of consumption. According to Oyebamiji [6], there is an increasing awareness of the strategic role that can be played by logistics as well as the benefits of leveraging logistics to enhance customer value. Due to such a realisation, the measurement of logistics performance has become a high priority.

The essential contribution of this paper is the evaluation of the effectiveness of logistics management practices in enhancing the quality-of-service delivery at a printing organisation in South Africa whose principal clientele are state departments and their statutory bodies. For the purposes of anonymity, this organisation will be referred to as Company A. As such, this paper will aid Company A to understand and improve its service delivery.

2 PROBLEM INVESTIGATED AND THE RESEARCH OBJECTIVES

2.1 Problem investigated

Excellence in logistics is a critical competitive capability that is becoming increasingly difficult for organisations to achieve. Company A has, yet not achieved excellence in its logistics management practices. The organisation has been facing several challenges in the logistics function. Product costs are continuously increasing because of incorrect deliveries and mixing up consignments. The current inventory management system is paper based, is unreliable and difficult to track. This has resulted in poor inventory management which sometimes results in shortages of raw materials which subsequently cause delays in production processes. These delays result in Company A not meeting its delivery schedules which impacts negatively on service delivery. The organisation also relies on manual customer complaints and management registers, which result in delays in addressing customer complaints. It continues to lose experienced and qualified artisans and administrative personnel to the private printing sector. This invariably impacts service delivery in terms of the lack of capacity to provide services. Inevitably, the Company A is, as a result, compelled to outsource a greater percentage of jobs.

2.2 Research objectives

The aim of this paper is to evaluate the effectiveness of logistics management practices in enhancing the quality-of-service delivery at Company A. The research objectives of the study were:

a. To evaluate the effectiveness of current logistics management;

b. To determine the key factors that affect the efficiency of logistics management practices;

c. To evaluate the impact of logistical practices on quality service delivery; and

d. To make recommendations to management on ways to improve the efficiency of logistics practices.

3 LITERATURE REVIEW

The literature review topics consisted of an overview of logistics management, the effectiveness of logistics management, logistics management practices, the importance of logistics management and service delivery. These main constructs made up the theoretical framework for the study and was used as indicators for the compilation of the research instrument (interview guide).

3.1 Overview of logistics management

Logistics management can be defined as the section of supply chain management that deals with the planning, implementation, and control of the effective and efficient flow of goods and services and related information from the point of origin to the point where they are consumed to satisfy customer requirements [7]. Logistics is described as the planning, organisation, and management of all things to do in the resources flow, from raw material till ultimate consumption and reverse flow of the manufactured product, with the focus to satisfy customers and different interest party’s needs and desires to grant a right customer service, low cost, low tied-up capital and small environmental penalties [2]. Logistics is additionally described as these things to do that relate to receiving the proper product or service in the proper quantity, in the proper quality, in the right place, at the proper time, giving to the proper customer, and doing this at a reasonable cost [2]. In most of the instance’s logistics is viewed from the standpoint of an operative way of transporting or moving substances or materials from one place to some other or producing service. The credibility of this operation is primarily based on how proper the design of the system is which leads to this type of logistics. Logistics systems include operative responsibilities, which consist of administration, operation and purchasing and optimistic responsibilities as well as design.

The focus of logistics management is on short-term procedures while supply chain management focuses on long-term activities. Logistics management activities include inbound and outbound transportation management, fleet management, material handling, warehousing, demand and supply planning, inventory management, and order fulfilment [8]. Furthermore, logistics management deals with various aspects of customer service, procurement, production planning and scheduling, and packaging. The goal of logistics management is to ensure that the right product is available at the right time in the right place to the ultimate customer.

3.2 The effectiveness of logistics management

By definition, effectiveness is a qualitative measure set by evaluators, such as customers. Francis and Waiganjo [3] are of the view that the concept of effectiveness is the ability of an actor to offer solutions that provide value. To an organisation, effectiveness refers to an external standard of how well the organisation fulfils the demand of the different groups that are concerned with its activities. With this understanding, logistics management, as a function within the organisation, plays a crucial role in delivering quality products and services to customers. Due to the current global trends and fiercer competition, across all industries, the role of effective logistics management in enhancing the competitiveness of an organisation is increasingly being recognised. According to Springinklee and Wallenburg [9], effective logistics management ensures a smooth flow of materials in the supply chain and assists in attaining organisational objectives through maintaining low costs and enhancing customer satisfaction.

Vlachos [7] described logistics management effectiveness with the extent to which an organisation is involved in delivering value to customers to achieve customer satisfaction; that is delivering the right product or service at the right time at the right place. To achieve effective logistics management, all the barriers to the free flow of products should be removed [10]. Ineffective logistics management involves poor coordination and management of functions, activities, and people from the point of raw material acquisition to the point of final delivery to the customer [7]. It is therefore critical for organisations to effectively manage and coordinate such functions and activities to attain customer satisfaction.

3.3 Logistics management practices

Logistics management activities generally encompass inbound and outbound transportation management, fleet management, warehousing, handling of materials, fulfilment of orders, designing of the logistics network, stock management, planning of demand and supply and overseeing of third-party logistics providers [11]. To various degrees, the logistics feature additionally consists of sourcing and procurement, manufacturing planning and scheduling, packaging and assembly, and client service. Some of the activities include warehousing, inventory management and transport management.

3.4 Service quality

Service quality is generally viewed as the output of the service delivery system, especially in the case of pure service systems. Manufacturing companies purchase raw materials from suppliers, transform them into finished goods to be sold to different customers. Market and customer needs have always been a concern whether in the private or public sector. Customer service is the major key activity of business logistics in the sense that it enables to determine the needs of the customers for logistics to be met. Without any doubt, quality of service is a very essential aspect of any enterprise associated activity. This is so, to marketer a customer's assessment of the quality of service and the level of satisfaction are perceived to affect bottom-line measures of organisational success [12]. Keeber [13] states that customer expectations refer the beliefs, behaviours, or actions that individuals anticipate regarding service performance when interacting with a company. Customer expectations may also include their desired outcomes from using a product or the service that a provider should give [14].

According to the service quality theory, it is expected that customers will decide that quality is 'low' if the overall performance does not meet their expectations and quality as 'high' when overall performance exceeds customer expectations. Closing the gap may require firming down the expectations or heightening the perception of what has been obtained by the customer. Douglas [12] mentions that the perceived quality of an offered service is the result of an assessment process because customers frequently make the comparison between the service quality, they assume with perceptions of the received service quality level. Jang and Jeong, [14] concluded that service quality is based on two variables: expected carrier and perceived service. Consumer behavioural intentions are additionally influenced by the standard of service quality [13].

3.4.1 The SERVQUAL model

Customer, service process, management, and employees are four fundamental concepts shaping the SERVQUAL model of service quality [15]. Customers' have needs, experience, and expectations about a particular service. Management and employees of the service providers have perceptions about customer needs and service delivery. Various methods have been suggested to measure service quality, the most well-known being that of the SERVQUAL instrument [15]. This instrument for measuring service quality is based on the differences between the perceptions and expectations of customers regarding the dimensions of service quality This method is based on the gap model of service quality. It defines quality as the function of gaps between the expectations of customers and their perceptions of the service delivered [16]. The SERVQUAL model utilises a complex questionnaire to measure the perceived quality of service hence, it is used frequently by scholars than business practitioners [15].

4 RESEARCH METHODOLOGY

4.1 The research design and instrument

The research design consisted of a qualitative and exploratory research approach which was used to gather data, which enabled the study to achieve the research objectives through data collection related to the experiences and perceptions relating to the factors affecting the effectiveness of logistical practices at printing organisation in South Africa. Data collection consisted of interviews and an interview guide was compiled and used to conduct the interviews. An audio recorder was used to record verbal and non-verbal cues.

4.2 The population and sampling in the study

The target population of the study reported in this paper comprised 50 employees from the supply chain department at Company A. These were the employees who had sufficient knowledge and information regarding logistical practices. Convenience sampling was used to select the sample for the study. For the purposes of this study, a sample of ten employees were interviewed.

4.3 Data collection and analysis

Data was collected by means of semi-structured interviews. The interview guide was utilised to elicit experiences and perceptions of participants regarding the factors affecting the effectiveness of logistical practices at Company A. The interview guide was pilot tested with participants from the identified sample. The interviews were recorded and transcribed verbatim. A thematic analysis was conducted to analyse data for this study and a coding data analysis technique was used to analyse data for the purposes of the study. The coding tool is widely used in qualitative research, mainly to identify trends and patterns in the data being analysed and it was found to be appropriate to analyse trends about experiences and perceptions of participants and to improve service delivery.

4.3.1 Thematic analysis

The thematic data analysis technique was utilised to obtain more insights on the effectiveness of logistical management challenges facing the company and to provide recommendations on ways to improve service delivery in Company A. The researcher analysed the data to identify themes that emerged from the interviews. The themes were derived from the list of logistics management challenges and categories obtained from the interviews. The goal was to accurately identify themes that would answer the research questions, attain the objectives, and solve the research problem.

5 FINDINGS AND RESULTS

5.1 Presentation of analysis and findings

The findings and results are aligned to the research objectives and the main literature constructs of this study. Part A presents the thematic analysis, whilst Part B provides the interpretation and discussion of the findings of the analysis of the research objectives.

5.1.1 PART A: Thematic analysis

The thematic data analysis aimed to accurately identify the dominant themes and patterns that would assist in achieving the research objectives. A six-step approach as suggested by Braun et al. [17], for conducting thematic analysis was utilised. The initial step in the data analysis process was for the researcher to familiarise herself with the gathered data. This was done through reading and understanding the data as well as identifying key phrases that are more relevant to the research questions. This process assisted the researcher to become acquainted with the data and to generate meaningful information from each transcript. Thereafter, a coding data analysis technique was used to organise data into categories. Emerging themes were identified, reviewed, and defined to have a meaningful relationship with the objectives and customer service delivery. Table 1 shows a list of the core and sub-themes which emerged from the analysis. These themes are the key causes of poor service delivery at Company A.

Table 1: Core themes, categories, and findings

Core themes	Sub-themes	Findings and results
Poor inventory management	a. Avoiding stockouts, b. Planning, and c. Checking and verification.	The majority of the participants were of the view that inventory management in Company A is ineffective. The feeling was that to operate the business smoothly, a well-functioning inventory management is required. a. Stockout or out of stock should be avoided in a manufacturing organisation because inventory is important for the continuation of the business [18]. b. Poor planning means that the schedule that the team members are supposed to follow is not properly set out. This means that the process will not be completed on time and will result in customers not getting their stock in time. c. A high 70% of the participants indicated that inventory management practices are effective to the extent that they enable the organisation to check and verify the inventory levels.
Effective transport management	a. Backlogs b. Poor service quality c. Inefficiency of operations	A high 80% of the participants were positive about the transportation logistics and as much as 60% mentioned that Company A has adequate measures in place to plan, organise and move inventory and finished goods from one point to another. Ttransportation is the linkage activity in logistics and is often the single largest cost in logistics processes and thus should be managed effectively [19]. a. The majority, (80%) of the participants indicated that Company A is doing its best to ensure that there are no backlogs. Only twenty percent (20%) of participants were unhappy about the current transportation management system within Company A. They expressed that we have backlogs due to inadequate transport infrastructure. b. The majority (60%) of the participants were happy with the transport service quality offered by Company A. However, they expressed that a relationship exists between transport and service quality. They mentioned that poor transportation systems have a direct effect on the level of service quality delivered. c. Transport management should aim at minimising the total cost of the system while enhancing efficiency. Speed refers to the time involved in completing a particular movement of inventory [3].
Inefficiency procurement practices and processes	a. Building supplier relationships b. Use of technology and e-procurement	The majority (90%) of the participants indicated that the current logistics management practices are ineffective and as a result, it fails to encompass the procurement practices necessary for efficient quality service delivery. Eighty percent (80%) of participants mentioned that procurement practices improve service delivery, efficiency, reduce costs and complaints from customers.

Core themes	Sub-themes	Findings and results
		a. The responses of the participants indicated that adopting and implementing best practices of procurement is crucial to improve the effectiveness of purchasing decisions. Sixty percent (60%) indicated that procurement best practices are responsible for building relations with buyers and suppliers. b. According to Gani [20], it is important to have a software system that streamlines different tasks is very important. Seventy percent (70%) of participants mentioned that having e-procurement is a sign of effective logistics management practices. Participants were of the view that e-procurement made it easy for Company A to order raw materials and to receive orders. However, the participant also indicated the costs that are associated with e-procurement as software needs to be bought and installed. Hence, there is poor e-procurement at Company A.
Poor warehouse processes and procedures	a. Poor receiving processes b. Poor storage facilities	The responses from the participant indicated that there are several processes and procedures which include receiving, storage and shipping. Management of labour is also crucial to allocate the right number of resources to prevent over or under allocation. Gitonga [10] mentions that resources should be adequately allocated. This was supported by Vlachos [7], who alluded that the use of ICT enables the organisation to have the right information at hand and real-time to check and verify transit of orders. a. Seventy percent (70%) of participants indicated that their receiving process is ineffective. b. The participants were of the view that there is poor storage infrastructure at Company A. Fifty percent (50%) of participants expressed that there is a need to improve the storage facilities to avoid damages.
Poor order processing	a. Order notification b. Order tracking	Order processing is the series of activities that a business follows to fulfil the customers' orders [7]. Seventy percent (70%) of participants were of the view that order processing plays a big role in ensuring quality service delivery. a. Order process and notification are critical to ensure that the right product is picked, sorted, labelled, and packed as well as loaded for transportation. Only twenty percent (20%) of participants were unsure about the order processes in the warehouse. b. According to Francis and Waiganjo [3], order management refers to the process of receiving, tracking, and fulfilling customer orders. Several factors influence the order processing timeframe which includes quality check, packaging, and inventory status of customer's product. Efficient and accurate order processing is important to ensure the success of any form of business.
Lack of ICT and information management	a. Inefficiency in technology b. Poor communication	a. Most participants were of the view that the current system that is ineffective as not all departments were using the same system. They felt that Company A is not taking advantage of the available technological management systems in the market and the old facilities are failing. Ninety percent (90%) of participants stated that ICT improves the ability of Company A to conduct activities faster and accurately. b. ICT improve the communication between different people of the organisation. ICT also promotes and encourages fast and more frequent communication, interaction and sharing of information between customers and suppliers.
Lack of adequate employee skills and competency	a. Shortage of skills b. Inadequate training and development	a. The responses from the participants show that the competence and skills of employees have a greater impact on the efficiency of logistics management. Eighty percent (80%) of participants expressed concerns regarding employee skills that are required to carry out jobs. They were also concerned about employee competencies.

Core themes	Sub-themes	Findings and results
		b. Cheong and Suthiwartnarueput [21] also expressed that the educational level of logistical staff has an impact on the efficiency of logistical processes and practices. The general feeling was that Company A has a problem of skills shortage. The training of all staff has an impact on the efficiency of logistical processes and practices.
Lack of resources	a. Depleted ICT infrastructures b. Poor management of physical human resources	a. There are inadequate IT infrastructures in the logistics department as a result, there is often a shortage of machinery parts due to a lack of tracking level of stocks. Participants indicated that there is a lack of resources within Company A which is affecting the performance of logistics management practices. b. There is a need to recruit sufficient human resources to effectively implement logistics practices. Gitonga [10] postulated that logistics management practices have an impact on the utilisation of the available resources to ensure quality service delivery. It frames proper strategies accordingly to continue all planned logistics of the organisation.
Poor planning	a. Failure to meet deadlines	a. There is a failure to meet the deadlines of many projects due to poor planning. Some of the participants were of the view that the effectiveness of logistics management practices is influenced by planning. The success of planning bears effects on the efficiency of logistics management practices. Eighty percent (80%) of participants mentioned that the way they plan determines the level of success. According to Bosire [22], most of the business strategies are failing due to poor execution, making effective logistics planning and strategy paramount to the efficiency of logistics management practices.
Poor quality service delivery	a. Production efficiency b. Communication c. Speed of service delivery d. Transparency	Participants indicated that logistics management practices are responsible for improving the quality of service offered by Company A. Seventy percent (70%) of participants mentioned that logistics management practices improved speed, accuracy and efficiency and reduce waste. a. Participants indicated that logistics management practices are important to improve production efficiency which will have a positive effect on service delivery. Eighty percent (80%) of participants were of the view that there are no adequate logistics management practices at Company A, hence, the production efficiency is low. b. The majority (70%) of the participants indicated that Company A should have effective communication to meet all the needs of the internal and external stakeholders. They added that communication is also important in the production process to ensure quality products are produced. c. The majority (90%) of the participants were of the view that logistics management is responsible for increasing the speed of services delivery. Participants further explained that logistics management also focuses on speeding up the production process through the use of advanced technology. This means that the customers are receiving their services as soon as they place orders. Seven (70%) participants also mentioned that speed of service delivery can also be in terms of communication. d. The responses from the participants also pointed out that logistics management practices result in improved transparency within Company A. The majority (70%) of the participants expressed that effective logistics management practices are focused on reducing corruption in the supply chain. Transparency initiatives in service delivery are relatively easy to define any attempt to place information or processes that were previously opaque in the public domain, accessible for use by citizen groups, providers, and policymakers.

5.1.2 *PART B: Presentation, interpretation, and discussion of the results of the analysis of the research objectives.*

Part B of the presentation, interpretation and discussion of the results was categorised into three sections, namely: Logistics management practices, factors affecting the efficiency of logistics management practices, and impact of logistics management practices on quality service delivery.

Logistics management practices: This section aimed to analyse all the participants' responses to the question on the effectiveness of the current logistics management practices. Questions were asked on the following aspects, namely, a common understanding of logistics management practices, assess the effectiveness of these practices, and to identify the best logistics practices that can be embraced to improve quality service delivery. The majority (80%) of the participants indicated an understanding of the logistics management practices and their effectiveness at Company A. The participants showed a high level of understanding of logistics management. The participants stated that most of the practices are not effective due to lack of resources, limited skills, and poor planning. The participants expressed that good inventory management, transport management and effective order process should be embraced at Company A to improve their effectiveness as well as improving quality service delivery.

Factors affecting the efficiency of logistics management practices: This section focused on responses to the questions on the issues that hindered the efficiency of logistics management and included the questions on the following aspects, namely, the role of ICT, information management, skills and competencies of employees, and the role of resources on logistics management practices efficiency. As much as 70% of the participants indicated that inadequate technology, skills, and competencies, as well as lack of resources affect the efficiency of logistics management practices. Participants also mentioned that ICT and information management have a significant role in the efficiency of logistics management practices.

Impact of logistics management practices on quality service delivery: This section sought responses to questions regarding the linkage between logistics management practices and quality service delivery. The questions revolved around the following issues, namely, the overall understanding of the impact of logistics management on service delivery, effects on communication, and effects on speed and efficiency. All participants were of the view that logistics management practices improve the overall quality of service delivery through improved communication and speed of delivery. In addition, the participants also mentioned that logistics management improves efficiency. Hence, the primary research indicated that the majority of the participants were of the view that effective logistics management practices are focused on eliminating corruption along the supply chain. The participants also suggested that management should keep track of the services and products while they are delivered. Effective logistics management enables managers to oversee the whole supply chain processes, and this allows management to identify the challenge that might affect the effective delivery of quality service.

5.1.3 Limitations of the research

As with all research, this study was not without limitations. The typical limitations of qualitative research apply. Although the research findings focused on one government organisation and therefore, they cannot be generalised. The study assumption to generalise the findings to other similar organisational sets up is supported by Creswell and Creswell [23], who mentioned that the findings may be transferrable to similar manufacturing and service delivery contexts.

5.1.4 *Management implications*

The achievement of the study objectives and the implementation of recommendations will assist management of Company A to improve the quality-of-service delivery at Company A. The implementation of effective logistical practices (adequate technology) will benefit management in enabling the organisation as the current ineffectiveness was motivated by lack of adequate ICT and information management, lack of adequate employee skills and competencies, poor planning as well as lack of resources. The implication for logistics management practices is dire; the seriousness of these ineffective processes requires management attention beyond organisational and support intervention at the national level.

6 CONCLUSIONS AND RECOMMENDATIONS

The conclusions of this study are based on the research findings in line with the objectives of the study. The following are note-worthy conclusions, linked to the findings and results of the study. It must be stated that the entire study is based on perceptions and individual experiences.

The first objective of the research study was to evaluate the effectiveness of logistics management practices at Company A. The study found that there is no effective inventory management and a poor inventory management system. Both the literature and primary data revealed that effective inventory management is important for the effectiveness of logistics management [24]. Logistics management projects should be responsible for avoiding stockouts, help to check inventory levels and help in the planning process. A good transport management system is important for the effectiveness of logistics management. Transport management should aim at minimising the total cost of the system while enhancing efficiency. There are poor procurement activities within Company A. Building good relationships with reliable suppliers results in improved customer services. It is recommended that Company A implement effective inventory management to improve the effectiveness of logistics management practices and processes.

The second objective of the research was to determine the key factors that affect the efficiency of logistics management practices at Company A. The study concluded that the lack of proper ICT and information management, inadequate employee skills and competence, lack of resources and poor planning were regarded as the major factors affecting the efficiency of logistics management. It is important to ensure the right technology is in place, the right data is used, and all the decisions are made from the customer’s perspective. Adequate employee skills and competencies are important to ensure that there are efficient logistics management practices at Company A. The study recommends that Company A should employ a change agent to oversee the training of employees to enhance their skills and capabilities to improve the efficiency of logistics management. It is also recommended that use of ICT be improved in line with the latest technological developments which are compatible with their logistics practices.

The third research objective of the research was to evaluate the impact of logistics practices on quality service delivery at Company A. The study revealed that effective logistics management practices result in improved production efficiency, improved communication, improved speed of service delivery and improved transparency. Both primary and literature review agreed that effective logistics management have an impact on quality service delivery. Logistics management practices improve production efficiency. The use of ICT and just-in-time inventory management helps to smoothen the process, as well as reducing the overall production costs. Effective logistical practices enable the organisation to update customers at any stage of their logistics experiences.

The fourth objective was to make recommendations to management on ways to improve the efficiency of logistics practices. The study recommends the implementation of a periodical customer service survey. This will help the organisation and industry to understand the expectations of customers, as well as knowing how to satisfy them. It is also recommended that Company A implements effective logistical practices (adequate technology) to enable the organisation to update customers at any stage of their logistics experiences.

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HYBRID AND BEYOND: MULTI-METHODOLOGY SYSTEMS FOR IT PROJECT MANAGEMENT IN SA BANKING

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ABSTRACT

SA's major banks have implemented significant changes to their IT project management approaches over the past decade and will likely continue to do so. Whereas these changes require significant investment and change-absorption, the benefits do not materialize as expected. In response, the possibilities and needs for the development of IT project management approaches and methodologies were investigated. Following a Systems Thinking critique of extant project management approaches and methodologies, a Multi-Methodology System for IT project management in SA banking was proposed; and design requirements were developed. The design requirements were presented to an expert sample of IT project practitioners and stakeholders in SA banking for validation. The validation justified the further development of the Multi-Methodology System for implementation in practice. The Multi-Methodology System was designed to adhere to systems thinking principles relating to Ashby's Law of Requisite Variety and incorporating the controllable adaptability presented by Stafford Beer's Viable System Model.

Keywords: Project Management Methodology, Information Technology, Systems Thinking, SA Banking

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1 INTRODUCTION

The theory-practice gap that is addressed in this paper, as it pertains to information technology (IT) project management methodologies and approaches, can be summarized as follows:

Agile and hybrid methodologies and approaches offer increased success over waterfall approaches [1], [2], but do not outperform waterfall approaches over all measured success factors [3]–[5] – explanations for and responses to these findings are needed.

A Systems Thinking critique of project management methodology is performed in an attempt to explain this theory-practice gap, and to explore the theoretical underpinnings for enhanced IT project management approaches and methodologies in SA banking. This results in the propositioning of a Multi-Methodology System as an approach to IT project management in SA banking.

This rest of this paper is organized into six sections. First, the Literature Survey covers project management methodology matters reported on from practice and then distinguishes multi-methodology systems from hybrid methodologies. The next section, Research Method, describes the approach taken to conduct this investigation. Thereafter, a Critical Literature Survey details a Systems Thinking critique. This leads to the Proposition: A Multi-Methodology System and some specific details relating to the Components of the Multi-Methodology System. Lastly, the Validation, Discussion of Results, and Conclusion describe the formal and informal validation, and the results and implication thereof – that Multi-Methodology Systems both require and deserve further research and development.

This paper is redacted from an open-source doctoral thesis in Industrial Engineering [6]. The thesis is frequently referred to in this document for more detailed explanations of contents given in summary here. Relevant page numbers and a link to the document accompany these references.

2 LITERATURE SURVEY

The literature survey describes the rise of hybrid approaches to project management. The rise in agile approaches was a response to the shortcomings of traditional, waterfall approaches. The adoption agile approaches, however, have not been without challenges. These challenges are described and believed to have caused the present domination of hybrid approaches. The literature survey culminates in the need to develop the theoretical underpinnings of hybrid approaches to project management.

The use of 'approach', 'methodology', and 'practice' as terms by Gemino et al in their 2021 paper [2] will be continued and developed in this paper. The 'approach' is the set of principles and guidelines that define the way a project is managed at the highest level of abstraction. The 'methodology' provides detailed operational guidance as to the management of a project. Methodologies consist of the combination of 'practices' by which the project is delivered.

2.1 IT Project Management Methodology in Practice

The success of agile over waterfall approaches has been established empirically [1]–[3]. Furthermore, the implementation of changes to project management approaches has been reported on [7]–[9]. There has also been research resulting in practical guidance, including review studies [10] and proposed tailoring criteria [11], [12].

Whereas criticisms of waterfall approaches and the virtues of agile, and hybrid increasingly, are accepted as stylized facts [13], organizations experience varying levels of success following the adoption of agile project management methodologies [14]; and the success of delivery through agile project management methodologies depend heavily on the implementation of the entire complement of agile practices.

It has also been suggested that Agile practices improve software team response effectiveness or efficiency, but not both [4]. Furthermore, teamwork quality and its effect on team performance is similar between Agile and Traditional teams [15]. Despite claims to the devolution of power to the team being enabled by agile, power hierarchies within and around the team may persist and 'self-managing' not be reached [16].

Similarly, even though IT project success rates have been rising, the measured rise was impacted by a change in the understanding of project management and project success and did not purely reflect an underlying improvement in IT project management [17]. Furthermore, it is much harder to determine if better functionality is delivered more efficiently to the market by the organization's project management function [18].

An analysis of the differences in the success rates of 617 software projects in SA were conducted according to five criteria groups [3]. These groups were process success, project success (the triple constraint), deliverable success, business success, and strategic success. Whereas agile approaches resulted in clearly improved overall project success, agile approaches only significantly improved the deliverable and strategic success. Aspects of project success (the triple constraint) and business success of agile approaches are proposed as concerns requiring investigation.

Inter- and intra-methodology dogmatism among project practitioners have been identified by formal research [19]–[21], and raised on online blogs and publications by professional organizations relating to project management methodologies [22]–[39]. It can therefore not be assumed that agreement on a 'best' best-practice exists.

Given the prevailing challenges experienced with agile approaches and disputes regarding project management approaches, the rise of hybrid approaches makes sense. There is empirical evidence for the success of hybrid approaches equalling that of agile approaches. This establishes hybrid as a leading project management approach [2]; and hybrid as an increasingly popular choice [40]–[44].

The evidence, based on observation and empirical work [17], [41], [42], [44]–[46], suggest that hybridized approaches to project management are increasingly the most common approaches to project management that are practiced.

The research question then emerges: Why does neither agile nor waterfall approaches achieve holistic success in practice? And what are the theoretical underpinnings required to formalize and holistically improve hybrid over both agile and waterfall approaches?

2.2 Hybrid, and Multi-Methodology Systems

Previous definitions of approaches, methodologies, and practices [2], [47] are further developed for use in this paper.

In previous definitions, methodologies are said to consist of a set of practices, but a similar approach-methodologies relation is not stated. It is therefore proposed that the reality, which has been poorly described, is that an approach consist of a Multi-Methodology System. It is only the Multi-Methodology System that can have the requisite variety to deal with the complexity of practice. And it is the Multi-Methodology System that needs to be formalized in order to significantly improve methodological approaches to project management.

The Multi-Methodology System arises (Figure 1) when the characteristics of the project and organization are responded to by drawing on the capabilities and practices available to project practitioners. It is argued that this is what already happens in practice, and that this Multi-Methodology System needs to be described and formalized in order to develop the theory of project management approaches to a level where it adequately describes the reality of practice and can, ultimately, be useful to practice.

Figure 1: Reactive Multi-Methodology System

This explanation will hopefully become clearer as the argument is developed in this paper; and a more detailed account of the content in this section can be found on pages 69-73 of the thesis (https://scholar.sun.ac.za/handle/10019.1/124580) from which this paper is redacted.

3 RESEARCH METHOD

The literature survey described the rise of hybrid approaches to project management.

A Systems thinking critique of project management approaches were conducted as a critical literature review.

A Multi-Methodology System that would address the systems thinking critique was conceptualised and propositioned.

The proposition was presented to peers and practitioners for their validation at conferences, focus groups, and interviews. Feedback was gathered through questionnaires and quantified.

A more detailed account of the research approach that was developed for the execution of the study can be found on pages 19-42 of the thesis (https://scholar.sun.ac.za/handle/10019.1/124580) from which this paper is redacted.

4 CRITICAL LITERATURE SURVEY

In attempting to make sense of the shortcomings of project management approaches in practice, three topics are covered. First, a brief explanation of the complexity of IT project management, in a setting like SA banking, is provided. Secondly, inadequacies in literature on tailoring is highlighted. Thirdly, the initial relationship between project management theorizing and Systems Thinking, and the subsequent diversion, is described. This results in the shortcomings of project management approaches for not adhering to systems thinking principles. This culminates in the Multi-Methodology System being proposed as an approach to project management which formalizes hybridization while adhering to Systems Thinking principles.

4.1 Complexity of IT Project Management in SA banking

The IT infrastructure of a bank typically consist of more than a hundred significant components, with significant interconnectedness and variation between legacy systems and newer systems [6], [48], [49]. An IT project may require changes to be deployed in multiple components in each component group (Figure 2), delivered by multiple development teams.

Figure 2: Component Groups of Banking Architecture

There exist great variations between the component groups, like the communication protocols between applications, gateways, and databases built using different programming languages. These differences can be as complex, and even more so, within component groups where a core banking system coded in COBOL (for the Hogan core banking system on IBM mainframe) communicates to a treasury system built using ABAP.

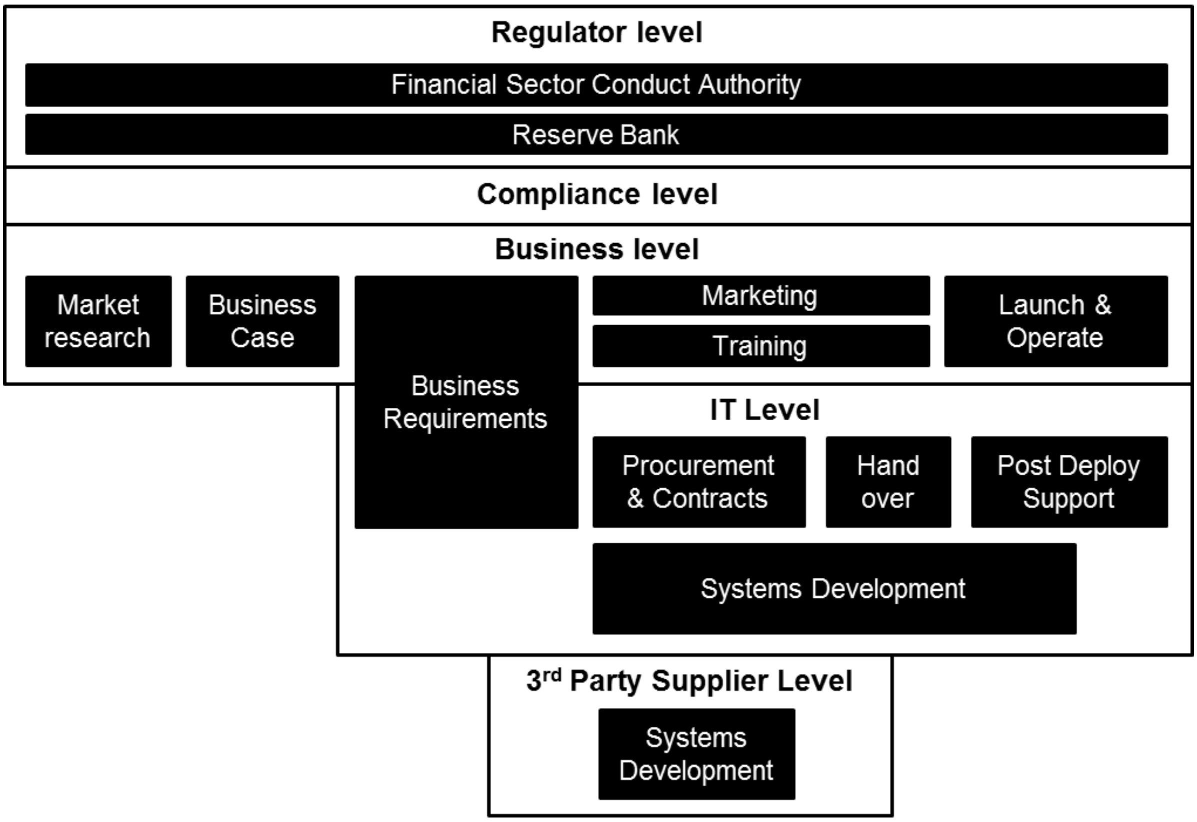

Figure 3: An example of the components of an IT project in SA banking

The technical challenges may be complicated but can be the least complex in a sense. What makes IT project in SA banking particularly complex is that the IT project management often includes the project management of the greater initiative, including 3rd party suppliers, business, and regulatory aspects. This is illustrated in Figure 3.

The argument is therefore that a single, predetermined approach is not likely to be adequate for the management of such complex interactions and integrations. A more detailed account of the content in this section can be found on pages 80-83 of the thesis (https://scholar.sun.ac.za/handle/10019.1/124580) from which this paper is redacted.

4.2 Tailoring

Despite the research on the tailoring of project management methodologies in practice referred to in the Literature Survey, this remains an understudied field. The common discrepancy arises from reporting on 'what' was done but failing to explain 'how' it was done [50]. Subsequently, a call for research on methodology tailoring and hybridization in practice was raised by the Project Management Institute [17]. Subsequent issues of the Project Management Journal, the Project Management Institute's journal, did not contain significant works relating to tailoring and hybridization.

It is, therefore, concluded that research into the theoretical underpinnings of project management approaches also need to make provision for tailoring and hybridization concerns. A more detailed account of the content in this section can be found on pages 67-79 of the thesis (https://scholar.sun.ac.za/handle/10019.1/124580) from which this paper is redacted.

4.3 No Silver Bullet – A Systems Thinking Critique

The early development of project management drew heavily on Systems Thinking as was found in systems techniques, such as cybernetics, systems engineering and systems analysis; and as practiced in aerospace, construction, and general engineering [51]–[53].

Following this early development, project management has typically focused on systemically quantifying and controlling projects' constraints [51] and aspects of project management, such as risk management [54]. The result of this early development can also be seen in the typical top-down management style of the project-delivering organization [53].

There have been calls, throughout the nineties, to introduce more Soft Systems Methodology characteristics into project management [54]–[57] and the publication of the Agile Manifesto in 2001 [58] may be seen as a result of thereof. Works have been published since describing the ways of applying Soft Systems Methodology characteristics into project management and the effects of doing so [59]–[64].

With regards to Multi-Methodology Systems, examples have been provided of developing a multi-methodology system from Soft Systems Methodology into project management and technology management, of which elements are applicable to IT project management in SA banking [65], [66]. Good overviews [57], [65] have been published from the origin of Multi-Methodology Systems up to the present day. Systemic ways of decomposing methodologies to identify detachable elements, which can be built upon have been published on [67]; and the combination of various systems thinking tools to form an approach akin to a Multi-Methodology System has been proposed too [61].

There is neither a lack of theory nor reports of application of hard and soft systems methodologies to project management. Furthermore, there are many different project management approaches and methodologies to choose from. Yet, Brookes' statement in 1987 [68], of there being no silver bullet to the challenges faced in software engineering, and to IT project management by extension, has been backed up by empirical findings [4], [13]–[15], [17], [40], [44], [46], [69]. With regards to the reports on the application of Systems Thinking approaches to project management, a general critique is that these attempts invariably lead to a predefined 'solution', instead of an adaptable, living system of project management.

Organizations either need to be able to adhere to the full set of requirements of a project management methodology or have flexibility in the methodological approach to projects – otherwise project managers and other stakeholders will necessarily attempt to sidestep the process in order to *get the job done* [70]. When the process is not adhered to, risks are incurred. Furthermore, when the process is willfully sidestepped, there is an increased probability that the resulting risks will be under-identified and under-reported.

Perhaps the problem could be that organizations still seek silver bullets to IT project management challenges. The silver bullet could be a hybridized project management methodology, tailor-made for the organization; or even approaches consisting of a set of three or five or so custom-designed project management methodologies from which a best-fit project management methodology could be selected and tailored for the project. The problem is that the largely pre-defined project management methodology, once sanctioned, is necessarily a top-down introduced set of requirements and capabilities, around which the delivery of work needs to be organized.

The predefined project management methodology violates Ashby's law of requisite variety [71], since the predefined project management methodology can necessarily not present practices, techniques, procedures and rules to deal with every emergent challenge that may be put to it, while still being a system that would also be lean enough for efficient use. It follows that a single methodology, even when fully adopted, would rarely enable the project management function to have the requisite variety of responses ready for all the questions that a complex project, in a complex environment, could ask of a project management methodology system [44].

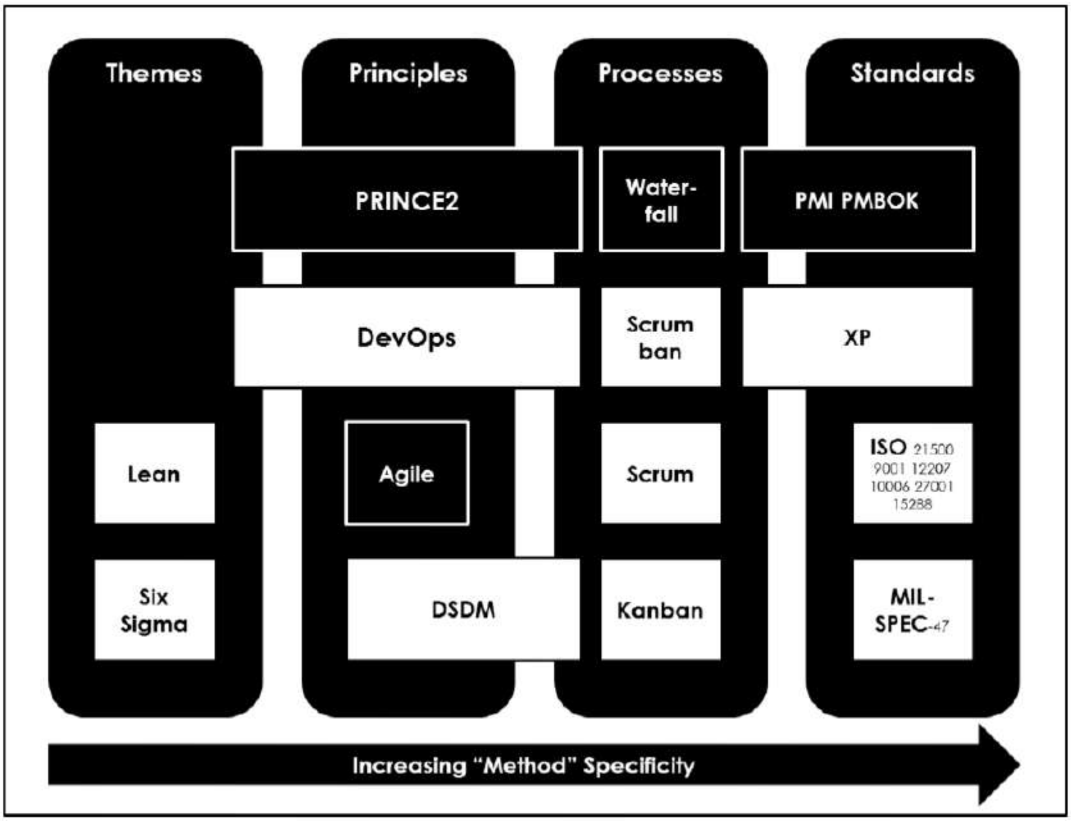

Figure 4: Themes, Principles, Processes and Standards of Project Management (Adapted from thedigitalprojectmanager.com)

Figure 4 is adapted from thedigitalprojectmanager.com [72]. While this picture is not accepted as settled fact, it provides a useful perspective. The approaches listed in Figure 4 differ in essence and utility. No single approach or hybrid could be used, predetermined, to produce a project management methodology or set of project management methodologies that would have the requisite variety to absorb the complexity presented by a large, complex portfolio of projects. Rather, the organization should retain the freedom to choose the necessary project management characteristics presented by the different approaches, as required by the project, the teams, and the organization, as is already occurring informally in practice [44].

Systems thinking theories that aim to deal with requisite variety, that has been applied to project management and reported on, include the Viable System Model [73]–[78], Systems of Systems [79], and Complex Adaptive Systems [80]. Unfortunately, these papers are hardly cited, and it seems as if limited impact was achieved. There remains an opportunity to apply the powerful, adaptive methods of Systems Thinking to project management and to report it to a wider audience for criticism.

Following the *No Silver Bullet* argument, evidence from practice, and subjecting project management methodology to a Systems Thinking critique, a conclusion is drawn regarding the failure of project management methodologies in practice: a single, predetermined project management methodology cannot be sufficient to the needs of a large, complex project in a complex organization; it cannot provide the requisite variety of responses, given the range of questions that the complex organization and its projects can ask of the project management methodology; and that the project management methodology should not be treated as a standalone component, but should be treated as a sub-system of the greater project delivery system.

The *No Silver Bullet* argument in software engineering has been ongoing and unrefuted since 1987 [68], [81]–[85]. It is argued that this state of affairs can be extended to IT project management – there is likely no silver bullet to the challenges faced in IT project management. A more detailed account of the content in this section can be found on pages 84-88 of the thesis (https://scholar.sun.ac.za/handle/10019.1/124580) from which this paper is redacted.

5 PROPOSITION: A MULTI-METHODOLOGY SYSTEM

From the critical literature review that culminated in a Systems Thinking critique of project management approaches, it emerged that an approach to project management is required which would adhere to the principles of Systems Thinking. The principles specifically focused on are requisite variety, adaptability, and control.

The Viable System Model is utilized as the chief theoretical foundation for the Multi-Methodology System. The Viable System Model was developed by Stafford Beer between the late seventies and middle eighties, and its claims have not been refuted since its inception [86]. The representation of the Viable System Model that follows is built on Beer's own work [87], descriptions by a respected Systems Thinking authors [88]–[90] and various works applying the Viable System Model to the field of IT [73], [74], [91]–[97]. The Viable System Model consists of five sub-systems, as illustrated in Figure 5, and is based on the structures prevalent in viable biological systems. These systems have the functions of planning, executing, monitoring, and controlling the viable system's present and future interaction with the environment.

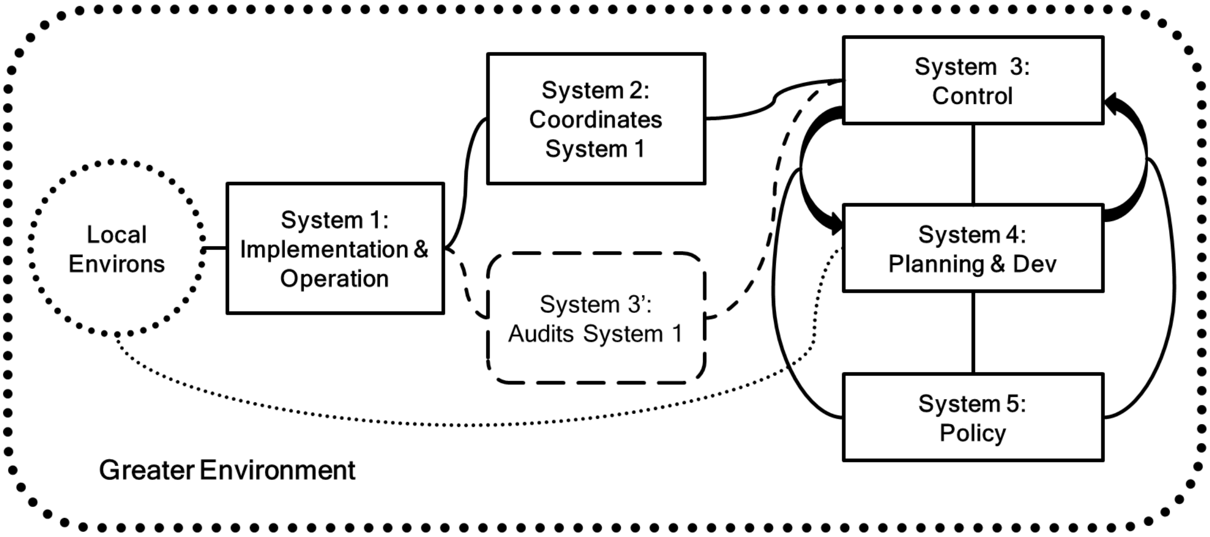

Figure 5: The Viable System Model

The Viable System Model strikes a rare balance by adequately describing and enabling control and auditing while providing variety and promoting adaptability. All systems are represented in System 5, where policy, or approach, is decided on. Planning and development in System 4 occurs while maintaining contact with the reality of the environment.

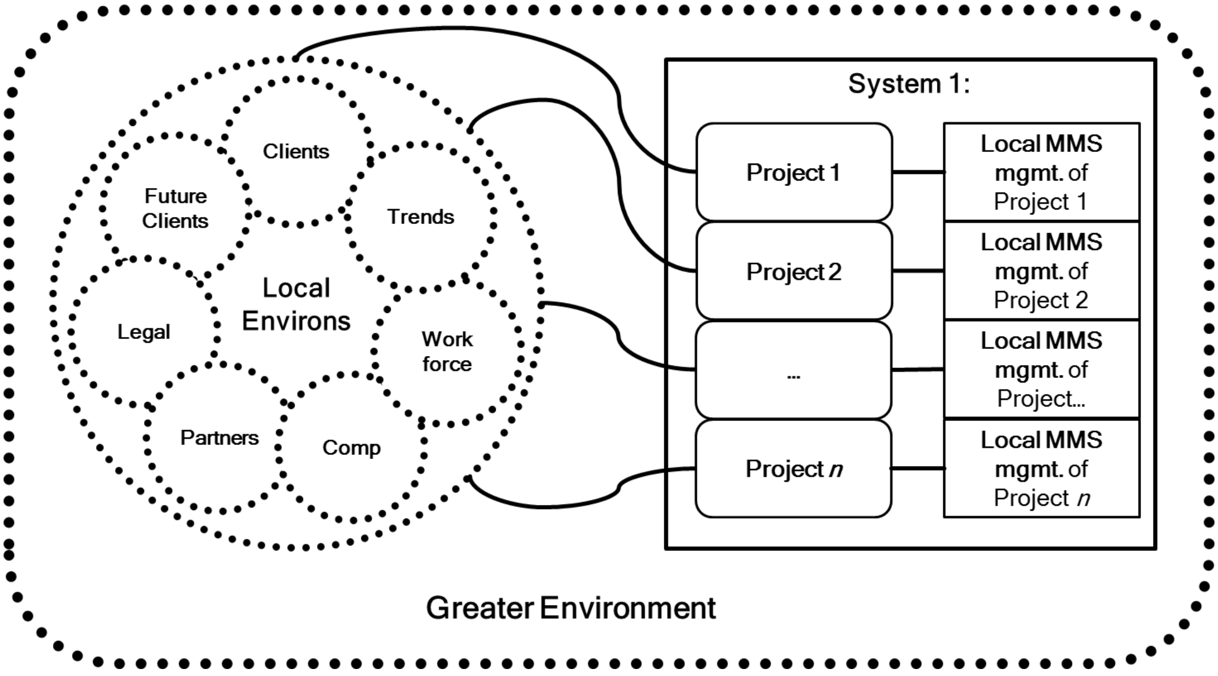

Figure 6: The Viable System Model - System 1

Adaptability is ensured by allowing for local management, as illustrated in Figure 6. System 1 is where actual, productive work occurs. Systems 2-5 are concerned with monitoring, controlling, integrating, and directing System 1. Local management of System 1 components increase both the adaptability and variety on offer in the Viable System Model. The important aspects to enable this functioning, is an understanding of which elements can be monitored, which can be coordinated and controlled, which can be planned for; and from which locations within the Viable System Model these functions can be delivered.

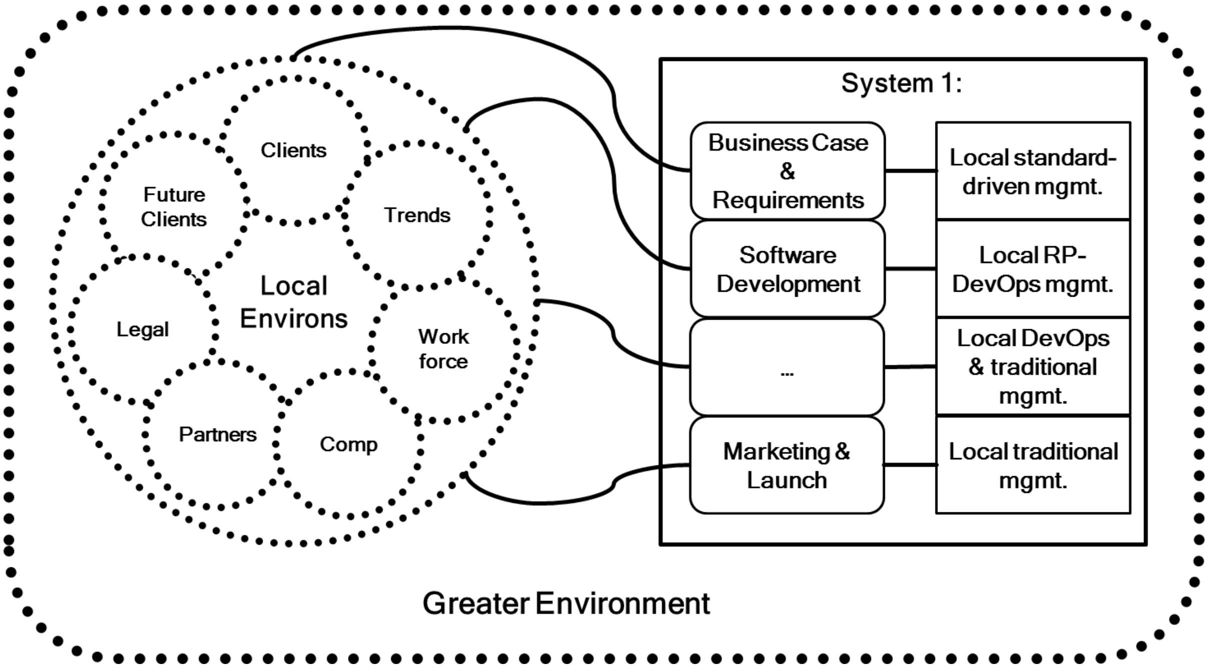

Figure 7: Multi-Methodology View of Viable System Model for a Project

Furthermore, it is important to note that none of the systems 2-5 are supposed to become viable systems individually, but System 1 – the project delivery function in this case – may become a viable system. Herein lies a particular antidote to autopoiesis which manifests as bloated support functions and middle management in practice.

In terms of IT project management, the project is per definition a temporary organization with a defined goal. Project Management is the local management of projects. In order to adhere to the Viable System Model idea, projects are to be locally managed employing Multi-Methodology Systems, as part of System 1. Autonomy needs to be allowed for project stakeholders to take decisions on the project management approach and best immediate responses to signals from the environment. The control of the project therefore resides within the project.

Multiple methodologies for a project, with reference to the Viable System Model, is illustrated for System 1 in Figure 7. The significant components of the project are individually managed. The delivery of the components is coordinated and audited, at the project level, as illustrated in Figure 5.

The project being a temporary organization that may become a viable temporary system – in and of itself – aligns with the assertion [47] that the application of project management approaches should progress from hybridizing an organizational project management approach to hybridizing an approach for the individual project.

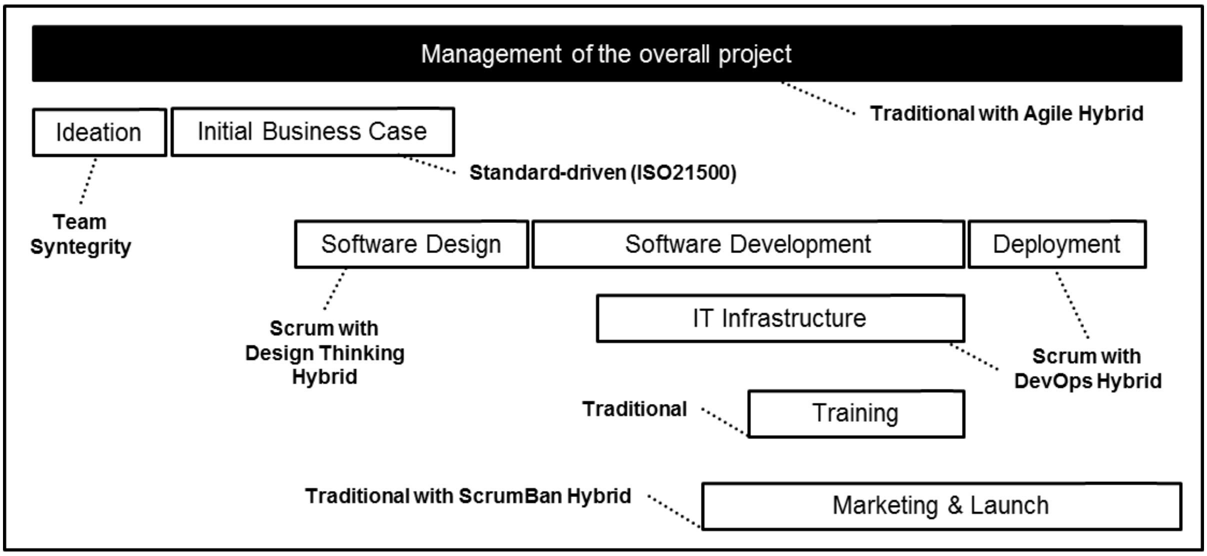

Figure 8: Multi-Methodology View

How does the Viable System Model translate to an approach to IT project management in SA banking? An average IT project in SA banking may be complex in the sense that it presides over the integrated delivery of multiple and disparate streams of work, as illustrated in Figure 8. Therefore, multiple methodologies are required for the components, or streams, of the complex project. A more detailed account of the content in this section can be found on pages 105-112 of the thesis (https://scholar.sun.ac.za/handle/10019.1/124580) from which this paper is redacted.

The result is a Viable Temporary System Model of the project that allows for the use of multiple methodologies in the delivery of an individual project. In order to enable the utilization of multiple methodologies, a Methodology Comparison Tool was proposed to enable the comparison of project management methodologies for mutually inclusive and exclusive characteristics.

6 COMPONENTS OF THE MULTI-METHODOLOGY SYSTEM

The Multi-Methodology System consists of the Viable Temporary System Model, a framework for the clustering of project work, a Methodology Comparison Tool and hybridization approach, and a method for the network arrangement of project work. These components are discussed in detail in the thesis of the originating study [6] and are only overviewed at a high level below.

The clustering of project work is a framework by which project work can be assessed and grouped into portions requiring similar management approaches. Aided by the Methodology Comparison Tool, individual, unique methodologies can then be customized for these portions of project work.

6.1 The Methodology Comparison Tool

The Methodology Comparison Tool prompts the assessment of the characteristics of project work, and the answers to the posed questions produce a decision path, as illustrated in Figure 9 and Figure 10.

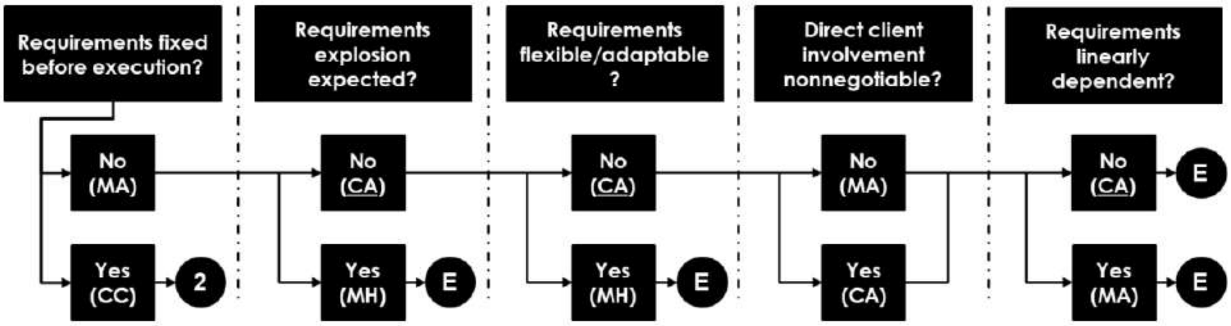

Figure 9: Methodology Comparison Tool Decision Path (1)

The decisions have the following outcomes:

- ‘Must Agile’ (MA) for a characteristic that demands an agile project management approach.
- ‘Can Agile’ (CA) for a characteristic that does not preclude an agile project management approach.
- ‘Must Waterfall (MW) for a characteristic that demands a waterfall project management approach.
- ‘Can Agile’ (CW) for a characteristic that does not preclude a waterfall project management approach.
- ‘Can Agile or Waterfall (CC) for a characteristic that does not preclude agile or waterfall project management approaches.
- ‘Must Hybrid’ (MH) for a series of characteristics demanding both agile and waterfall project management approaches.

The decision process as described above provides guidance in choosing a base methodology. This process can then be repeated at deeper detail as it pertains to the mutually exclusive and hybridisable characteristics between methodologies.

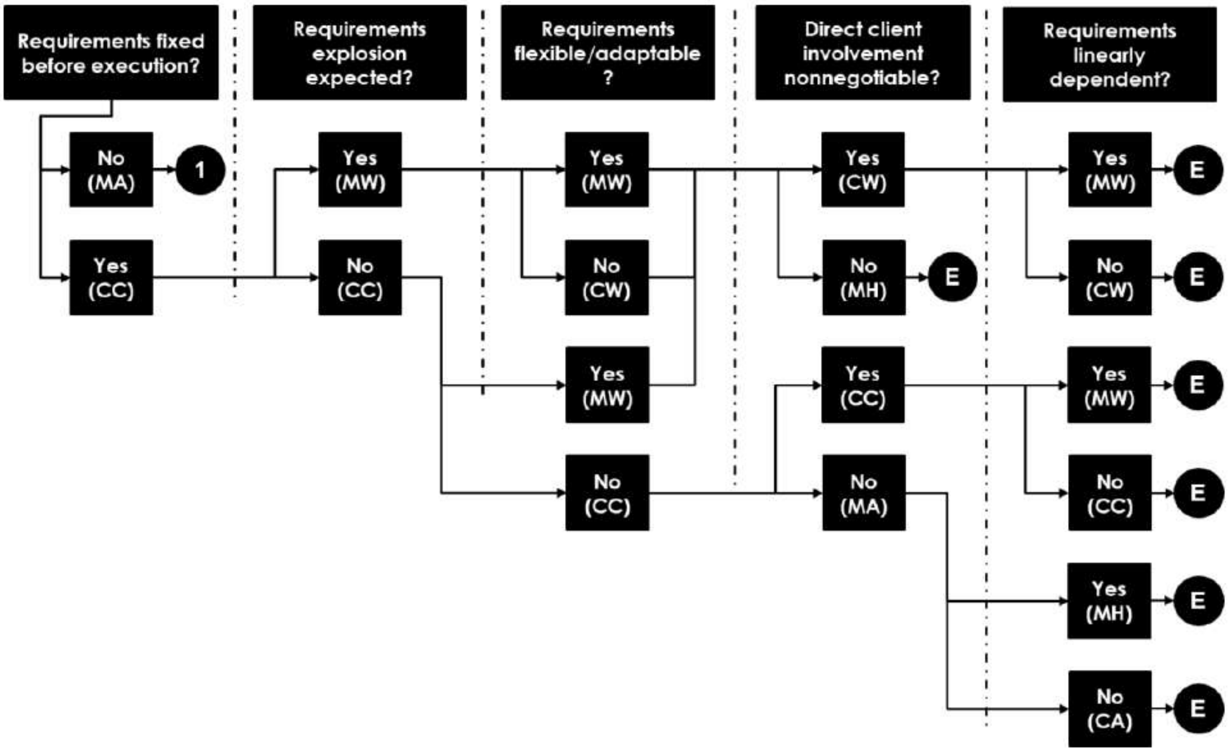

Figure 10: Methodology Comparison Tool Decision Path (2)

A more detailed account of the content in this section can be found on pages 119-132 of the thesis (https://scholar.sun.ac.za/handle/10019.1/124580) from which this paper is redacted.

6.2 The Network-Arrangement of Project Work

In order to integrate project delivery across multiple portions (or streams) of work individually delivered by unique methodologies, it is proposed that lean governance would focus on the resources, information, and artefacts that flow inter- and intra-project between different 'units' of work. These units of work are loosely defined as being similar to the traditional 'work package' or agile 'sprint'.

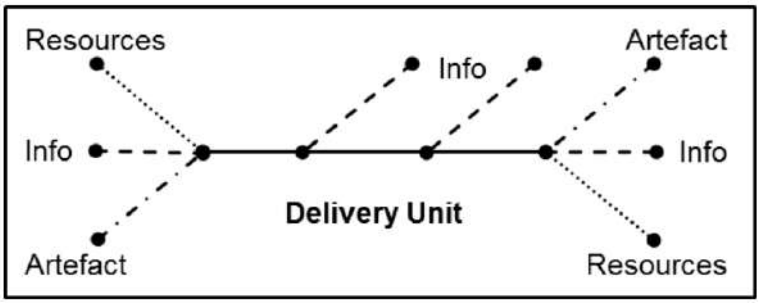

Figure 11: Network Arrangement of Delivery Units

Referring to Figure 11, it is argued that the flow of resources, information, and artefacts between delivery units presents the fundamental nodes by which delivery throughout an entire portfolio can be network-arranged. A more detailed account of the content in this section can be found on pages 132-135 of the thesis (https://scholar.sun.ac.za/handle/10019.1/124580) from which this paper is redacted.

7 VALIDATION, DISCUSSION OF RESULTS, AND CONCLUSION

7.1 Validation of the Early, Conceptual Proposition by Peers

Figure 12 contains quantified qualitative feedback from three presentations of the early, conceptual proposition at two industrial engineering conferences. After the presentations and subsequent informal discussions, delegates were requested to fill out questionnaires. The questionnaires requested information relating to the delegates' project management related experience and qualifications. Furthermore, Likert Scale responses were requested to indicate if delegates understood the proposition as presented, if delegates estimated the proposition and the implied research as needed in project management theory and practice, and if the proposition was deemed potentially useful to the tailoring and hybridization of project management methodologies.

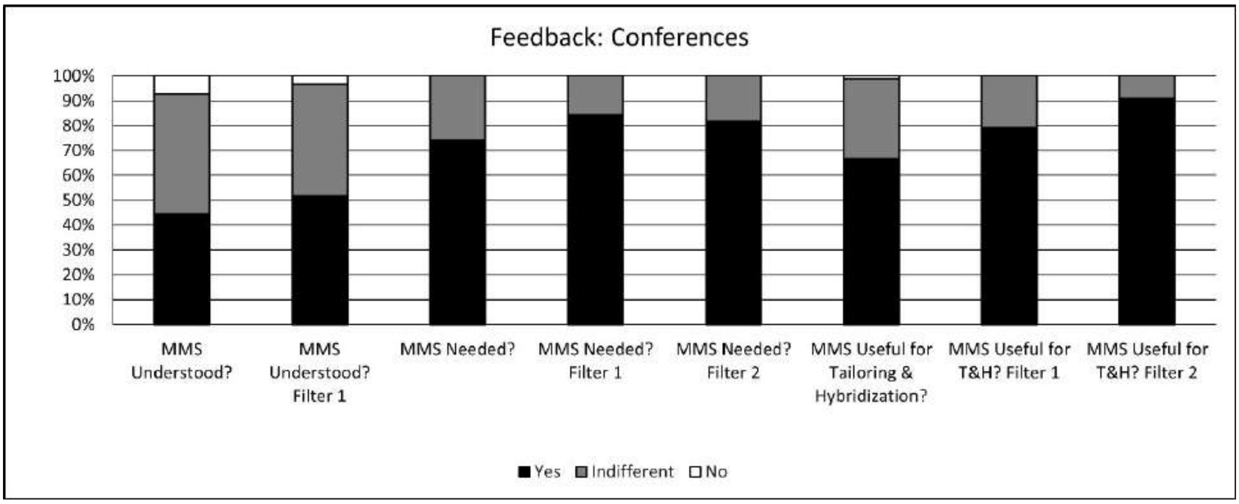

Figure 12: Feedback on Conceptual Proposition from Engineering Conferences

A first filter is applied to the feedback to select for respondents who had some project management education or qualification and were actively involved in project management. A second filter is applied to select for respondents who claimed to have understood the Multi-Methodology System as presented. This filtered sample's responses were expected to represent the most useful feedback.

Feedback returning mostly indifferent or negative responses would have presented a strong argument for halting or majorly redirecting the research. The feedback was mostly positive, and overwhelmingly positive after filtering the sample for respondents who were qualified and experienced in project management and claimed to have understood the proposition as it was presented. This feedback was interpreted as an indication that the early, conceptual proposition presented an opportunity for which further research and development were justified.

The discussion following the presentation (before the questionnaires were filled out) provided for the opportunity to gather informal feedback. The most common criticism was that the majority of responding delegates would prefer to see how such a proposition worked in practice over judging a conceptual presentation. Clarification of the unique value add of the Multi-Methodology System over existing approaches to project management were requested in all three sessions.

A more detailed account of the content in this section can be found on pages 74-76 of the thesis (https://scholar.sun.ac.za/handle/10019.1/124580) from which this paper is redacted.

7.2 Validation of the Multi-Methodology System Design Requirements by Practitioners

After this first validation, the propositions were further developed to produce the design requirements for a Multi-Methodology System as an approach to IT project management in SA banking. The design requirements were validated during one-on-one and small group sessions with IT project management practitioners in SA banking during which the design requirements were presented and explained. Structured (questionnaire) and unstructured feedback was requested from participants at the end of each session.

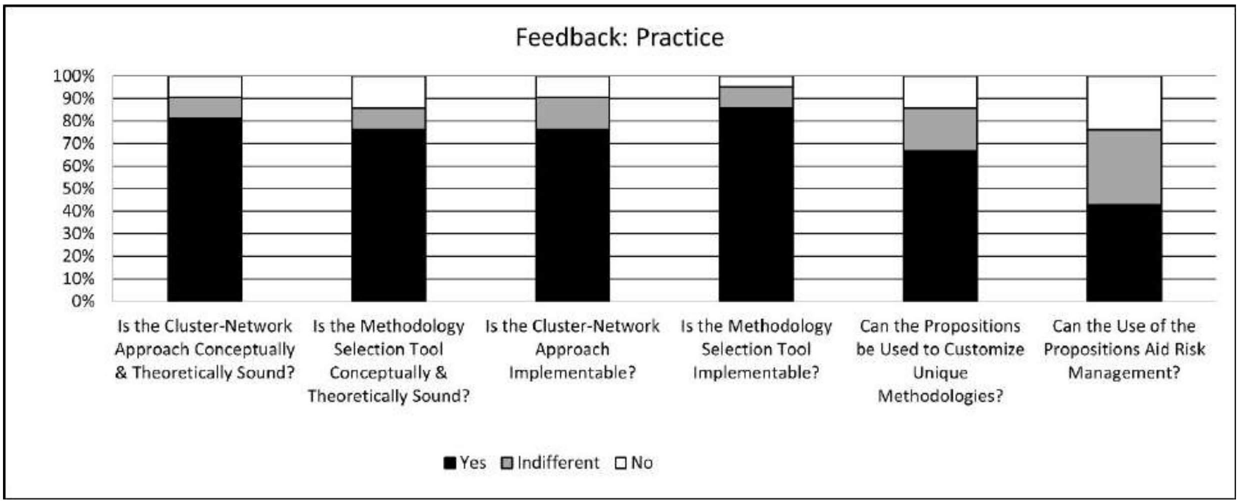

Figure 13: Feedback on Proposition from Practitioners and other Stakeholders

A sample of 21 practitioners participated in the validations. The quality criteria for the sample came down to ensuring good coverage of the major SA banks, an adequate range of key project stakeholders, IT project management experience, relevant education and qualifications. The sample represented 49 IT project practitioner and stakeholder roles, ranged from analysts to directors, and ranged from highly qualified persons to those who are largely self-taught.

The participants were asked if they understood the propositions, if the propositions seemed theoretically and conceptually sound, if the propositions seemed implementable, and if it could be used in the hybridization of unique methodologies. A 'control' question was added, relating to risk management. Nothing was mentioned relating to risk management during the validation session and it was expected that the response to the question should be significantly different from the other responses if participants were attentive and honest.

The feedback represented in Figure 13 was used to determine if the propositions were expected to be valuable to the theory and practice of IT project management and if further development for the implementation of the propositions in practice could be deemed as justified. The feedback was overwhelmingly positive and indicated that the proposed future actions and efforts were justified.

A more detailed account of the content in this section can be found on pages 162-186 of the thesis (https://scholar.sun.ac.za/handle/10019.1/124580) from which this paper is redacted.

7.3 Conclusion

This paper presented a Systems Thinking critique of predetermined project management approaches and methodologies which culminated in the propositioning and validation of the design requirements for a Multi-Methodology System as an approach to IT project management in SA banking. Following the positive validation, future work includes the further development of the Multi-Methodology System for implementation, testing, and further development in practice.

Moreover, this paper presents a clear example of the novel roles that industrial engineers can play within IT project management in SA banking. Hard Systems Thinking and the relating 'Iron triangle' measurements and improvements are well-established throughout the practice and research of project management [98]. Increasingly, there is the need and opportunity for the application of a more holistic systems-approach and multiple methodologies to project management in general [99], and to IT project management in SA banking in particular, as the case was herewith put forth.

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A CONCEPTUAL FRAMEWORK TO ANALYSE THE KEY SUCCESS FACTORS OF LOGISTICS SMES IN SOUTH AFRICA

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ABSTRACT

The study explores critical success factors for small and medium enterprises (SMEs) in the South African logistics sector. A conceptual framework is developed from extant literature to guide the qualitative exploration of the views, experiences and motivations of selected owners/senior management of logistics SMEs regarding the success factors for their companies. From a critical review of the literature, it is proposed that access to finance, business location, business planning, owner/manager skills and educational attainment, staffing decisions, customer relationship management and competitiveness are among several key factors in the internal and external environment, and owner characteristics, influencing the business success of logistics SMEs in South Africa.

Keywords: SMEs, logistics sector, business success factors

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1 INTRODUCTION

Small and Medium Enterprises (SMEs) play a significant role in global economic growth and development. In South Africa (SA) it is estimated that SMEs account for as much as 91% of formalised businesses and employ approximately 47% of the country's workforce [1], [2]. Furthermore, SMEs contribute more than 20% to the country's gross domestic product (GDP) and account for approximately 6% of payable corporate taxes [2].

Development and sustainability of SMEs is an area of increasing importance, as these businesses contribute significantly to the economy and play a vital role in reducing unemployment rates and improving wealth distribution.

According to the SME Landscape Report, South Africa is made up of relatively young businesses with approximately 60% of owners currently in operation for less than three years [4]. Almost 80% of small businesses fail within the first three years of operation [5]. Research suggests that the main obstacles for SMEs in developing countries is not their small size, but rather their isolation and lack of know-how, which hampers access to markets, critical information as well as financial and operational support [6]. SMEs generally do not attract professional degree graduates or experienced staff, and as a result develop their own set of processes and systems over several years [7]. As such, these businesses potentially have a wealth of knowledge and expertise to share, and it follows then that the factors contributing to the growth and success of SMEs should be investigated.

The purpose of this study is to identify key success factors of small to medium logistics businesses in South Africa. Logistics was chosen due to the ease of access to data, coupled with the fact that South Africa's logistics industry is one of the biggest contributors to the country's GDP [4], this study will focus on SMEs in the logistics sector. Only literature will be reviewed.

Objective of this paper is to develop a conceptual framework which provides a basis for further study of the logistics SMEs in South Africa.

2 METHODOLOGY

A systematic search of studies for review was completed by using keywords such as "logistics businesses in South Africa" and "business success factors of logistics SMEs" to search online databases. Databases that were searched include Wits LibGuides, ScienceDirect, Emerald Insight, ResearchGate, Google Scholar and MyScienceWork. Data from relevant studies were extracted and categorised, which categories are presented as sections that follow. These include definitions and classification, importance of SMEs, the logistics industry, business success factors for SMEs, among others. To ensure the literature review is comprehensive and unbiased, as many sources as possible that could be found matching the keywords were extracted, in total 75 sources were found and referenced across multiple scholarly journal articles, conference papers, newspaper articles, academic reports, websites and textbooks. Patterns were sought in the data for common agreement on themes.

The data were categorised into key themes developed from the literature and used to develop a conceptual framework. The way this was done is explained later in the paper.

3 LITERATURE REVIEW

3.1 SME Definition and Classification

SME definition and classification varies based on the economic size of countries [8]. Due to the diversity of these businesses, most countries accept that the number of employees is a common measurement of SMEs definition. The South African National Small Business Amendment Act defines a small business as "a separate and distinct entity, including co-operative enterprises and non-governmental organisations, managed by one owner or more which, including its branches or subsidiaries, is predominantly carried on in any sector or subsector of the economy [13]". SMEs are further classified by industry and economic activities carried out by the firm. SMEs that focus on logistics operations form part of the transport, storage and communication category as outlined by the Standard Industrial Classification [14]. Principal parameters for classification of these SMEs include total full-time equivalent of paid employees and total annual turnover. Only SMEs operating in the formal sector will be considered for this study. This refers to all medium, small and very small businesses as classified in accordance with the South African National Small Business Amendment Act.

3.2 The Importance of SMEs

SMEs are considered the "lifeblood of modern economies" [15]. These businesses stimulate and advance the development of entrepreneurship, industry and the economy [16]. Research shows that the economic growth of a country is closely linked with SME development [16]. In relation to this, a study conducted by Moodley [17] explains that SMEs are important because of their potential for job creation and wealth distribution, which in turn enhances the developmental activities of a country. Due to their size and informal structures, SMEs are flexible and can therefore provide a variety of goods and services, some of which larger organisations are not able to provide to consumers [18]. This ultimately improves the competitiveness of countries on a global platform. Further, SMEs can be viewed as incubators for entrepreneurial talent and new ideas because they provide a platform for innovation and diversification through the development of new and unsaturated sectors of the economy [19].

3.3 The Logistics Industry

Logistics can broadly be described as the management of flow of goods such as equipment, food and inventory from point of origin to point of consumption [20]. As such, the logistics industry provides services that no modern society can do without and is an essential function in business. The main aspects of logistics are packaging, storage and transportation, which is underpinned by information flows from the materials handling process through to delivery at final destination [20].

3.3.1 The South African logistics environment and SMEs

With a sophisticated logistics infrastructure relative to that of other African countries, South Africa acts as a valuable gateway to sub-Saharan Africa. A study conducted in 2018 by Stellenbosch University in conjunction with the World Bank estimates that the total annual turnover for the logistics sector in South Africa was approximately R480 billion, with the cost of logistics accounting for 11.8% of the country's GDP [21]. In 2018, The World Bank Logistics Performance Indicator (LPI) placed South Africa in the 33rd position out of 160 countries [22]. The LPI utilises a weighted average of the scores related to six criteria to measure a country's performance, namely, infrastructure quality, clearance process (including customs) efficiency, international shipments pricing, logistics quality and competence, tracking and tracing ability and shipment timeliness [22].

However, an industry study revealed that the current South African logistics environment is characterised by inefficiencies and poor service reliability, mainly related to underfunded government-owned infrastructure and an imbalance in freight flows between road and rail [23] As a result, businesses operating in the logistics sector face numerous challenges. The main challenges have been summarised as follows [23]: Maintenance and Infrastructure, technology adoption, skills shortage and labour unrest, and government support. Given that the country serves as a gateway to the Southern African Region, the growing need for transparent, flexible, and easily adjustable logistics services in South Africa offers numerous new opportunities to small business owners [24]. However, as the nature of this industry requires extensive planning and implementation of complex processes, coupled with the lack of skilled workers and ever-increasing costs of operations, small and medium logistics business owners are often faced with numerous challenges and barriers to success. This highlights the need for additional research relating to the survival of logistics SMEs in South Africa and further supports the purpose of this study.

3.4 Business success factors for SMEs

Pasanen [25] explained that the success factors of SMEs can be measured by five factors, namely, the firms age, growth in terms of turnover, the owner/managers self-evaluation of business success, the owner/managers satisfaction of business success, and the firms competitive power in the market. Lussier and Pfeifer [26] attributed success to the ability of the business to survive, that is, in order to be classified as successful, businesses should generate an industry-average profit for the previous three years of operation. In general, business success is often related to a company's financial performance and sustainability [27]. As such, for the purposes of this study, business success will be linked to two aspects: 1) financial profitability (businesses operating with a positive revenue after all costs and expenses related to the business activities have been paid) and 2) business sustainability (businesses operating in the industry for five years or longer). It is noted that the extant literature related specifically to logistics SMEs in this field is scarce, providing further rationale of this study.

3.4.1 External factors

External factors relate to all aspects of the business which cannot be controlled and influenced by the firm's actions. Simpson et al. [28] explained that factors external to the company may facilitate or hinder SME business success. Further to this, Dahlqvist et al. [29] found that external factors present opportunities and threats which affect all entrepreneurs operating within that environment, despite their business area of interest, background or education. External factors in relation to the South African environment include access to funding and capital, availability of skilled workers, government support, public infrastructure and market conditions [30]. In South Africa, a pertinent aspect with regard to external factors is that of access to resources and government support. Nasser et al. [31] explains that government support programs play a vital role in ensuring SMEs get the support and knowledge required to facilitate growth and sustainability. In South Africa, even though support is offered in terms of incentive programmes to encourage the founding of new small businesses SMEs generally have limited knowledge relating to how to access them as information regarding these support mechanisms is not easily retrievable [32], [33]. To gain access to these programs, small business owners are often faced with complex application processes only to realise that these programs offer minimal flexibility and are insufficient or inadequate for actual SME needs [34], [35].

3.4.2 Internal factors

Dockel and Ligthelm [36] explain that internal business environments are of considerable concern as 65% of SME failure can be attributed to firm-based deficiencies [36], [37]. Internal factors relate to all aspects of the business which are controlled and influenced by the firm's actions and have a direct impact on business success [34], [38]. These include but not limited to staffing decisions, use of professional services, business planning (business plan and the goals of the firm), cashflow management, record keeping, new technology adoption, competitive strategy and customer relationship management (CRM).

3.4.3 Owner/Manager Performance

Wickham [39] expressed that entrepreneurial performance results from a combination of industry knowledge, general management skills, people skills and personal motivation. Entrepreneurial performance can also be described as the human capital of the owner. Human capital is also considered an asset or resource [40]. Even though it is categorised as an internal factor, a considerable amount of literature reviewed advocates that the human capital of the entrepreneur, such as business skills, capabilities, previous experience and personal characteristics is central to influencing development, survival, and competitiveness of SMEs [30].

3.4.4 Related work

Various authors have considered factors leading to SME business success, in varying contexts, that this study can draw from in considering concepts applicable for logistics SMEs in South Africa. Ibrahim and Goodwin's [41] study of the aspects contributing to success of SMEs indicated that entrepreneurial behaviour and managerial skills were the principal elements of business success. Lussier [42] developed a theoretical model to predict the success versus failure of SMEs and identified 15 factors, namely adequacy of start-up capital, record keeping and financial control, industry experience, management experience, business planning, availability of professional advisory, business owner education, staffing quality, product/service timing, economic timing, business owner age, existence of business partners, business-owning parents, minority business owner and marketing skills. Lussier and Halabi [43] tested the model and results indicated that there were significant correlations between the success variables identified in Lussier's model with an interesting finding that small business owners tend to rarely seek help from professional advisors. Lussier's original theoretical model was subsequently modified to include the internet as an influencing factor in business success.

Kuratko and Hodgetts [44] identified four factors of SME success, namely the existence of a business opportunity, the management ability of the owner/senior managers to skilfully allocate scarce resources across the organisation to meet business requirements, capital investment and access to credit, and the use of modern business methods. Ndwandwe [45] supports this notion and reports that SMEs are severely impacted by South African banks' risk averse approach to funding. This is also reported elsewhere as Zairani and Zaimah [46] find similar stance with banks in Malaysia.

Ghosh et al. [47] find that SMEs attributed their success to satisfying customer needs, a close working relationship between the top management and employees, regionalisation, leadership and availability to financial and technological resources and support. Muriithi [48] explored qualitatively the role played by African SMEs and identified the following key factors for business success, namely, creation of policies enabling SME development supported by appropriate legal framework, business infrastructure, continual power supply and accessible financial supply. Chittithaworn et al. [6] conclude that SMEs characteristics, the way of doing business, focus on the customer and market, access to resources and finance and the external environment were the main factors related to business success.

Benzing et al. [49] studied firms among Turkish entrepreneurs and found that owner's honesty and friendliness, social skills and good customer service were perceived as important determinants in relation to business success. The study also identified that the prevailing complex tax structure, unreliable employees, the inability to maintain good records and a weak economy were the most challenging aspects for these businesses. Hussain-Naqvi [50] used the studies of Benzing et al. [49] and the Asian Development Bank [51] to conduct a qualitative inquiry on the critical factors of failure and success of SMEs based in Pakistan and identified the principal success factors as customer service, knowledge of business and the past experience of managers. The principal failure factors were identified as a lack of access to financial capital, inappropriate government support, poor infrastructure and corruption.

Lampadarios [63] carried out a study among SMEs operating in the chemical manufacturing industry in the UK using qualitative data from owner/senior managers and found that customer relationship management, market and product development, human capital and strategic planning were the most important factors of success for chemical manufacturing SMEs in the UK.

Lumbwe et al. [52] explain that location decisions are a critical factor which provides various opportunities and sometimes threats, which often appear as business advantages or impediments. The study found that the starting point of many SMEs are based on informal decisions, such as the hometown of the business owner, and change as the business develops and grows. Lumbwe et al. [52] advocated that owners and managers must pay careful attention to the location decisions and identified that electricity affordability, customer flows, safe and healthy areas of business as well as business performance were all influencing elements of location decisions.

Neshamba [53] conducted a study amongst Kenyan Entrepreneurs which suggested that the owner-manager's previous experience, access to capital and understanding the needs of customers were critical success factors. In support of this, Pratt's [54] investigation of Kenyan entrepreneurs found that previous experience and business skills, availability of capital and support of family members are key factors in relation to business success.

In the South African context, Rogerson's qualitative [55] study of successful clothing manufacturing SMEs based in Gauteng, South Africa yielded five factors linking to successful SME development in post-apartheid South Africa. These are summarised as follows, namely, enterprises have a better chance of success if they are created because of a demand-pull rather than push; business location plays an important role in terms of business development; education and training are positive influences and ultimately enhance strategic decision making; immigrant entrepreneurs, particularly those from outside the Southern African Development Community, were highly skilled, well-educated and well connected in terms of global networks; and business clusters promote a cooperative and competitive environment as the potential for joint action, positive learning and replication are improved.

Another study by Rogerson [56] concludes that three crucial aspects for SME success were those which were aligned to organisational structure, the adaptiveness and strategic learning of enterprises and most importantly, the capabilities and aspirations of the entrepreneur.

Aigbavboa et al. [57] conducted a quantitative study to explore the critical success factors necessary for the survival of construction SMEs in Gauteng, South Africa. Their findings indicated that perceived critical success factors for business were, namely, good quality of work, good cash flow management, contractual understanding, having a business plan, an effective communication channel in the organisation, maintaining good relationships with clients, proper record keeping, recruiting qualified staff and availability of effective marketing strategies.

Ramukumba [58] conducted a study among SMEs in the Western Cape and the results ranked the SMEs owner's views of identified critical success factors as follows, the ability of the SME to attract repeat customers; product performance; generate enough cash; advertising & promotion; skilled workers; and competitive pricing respectively. A compelling finding of this study indicated that skilled workers are viewed as non-essential to business success in the SME sector. The study inferred that the skills deficit in South Africa makes it challenging for these businesses to attract and retain highly skilled employees therefore SMEs are more likely to employ a low-skilled labour force [58].

The SME Survey [59] has been conducted since 2003 and focuses on topics related to SME competitiveness and performance in South Africa. The latest available survey results from 2018 was based on the telephonic interview responses from 1400 South African SME decision-makers and included companies from various sectors. One of the focus areas of the survey was that of future technologies, which included artificial intelligence, big data, blockchain, IoT, 3D printing, virtual reality and crowdsourcing. The interpretation of this is that in order for SMEs to stay relevant and competitive they must be open to the adoption of new technologies. Of the sample, 70% of SMEs indicated that they are ready to adopt new technologies but only if it makes business sense. SMEs cautious approach is justified by the increased expenditure and cash flow constraints these businesses face when adopting and implementing new technological offerings.

The survey also aimed to examine the future of the accounting function and the role accountants play in these businesses. From a technological perspective, findings indicated that many SMEs still make use of outdated accounting solutions, as 27% reported using Excel spreadsheets for financial capturing and reporting. An interesting finding also revealed that while 86% of SME decision-makers hire accountants to fulfil the primary role of bookkeeping, a growing number, approximately 41%, rely on them for financial advice suggesting that there is a growing need for progressive financial services.

In the broader business environment, the top three external factors of concern for SME owners were that of the competition (46%), closely followed by South Africa's growing water shortage crises (a reaction to the announcement of the "Day Zero" water crises in Cape Town) and crime. Cash flow and recruiting the right staff were the top internal factors of concern.

3.5 Covid-19 Pandemic and the Effect on South African SMEs

Although this research aims to study the critical success factors under normal business conditions, the current COVID-19 pandemic and its effect on SMEs must be acknowledged. The pandemic has caused immeasurable human suffering across the world as well as severe business disruptions, particularly on small business. A recent survey conducted by McKinsey and Company [60] indicated a strong decline in business confidence and SME profitability in SA, with over a third of the small businesses surveyed indicting an expected revenue decline of between 5% - 50% between 2020 and 2021 and more than 40% of all SMEs already having to reduce capacity by laying off employees.

According to the survey, SMEs in South Africa are facing "unprecedented challenges" with many of the issues having been exacerbated by the ongoing pandemic. These have been summarised below [60].

Access to funding where 36% of respondents indicated that they were not receiving any government loans or funds as a means to support their business during this turbulent period. Other than not qualifying, the main reasons for this were that owners were not aware of the opportunities or did not know how to access the information needed to apply for business support.

Reduced demand were between 40% to 60% of respondents indicated that they expect to make a loss of more than 5% in the current financial year because of the ongoing crises.

Access to markets given that often, SMEs are overly dependent on a small number of clients. Due to the lockdowns that were imposed across the country, several SMEs highlighted the ongoing struggle to promote their business and connect with new buyers.

Staff empowerment. According to the survey, owners have struggled to empower employees and thus have difficulties relying on staff to lead and drive the business, especially during the "work from home" situation. This is because in most cases SMEs do not have clear day-to-day operating procedures with well-defined roles and responsibilities, making it difficult for employees to partake in the strategic decision-making process.

Cashflow management given that often, SMEs are highly dependent on clients honouring payment agreements and settling invoices on time because they have limited cashflow. Due to the pandemic, several SMEs reported severe cash flow constraints on the business stemming from a lack of adherence to payment agreements by existing customers.

The financial, operational and strategic structures that are prevalent in larger organisations are uncommon in SMEs and therefore many of these businesses lack the resilience and agility required to successfully deal with the difficulties imposed as a result of the COVID-19 pandemic. However, because of their critical role in job creation and growth, protecting and enabling small businesses during this period is critically important, particularly because their survival and development is likely to be a key driver for economic recovery. According to the survey, in order to support their survival and success during this turbulent period SMEs are focusing on the following areas: financial stability, access to new markets and customers, strong customer engagement, supply chain stability, workforce reliability and robust post-crisis strategies. In support of this notion the president of South Africa, Cyril Ramaphosa, stated that: "*If we are to achieve the goal of the National Development Plan for SMMEs to create at least 90% of the targeted 11 million new jobs by 2030, we need to pay far closer attention to developing small businesses* [61]."

4 RESULTS

The literature review served as an overview to key constructs of this study and consequently helps develop the conceptual framework. Existing literature from journals, textbooks, articles and business websites was reviewed to explore the factors influencing business success. For clarity, the key factors of SME success reviewed in the literature have been summarised in Table 1:

Table 1: Summary of Key Business Success Factors from Literature Review [Developed by Authors]

CATEGORY	SUCCESS FACTOR	LITERATURE REVIEW
Internal Factors	Age of firm	Pasanen [25]
	Record keeping	Lussier [42], Benzing et al. [49], Aigbavboa et al. [57]
	Competitive strategy	Pasanen [25], Ramukumba [58]
	Customer relationship management	Lampadarios [59], Ghosh et al. [47], Chittithaworn et al. [6], Neshamba [53], Benzing et al. [49], Hussain-Naqvi [50], Aigbavboa et al. [57], Ramukumba [58], McKinsey and Company Survey [60]
	Product/service quality	Aigbavboa et al. [57]
	Availability of skilled workers	Ramukumba [58]
	Marketing strategies	Lussier [42], Aigbavboa et al. [57], Ramukumba [58]
	Staffing decisions (hiring and reliability of staff)	Lampadarios [59], Lussier [42], Chittithaworn et al. [6], Aigbavboa et al. [57], The SME Survey [59], McKinsey and Company Survey [60]
	Adoption of new methods and technology	Kuratko and Hodgetts [44], Rogerson [56], The SME Survey [59]
	Cashflow and revenue management	Aigbavboa et al. [57], Ramukumba [58], The SME Survey [59], McKinsey and Company Survey [60]
	Staff empowerment	McKinsey and Company Survey [60]

CATEGORY	SUCCESS FACTOR	LITERATURE REVIEW
	Location decisions	Rogerson [55], Lumbwe et al. [52]
External Factors	Access to funding and capital	Lussier [42], Kuratko and Hodgetts [44], Ndwandwe (1998), Zairani and Zaimah [46], Muriithi [48], Chittithaworn et al. [6], Neshamba [53], Pratt [54], Hussain-Naqvi [50], Rogerson [56]
	Government support, policies and regulation	Muriithi [48], Hussain-Naqvi [50], Rogerson [56]
	Use and availability of professional services	Lussier [42], Rogerson [56], Aigbavboa et al. [57], The SME Survey [59]
	Market conditions/Business environment	Lussier [42], Chittithaworn et al. [6], Benzing et al. [49], Rogerson [56]
	Business planning and strategic decision-making	Lampadarios [63], Lussier [42], Rogerson [56], Aigbavboa et al. [57],
	Public infrastructure	Muriithi [48], Hussain-Naqvi [50]
	Access to new customers	McKinsey and Company Survey [60]
	Previous experience and Industry Knowledge	Wickham [39], Lussier [42], Neshamba [53], Pratt [54], Hussain-Naqvi [50]
Owner/Manager Performance	Skills and capabilities (management, social)	Ibrahim and Goodwin [41], Lussier [42], Kuratko and Hodgetts [44], Pratt [54], Benzing et al. [49], Rogerson [56], Wickham [39]
	Educational Attainment	Lussier [42], Rogerson [56]
	Family background and support	Lussier [42], Pratt [54]
	Motive for starting the business	Kuratko and Hodgetts [44]
	Aspirations	Rogerson [54]

The study of existing literature revealed that the subject matter is both complex and inconsistent as business success can be attributed to a diverse range of influencing factors. From the literature review, it is evident that researchers do not unanimously agree upon the factors that contribute to the success of SMEs. This is largely driven by differing perspectives of success and the complex interrelated nature of these factors [6]. The considerable variation of literature regarding this field of study further emphasises the challenges small businesses might encounter in trying to understand how to focus their efforts to create sustainable enterprises. In addition, the literature is not clear if these factors are industry-specific or applicable to SMEs in all sectors.

4.1 Framework Design

Miles and Huberman [62] describe a conceptual framework as the researcher's map that explains the main aspects to be studied. A conceptual framework can take a graphical or narrative form. It is intended to guide the researcher's objectives and can evolve over the course of the study.

The conceptual framework draws on the prominent themes presented in the literature review. As outlined in the previous sections, there are various factors which contribute to business success of SMEs. To clearly present the context of this study the success factors of SMEs were grouped into three categories, namely: External factors of success, internal factors of success and the owner/managers performance.

A graphical representation of the high-level conceptual framework is displayed in Figure 1.

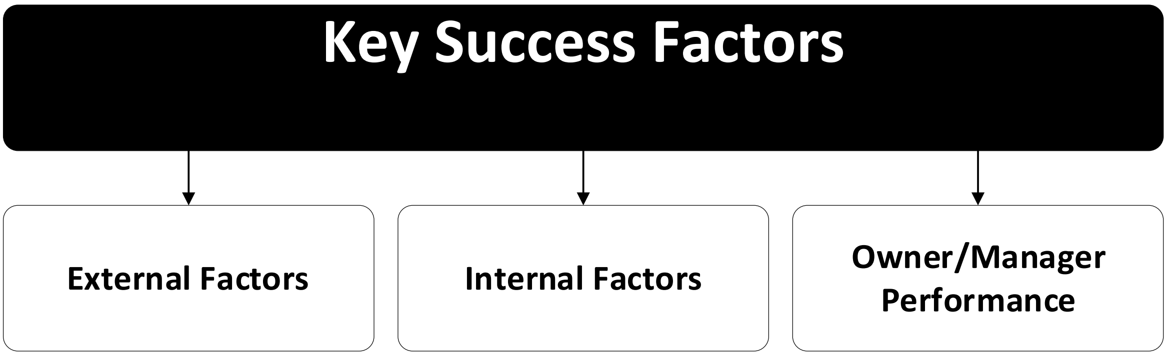

Figure 1: Framework for Study [Developed by the Authors]

There is no universally agreed framework for conducting research in the field of SME success ([42],[28]). The underlying support and foundation for framework is based on the extant literature and originates from a number of influential studies and models in the area of SME success that have been conducted across various geographical regions and industry sectors, including that of Lussier [42] and Lampadarios [63].

4.2 Conceptual Framework

Through an amalgamation of existing theories on business success factors and with a focus on logistical considerations, the factors shortlisted for further consideration in this study have been graphically presented in **Error! Reference source not found.** 2.

The conceptual framework does not serve as an exhaustive list of success factors, but rather to illustrate the focus of the study, which is aimed at investigating if the factors identified from the literature reviewed positively influence the business success of logistics SMEs in South Africa. As such, the conceptual framework can be used as a tool for data collection.

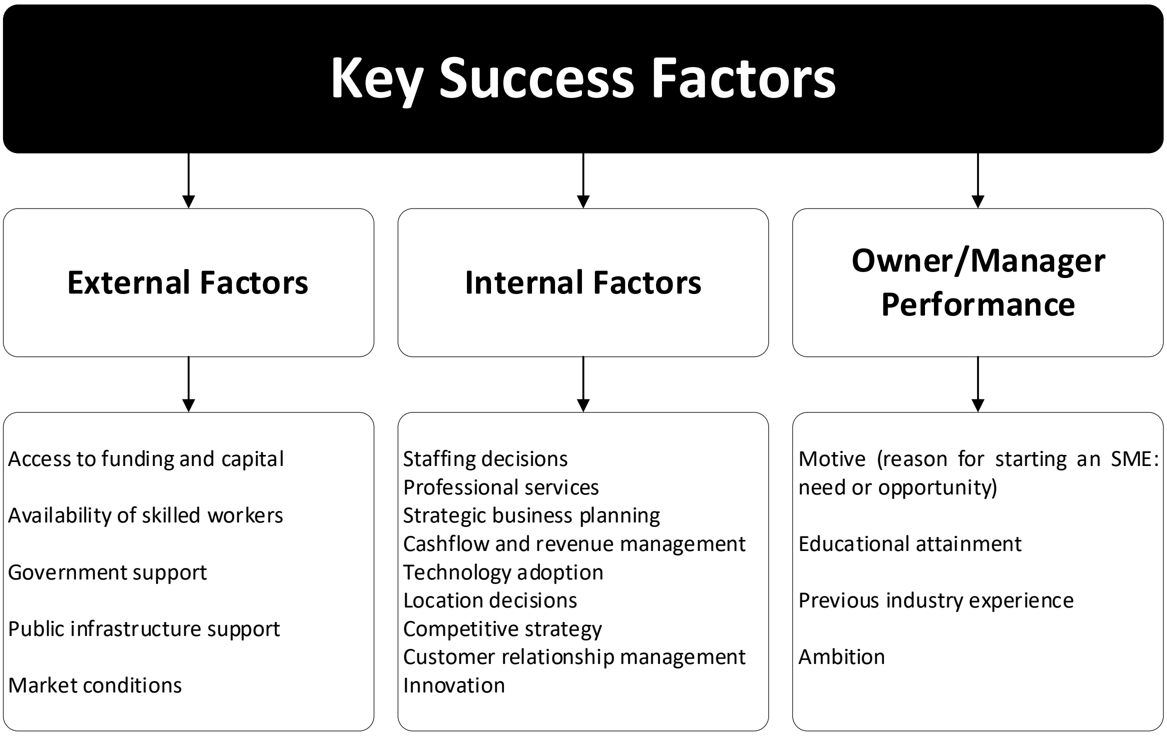

Figure 2: Conceptual Framework [Developed by Authors from an Amalgamation of the Existing Literature]

5 CONCLUSION

For the researcher to become familiar with relevant concepts a review of the existing literature related to SME success factors was undertaken. This served as a starting point for further development of this research study. The literature study achieved the following: clarifying key definitions and concepts used in the study; underlining the importance of SMEs in South Africa; providing an overview of the South African logistics industry (section 3.1 and 3.3.1); identifying previous research studies on SME success. This enabled the development of the conceptual framework, in which relevant factors of business success were identified from related works. The conceptual framework suggests that access to finance, business location, business planning, owner/manager skills and educational attainment, staffing decisions, customer relationship management and competitiveness among several other key factors influence the business success of logistics SMEs in South Africa. This provides the basis for data collection and analysis. Hence the stated objective of the paper was achieved.

Further, in identifying key success factors from the literature, it was noted that researchers do not unanimously agree upon the factors that contribute to the success of SMEs, as there is wide divergence of opinions. This state of affairs is unhelpful to SMEs that wish to receive practical advice on how to achieve success and want to be guided where they should focus their efforts. Moreover, the several factors identified in the literature may not all be relevant to different settings and may be industry specific. In line with this grey area identified, the paper advocates further investigation of these factors, particularly to establish whether they are applicable to success of logistic SMEs in South Africa.

Due to the time constraints of this investigation, a cross-sectional design is envisaged to allow collection of information at a single point in time and enabled completion of the study within a few months [65].

At the time the study was undertaken, no statistics could be found regarding the number of logistics SMEs in South Africa. An accessible population to the researcher will then be considered.

For future work, it is proposed that the framework be tested among selected owners/senior managers of logistics SMEs regarding the success factors for their companies, with deductive reasoning being employed. A review of other studies in this field which made use of a deductive qualitative approach for confirmatory and explanatory analysis purposes further supported the use of a similar approach for further study of this research. This included the work of Lampadarios [42], in which the collection of qualitative data was based on pre-determined factors to confirm if the general theories of success factors were applicable to SMEs in the UK chemical industry. Another study conducted by Eriksson and Li [64] made use of a structured approach in which preliminary theories and concepts on success factors were used to guide the research and the data collection process in order to describe and analyse some of the factors that influence the success of entrepreneurial SMEs in the Gnosjö Municipality in Sweden.

Among questions that are suggested for further investigation include the following:

- Which are the most relevant factors for success of logistic SMEs in SA?
- Are the factors absolute or are they interrelated? If interrelated, to what extent and between which factors?
- Are the factors to be pursued sequentially or simultaneously?
- How significant are each of the factors identified for success of logistic SMEs in SA?
- How important is the role of Government support for logistic SMEs in SA, as this is often touted as a make-or-break enabler for SME success in general?
- How do logistic SMEs in SA deal with external factors that are beyond their control?

The outcome of investigations to questions above and others related to them would provide a firm basis for confirming or modifying the conceptual framework proposed in this paper and lead to well-supported practical recommendations to logistic SMEs in SA on how to achieve business success.

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A SYSTEMATIC LITERATURE REVIEW ON PRESCRIPTIVE ANALYTICS IN INDUSTRIAL ENGINEERING APPLICATION DOMAINS

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ABSTRACT

Business analytics and the application thereof have received considerable attention over the last few years due to the increasing complexity linked to decision-making processes. These methods assist organisations in driving decisions while creating business value. According to the literature, the academic domain focuses mainly on descriptive and predictive analytics. For this reason, prescriptive analytics is the primary focus of this study. Prescriptive analytics is linked to the decision-making process and is concerned with making an optimal decision while considering different business constraints. This study aims to investigate the existing literature on prescriptive analytics in industrial engineering application domains by conducting a systematic literature review. The categories investigated in this study include probabilistic models, machine learning, mathematical programming, evolutionary computation, simulation and logic-based models. The study will contribute to research by identifying prescriptive analytics current applications in the literature, the shortcomings of this field and potential future research opportunities.

Keywords: Business analytics, prescriptive analytics, systematic literature review

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1 INTRODUCTION

For years' big data has been a subject matter among many academics and practitioners [1]. Big data analytics enhances an organisation's competitiveness, innovation and productivity [2]. Analytics is divided into two primary sections: Business intelligence (BI) and advanced analytics (AA). Business intelligence is concerned with reporting and queries. Advanced analytics, also known as business analytics, is concerned with implementing modelling techniques to recognise patterns in big data [2].

Business analytics applies methods from operations research, machine learning and information systems for optimal decision-making [3]. Business analytics is divided into three main stages: descriptive, predictive, and prescriptive. Descriptive analytics addresses the question of "What had happened? Predictive analytics addresses "What will happen?" and prescriptive analytics addresses "Why will it happen?" [4]. All of these questions are answered using extensive data.

Lepenioti et al. [4] stated that descriptive analytics recognises patterns in historical data. Furthermore, these patterns can detect problems or potential opportunities for the organisation. Predictive analytics predicts if an event will occur based on the patterns recognised by descriptive analytics.

Prescriptive analytics provides proactive decision-making based on the results obtained from predictive analytics [4]. Prescriptive analytics takes the output of predictive analytics and applies artificial intelligence, optimisation algorithms and many more methods to make the optimal decisions and provide valuable future recommendations [4]. All three analytical stages are crucial to creating business value and should be used together.

Descriptive and predictive analytics are widespread in academic literature. However, there is a limit to the application of prescriptive analytics [4]. For this reason, this study aims to investigate existing literature on prescriptive analytics in various industrial engineering application domains. By conducting the proceeding, limitations and gaps in the literature can be identified, followed by valuable future recommendations. Lepenioti et al. [4] provided an overview of the different methods applied in predictive and prescriptive analytics, as demonstrated in Figure 1.

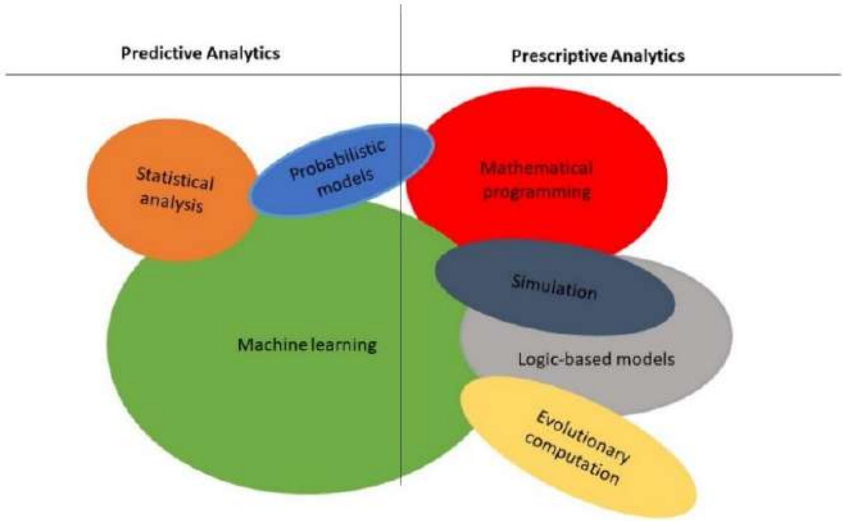


Figure 1: An overview of predictive and prescriptive analytics [4]

Statistical analysis is mainly seen as predictive analytics. In contrast, machine learning and probabilistic models are both predictive and prescriptive. However, mathematical programming, simulation, logic-based models and evolutionary computation are defined as prescriptive analytics.

According to Larson and Chang [5], prescriptive analytics has gained more attention in the literature over time. Prescriptive analytics is seen as the next step in increasing the maturity of business analytics [4]. In order to achieve the aim of this study, the following objectives are identified:

1. Provide a detailed overview of business analytics, including descriptive, predictive, and prescriptive analytics and the applicable methods.
2. Conduct a systematic literature study on prescriptive analytics in different industrial engineering application domains.
3. Identify the need and provide valuable future recommendations based on the results.

This study provides an overview of prescriptive analytics and a detailed discussion of the applications of these methods in the academic literature. An overview of prescriptive analytics is provided in Figure 2.

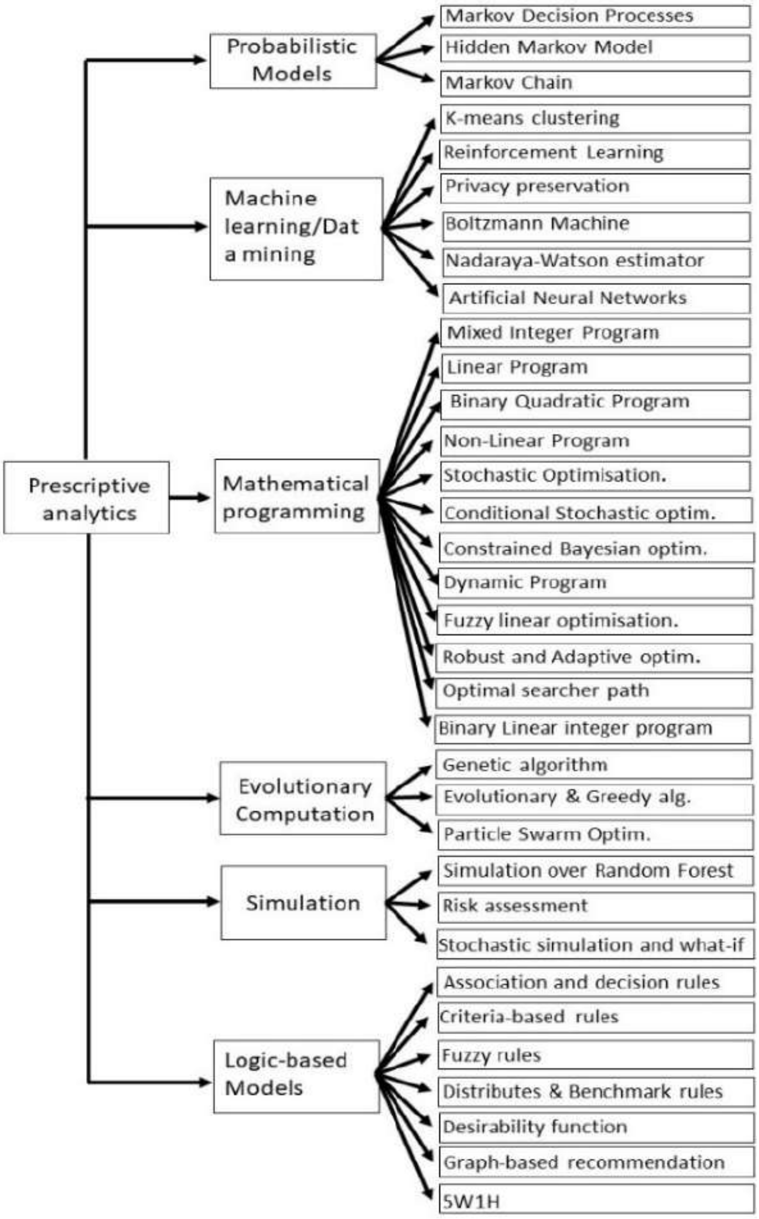


Figure 2: An overview of prescriptive analytics

Each prescriptive method is described in detail, as explained by Lepenioti et al. [4]:

Table 1: Prescriptive analytics methods

Method	**Description**
Probabilistic Models	Probabilistic models include uncertainty between causal relationships [4]. These methods are also known for predicting the probability of an event occurring and are not necessarily based on historical data. Markov decision processes, Markov chains and hidden Markov models form part of probabilistic models.
Machine learning	Machine learning is defined as a subset of artificial intelligence. Machine learning consists of supervised, unsupervised, semi-supervised and reinforcement learning. These algorithms are built and trained using historical data to address classification and regression problems. Machine learning algorithms learn from the data. Therefore, the data must be prepared and pre-processed before applying it to the algorithms. Patterns are identified in data sets, and these evaluations are used to make predictions. Examples of machine learning algorithms include the random forest, the decision tree, K-neighbor, and artificial neural network. Machine learning is applied in the petroleum industry [6] and forecasting and customer segmentation [7].
Mathematical programming	Mathematical programming is a subset of mathematics, operational research, and management science. These models are formulated to allocate resources while maximising profit or minimising cost. The model consists of an objective function subject to various constraints and is applied in multiple industries. Mathematical programming includes stochastic optimisation, linear and non-linear programming, and integer programming. Mathematical programming is used in optimal brochure pricing [8] and low carbon economy [9].
Evolutionary computation	Evolutionary computation algorithms are applied to solve problems in data-rich environments. Evolutionary computation is defined as a subfield of artificial intelligence. It is an algorithm used for global optimisation and is mainly inspired by biological evolution [10]. Evolutionary computation includes generic algorithms and the particle swarm algorithm. For an example of evolutionary computation, refer to [11] for data-driven optimisation in the industry.
Simulation	Simulation is typically done on a specific software where the reality or a real-life situation is modelled. Simulation modelling is used to evaluate a situation's current and future state by changing variables in the system. According to Lepenioti et al. [4], simulation is used primarily in prescriptive analytics, safety, quality, and design. Type of simulations includes stochastic simulation, what-if analysis, and risk assessment simulation. Simulation is applied for product portfolio design [12] and complex event processing [13].
Logic-based model	Logic-based models include rule-based systems and domain knowledge that assist with optimal decision-making. Logic-based models include fuzzy rules, criteria-based rules, and graph-based recommendations.

A systematic literature review is conducted in Section 2 to identify the existing prescriptive analytics methods in the academic literature.

2 A SYSTEMATIC LITERATURE REVIEW

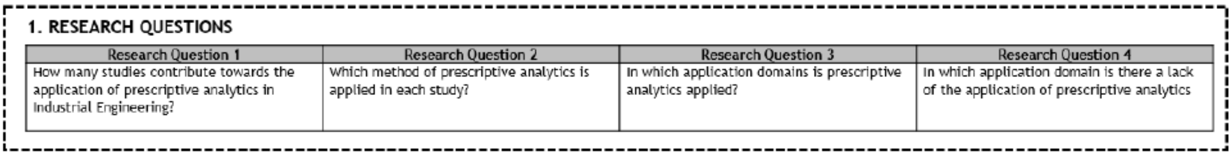
A systematic literature review was first applied in the medical industry. It was stated that results obtained from scientific experiments were more reliable than opinion-based results. This study provides an overview of current research and is identified as a secondary research study [14].

2.1 Research Method

The systematic literature review conducted in this study on prescriptive analytics followed the guidelines outlined and proposed by Kitchenham et al. [15], Kitchenham [16] and Bisset and Terblanche [17].

2.1.1 Research Questions

In order to achieve the aim of this study, the following research questions, as shown in Figure 3, were formulated.



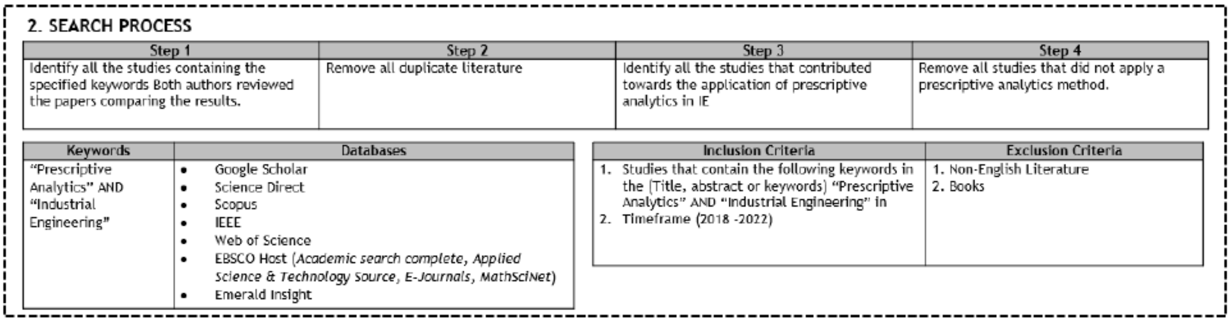
1. RESEARCH QUESTIONS

Research Question 1	Research Question 2	Research Question 3	Research Question 4
How many studies contribute towards the application of prescriptive analytics in Industrial Engineering?	Which method of prescriptive analytics is applied in each study?	In which application domains is prescriptive analytics applied?	In which application domain is there a lack of the application of prescriptive analytics

Figure 3: Research Questions

2.1.2 Search Process, Data Collection and Analysis

A search process was developed to ensure that all relevant studies were included in this systematic literature review. Figure 4 shows the appropriate steps that were followed in achieving this. Figure 4 also clearly indicates the keywords, databases, inclusion and exclusion criteria used in this systematic literature review.



2. SEARCH PROCESS

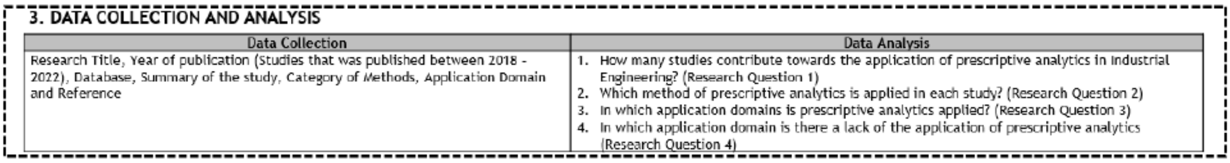
Step 1	Step 2	Step 3	Step 4
Identify all the studies containing the specified keywords Both authors reviewed the papers comparing the results.	Remove all duplicate literature	Identify all the studies that contributed towards the application of prescriptive analytics in IE	Remove all studies that did not apply a prescriptive analytics method.

Keywords	Databases
"Prescriptive Analytics" AND "Industrial Engineering"	• Google Scholar • Science Direct • Scopus • IEEE • Web of Science • EBSCO Host (*Academic search complete, Applied Science & Technology Source, E-Journals, MathSciNet*) • Emerald Insight

Inclusion Criteria	Exclusion Criteria
1. Studies that contain the following keywords in the (Title, abstract or keywords) "Prescriptive Analytics" AND "Industrial Engineering" in 2. Timeframe (2018 -2022)	1. Non-English Literature 2. Books

Figure 4: Search Process

Figure 5 shows the categories of data that were collected during the systematic literature review. This data was analysed accordingly in order to answer the research questions as formulated in Section 2.1.1. The research was conducted for the period from 2018 to 2022.



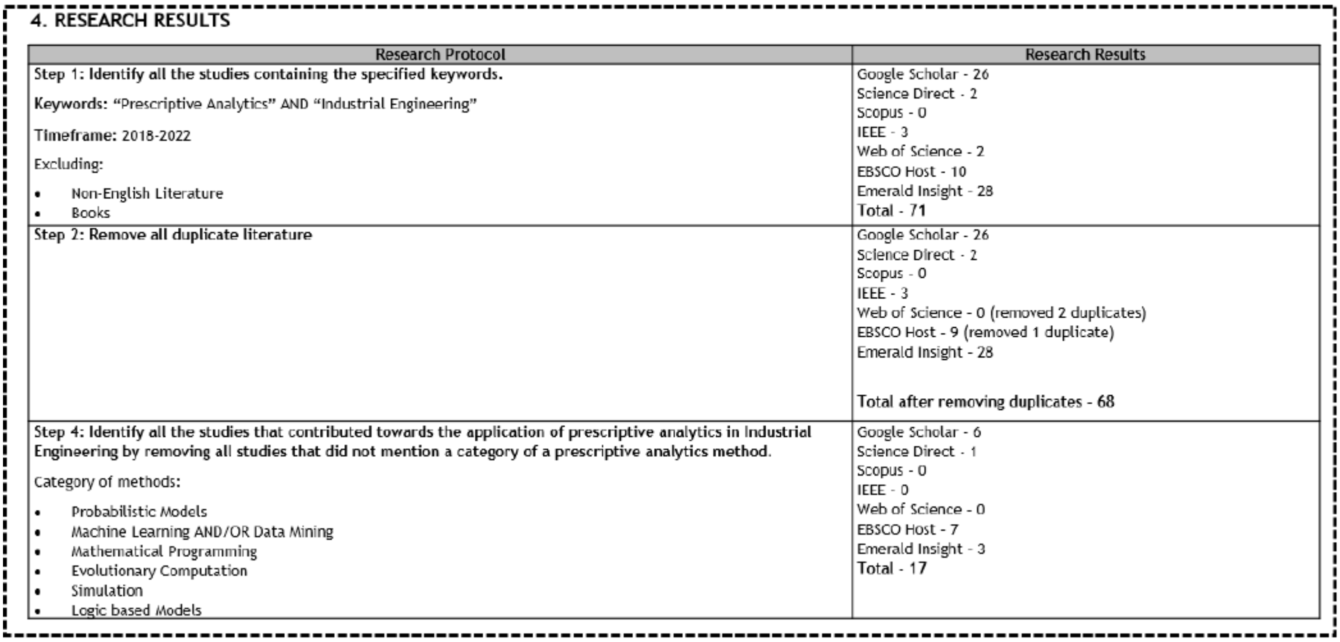
3. DATA COLLECTION AND ANALYSIS

Data Collection	Data Analysis
Research Title, Year of publication (Studies that was published between 2018 - 2022), Database, Summary of the study, Category of Methods, Application Domain and Reference	1. How many studies contribute towards the application of prescriptive analytics in Industrial Engineering? (Research Question 1) 2. Which method of prescriptive analytics is applied in each study? (Research Question 2) 3. In which application domains is prescriptive analytics applied? (Research Question 3) 4. In which application domain is there a lack of the application of prescriptive analytics (Research Question 4)

Figure 5: Data Collection and Analysis

2.2 Discussion of Research Results

From Figure 6, it is evident that a total of 17 studies were identified. These studies are explained in detail in Table 2.



4. RESEARCH RESULTS

Research Protocol	Research Results
Step 1: Identify all the studies containing the specified keywords. **Keywords:** "Prescriptive Analytics" AND "Industrial Engineering" **Timeframe:** 2018-2022 Excluding: • Non-English Literature • Books	Google Scholar - 26 Science Direct - 2 Scopus - 0 IEEE - 3 Web of Science - 2 EBSCO Host - 10 Emerald Insight - 28 **Total - 71**
Step 2: Remove all duplicate literature	Google Scholar - 26 Science Direct - 2 Scopus - 0 IEEE - 3 Web of Science - 0 (removed 2 duplicates) EBSCO Host - 9 (removed 1 duplicate) Emerald Insight - 28 **Total after removing duplicates - 68**
Step 4: Identify all the studies that contributed towards the application of prescriptive analytics in Industrial Engineering by removing all studies that did not mention a category of a prescriptive analytics method. Category of methods: • Probabilistic Models • Machine Learning AND/OR Data Mining • Mathematical Programming • Evolutionary Computation • Simulation • Logic based Models	Google Scholar - 6 Science Direct - 1 Scopus - 0 IEEE - 0 Web of Science - 0 EBSCO Host - 7 Emerald Insight - 3 **Total - 17**

Figure 6: Research Results

Table 2: Results of the systematic literature review

No.	Title	Abstract / Summary	Year	Database	Category of Methods	Application Domain	Reference
1	Quality 4.0—the challenging future of quality engineering	**Purpose:** This paper aims to provide a quality discipline framework to support the fourth industrial revolution. This is also referred to as quality 4.0. The authors offer future directions for quality and reliability engineering. **Design/method:** Quality framework **Findings:** The authors discussed topics including and not limited to quality-driven disciplines, health monitoring, and the integration of innovation and quality. The authors concluded that these topics still do not provide a concise picture of quality 4.0 and recommend that other researchers update this body of knowledge.	2020	Google Scholar	Simulation	Industry 4.0 / Quality 4.0	Zonnenshain and Kenett [18]
2	Probation Status Prediction and Optimisation for Undergraduate Engineering Students	**Purpose:** This paper formulates a plan to monitor student characteristics that may support and improve the educational admission process. **Design/method:** Machine learning algorithms included logistic regression, deep learning, decision tree, random forest and gradient boosted tree. An evolutionary optimisation algorithm was also used for this study. **Findings:** The gradient boosted tree provided the highest accuracy of 96.2%.	2021	Google Scholar	Machine Learning	Academic	Yanta et al. [19]
3	A Relative Study on Analytical Models	**Purpose:** This paper analyses the academic literature's prescriptive and predictive analytics framework. These include the studies, techniques applied and their execution. **Design/method:** A comparative research study (Literature review). **Findings:** Based on the results obtained, future research recommendations were provided	2021	Google Scholar	Machine Learning	Ecommerce	Attri et al. [20]
4	Gulf Coast port selection using multiple-objective decision analysis	**Purpose:** A port model was developed for an aid shipping line that selects the best port on the US Gulf Coast. **Design/method:** Cost model and Monti Carlo simulation **Findings:** The Houston port was identified as the best option whilst analysing the demonstration model and its assumptions. The value model provided improvement opportunities for future research.	2019	Google Scholar	Simulation	Supply Chain: Transport	De Icaza et al. [21]
5	A Survey on Data-Driven Predictive	**Purpose:** This paper overviews machine learning and deep learning models for predictive maintenance.	2021	Google Scholar	Machine Learning	Supply Chain: Transport	Davari et al. [22]

	Maintenance for the Railway Industry	**Design/method:** Designed survey **Findings:** Based on the results, future research recommendations are provided.					
6	Supervised or unsupervised learning? Investigating the role of pattern recognition assumptions in the success of binary predictive prescriptions	**Purpose:** This paper investigates why machine learning lacks effectiveness for pattern recognition. **Design/method:** Scoping literature review **Findings:** This paper concluded that the machine learning efficacy could be improved by rethinking the assumptions made for pattern recognition.	2021	Google Scholar	Machine Learning	Academic	Jafari-Marandi [23]
7	Wartime industrial logistics information integration: Framework and application in optimising deployment and formation of military logistics platforms	**Purpose:** This paper demonstrates a five-layered wartime logistics information integration framework. Also, to provide an analysis of wartime logistics systems from an industrial information integration perspective. **Design/method:** Five-layered framework for industrial logistics information integration **Findings:** This study concludes that a systematic procedure for wartime industrial logistics information integration is formulated.	2021	Science Direct	Simulation	Supply Chain: Logistics	Li et al. [24]
8	Pitfalls and protocols of data science in manufacturing practice	**Purpose:** This study provides a framework to integrate machine learning and mathematical programming as a decision-support system to optimise sequential decision-making. **Design/method:** Hidden Markov model (predictive analytics) and a distributionally robust dynamic optimisation model (Prescriptive analytics). **Findings:** This paper shows the practical importance of the framework by providing valuable information from the data to optimise sequential decision-making.	2022	EBSCO Host	Machine Learning and Mathematical programming	Supply Chain: Transport	Lee and Chien [25]
9	Coupled Learning Enabled Stochastic Programming with Endogenous Uncertainty	**Purpose:** This study aims to develop a coupled learning algorithm to optimise candidates' decision-making. **Design/method:** Coupled learning algorithm optimisation (CLEO) **Findings:** This study demonstrated the computational potential of the data-driven approach formulated in this study.	2022	EBSCO Host	Machine Learning Simulation	Supply Chain: Transport/Logistics	Liu et al. [26]
10	A Machine Learning Approach to Enable Bulk Orders of Critical Spare-Parts in the Shipping Industry.	**Purpose:** This study aims to follow a methodological approach to enable the bulk ordering of spare parts by designing a decision support tool. **Design/method:** Machine learning and simulation	2021	EBSCO Host	Machine Learning and Mathematical programming	Supply Chain: Logistics	Anglou et al. [27]

		Findings: The decision support tool yields a 9% overall cost reduction of spare parts over two years.					
11	A systematic literature review of supply chain decision making supported by the Internet of Things and Big Data Analytics.	**Purpose:** This study aims to propose a framework for HR recruiters to improve the recruitment process in an organisation. **Design/method:** Systematic literature review **Findings:** This study shows that the framework can formulate a balanced plan while improving both diversity and success rates.	2021	EBSCO Host	Machine Learning and Mathematical programming	Supply Chain	Koot et al. [28]
12	Employees recruitment: A prescriptive analytics approach via machine learning and mathematical programming.	**Purpose:** This study aims to develop a linguistic summarisation (LS) to generate natural language-based summaries using raw data in the supply chain management field. **Design/method:** linguistic summarisation (LS) **Findings:** Based on the results, valuable future recommendations are provided to help increase the supply chain performance.	2020	EBSCO Host	Machine Learning Mathematical Programming	Supply Chain: Logistics	Pessach et al. [29]
13	An asset-management oriented methodology for mine haul-fleet usage scheduling.	**Purpose:** This study aims to formulate a five-phase analytics framework to identify pitfalls for intelligent manufacturing. **Design/method:** Five-phase analytics framework using descriptive and predictive analytics. **Findings:** This framework offers valuable future research on the strategic decision-making of assets subject to operations maintenance.	2018	EBSCO Host	Machine Learning	Industry 4.0	Nakousi et al. [30]
14	Using Bayesian belief network and time-series model to conduct prescriptive and predictive analytics for computer industries	**Purpose:** This study aims to develop a novel framework of the random forest, Bayesian belief network and a time-series model. **Design/method:** Three personal computer firms were used to validate the framework. **Findings:** Based on the results obtained in this study, valuable future recommendations are provided.	2018	EBSCO Host	Machine Learning	Technology	Wang et al. [31]
15	A systematic literature review of data science, data analytics and machine learning applied to healthcare engineering systems	**Purpose:** This paper assesses the academic literature on data analytics (big data, data mining and machine learning). **Design/method:** Systematic literature review **Findings:** This study identified 576 papers, and valuable future recommendations are identified.	2020	Emerald Insight	Machine Learning	Academic: Research (SLR)	Salazar-Reyna et al. [32]

16	Impact of Industry4.0/ICTs, Lean Six Sigma and quality management systems on organisational performance	**Purpose:** This paper evaluates the impact of Inter of Things, artificial intelligence, robotics etc., on 22 organisational performance indicators of lean six sigma and quality management systems. **Design/method:** Survey **Findings:** This study concluded significant differences among 20 organisational performance indicators, including delivery performance, inventory etc.	2020	Emerald Insight	Machine Learning	Manufacturing Service Enterprises	Yadav et al. [33]
17	Critical success factors for lean six sigma in quality 4.0	**Purpose:** This study addresses the gap between critical success factors and leans six sigma. **Design/method:** Questionnaire - The authors evaluated Cronbach's alpha, and the responses received. **Findings:** Based on the results obtained, it was concluded that this study would assist organisations in adopting industry 4.0.	2021	Emerald Insight	Machine Learning	Industry 4.0	Yadav et al. [34]

Each study is identified based on the title, abstract, year of publication, database, prescriptive method, application domain and reference. Based on the results, the research questions are answered.

2.2.1 *Research Question 1: How many studies contribute toward the application of prescriptive analytics in Industrial Engineering?*

Figure 6 and Table 2 show that 17 studies were selected after removing the duplicates. Figure 7 demonstrates the number of publications per year group.

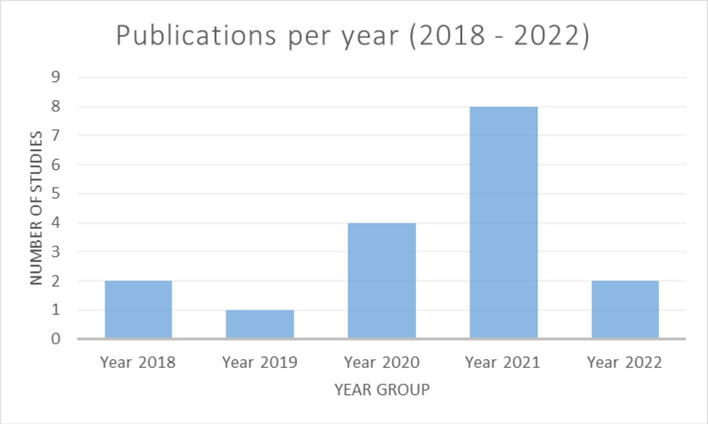


Figure 7: The number of publications per year group

Figure 7 shows that a total of eight studies were published in 2021, four in 2020, two in 2018 and 2022, and one in 2019. The percentage of publications per database is depicted in Figure 8.

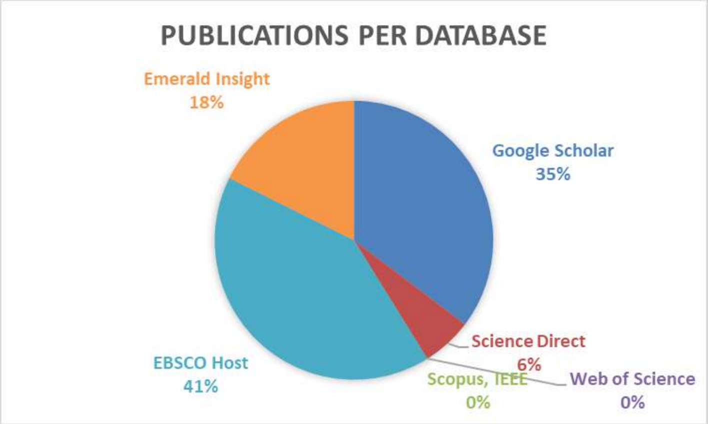


Figure 8: The percentage of publications per database

It is apparent from Figure 8 that 41% of the publications were from EBSCO Host, 35% from Google Scholar, 18% from Emerald Insight, and 6% from Science Direct. It is also clear that after removing the duplications, 0% of publications were from Scopus, IEEE and Web of Science.

2.2.2 *Research Question 2: Which method of prescriptive analytics is applied in each study?*

As stated in the research method, the primary focus of this study was the six categories of prescriptive methods: Probabilistic Models, machine learning, mathematical programming, evolutionary computation, simulation and logic-based models. Figure 9 depicts the percentage of publications per prescriptive method.

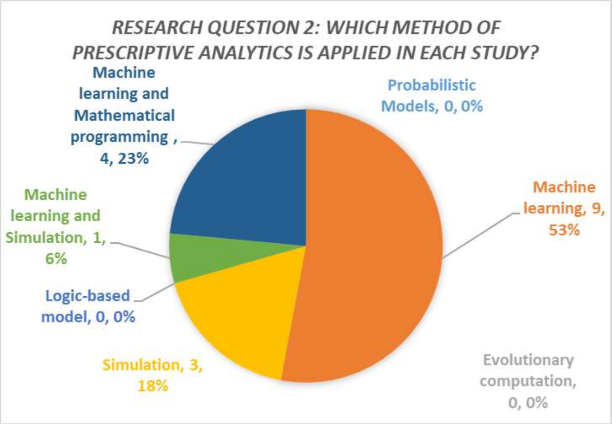


Figure 9: A demonstration of the methods applied in the literature

Figure 9 shows that 9.53% of studies applied machine learning, 4.23% applied machine learning and mathematical programming, 3.18% applied simulation, and 1.6% applied machine learning and simulation. Various studies applied machine learning methods to analyse data and make predictions, followed by the formulation of optimisation models. From Figure 9, the gaps in literature can also be identified: Logic-based models and evolutionary computation. Figure 2 shows that these methods include fuzzy rules, graph-based recommendations, genetic algorithms and particle swarm methods.

2.2.3 Research Question 3: In which application domains is prescriptive analytics applied?

Figure 10 shows the percentage of publications per application domain.

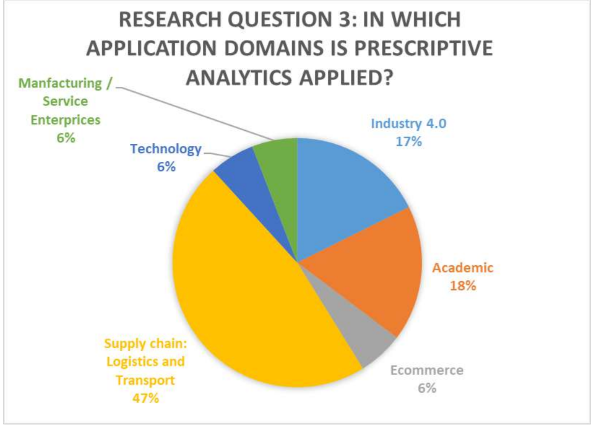


Figure 10: The percentage of publications per application domain

From Figure 10, it is clear that 47% of studies were published in the supply chain industry, 18% in academic, 17% in industry 4.0, and 6% in eCommerce, technology and manufacturing.

The supply chain industry comprises various application domains, including transportation and logistics. Koot et al. [28] conducted a systematic literature review on decision-making in the supply chain industry, specifically focusing on Inter of Things (IoT) and big data analytics.

2.2.4 Research Question 4: In which application domain is there a lack of the application of prescriptive analytics

The systematic literature review results show the prescriptive methods applied in the industrial engineering application domains. Industrial engineers work in all of these industries, and it is evident that the supply chain industry is the most popular in the academic literature. This analysis also provides an opportunity to identify the lack in the literature. These industries include and are not limited to finance, agriculture, and retail. Prescriptive analytics can be applied in these industries to make optimal decisions and optimise strategies accordingly.

3 CONCLUSIONS AND FUTURE RECOMMENDATIONS

Business analytics has received considerable attention over the last few years due to the increasing complexity of decision-making processes. These methods assist organisations in driving decisions while creating business value. Business analytics applies methods from operations research, machine learning and information systems for optimal decision-making. Business analytics is divided into three main stages: descriptive, predictive, and prescriptive. Descriptive and predictive analytics are widespread in academic literature. However, there is a limit to the application of prescriptive analytics.

This study investigated existing literature on prescriptive analytics in various industrial engineering application domains. The systematic literature review followed the guidelines outlined and proposed by Kitchenham et al. [15], Kitchenham [16] and Bisset and Terblanche [17]. Four research questions were formulated, followed by a search process, keywords, databases, and inclusion and exclusion criteria.

The systematic literature review identified limitations and gaps in the literature. First, 17 studies were identified in the literature. The number of publications per year and database were identified. The various application domains were identified, and it was concluded that most studies were published in the supply chain industry. This review also provided an opportunity to recognise the limitations in the literature. From the review, it was evident that there was a lack in the following prescriptive analytics methods: Logic-based, probabilistic models and evolutionary computation. The following gaps were identified in the application domains: Retail industry, finance and agriculture.

For future research, it will be recommended that the review is not restricted to only industrial engineering. By extending the search, more research studies will be identified, and a more concise conclusion can be made on all application domains. To add value to the academic literature and to address the gaps and limitations in the literature, it will be recommended that industrial engineers focus more on other prescriptive methods, including logic-based, probabilistic models and evolutionary computation. Industrial engineers can add value to all industries, and it will be recommended that other sectors also be considered, including the retail industry, finance and agriculture.

In the retail and finance industry, prescriptive analytics can be used for direct marketing and optimising campaign strategies. Machine learning methods, including the random forest, can analyse data and recognise patterns to make optimal predictions. Mathematical programming models can be formulated to make decisions to obtain maximum profit. In the agriculture industry, prescriptive analytics can be used to determine optimal crop yields, optimise farm equipment and improve profitability [35]. Prescriptive analytics is seen as the next step in increasing business analytics maturity. This paper contributed to the academic literature by identifying the limitations and providing valuable future recommendations for industrial engineers.

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TOOL WEAR MONITORING AND PREDICTION IN MACHINING PROCESSES BY MEANS OF CONVOLUTIONAL NEURAL NETWORKS

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ABSTRACT

In order to minimize the effect of tool wear during machining operation, there is a need to monitor the progressive cutting tool wear in relation to work piece. The aim of the research is to monitor and predict the tool wear during milling operation of an underground chutes with the objectives of improving quality of the products and the overall lead time of the process. A total of twenty-seven (27) experimental data runs was conducted on the force profile with normal and defected casting using CNC lathe machine with buit-in load sensors. The data were used to train a Convolutional Neural Network (CNN) model with deep learning capabilities via back propagation. The input variables for the CNN model were feed rate (76.2, 127.0 and 228.6 mm/min), depth of cut (0.381, 0.635 and 0.889 mm) and the average peak force in the y-direction gathered in-process via dynamometer. A total of 500 training cycles were used to establish the CNN system, after which five (5) experimental testing cuts were conducted to evaluate the performance of the system. From the results of the test, it was evident that the system could predict the tool wear in-process with an average error of ±0.018 mm. In the case of work piece with defects, the model was taught to stop the process, retract the tool and modify the cutting parameters. Artificial Intelligent has proof to be good technique for the optimization of production process of steel work.

Keywords: Convolutional Neural Network, Machine Learning, Force Profile, Tool wear

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1 INTRODUCTION

Machining is a process in which a material is cut into a desired final shape and size by a controlled material removal process [1]. Studies have shown that total South Africa expenditure on machining process is between 3-5 % of the annual South African gross domestic product (GDP) [2]. However, despite the importance of this process in both economic and technical values, it still remains an un-automated process, thus causing set back in the sector by prolonging the delivery time and low quality outputs [3]. Before the advent of tool monitoring and prediction system, industries used tool conditions like use until failure, use until wear, use until average tool life and change with human judgment as the basis for tool life [4]. Change of tool with human judgment was based on the criteria like edge failure, visual inspection, finger mail test of cutting edge, changes in cutting sound, surface roughness, increased power consumption and cumulative cutting time [4]. However, the practice of tool condition and change tool criteria are not reliable, expensive, produced low quality products and sometimes wasteful, invariably loss of money and long production lead time are inevitable [1, 4]. The feasible solution to these problems is the adoption of in-process tool wear monitoring and prediction system which is part of automated machining which involve application of systems with diverse in-built algorithms such as Fuzzy Logic and Artificial Neural Network (ANN) to monitor tool wear indirectly [4].

Crossing into the twentieth century, the growth of economy through the manufacturing sector is increasing [4] and according to the prediction of Morley and Moody [5], that manufacturing would geometrically grow over the next decade through advent of internet, manufacturing is now tending toward E- manufacturing [4]. The core E-manufacturing research that is emerging revolves around intelligence maintenance system (IMS) as proposed by [6]. The important aspect of the IMS is a monitoring system known as Watch Dog Agent [4]. This rapidly performed asset evaluation by continuous monitoring and prediction [4]. For the sustainability of IMS, more focus should be on intelligence machining in which an automated monitoring tool conditioning system is built to centres on tool breakage and tool wear [4].

Tool wear is a common phenomenon seen to degrade machined surface texture and causes inaccuracy in work geometry [1]. It also affects significantly tool life and production cost [7]. Thus, it is essential to design a smart system able to monitor the progression of the tool wear during the machining process. This would allow the identification of a worn tool in order to be replaced as well as increase the accuracy of the cutting process and thereby ensures the achievement of the technical specification requested to reach the suitable geometry of the machine components [8].

Several works have been going on over two decades by researchers on automated monitoring in the aspect of tool breakage using accelerometer, tool/workpiece contact resistance and acoustic emission [9-12]. Automated monitoring in tool breakage is less complicated compared to tool wear [4]. Cutting force signal was appreciated in the sense that the signal change is easily noticeable when tool breakage occurs unlike tool wear which is more complex due to the small change in the signal as to be detected by a dynamometer [4]. Studies have shown that tool wear monitoring using dynamometer is much sensitive than other sensors [4]. Some authors have recently work on tool wear monitoring system using various methodologies. Palanisany et al. [13], worked on the prediction of tool wear using regression and Artificial neural network (ANN) models in End-Milling operation with focus on the flank wear of the cutting tool. The two models were used to predict the flank wear. Wang et al. [14] also worked on forced based tool wear monitoring system for milling process based on relevance vector machine (RVM) and SVM classifier. Both classifiers were compared in the realization of multi category classification of tool wear status during milling operation. Another recent work on tool wear monitoring systems is Gouarir et al. [1] which was on in-process tool wear prediction system based on machine learning techniques and force analysis. Ulas et al. [15] worked on vibration prediction in drilling process with HSS and Carbide drill bit by means of artificial neural network. The works of [1] and [15] were similar to the present study based on the fact that their methodologies were based on experimental data. The in-process tool wear monitoring and prediction adopt adaptive control to communicate continuously with the machine learning model to seek the best adjustment feed rate and spindle speed that allows the optimization of the wear and prolong the tool life. However, most reported work using an ML model are offline techniques. The novelty of the approach presented here is the combination of the self-learning and self-adaptive components operating simultaneously online as one body to produce an in-process smart tool wear detection and prediction system. The self-learning component allows the system to learn, identify and predict the tool flank wear using the CNN. The self-adaptive component takes into account this prediction and the information delivered by the force sensor to determine the best adjustment to the machining process and extend tool life. This study conducted the cutting force analysis of the machining experimentally to find out the best force combination for monitoring and predicting tool wear. The use of force signals detected through dynamometer along with machining parameters as input variables for the expert system (CNN) are harness for the development of the in-process tool wear monitoring and prediction system. The study aimed at in-process monitoring and prediction of tool wear during milling operation of underground chutes in steel work based on force profile of normal casting and casting with blow holes with the objectives of improving the quality of the final product, reduce the production lead time and safe cost.

2 METHODOLOGY

The methodology for the in-process tool wear monitoring and prediction is discussed in this section.

2.1 Proposed Model for in-process wear Monitoring and prediction System

The in-process tool wear monitoring and prediction system harness experimental gathered data to train the CNN in order to recognize the behavior of tool and work piece via force profile to be able to predict wear. The adaptive control (AC) communicates with CNN to apply the necessary adjustment between the input variables (feed rate and depth of cut,) to obtain the optimal force, which is the goal of the combination [1]. Satisfaction of the two conditions optimizes the tool life and improve surface finish [1]. Figure 1, shows the schematic diagram of the proposed model.

2.2 Experimental Set-ups

In this study, an experiment was conducted to determine the force profile of casting with blow holes and normal casting during milling operation. The work piece was processed with 3-insert mill cutter of 1.23” cut diameter at 4 different cutting speeds (15, 20, 25 and 30mm/min), feed rate values of (76.2, 127 and 228.6 mm/min), Depth of cut (0.381, 0.635, 0.889 mm) and flank ware (0.25, 0.35 and 0.45 mm). The cutting force profile was established with a total of 27 experimental runs. Figures 2 shows the image of the milled hopper wheel assembly. The tool wear in the x, y, z axis is measured while the milling operation is on. A dynamometer attached to the cutting tool holder will measure the cutting forces and feed them to a CNN program that has deep learning capabilities. The CNN model that receives the experimentally obtained data is developed in a matlab software. The input parameters to the CNN model are cutting speed, feed rate, depth of cut and the cutting force profile while the tool wear in x, y, z direction is used as output. The experiment was carried out on VNC-550 Industrial CNC milling machine with FANUC control limit. Figure 3 shows the experimental setup. Table 1 presents the specification of the CNC milling machine and the cutting parameters of the machining operations.

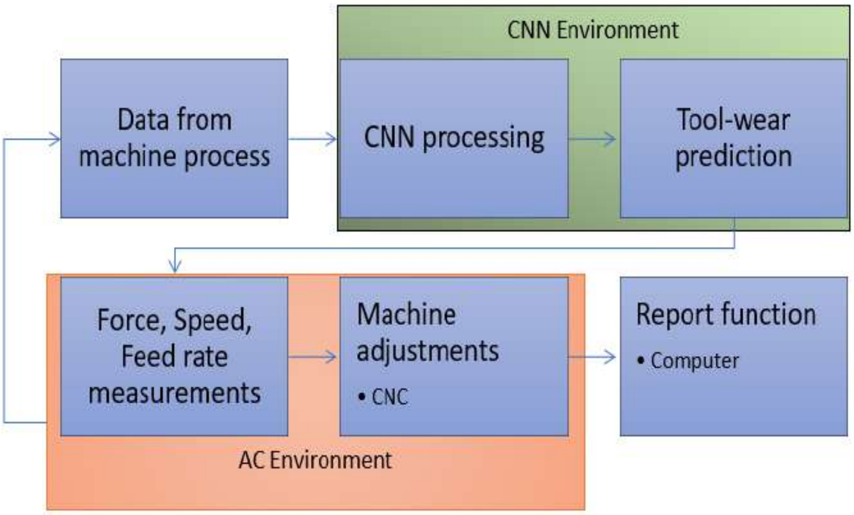

Figure 1: Methodology for in-process tool wear Monitoring and Prediction

Table 1: Specification CNC milling machine

S/N	Specification	Value
1	Power of Spindle Motor	0.37KW
2	Spindle Speed range	0-3600 rpm
3	Power of feed motor	0.18 KW
4	Torque of Spindle and Feed motor	20 Kg.m
5	Feed (x and y direction)	0.06-0.12 mm/min
6	Number of Flutes	4
7	Diameter of the Cutter	15 mm
8	Rake angle of the Flute	12 °
9	Helix angle of the Flute	30 °
10	Drilling Work piece	AISI D3 C2080 steel work
11	Milling Work piece	120 x 50 x10 mm
12	Material of the cutter Material of drill bit	Uncoated Tungsten Carbide (P20 grade) HSS Carbide drill bit (8 mm Diameter)
13	Hardness	28 HRC
14	Radial Depth of cut	10 mm
15	Cutting Speed Rang	15-30 m/min

Figure 2: Machined hopper wheel assembly

Figure 3: Set-up of the Machining Operation

2.3 Measurement of Force Profile and Tool wear

Influence of cutting force on tool wear is significant during milling. It also helps in setting require cutting parameters or selection of cutting tool. Thus, the method of tool wear monitoring in this study is based on force profile using a Kistler Piezoelectric dynamometer 60 KN, type 9255C, where Fx, Fy and Fz represent the three orthogonal force component exerted during the milling operations sampled at 50 KN/channel. The transmitted force signals during the operation were amplified by calibrating an amplifier to be sensitive to the piezo sensor dynamometer by considering the value of the force [4]. The signals were received by data acquisition system ZDAQ9191 through implemented module N19215 and then monitored via signal express [4]. The data was stored in data base to train CNN model. The cutting force profile is shown in Table 2.

Table 2. Results of the Cutting Force

Feed Rate (mm/min)	Depth of Cut (mm)	Flank Wear (mm) 0.25	0.35	0.45
76.2	0.381	0.31	0.23	0.11
	0.635	0.39	0.29	0.18
	0.889	0.45	0.35	0.21
127	0.381	0.39	0.28	0.16
	0.635	0.48	0.37	0.27
	0.889	0.56	0.42	0.35
228.6	0.381	0.45	0.31	0.21
	0.635	0.52	0.40	0.33
	0.889	0.62	0.43	0.44

3 DESCRIPTION OF THE CONVOLUTIONAL NEURAL NETWORK ARCHITECTURE

Deep learning model is proposed due to its ability to find intricate structures in high dimensional data. Deep learning is making heavy waves in image and speech recognition [16, 17] and natural language processing. It has found application in convolutional neural network (CNN) [18] with further development to handle time series data classification [19-21]. The CNN adopted has the ability to encode multivariate time series data collected from the sensor channel images which will be used as input to train the CNN. The required model needs to be fed with actual data from the machining operation before it can process it to give useful information to the machine The convolution layers would have filters in their classification process that are responsible for cleaning up noise as they match the received segmental pieces of image data to the learned/ known patterns. This noise may be in the form of coolant drops or fine chips on the cutting tool tip. The last layer outputs the predictions of the tool-wear progression and hence, an estimation of when the cutting tool needs to be changed. In the case where a work piece has blow holes, the model will be taught to treat such a work piece differently. This is because for normal circumstances, the model will predict tool life depending on gradual tool wear, but the presence of blow holes cancels out gradual tool wear by instantly chipping the cutting edge. This step is essential to differentiate between a normal material and one with defects. Upon detection of load spike, the model needs to stop the process, retract the tool for special examination before modifying the cutting parameters accordingly. The imaging data comes from a microscopic camera (Figure 4) which takes images of the cutting tool ideally in-between successive cuts during the machine learning stage. The camera is shielded away during the cutting process to avoid lens contamination from coolant steam, splashes and chips. The set-up may be arranged as follows.

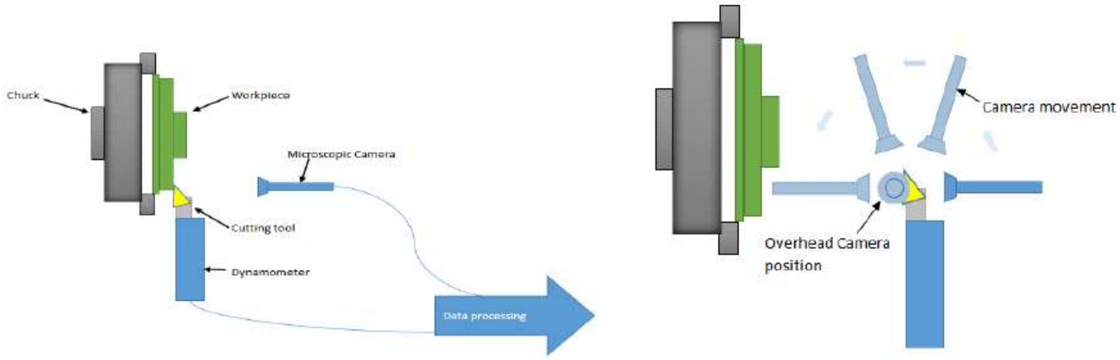

Figure 4: Typical arrangement of imaging process during machining

In the imaging process, the tool will be retracted away from the work-piece for the camera to travel over the cutting tip to take images. Upon receiving these images, the CNN in its processing, will be able to compare the actual image to the predicted image and make self-corrections on its prediction. This way the accuracy of the predictions keeps improving. The Adaptive Control (AC) module keeps track of changes of information fed from the CNN and effects the required adjustments that will be sent as a signal to the CNC machine in order to maintain optimum conditions of machining. The Report function can be programmed to send email notifications to the applicable staff to attend to the communicated requirements. The info in the email could range from estimated tooling requirements to complete a task, to information regarding general machine performance across different products. This system can be applied to all CNC machines in the factory but will need some modifications on the manual lathe and radial drilling machine. The AC environment will not be able to work on manual machines due to the lack of automation. For such machines, only the CNN module will be functional, so the benefits of tool-wear prediction will still be attainable. Figure 5 presents the architecture of the proposed convolutional neural network

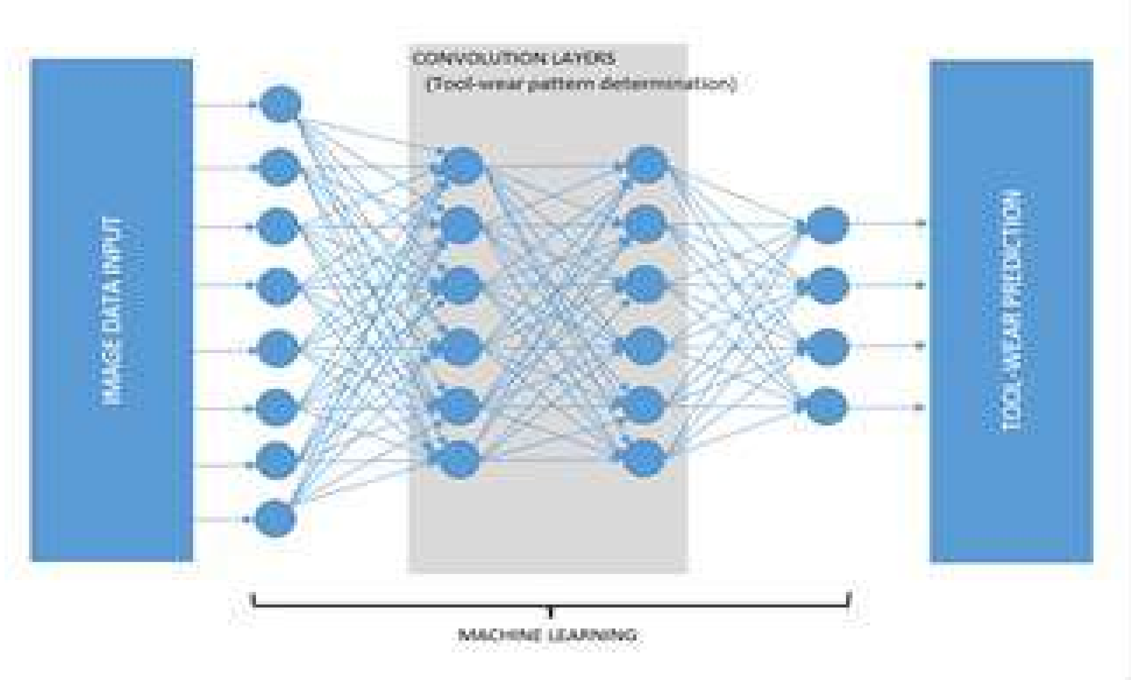

Figure 5: Schematic of the Proposed Convolutional Neural Network Architecture

4 RESULTS AND DISCUSSION

This section describes in detail the development of the CNN training system and testing of the results for the CNN system

Development of CNN Training System

The CNN training scheme was carried out via the following steps:

Step 1: Determination of the network structure, initial connection weight and the offset. This was achieved by using one layer each for both input and output. Hence, the total number of layers for the CNN network used was 3, making the weight load to be reduced. The feed rate, depth of cut and cutting force were selected as the input neurons while the tool wear was selected as the output neuron. The only element unknown of the CNN structure was the number of neuron for the hidden layer(s). The number of neuron limit was set to 10 in order for the CNN to be realistic. The identification of the optimized structure was achieved by comparing the root mean square error of each hidden layer as presented in Table 3.

Table 3. Root Mean Square Values Errors of the Hidden Layer

Hidden Layer	Node	RMS Error	Hidden Layer	Node	RMS Error
One Hidden Layer	1	0.0776	2 Hidden Layer	1-1	0.0788
	2	0.0749		2-2	0.0794
	3	0.0718		3-3	0.0809
	4	0.0792		4-4	0.0728
	5	0.0622		5-5	0.0918
	6	0.0610		6-6	0.0724
	7	0.0811		7-7	0.0511
	8	0.0686		8-8	0.0501
	9	0.0616		9-9	0.0666
	10	0.0512		10-10	0.0902

Comparing the RMS errors for training cycle of 500, the structure 8-8 has the lowest RMS error. Thus, structure 3-8-8-1 was selected as the optimized structure.

The initial connection weight and offset was set to 0.025. According to equation 1, the output of the neurons for the first hidden layer was:

$$xj = F\left(\sum_{i=1}^{3} 0.025xi - 0.025\right) \tag{1}$$

Where xi is the feed Rate

$$1 \leq j \leq 8 \tag{2}$$

The output of the neurons for the second hidden layer is presented in equation 3

$$xk = F\left(\sum_{j=1}^{8} 0.025xf - 0.025\right) \tag{3}$$

$$1 \leq k \leq 8 \tag{4}$$

The output of the neuron for the output layer is presented in equation 5

$$y = F\left(\sum_{k=1}^{8} 0.025xk - 0.025\right) \tag{5}$$

Where y is the magnitude of the wear

Step 2: present input and desired output from the 27 training data set.

Step 3: calculate the actual and desired output and the error between them. The weight of the networks is to be adjusted. Repeat step 2 -5 for each training pair until the error of the entire set is reasonably low. Training cycle of 500 brought the rms error as low as 0.05

4.2 Testing of the Results for the CNN structure

Five (5) machining parameters were selected from the cutting force profile in y-direction for testing the CNN system to predict values for tool wear as presented in Table 4

Table 4. Testing of the CNN System

S/N	Feed Rate (mm/min)	Depth f Cut (mm)	Cutting Force (v)	Actual Wear (mm)	Predicted wear (mm)	Error (mm)
1	76.2	0.381	0.31	0.23	0.26	0.03
2	127	0.889	0.42	0.35	0.35	0
3	228.6	0.635	0.33	0.45	0.47	0.02
4	76.2	0.889	0.45	0.21	0.21	0
5	228.6	0.301	0.45	0.25	0.21	-0.04
					Avg	∓0.018

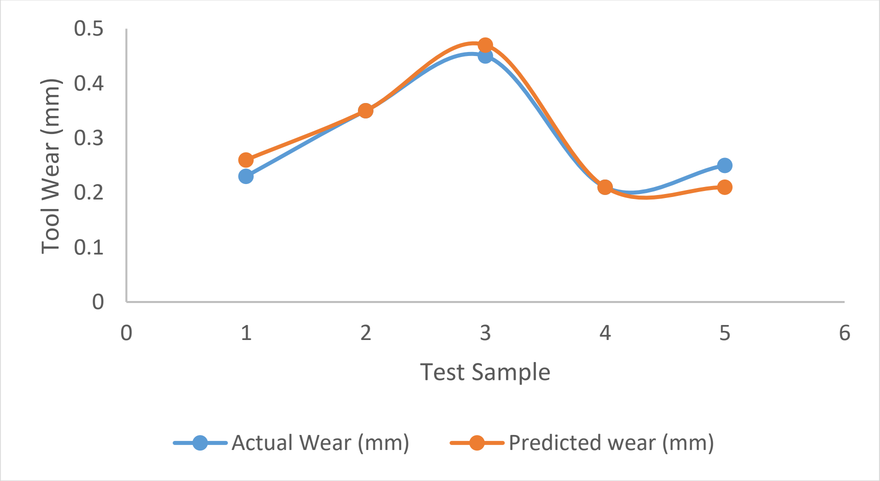

Figure 6: Comparison of Actual wear against Predicted wear

The average RMS error suggested that the proposed CNN system could reasonably predict in-process tool wear.

5 CONCLUSIONS

1. This research has demonstrated the use of Artificial Intelligence in the monitoring and prediction of tool wear in machining process via Deep Learning capabilities of the proposed model.
2. The proposed Artificial Intelligence architecture offers improvements in the prediction of tool wear with an average error of ±0.018 compared to the actual tool wear.
3. The estimation of the cutting force profile using average peak force in the y-direction enhanced the input for the in-process tool monitoring and prediction system

6 LIMITATIONS AND RECOMMENDATIONS

1. During the experimentation, there are some other in-process issues faced like tool breakage when dealing with casting with blow hole. The in-process tool monitoring and prediction was limited to tool wear. Further study is recommended for in-process tool breakage prediction.
2. In further study, the number of experimental runs and training data should be large as it would impact on the accuracy of the prediction.

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LEAN MANUFACTURING IN SPHEROIDISATION OF TI6Al4V

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ABSTRACT

In South Africa, spheroidisation of Ti6Al4V is new, and thus much research is needed to make it more efficient and economically sustainable. Lean manufacturing can be applied in additive manufacturing and is shown to run on similar principles. This article extends lean manufacturing application in spheroidisation of additive manufacturing materials. The researchers also conducted a literature study to summarise previous research. The research investigated the potential material wastes that can occur in spheroidisation and the methods of mitigating the wastes. From current sources and investigations, most of the material is lost in the plasma torch which vaporises the material. The research sought to identify ways to minimise the waste by setting the correct process parameters that would ensure little powder is vaporised. The research also seeks to find out other areas where the production process can be improved thus cutting costs.

Keywords: Spheroidisation, Additive Manufacturing (AM), Lean Manufacturing,

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1 INTRODUCTION

In selective laser melting material can eventually lose its ability to sinter efficiently. Spheroidisation can bring the material back to its original form [1]. The powder used in additive manufacturing needs to have spherical particles, with a powder density above 99.9% and high flowability [1]. Spheroidisation is a manufacturing technique that operates by running metal powder through a high temperature plasma typically at 3000 K to 10000 K [1]. The main product is spheroidised titanium alloy (Ti6Al4V) powder which is discussed in the article. This article highlights the lean applications in spheroidisation. Lean manufacturing can be applied in spheroidisation of titanium alloy if all process parameters are followed. This was a quantitative and qualitative research approach used with the aid of experimental runs on the 15-kW Tekna system which is used to spheroidise metal powder. One on the runs was done with a 11-kW of power using only argon as a carrier. The second spheroidisation run was done with 12-kW of power using argon and helium. The aim was to investigate the possibility of minimizing the heat required to spheroidise the titanium. The other aim was to investigate the possibility of reducing waste within the spheroidisation process while maintaining high powder quality. One of the problems with high heat in plasma spheroidisation is the loss of powder. When powder is lost, there is a possibility of altering the elemental composition and thus reducing the possibility of elemental analyses. The research highlights the importance of spheroidisation within additive manufacturing.

2 LITERATURE

Lean manufacturing (production) is a corporate concept, a strategic tool, and a process improvement program that helps companies reduce costs, gain a competitive edge, and increase quality and profitability [2]. From past literature there are few articles that discuss lean manufacturing in spheroidisation [3] [4] [5]. The articles mainly discuss lean manufacturing in additive manufacturing [6] [7]. A literature review was conducted by the researchers at the SAIIE highlighting on how lean manufacturing has been applied in Additive Manufacturing (AM) [8]. The article emphasized the parallels between lean manufacturing and additive manufacturing. Both strategies reduce wastes in their execution. It is evident that additive manufacturing helps to achieve the lean manufacturing by reducing material waste [9]. Additionally, additive manufacturing minimizes overproduction, shipping, and inventory for small amounts. Because the cost of dies does not considerably rise with part complexity, additive manufacturing is scarcely impacted by overprocessing [9]. The lean manufacturing idea of meeting customer expectations can be accomplished with additive manufacturing technology without raising costs or turnaround times. There is more work to be done for larger batches, even though the literature has proved that additive manufacturing technology alone eliminates wastes and excessive expenses for small quantities [3] [4]. [9] [10]. In some articles lean manufacturing is seen to have similar traits as AM. The research gap is that there were no studies found on application of lean in spheroidisation of Ti6Al4V. The research addresses the research at Necsa by observing the spheroidisation process and recording areas where lean manufacturing is applied in the whole process.

During the spheroidisation process, titanium can also be lost and methods to reduce the loss are important to ensure economic sustainability [11] [12] [13]. The article describes the processes parameters that make spheroidisation more economical. The important process parameters are the ratio of helium and argon which can reduce the powder required to spheroidise the powder. This can also reduce the metal lost through vaporization. As lean manufacturing is a waste reduction technique this can be descried as lean application in spheroidisation.

The article will focus of the waste reduction techniques of lean manufacturing. The steps to apply lean are:

1. Identify customer perception of value
2. Map value stream which means outlining the activities in order and how each contributes to value.
3. Establish the flow of activities
4. Ensure work is carried out only when needed
5. Ensure continuity [14].[15].

2.1 Previous Findings

In scholarly articles, there were no articles found in an application of lean manufacturing in spheroidisation. This research seeks to address the gap and identify the areas in spheroidisation that lean manufacturing can be applied. The articles found relate lean manufacturing to additive manufacturing [16] [6] [7] [17] [18]. There are characteristics of powder which overlap, which include

1. Flowability
2. Powder shape
3. Powder density
4. Powder size

The most important physical characteristic in powder is flowability and density [19] [20]. Lean manufacturing requires reducing waste. In a commercial set up testing for flowability, we can assume the powder is spherical without analyses [21]. Eliminating unnecessary testing can cut down cost. SEM can be used occasionally to verify spherical shapes in titanium alloy.

3 METHODOLOGY

The information in the article was deducted from various spheroidisation runs carried out with the 15kW Tekna system. The spheroidisation runs were also used investigate the possibility of lowering the titanium loss by using pure argon and lowering the plasma power. The primary emphasis was to ensure that there is minimum titanium powder loss in the spheroidisation process.

Aim

The main aim was to improve the spheroidisation ratio with the minimum loss of powder. The process parameters were derived from past records and experimental runs. Table 1 shows the experimental set-up

3.1 Experimental Set Up

Spheroidisation was carried out with two different process parameters one using plasma powder of 11-kW and the other using 12-kW plasma power. Table 1 shows the two process parameters used for the experiments carried out. The experiments done with the 11-kW settings were better suited for lean manufacturing as there was less waste involved in maintaining the process parameters. For each set up 50 grams of powder was used. The powder was also weighed after the spheroidisation to check for powder loss. The 12-kW settings were suited for superior powder as it produced better quality powder of higher spherical ratio.

Table 1: Process parameters for spheroidising Titanium with the 15-kW Tekna System

Power Settings	Amount of powder used	Helium flow rate	Argon	Helium flow rate
12-kW	50g	Litres per minute	32 litres/minute	1 kg /hr
11-kW	50g	0 litres/minute	52 litres/minute	0.9 kg/hr

When using 11-kW power argon can be used in place of helium which is more cost effecting. In the 11-kW setting there is less vaporisation that occurs due.

After carrying out the spheroidization the quality of the powder was verified by checking the

- Flowability
- Powder density
- Powder morphology
- Powder chemical composition

3.2 Defining Customers' perception of value

The first step is identifying the factros that a customer perceives as value before applying lean manufactruing. The processes that a customer defines as critical for titanium powder are:

1. Flowability and powder density.
2. Chemical composition and elemental composition
3. Powder shape, powder size and powder porosity.

Table 2 shows the customer requirements for additive manufacturing powder. These values were also used when analyses were carried out on spheroidised powder to check that the powder met the quality standards.

Table 2: Powder Properties for Additive Manufacturing

Property	Standard
Flowability	50 grams should be flow through a standard hale flow meter in less than 30 seconds.
Powder density	99.9%
Powder size	50 µm -200 µm
Powder shape (spherical)	80% of the powder should be spherical.
Chemical composition oxygen	0.09%
Hydrogen	0.01%
Nitrogen	0.01
Elemental (composition)	6% aluminium and 4 % vanadium must be maintained

The primary goal of lean manufacturing is to deliver value to the customer at the lowest cost possible. This is done by eliminating waste and practicing good manufacturing techniques.

3.3 Mapping the value stream

Withing Necsa the value adding activities are mapped in Figure 1. Knowing these activities and the order in which they fall can help in identifying the areas of waste.

3.4 Spheroidisation Process flow

Spheroidisation begins with the loading of titanium into the feeder, however there are some process criteria that must be followed before loading the powder. Leak inspections must be conducted prior to the start of the system to guarantee that it is airtight. The powder is fed into the feeder after the leak check. The helium and argon gas flow rates are then adjusted. The rate of powder flow is also set at the start. Figure 1 depicts the initial full process chain for powder spheroidisation at Necsa. The spheroidisation and sonication processes are the two key processes that add value to the powder, but the article focuses on the spheroidisation. The other steps are essentially quality tests that add no value to the powder but ensure that it meets the requisite parameters. The process flow was fine-tuned to concentrate on spheroidisation. The detailed process chain for the spheroidisation process is shown in greater detail in Figure 2.

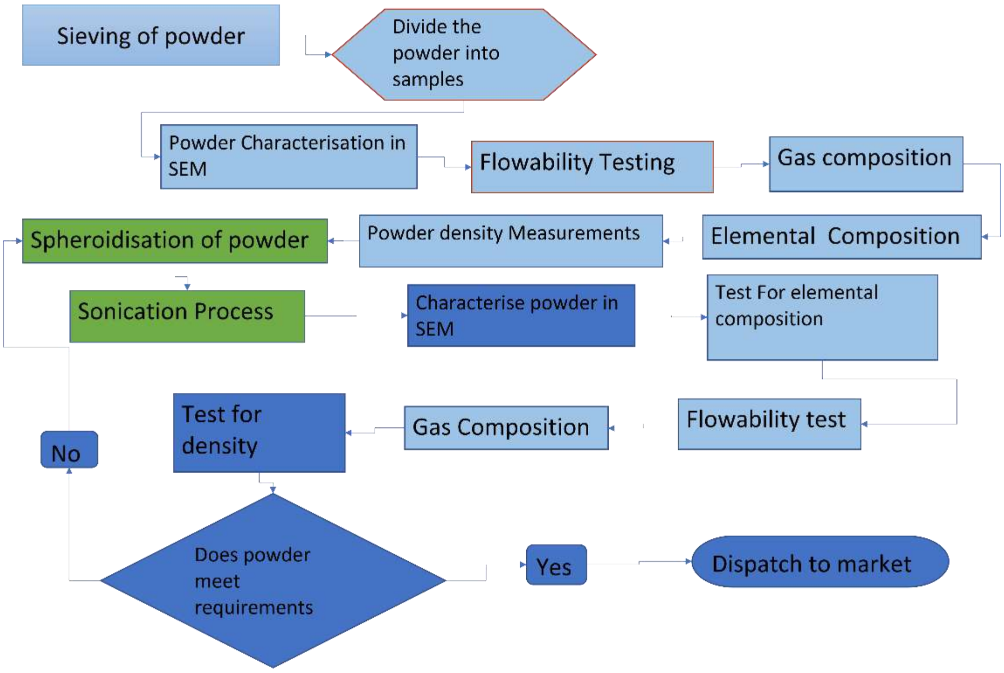

Figure 1: Value Stream at Necsa for spheroidisation

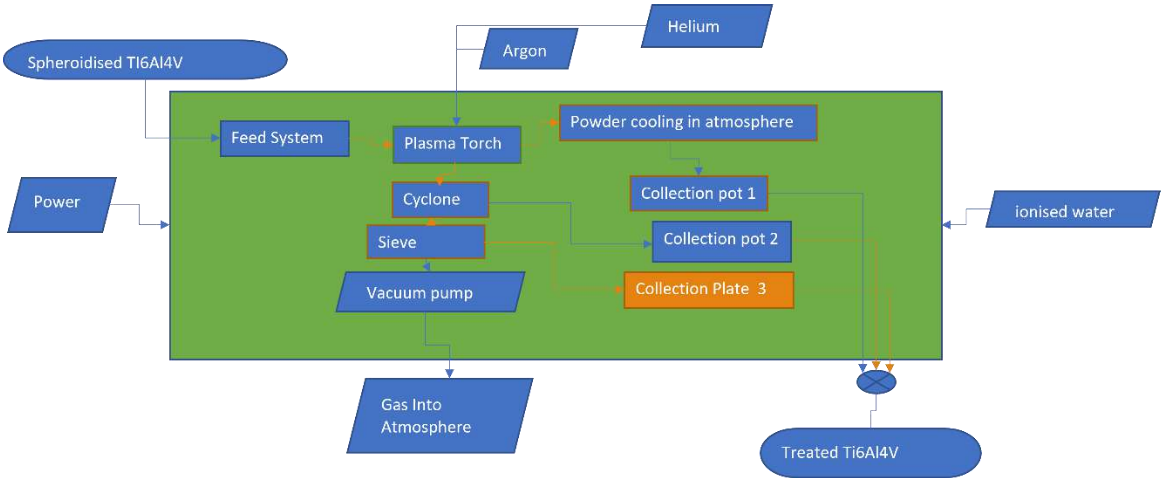

Figure 2: Spheroidisation in detail

3.4.1 Process parameters that influence cost

Temperature-Temperature of the plasma can affect powder consumption and the amount of ionized water needed. The temperature is governed by plasma power.

Feed rate-Feed rate can increase spheroidisation time and gases required for spheroidisation. A slower feed rate also entails more material is subject to vaporization entailing loss is material.

Resident time of powder in plasma – Longer resident time means better spheroidisation but increases the time spent in spheroidisation.

Gas flow rate- The gas flow rate affects the spheroidisation ratio and speed of the entire process. It is therefore important to find the optimum gas flow rate which brings the highest yield at the minimum gas utilization.

The initial quality of the powder can also have an impact on the process parameters requirements required. If the powder is course, it may require more power to spheroidise than smaller particles.

3.4.2 Sonic Cleaning System (Floatation)

The sonication process is not available at Necsa; however, it has been shown that the plasma treated powder needs further processing to remove nano particles. The sonification process is the process in which nanoparticles are removed from a sample hence enhancing the overall quality of the sample. The sonic cleaning system is a critical machine for the reconditioning of Ti6Al4 V.

The sonic cleaning system has the capability to

- Remove fine particles (soot)
- Improve purity
- Improve flowability
- Increase tap density
- Reduces powder stains
- Improves surface finish

3.4.3 Scanning Electron Microscopy

For powder characterization the Scanning Electron Microscope (SEM) is used [22]. The SEM investigates the:

- Particle size distribution
- Particle shape
- Porosity
- Average particle size.

3.4.4 Density Measurements

Density is an attribute of AM powder as it can affect the strength of the final printed product. The AccuPyc II - Micromeritics AccyPyc Gas Displacement Pycnometer is one of the tools used at Necsa to measure density. This is a non-destructive method uses helium as the displacement gas [23].

3.4.5 Flowability

Flowability is also critical to ensure the powder flows well during printing. The hall flow meter is used to measure flowability and is a low investment activity with little or no running cost [24].

4 AREAS OF IMPROVEMENT FOR LEAN MANUFACTURING WITH REFERENCE TO SPHEROIDISATION

After identifying the major activities, the researcher focused on the critical areas where waste can be reduced without compromising on quality. The major wastes that can occur are energy consumption, helium consumption. Another area where potential waste can occur is vaporisation of titanium. Titanium alloy contains vanadium and aluminium, which have different melting points. If vaporisation occurs, the elemental composition can be altered, thus changing material properties. **Error! Reference source not found.**Table 3 shows the time for each activity that takes place at Necsa.

From the table, the most expensive test is the elemental analyses, which are carried out on a weekly basis. The elemental composition of the titanium can be controlled using the correct process parameters. In an industrial setup, the elemental analyses can be removed from the process flow.

The best process parameters to reduce powder loss while producing a powder of high quality is by reducing, he helium and increasing argon. This can allow for less power to be used during the spheroidisation. If the powder loss is close to zero, the need to do an elemental analysis can be reduced and focus can be placed on the oxygen test, which is close to 39 Rands per analyses. The elemental analyses frequency needs to be reduced as it is an expensive process typically 2000 Rands per analyses at the time of publication of the article.

Table 3 Time per Activity

Activity	Time
Spheroidisation	1hour
OHN analyser	30mins
Hall flow Meter	20mins
Density Measurements	N/A
Elemental analyses	N/A

Microscopy	0.5 hours
Sonication	14 hours

The activity that takes the longest is the sonication process, which takes up to 14 hours of production time. The spheroidisation process in the 15-kW Tekna system can produce 1 kg per hour. To improve the production rate, the flowability can be increase. Increasing the flowability carries the risk of material vaporisation, thus increasing material waste. Helium consumption can be increased to reduce power require this saving on energy. For each manufacturing firm, they will have to decide if power saving, helium saving or saving time is important. All this will depend on the customer demand.

Another critical element that needs to be preserved is the titanium alloy as it is costly and high levels of vaporisation can lead to reduced final product quality. By improving process parameters, some analyses processes can be minimised. These processes include quality checks, which check properties which are overlapping. The spherical shape can influence the flowability and thus checking for flowability can be adequate and minimised the need to check for particle shape. This is done assuming that the powder contains minimum nanoparticles.

Minimising destructive testing is also critical in reducing waste in spheroidisation. For lean manufacturing to be implemented, standard operating procedures are developed to ensure that every step is followed, and that material is traceable at each stage of production.

Lean manufacturing will also ensure that workflow commences only on customer demand.

Table 4:Material loss per kilogram Spheroidised

Material	**11-kW Settings**	**12-kW Settings**
Titanium powder loss	50 grams	250 grams
Helium loss	0	0.16 kg
Argon Loss	5.48 kg	3.37 kg

Table 4 shows the material loss of each of the two process parameters used during the spheroidisation process. These results were extracted from the experiments and show that lean manufacturing can be implemented in spheroidisation by adjusting the process parameters. The 11-kW settings show that you can reduce the spheroidisation powder and helium consumption and maintain powder quality. The helium is replaced with argon which is a more cost-effective gas. The helium saved may seem insignificant, but the cost of helium was 1533 Rands per kilogram while argon was 13.40 Rands per kilogram at the time the study was carried out.

Reducing material loss though process parameters is critical in ensuring that the process is highly efficient. The area that needs to be focused on is the spheroidisation with reference to the energy consumption and helium consumption. In the quality check phase, there are properties that are related which can be investigated with a single analysis during a commercial run.

The process parameter that cannot be generalized are elemental composition and oxygen content [25]. The process parameters that can alter elemental composition are plasma temperature, which is directly affected by power. Using low power can minimise vaporisation that can alter elemental composition. This will also reduce titanium losses, as there will be less vaporisation. With less titanium losses, the elemental composition tests can be reduced, and labour cost and overhead can be reduced.

Flowability is another important factor in the Ti6Al4V properties. In many AM machines the flowability affects the printing quality. Another property that is critical is the tap density, which can also be done with similar equipment to the hall flow meter.

When investing in spheroidisation technology, there is little need to invest in SEM as the spherical shape can be confirmed by the flowability of powder. If the need arises to check for particle properties, the SEM machines can be outsourced. The investment cost of an SEM is typically 4 000 000 Rands, which can be extremely high for a starting business. If the process parameters are applied well to the investment in SEM, technology can be eliminated for quality checks. Necsa is a research institution, and the SEM machines are strategic investments which are used by multiple industries thus, the spheroidisation cost is not highly impacted.

With chemical composition there is little that can be done to reduce investment cost as chemical composition is not independent of other powder properties. The advantages with the chemical composition analyses are the fact that the running costs are low, and the process uses minimum recourses. The only way to reduce waste is also through the improvement of process parameters during spheroidisation. The OHN-836 analyser used for chemical analyses consumes high amounts of energy and often require a lot of energy to start up. This can be, mitigated by maximising resource utilisation within the value chain by hiring out the analyser to different organisations.

Table 5: Relationship Between powder Properties

	Flowability	Powder density	Morphology	Powder size	Powder shape	Chemical composition	Elemental (composition)
Flowability	🟩	🟩	🟩	🟩	🟩	🟥	🟥
Powder density	🟩	🟩	🟩	🟨	🟩	🟥	🟨
Morphology	🟩	🟩	🟩	🟩	🟩	🟥	🟥
Powder size	🟩	🟨	🟩	🟩	🟩	🟥	🟥
Powder shape	🟩	🟩	🟩	🟩	🟩	🟥	🟥
Chemical composition	🟥	🟥	🟥	🟥	🟥	🟩	🟨
Elemental (composition)	🟥	🟥	🟥	🟥	🟥	🟨	🟩

- Green entails they are highly related
- Red entails there is minimum relationship
- Yellow entails related but not directly

5 RELATIONSHIP BETWEEN MATERIAL PROPERTIES THAT ARE PERCEIVED AS VALUE

The attributes of the powder that contribute to the quality are related to an extent. Table **5** shows the extent to which these attributes are related. Grouping the related attributes can help find the properties of powder that can be tested using one piece of machinery. Reducing testing equipment is critical as it can also reduce quality checks which can be time consuming and highly expensive[26].

Flowability is an attribute that is affected by most of the powder properties. The chemical composition and elemental composition do not affect flowability to a greater extent. By placing focus on flowability, the other attributes of the powder are dealt with. A spherical Powder shape ensures friction between powder particles is minimal. When powder size distribution is minimal, powder can easily flow with less friction[27] [1].

Powder density is affected by morphology. When there is a high powder size distribution, the smaller particles can tightly pack into spaces of the bigger particles. However, if the powder size distribution is too high, friction between particle scan be increased. Chemical composition is independent of powder shape and size, as it is simply a measure of chemical substances in the titanium. Elemental composition is also independent from other attributes of the powder and therefore needs to be monitored on its own. Powder flowrate affects the powder characteristics. High flow rates can increase powder amalgamation within the powder and low flow rates can reduce spheroidisation ratios. Introduction of helium can also affect the rate of powder attributes. More helium allows for high spheroidisation at low temperature. This can further reduce waste within the process.

5.1 Suggested Process Flow

The initial process chain followed a straight line which means all activities take place in succession and each activity needs to wait for another to complete. The best way to implement lean is by arranging some of the activity in parallel as shown in Figure 3.

Figure 3: Modified Process Chain

Figure 3 shows the modified process chain after applying lean manufacturing. The new process chain allows for a shorter time span for the spheroidisation. The time span can be reduced by an hour.

6 BENEFITS OF LEAN MANUFACTURING STRATEGIES IN SPHEROIDISATION

With regards to spheroidisation, lean manufacturing can reduce waste and set up a system where standard operating procedures are followed. Lean manufacturing can also ensure that defects are reduced within the production line[28].

The waste that was minimised by optimising the powder was:

1. Powder loss by 20%
2. Waste of process by minimising elemental analyses.
3. Minimising helium usage.
4. Minimising power as using argon can reduce the power required to spheroidise.

In a production setup, the method to ensure powder morphology is consistent is through a sieve with known parameters. Measuring morphology with Laser Diffraction can be costly and thus increase production cost. Applying a sieve to extract the powder that is required is the most cost-effective method, assuming the process parameters were carried out correctly.

7 DISCUSSION

The spheroidisation itself is a lean manufacturing technique as it reduces waste of material in additive manufacturing. During the spheroidisation process waste can also be reduced by changing process parameters which include heat (power) and gas concentration.

Lean manufacturing strives to eliminate waste and while improving quality. There is an option of having superior product or having a low-cost product. The 12-kW settings for spherodisation allow for a superior product which the 11-kW allow for a cost effective product. Finding the optimum parameters to produce high quality product at a low cost was important in the lean manufacturing. This can be achieved at a power of 11-kW and using argon as sheath gas. Using theses parameters allows the facility to use less power and cut down on helium which is a relatively expensive gas. The level of quality at Necsa is defined using ASTM standards. These standards define the value in the powder which includes flowability, particle size distribution and powder density.the 12 kW settings are used for producing a superior powder but powder loss ocurs due to vaporisation which entails more material waste. Using the 11-kW settings can make powder that is acceptable for most additive manufactruing purposes and thus using the 11-kW power is sufficient. Using the 11-kW settings with argon as the sheath gasagorn is best suited for lean manufactruing.

8 CONCLUSION

Lean manufacturing in spheroidisation is decribed in the article. The paper highlited the lean principles applied in spheroidisation. The spheroisation process has room for improvement in terms of reducing waste within the process. The paper also highligtted the relationship in powder characteristics and how their relastionships can be used to develope a more economic process chain by eliminating processes that unnecessary within the process chain of spheroidisation of Ti6Al4V.

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MAKING DECISIONS IN A COMPLEX WORLD - A SYSTEMS THINKING PERSPECTIVE

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ABSTRACT

Everyday life requires that numerous decisions be made. These decisions can range from the mundane, such as what to have for lunch, to the difficulty of where to invest funds and generate an acceptable return. These decisions are made against the backdrop of the complex socio-technical world in which we work and live. Systems thinking is generally accepted as one of the methodologies used to make sense in a complex world. This paper examines the process of making decisions from a systems thinking perspective within a situational awareness framework to identify approaches that can be used in complex situations.

Keywords: situational awareness, complexity, systems thinking, socio-technical system

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1 INTRODUCTION

Numerous decisions must be made daily within a personal and professional context. This context is defined by the world in which the decision must be made and the circumstances within which the decision must be made. This world can be considered to consist of both natural elements and created artefacts [1]. In the present day context, this world can further be characterised by an increasing interaction and interdependence between humans and the created artefacts, resulting in a complex socio-technical system [2]. Such a socio-technical system emerges when two separate but interdependent systems, the social and the technical, interact to create a single environment [2], [3]. The social environment refers to the various characteristics of the inhabitants of the world involved in the decision-making process, the relationship between these inhabitants, the reward systems, and the authority structure present in this world. The technical part includes the various processes, tasks and technologies required in such a socio-technical system [4].

The context within which the decision must be made refers to the system factors and the individual factors that come into play when making a decision [5].

The type of decisions made within this socio-technical system can range from simple to complicated to complex. A decision can be called simple if the number of elements or aspects involved is limited and the decision only takes place at a hierarchical system level [6]. A decision can be considered to be complicated when the relationship between the various elements within the system is based on fixed relationships. These fixed relationships allow reasonable predictions of the time, cost, and technical resources required to support the decision [7].

Complex decisions will be required where a complex system is encountered. Complex systems exhibit a certain degree of self-organisation. This self-organisation creates a new, emergent behaviour that is not recognisable in the individual parts [7], [8]. Another distinguishing feature of complex systems is their usefulness, as they have a definable objective and function [8]. In order to understand the behaviour of a complex system, one must understand the behaviour of the individual parts and how they interact with one another. Therefore it is not possible to understand the whole without understanding the individual elements, and it is not possible to understand the individual elements without understanding their interaction [8]. Deciding within a complex system will test man's ability to act as an effective, timely decision-maker when operating within these complex systems [5].

1.1 Research methodology

The research methodology used for this paper is exploratory research, using literature as the primary data source to study the decision-making process and potential mistakes or challenges encountered [9]. The results of the exploratory research were further augmented by an inductive reasoning process taking into account the more than 30 years of experience of the researchers in the field of complex, social technical systems. This research methodology was chosen to help identify the various boundaries of the environment in which the decision-making process takes place and to identify salient factors and variables applicable to this research area. The systems thinking approach used in this paper is based on the critical systems thinking perspective defined by Jackson [10].

1.2 Paper layout

This paper is organised in the following way. In the next section, the decision-making context is viewed as a complex system. The following section applies a systems thinking perspective to the decision-making process that includes a causal loop model showing the interactions and interdependencies between the different system elements. The last section concludes and identifies possible areas for future research.

2 WHY AND HOW ARE DECISIONS MADE?

Decisions are made as precursors to an action that intends to advance a given situation† toward the desired situation. Once the decision is made, and the actions associated with the decision are taken, the current situation will be changed. This change can either be in the desired or undesired direction, which may require an additional decision. A complex system typically has a high dynamic complexity resulting from the time delays between making a decision, implementing the decided action and evaluating the results. The effect of this delay is to slow down the learning loop, reducing the improvement that can be achieved within a given time [11]. This concept is shown in Figure 1.

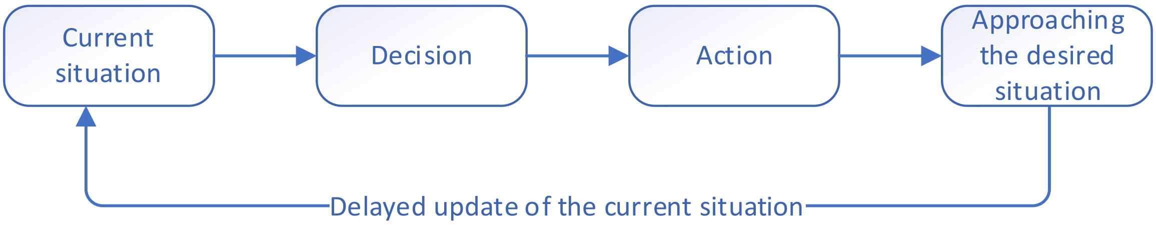

Figure 1: Purpose for requiring a decision.

The INCOSE Systems Engineering Handbook [7] identifies the process of managing the decision-making process as one of the core technical management processes of the systems engineering process. It defines the purpose of this process as:

> *"…. to provide a structured, analytical framework for objectively identifying, characterising and evaluating a set of alternatives for a decision at any point in the (project) life cycle and select the most beneficial course of action."* [7]

Figure 2 presents the Input – Process – Output (IPO) diagram for the decision management process.

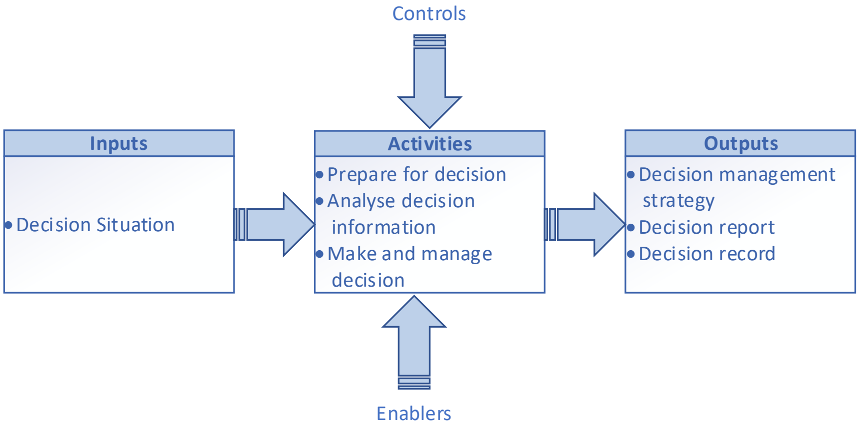

Figure 2: Input-Process-Output diagram for the decision management process (Redrawn from [7])

The input to the process, the decision situation, relates to the why, which leads to a need for a decision. The specified activities of preparing decisions, analysing decision information, and making and managing decisions include defining the decision management strategy, preparing the decision statement, and framing and structuring the decision intended to produce the outcomes. The outcome of the decision management process is the strategy used to make the decision, the analysis report, and a record of the decision.

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† The general state of things; the combination of circumstances at a given time [37]

While the stated activities of decision preparation, analysis of decision information, and decision making appear very simple, experience shows that decision-making can be notoriously tricky. Nutt [12] identifies three reasons that contribute to difficulties in decision-making. Reasons include (1) failure to practice participatory decision-making, (2) time pressure experienced to gather relevant information and make the decision, and (3) failure to articulate the why in terms that evoke collaboration between stakeholders and not try to assign blame.

The decision-management process described here does not occur in isolation but within a specific context or system that directly impacts the decision-making process. This concept is illustrated in Figure 3.

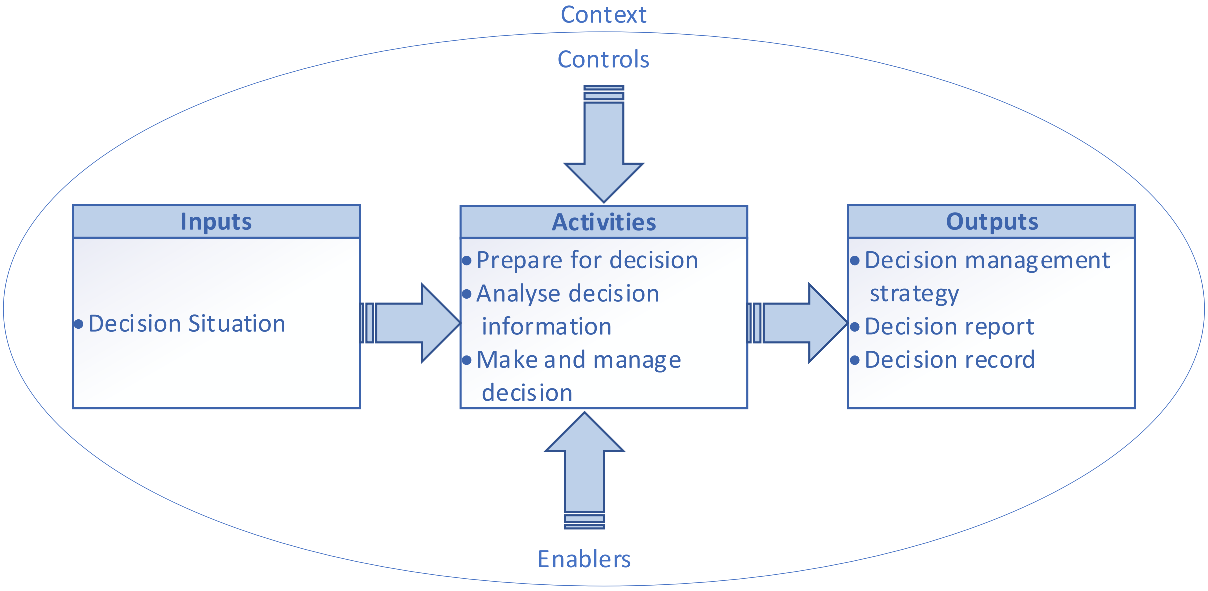

Figure 3: Decision management process, including the context within which the process must operate

Further insights into the context in which the decision-making process takes place can be provided by creating an awareness of the prevailing situation and environment. This awareness is also called situational awareness and can be defined as perceiving environmental elements and events concerning time or space, understanding their meaning and projecting their future status [5]. Figure 4 shows a graphical representation of such a situational awareness model. Increased situational awareness should lead to an improvement for successful decision-making under various conditions [5]. There will typically be an optimum level of situational awareness after which the amount of information will exceed the capability of the decision-maker resulting in reduced decision quality [5].

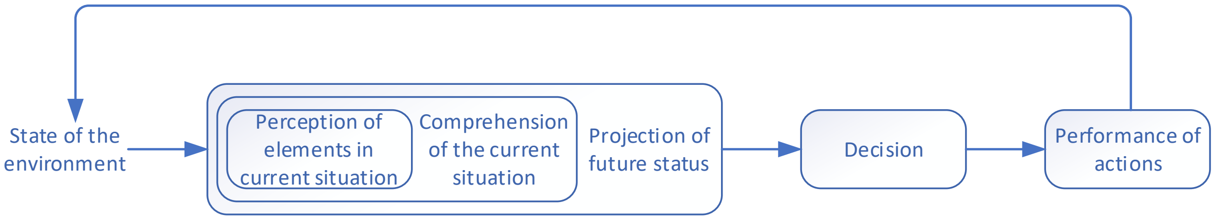

Figure 4: Model of Situational Awareness (Redrawn from [5])

Situation awareness is built up from viewing the situation from three aspects:

1. What is happening now?
2. What does this mean?
3. What does this foretell of the future?

The decision-maker's perception‡ of the current situation is described by the information available when the decision is made. This information is derived from the available data and the metadata describing the situation. The decision makers knowledge of the current situation describes the decision maker's understanding§ of the current situation. Knowledge tells us what to do based on accumulated experience. It dictates something. Projecting the current situation into the future is a function of the decision-makers understanding in the sense that it guides, predicts, and recommends what can be done under circumstances that have not previously occurred. It must be noted that situational awareness is a concept distinct from the act of decision-making [5]. Although situational awareness consists of the decision-makers knowledge of the context at any point in time, this knowledge also includes temporal aspects of that environment, relating to both the past and the future [5]. Situational awareness can therefore be seen as one of the most important precursors to decision making. However, many other factors may also play a role in turning good situational awareness into a quality decision [13] that is also elaborated on in the following sections.

3 THE DECISION-MAKING CONTEXT AS A COMPLEX SYSTEM

3.1 Understanding complexity

In the previous section, it was postulated that making complex decisions is more challenging than simple or complicated ones. The decision maker's understanding of complexity in general and the specific complexity encountered in the context of decision making will significantly improve the decision maker's situational awareness, leading to potentially better decisions. The following key features can be used to describe a decision-making context [10]:

- Systemic and synergistic: Is interconnected and results from many causes that interaction and lead to a complex sequence of events
- Can be multi-scalar with interactions across many systems levels
- Exhibits variety, diversity, variation, and volatility that can create both resilience and adaptability within the complex system
- The elements can be path-dependent, contingent on the local context, and the sequence of events
- Changing episodically: May demonstrate resilience at one time, flipping into new regimes at another time
- Can possess more than one future
- Can organise and self-regulate and, in some circumstances, produce new, emerging traits

Some or all the following characteristics can be further recognised in complex systems:

- The structure of the complex system allows it to behave in complex ways. With too little structure, the system can behave more randomly but not functionally. Complex

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‡ becoming aware of something through the senses [37]

§ The capacity for rational thought, inference or discrimination [37] behaviour is possible when the behaviour of the system is constrained. On the other hand, a fully constrained system will not show any complex behaviour either [14].

- Since different descriptions of a complex system decompose the system in different ways, the knowledge gained from each description is always relative to the perspective from which the description was made. This occurs since a specific description can only account for a limited number of system properties. Not all micro features can be considered when describing the system's macro behaviour (or emergent behaviour). The description is a reduction in complexity. However, macro behaviour is not the result of anything other than the micro-activities of the system. However, it is challenging to describe macro behaviour using only the micro features [14].

To understand a complex system in more detail, we must understand its complexity. Also, since complex systems are open systems, we need to appreciate the complete environment of the system before we can understand the system. Of course, the environment itself is complex. The comprehension of complex systems is based on the models we make of those systems. The function of these models is to simplify specific parts of the system thus reducing the systems complexity and not replicating the system. This means that some aspects of the systems are always left unconsidered. The problem is compounded by the fact that what is left out interacts with the rest of the system in a non-linear way. Therefore we cannot fully predict what impact the complexity reduction will have as the system and its environment evolve and change with time [14].

We cannot have complete knowledge of complex systems. There is no stepping out of complexity (we are finite beings), so there is no frame to frame. We choose our frameworks. This choice need not be arbitrary at all, but it does mean that the status of the framework (and the framework itself) must be continually revised. Any knowledge of complex systems is always provisional [14].

3.2 Dealing with complexity

An intuitive approach to dealing with complexity is to break down the situation that requires the decision to be made, into several smaller and more manageable parts. This method is called the reductionist approach. This approach will cause problems when applied to complex problems because complex systems contain interconnected parts, with the relationships between the parts typically being more important than the parts themselves[15], [16]. Furthermore, these problems can be attributed to the ambiguous ways a problem situation can be defined, depending on the viewpoints and mental models of the researcher, investigator, or other stakeholders. Mental models are used to glean information regarding the structure and relationships of dynamic system when a physical representation of the system is not available [17].The world where the problem occurs may also exhibit the VUCA characteristics of volatility, uncertainty, complexity, and ambiguity. These problems are also known as messy or wicked problems [18].

As a result, there are no clear criteria as to when a problem has been solved, or a specific goal has been achieved [19]. Any added effort can only improve or shed more light on the situation [2], [20]. These shortcomings can be attributed to the inability to define and conduct repeatable experiments.

An alternative approach is to view the problem first as an investigation activity and second as an improvement activity. In both investigation and improvement activities, the first step is to establish a current baseline within a given problem scenario**, identify areas for improvement, make changes by applying those improvements to the problem scenario, and reassess the current state of the problem scenario. Once these improvement changes are made, a new

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** A postulated sequence of possible events [37] baseline can be determined and compared to the original baseline to determine if improvements have been realised [21].This behaviour is also demonstrated in Figure 1 and Figure 4 where the feedback loop from the end of the process to the start can be identified.

Systems thinking is a framework that helps us to approach complex issues holistically [22]. Systems thinking can be applied in many different disciplines and areas of practice. Both quantitative and qualitative approaches have been used to pursue academic and functional goals, including the study of human involvement in systems [22]. An important application of systems thinking is to support decision making. Systems ideas are compelling in helping us organise our thoughts to make sense of very complex issues. Furthermore, using systems ideas in decision making directly contributes to understanding their usefulness and value as a framework for thought. So practice encourages thinking [22].

4 LOOKING AT THE DECISION-MAKING CONTEXT FROM A SYSTEMS THINKING PERSPECTIVE

4.1 What is a system?

A system can be defined by identifying the elements, the interconnections between the elements as well as a function or purpose [23]. The INCOSE System Engineering handbook defines a system as an "…integrated set of elements, subsystems, or assemblies that accomplishes a defined objective. These elements include products (hardware, software, firmware), processes, people, information, techniques, facilities, services and other support elements" [7]. Based on this definition, one can then postulate that the decision-making process and the context in which a decision is made can be classified as a system. The elements of the system are the various stakeholders and decision-makers and the decision-making processes used. The purpose of the system can be identified as to improve the quality of decisions made.

4.2 Systems Thinking

Jackson [24] identified four stages in systems thinking that can be applied in practice:

- Stage 1: Explore the problem situation
- Stage 2: Produce an appropriate intervention strategy
- Stage 3: Intervene flexibly
- Stage 4: Check on progress [24]

Within the scope of the research content presented in this paper, only the first research stage into the problem situation is addressed. This discussion takes place in the context of a causal loop model that identifies the interactions and dependencies between the various elements present in the system and with an understanding of the nature and behaviour of the system, including the feedback loops that exist.

Causal loop models provide a means to identify the feedback structures in any domain [11]. Causal loop models are one of the methods used in system dynamics modelling. System dynamics modelling provides a mechanism for complex systems defying intuitive solutions. As such, system dynamic modelling assists the audience in perceiving the situation or problem and enhances learning in a complex world. A system dynamics model needs to communicate with the audience and change previous mental models that may be in place [11], [25].

4.3 System elements within a decision-making context

The following system elements are some of those that can be identified that may affect the situational awareness of the decision-maker and, consequently, the decision quality. These factors were identified from the literature survey as well as inductive inference by the researchers based on their collective experience:

- **Time Pressure:** The time available to the decision-maker to gain the necessary situational awareness will significantly affect the sense that can be made from the situation within the context of the problem [26]. Time pressure may force the decision-maker to take shortcuts or copy practices recommended by consultants [12].
- **Time Required:** The knowledge that constructs situational awareness is built over time and cannot be accelerated. This knowledge includes temporal aspects of the problem environment that relate to both the past and the future [5].
- **Decision-making technique selection:** There are many decision-making techniques. The decision-maker may prefer some decision-making techniques based on various factors such as familiarity with a specific technique or not having experience with other techniques. However, this may not necessarily be the most appropriate technique and can negatively impact situational awareness and decision-making [12].
- **Relevant information availability:** Situational awareness is also a function of the system defined in terms of how far the system provides the information needed and in what form it provides it [12].
- **Domain Knowledge:** The decision-maker needs domain knowledge to complement situational awareness. The required level of domain knowledge includes not only familiarity with business operations but also domain knowledge that describes the nature and culture of the organisation [27]. If the decision-maker does not have the required domain knowledge, he or she should avoid fixations and prejudices that can lead to an incomplete understanding of the situation [28].
- **Technical knowledge:** The decision-maker also needs a base of technical knowledge. This technical knowledge includes the fundamentals of the various technologies in the domain and knowledge of items such methods and tools that can be used [29], [30].
- **Misinformation:** Misinformation can be introduced by various stakeholders who are either involved in the information-gathering process or may be influenced by the outcome of the decision. A stakeholder in this context is any party involved in or affected by the process to gain situational awareness.
- **Decision-maker's dual nature:** It can be argued that the decision-maker can exhibit a dual nature within the decision-making process. On the one hand, the decision-maker as an individual can have their perspective and perception of the question to be answered. On the other hand, as stakeholder representatives, the decision-maker may have different concerns, priorities and responsibilities [31], [32].
- **Communication Challenges:** Communication plays a vital role in the situational awareness process, whether verbal or written. Besides the regular communication aspect inherent in the human and social nature of the decision-maker, additional problems can arise when such a process is carried out by multinational teams across national and international borders. In such situations, the decision-maker may not only have to deal with a lack of face-to-face communication but also with issues such as different time zones and cultural diversity, which can lead to misunderstandings and even conflicts in the process [33], [34]. Communication can be further hampered in international projects, where the native language of the different stakeholders and decision-makers may not be the same. This type of situation could easily lead to misunderstanding of the issue and lead to wrong, incomplete or ambiguous situational awareness and incorrect decisions.
- **Conflict:** Conflict often arises in situations where group interaction is present. Aspects that can create conflict in the decision-making process are most likely found where

there is limited domain knowledge, vacillating or conflicting problem definitions, and a breakdown in communication and coordination [35].

- **Decision-Makers Personality:** The ability of the decision-maker to handle the conflict identified in the previous bullet in a positive way can be used to counteract resistance to change and stagnation in the elicitation process.
- **Understanding of the question to be answered:** The ability of the decision-maker to understand the full implication and scope of the question or problem to be decided on, is imperative to achieve a sufficient level of situational awareness.
- **Decision-maker's experience:** The experience of the decision-maker must also be such that the person can analyse the situation and choose the right decision-making technique that will give the best results. The knowledge and experience of the decision-maker to understand the situation and make decisions plays an essential role in the process and directly affects the outcome.

4.4 Decision-making causal loop diagram

4.4.1 Description

A decision-making causal loop diagram can now be constructed using the parameters identified in section 4.3. The purpose of this diagram is to visualise the different elements of the system, the interconnections between these elements. The purpose of this exercise is to better understand the different interactions between the various elements and any feedback loops that may exist. The interactions between the different elements were determined in a deductive process. The causal loop diagram shown in Figure 5 was constructed from the elements identified previously using the Vensim Systems Thinking and Systems Dynamics software.

4.4.2 Discussion

A causal loop model is read regarding the effect when the causative effect increases or decreases. An example of this is re-examining the factors that influence decision quality. From the causal loop model shown in Figure 5, as the decision maker's understanding of the question increases, so does the quality of the decision. Similarly, increasing the decision maker's domain knowledge and technical knowledge leads to a better understanding of the question. The process can be repeated on the other elements of the causal loop diagram, improving the overall understanding of the interdependence of these elements on the quality of the decision.

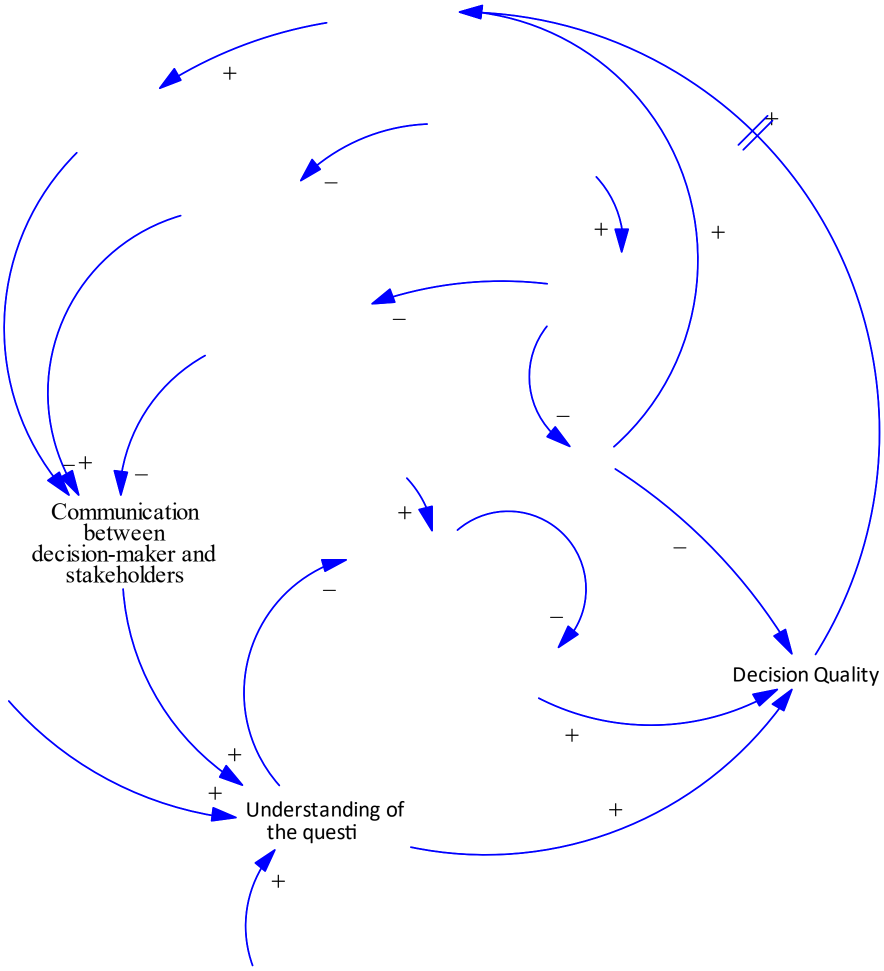

Figure 5: Causal loop diagram for situational awareness within the decision-making process

4.5 Decision-making Ishikawa model

4.5.1 Description

An alternative way to look at the interaction between the elements, is to identify the factors contributing to the decision quality element. These factors are derived from the causal loop model and is shown in the form of an Ishikawa or fishbone diagram This diagram is shown in Figure 6. This diagram was also constructed using the Vensim Systems Thinking and Systems Dynamics software.

The diagram was constructed by identifying the following relationships:

1. The element "decision quality" can potentially be impacted by the decision makers' understanding of the question to be answered, the decision maker's experience, the time required to make the decision, and the availability of the relevant information required in the decision-making process.
2. There are also secondary factors that impact the primary factors. As such, the decision-makers understanding of the question is again dependent on the domain knowledge and the Technical Knowledge of the decision-maker, as well as the level and quality of the communication between the decision-maker and the various stakeholders that may

hold the required information that the decision-maker requires for situational awareness.

3. In the same manner, it can be observed from Figure 5 that the time required is a factor in the decision-making technique selected and that the availability of relevant information depends on the misinformation level.

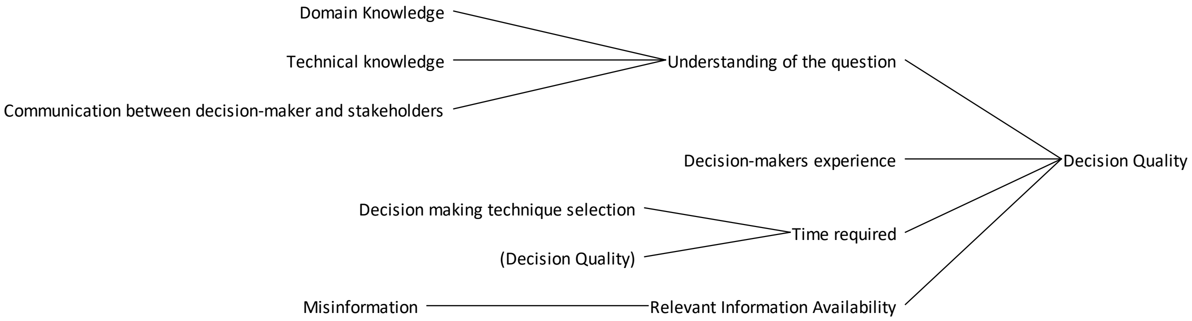

Figure 6: Factors that can influence Decision Quality

4.5.2 Discussion

The graph in Figure 6 does not indicate the various factors' effect on either a reduction or an increase of the decision quality parameter. However, this diagram is excellent to identify both first level elements impacting the Decision Quality and second level elements impacting the Decision Quality via first level parameters.

4.6 Feedback loops

An alternative way to analyse a complex causal loop model is to look at the feedback loops within the model. When the loop polarity of the feedback loop is positive, it can be said that the loop behaviour will typically be a growth-producing loop or an unstable loop. When the loop polarity of the feedback loop is negative, the loop behaviour can be said to be typically homing or a stable loop [36].

The elements of one of the feedback loops that can be identified are shown in Figure 7. This feedback loop was identified using the functionality of the Vensim software tool.

The feedback loop can be interpreted in the following way:

- The pressure on the decision-maker to make a timely decision can potentially lead to an increase level of conflict among the various stakeholders
- This increase in conflict among the stakeholders will reduce the level and quality of the communication between the decision-maker and the stakeholders.
- This decrease in the level of communication will then decrease the understanding of the question or situation to which the decision pertains.
- A decrease in the understanding of the question or situation will then lead to a decrease in the quality of the decision.
- The relationship between the decision quality element and the time pressure element includes a delay in the effect of the one element on the next. The quality of the decision will not immediately be known, resulting in a possible delay in identifying any correcting actions that must be taken. This delay will further increase the time pressure on the decision-maker to make a new or corrected decision.

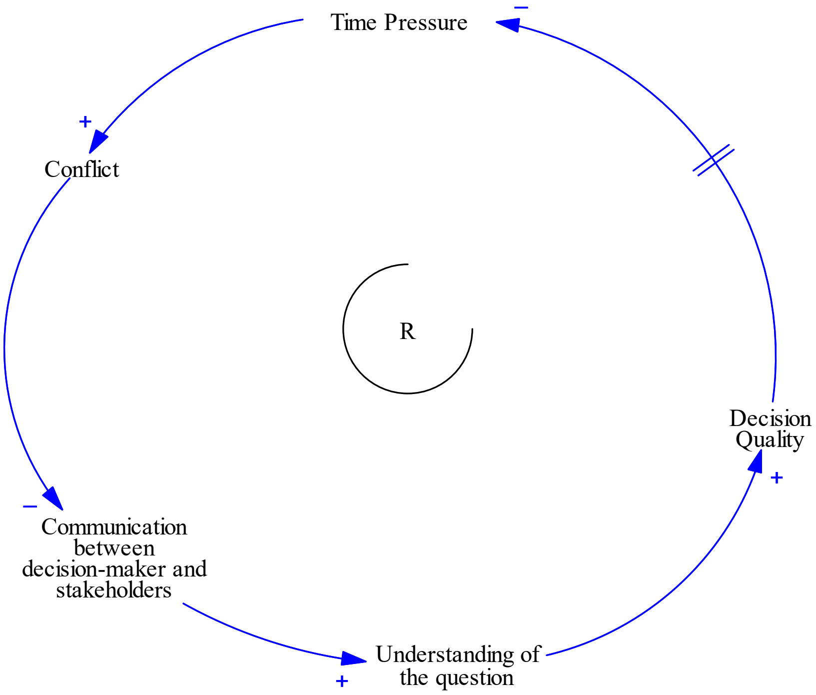

Figure 7: Positive or growth-generating feedback loop

5 CONCLUSION

Decision-making within a complex socio-technical system can be a challenge for the decision-maker. A method identified in the literature to support the decision-maker in the decision-making process is to increase the situational awareness within the context of the problem situation.

Systems thinking as a methodology is proposed as one of the ways to gain a better understanding of the behaviour of complex systems. This paper proposed a causal loop model that examines the different elements that can contribute to the decision quality element of the system. The casual loop model was further analysed to identify the elements that interact, leading to the decision quality element and a possible feedback loop. This feedback loop has been identified as a reinforcement loop, indicating that the behaviour will only grow over time. The presence of the positive feedback loop can also be interpreted that no definitive or correct solution is possible within a complex system but that each opportunity for investigation should be treated as a learning and improvement activity.

Even though the research methodology and the resulting causal loop that was developed only served to illustrate a small part of the bigger picture, some insight regarding the decision-making process and complexity could already be gained from it. This insight includes aspects such as the interaction between conflicts within the workplace, communication within the organisation and the time required to decide. An example of where a similar real-life situation occurred was when the decision was made to launch the Challenger Space Shuttle despite all the warning signs present.

5.1 Further research

This first-order theoretical model presented in this study can be further developed by taking the concepts to various types of industries and evaluating the concepts against actual decision-making situations. The results of practical studies can then again be used the updated model can be transformed into a stock and flow type system dynamics model that can simulate situational awareness and decision-making processes.

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THE INFLUENCE OF THE 4TH INDUSTRIAL REVOLUTION ON GREEN ENTREPRENEURSHIP IN THE SOUTH AFRICAN CONTEXT: A SCOPING FRAMEWORK

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ABSTRACT

The emergence of COVID-19 could not have come at the right time during the Fourth Industrial Revolution (4IR) dispensation. The realities of 4IR dismantled the physical boundary between manual and digital operations. A scoping review was adopted for this study, drawing, Google scholar, Business strategy and the environmental sustainability, IEEE Access, journals of entrepreneurship, theory and practice, international journals of energy, economics, and policy, Unisa thesis and dissertation library, South African 4IR website, from 2018-2022 contextualised in South African context. The study adopted qualitative analysis using a thematic content analysis tool to gain an in-depth understanding of 4IR within green entrepreneurship. Through a literature review, 150 resources were reviewed for effective, reliable scoping, only nineteen met the scoping review criteria. Some of the results from the literature reveal that 4IR may influence the development and adoption of green entrepreneurship through digitalisation, policies, and socio-technical advances in education.

Keywords: Fourth industrial revolution, green entrepreneurship, system engineering.

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1 INTRODUCTION

The realities of 4IR dismantled the physical boundary between manual and digital operations. Therefore, the purpose of this study is to review how 4IR influences the green entrepreneurship spectrum. Green entrepreneurship is proven to serve as a missing link in facilitating the economy globally **[1]**, at the same time, pressures emerge post-COVID-19 where enterprises inclusive of green enterprises would be expected to thrive post-COVID-19 operating within the new normal. The current study contributes to closing the gap on using the above 4IR framework as well as engineering processes for green entrepreneurship utilising a scoping review method.

2 LITERATURE REVIEW

The literature review of the current study focuses ON environmental challenges and green economy, green entrepreneurship and 4IR, system engineering and OPTIMISATION within green entrepreneurship explained below.

2.1 Environmental challenges and the green economy

The various environmental challenges are water scarcity, lack of access to clean water lack of access to energy, waste management, lack of food security, and carbon emissions from cars [2]. The latter challenges call for green entrepreneurship action as follows: capabilities of society members to turn the challenges mentioned above into opportunities to save the environment and, simultaneously, benefit society and the economy with the lenses of 4IR.

The existing literature on green entrepreneurship focuses on remedying challenges such as lack of financial and non-financial support, lack of infrastructure, and clientele [3-20], but with less focus on looking at the solutions from the 4IR and engineering point of view in coping and thriving during and post-pandemic.

Green entrepreneurship focuses on the triple bottom effect looking at the social, environmental, and economic spheres. It encompasses the circular economy, green economy, and social transformation. Business owners are often expected to perform on the latter unpopular practice. Previous researchers have suggested that a person is pushed into entrepreneurship because of being dissatisfied with their current job and pulled into entrepreneurship because of market opportunities [6; 21-23)

South Africa is a developing country with many socio-economic issues; poverty and unemployment are the most extreme. The COVID-19 pandemic worsened these socio-economic issues as the unemployment and poverty rates drastically increased. As a result, millions of people have lost their jobs, and thousands of businesses must shut down. Notably, there needs to be an intervention to help cope and thrive during and post the COVID-19 pandemic within green entrepreneurship as technology incorporates 4IR and engineering processes.

Employment has been a goal of the public sector. Therefore, the best alternative that will help create jobs and poverty alleviation meets societal needs and generate work while saving the environment is green entrepreneurship and thrive post-COVID-19, which raises double jeopardy of challenges. These challenges can be viewed from a positive lens of turning these challenges into success. The generation of profits and saving the environment alone is not adequate. The humanistic attributes and well-being of green entrepreneurs and optimisation of green entrepreneurship technology are required. Thus, the need to introduce the field of optimisation as part of industrial engineering. The tactics mentioned above and strategies may assist green entrepreneurs in adapting and coping with changing environments.

Green entrepreneurship is a growing movement utilised to change the perceptions of individuals who want to venture into business. In the current study, we deconstruct green entrepreneurship through the lenses of green entrepreneurship as a social construct, as well as the integration of 4IR and optimisation.

2.2 Green entrepreneurship and 4IR

The green economy is characterised by eight thematic areas: sustainable energy, water, agriculture, transport and mobility, consumption, production, tourism, and waste management [24]. South Africa has identified key area priorities through the national development plans agenda 2030, wherein green economy thematic areas, namely, sustainable energy, waste, agriculture, transport, and mobility as well as waste management are included [25]. The 4IR framework is a missing link in the complete adoption and diffusion of those mentioned above prioritised key green thematic areas with the integration of entrepreneurship. The 4IR is defined as the mechanism and process looking at the technological, genetic engineering, and social sphere with characteristics such as artificial intelligence, diffusion, the internet of things, computing, and robotics [26]. There is no publication on 4IR and green economy, and green entrepreneurship. However, there are few efforts on 4IR, generic entrepreneurship, and sustainability [27-31]. There is one effort on 4IR and renewable energy (Dogaru, 2020). Other efforts on blockchain and businesses (27; 32-42) with less focus on green entrepreneurship and 4IR.

2.3 System engineering and optimisation

Systems engineering is the practical design, construction and implementation of design and processes, structures, equipment, and systems, considering scientific, economic and efficiency spheres [43-46]. Several scholars defined systems as interrelated parts for a common ground and end goal [33]. It is argued that systems engineering looks at a system within and outside a whole, how it could be generated and incorporated, and the factors that may hinder or serve as an obstacle to its total efficiency and life cycle. Systems engineering provides an effective and efficient framework with the lenses of the following: identifying customer needs, the system operational environment, interfacing systems, logistics support requirements and capabilities of operating personnel [33].

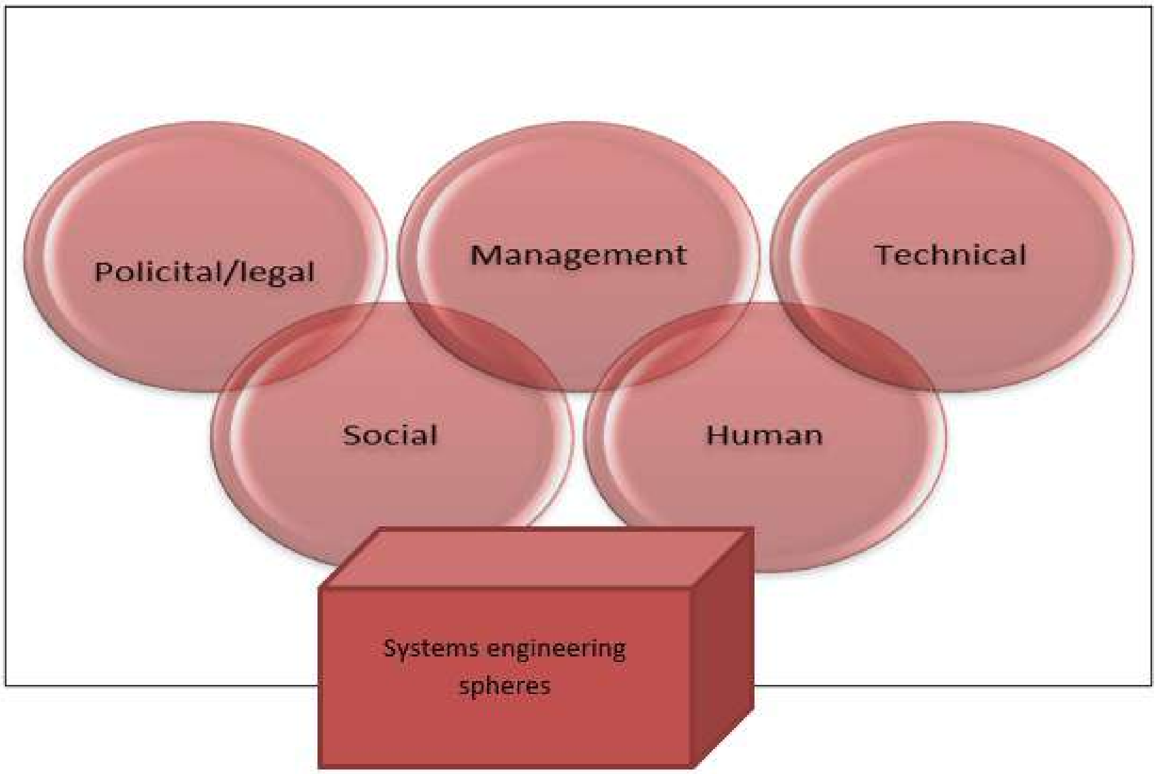

Figure 1 (Adapted from [47])

Those mentioned above are all relevant and intertwined into the current study. For instance, the human side can be looked at from the well-being of a person behind the machine, that even though the machine is doing the work, the well-being of the person behind the machine needs to be materialised. The social aspect can translate through what translated into having a representative from community members, triable kings, and cartoon characters to instil a green entrepreneurial mindset in children [9-10]. The management pillar can be used as a yardstick to secure infrastructure and ensure enough investment and resources for implementing 4IR within the South African context. The political will from policymakers and politicians is needed to buy and influence the legislative core mandate of the fourth industrial revolution within green entrepreneurship. The technical pillar or characteristic will then ensure optimisations, efficiency, and performance of the 4IR within the green entrepreneurial sector. The latter serves as a scoping review as a mechanism such observations and some modelling will need to take place to test and validate the scoping review.

3 RESEARCH QUESTIONS

How can the 4th industrial revolution be utilised to accelerate green entrepreneurship?

How can system engineering and optimisation be utilised to accelerate green entrepreneurship?

4 RESEARCH METHODOLOGY

A scoping review, particularly from a qualitative perspective, was adopted for this study drawing from technological forecasting and social change, Google scholar, business strategy and the environmental sustainability, IEEE Access, IEEM, journals of entrepreneurship, theory and practice, international journals of energy, economics and policy, advances in science, technology and engineering systems journals, international journal of environmental research and public health, empirical international entrepreneurship, Unisa thesis and dissertation library, South African 4IR website, the world view of entrepreneurship, management and sustainable development, conference on e-business, e-services and e-society. The criteria used were 4IR, industrial revolution and green entrepreneurship, simulation, optimisation, systems engineering and green entrepreneurship; 4IR and productivity within the green SMEs from 2018-2022 in South Africa. The study adopted a qualitative and thematic content analysis to understand 4IR within green entrepreneurship. Through a literature review, 150 resources were reviewed. Then subsequent steps involved removing duplicates of sources in which N=23 met the criteria, then for effective, reliable scoping, only 19 met the criteria [see table 1]. Sources such as magazines, newspapers, and news bulletins are excluded. The current study uses scoping review as there is not much literature on the topic. Sources were consulted using the mentioned criteria and summarised in table 1. The scoping review is relevant compared to a systematic review as it creates an awareness and indication to examine the evolution of a review for scientific facts. For effective scoping (35), the following guidelines are enforced based on the Johan Brigs Institute. Types of evidence available, clarification and definition of terms, the methodology adopted in the specific field, and critical characteristics or key factors related to a concept under investigation set a solid foundation for a systematic review and Identification and analysis of knowledge gaps [35]. Rigour, trustworthiness and transparency served as validity and reliability criteria of the study of the current study. Published articles and university websites were reviewed based on the criteria above.

The focus of this study is to explore the existing literature on 4IR and green entrepreneurship as well as optimisation and system engineering within green entrepreneurship. Therefore a qualitative approach is more suitable to allow for a rich, in-depth synthesis of existing literature.

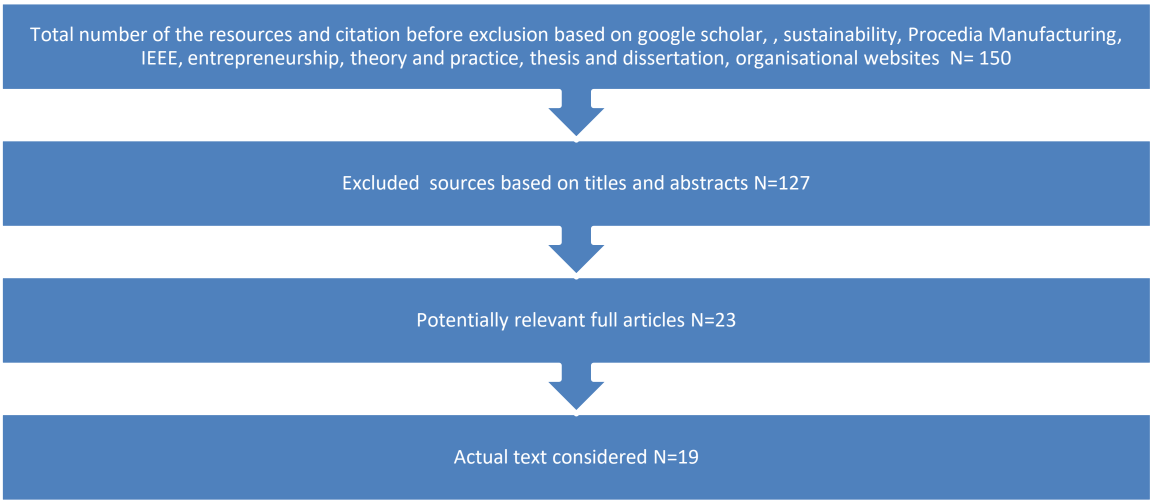

Figure 2 Systematisation of how data was extracted

Table 1: Results

Types of evidence available	Key characteristics or key factors related to a concept under investigation [themes from the study grouped]	Number of sources from the articles as well as websites	Identification and analysis of knowledge gaps	The implication of 4IR and green entrepreneurship in SA	Source
4th industrial revolution and green bonds [33-34]	Green bonds and the use of blockchain in facilitating green investment	2	4th industrial revolution and green entrepreneurship mindset serve as a research agenda.	Agility and policy formulation within green entrepreneurship.	Technological Forecasting and Social Change Google Scholar
Blockchain, 4th industrial revolution and generic business [27]	Blockchain facilitates business transactions, international trade, and financial domains.	1	4th industrial revolution and the holistic green entrepreneurship key driver or ecosystem.	4IR to address socio-economic factors	Technological forecasting and social change
4th industrial revolution and renewable energy [33, 34, 36] Energy efficiency and green entrepreneurship [37] Renewable energy enterprise ecosystem [9] Renewable energy into the cloud [37].	Robotics, 3D printing, genetics, internet of things focus only on renewable energy. IoT, smart agriculture, cloud	4	4th industrial revolution and waste management, sustainable water, sustainable transport and mobility, agriculture, tourism and sustainable energy enterprises.	Regulation of 4IR infrastructure and political will.	Technological Forecasting and Social Change Business Strategy and the Environment. IEEE Access International Journal of Energy Economics and Policy (IJEEP) Advances in Science, Technology and Engineering Systems Journal,
Artificial intelligence and generic	4IR to selling and scaling, and use	4	The focus on artificial intelligence, 4th industrial revolution	3D scanner for advanced design and green entrepreneurship.	Entrepreneurship Theory and Practice

entrepreneurship [28] SMEs and 4th industrial revolution in Africa [29] 4IR framework, ICT and SMEs in South Africa [30-31]	4IR to assist with SME growth, strengthening of roles, hub and fostering partnership. ICT evaluation within SMEs State of readiness in township-based business.		framework and green entrepreneurship is missing a link. The internet of things and the internet of people within the green entrepreneurship key ecosystem serve as a missing research gap. Green technology and enterprises from the African context with the integration of time and series data serve as a research gap.		UNISA'S thesis and dissertation library
Entrepreneurs, environmental sustainability, and the digital era [23] Environmental sustainability and 4th industrial revolution [green products and green process [38]	IT, the warm value of altruism, regulatory support, push and pull factors concerning environmental sustainably and entrepreneurship. Eco-friendly practices and 4IR.	2	The whole complexity and nuances of the 4th industrial revolution and environmental sustainability call for a research agenda	Socio-technical blockchain, internet of people mechanism.	International journal of environmental research and public health
Green entrepreneurial supply chain optimisation [39]	Minimising emissions from food producers to the customer [fundamentals of supply chain]	1	Research agenda to be formulated between green entrepreneurship and optimisation from the strategic level and not the operational level only	Robots for to accelerate sustainable agriculture.	Empirical International Entrepreneurship
Green entrepreneurship and system dynamic review [8]	Simulation of key drivers of green entrepreneurship with the lenses of system dynamics.	1	Green entrepreneurship and 4th industrial evolution with the integration of system dynamics from region to region and application of region from region serves as a missing link.	Smart surveillance. Water, energy, agriculture, transport, and waste monitoring devices.	IEEE International Conference on Industrial Engineering and Engineering Management (IEEM) South African Centre for 4th industrial revolution website
Environmental entrepreneurship and innovation [10]	Environmental entrepreneurship incorporates behavioural and social [psychology], stakeholder mapping inclusive of the community at large and simulation of the results.	1	Only two elements of innovation and the social sphere are addressed. An empirical study is required.	Raising awareness of the internet of things and the internet of people	Advances in Science, Technology and Engineering Systems Journal.
Environmental outcome through	Green innovation performance tools	1	Social impact with regards to 4iR	Time series concerning agenda	Sustainability

simulations of the system onto green entrepreneurship to support system engineering [40]	as well as green entrepreneurship orientation.		serves as a missing link.	2030 of the national development plan of South Africa.	
Green entrepreneurship and manufacturing to reinforce productivity and optimisation [41] Smart manufacturing and SMEs [42]	Green entrepreneurship, organisational identity, and competencies within the manufacturing sector	2	The principles of 4IR, in conjunction with optimisation and productivity within the green entrepreneurship market, serve as a research agenda.	Additive manufacturing Mathematical modelling	World Review of Entrepreneurship, Management and Sustainable Development, Conference on e-Business, e-Services, and e-Society

5 RESULTS AND DISCUSSION

As per table 1, the results are **quantitativ**e, one in **qualitative** methodology with a non-existent focus on scoping review structure, whereby the current study contributes. Furthermore, the optimisation and simulation characteristics further contribute to the current study.

Types of evidence available, key characteristics or key factors related to a concept under investigation, the methodology adopted in previous research related to the study, Identification and analysis of knowledge gaps as well as implication to the South African context is illustrated in table 1. The use of 4IR can assist with making work effective and creating jobs. Jobs can be created by training individuals on how to use the 4IR tools and then make profits from the green entrepreneurial sectors such as agriculture, waste management, water, transport, and mobility, as well as energy. The use of automation, blockchains, coding and other innovations in the pursuit of creating an entrepreneurial mindset can be instilled in the South African context. The training on technology transfer and patenting of ideas in the areas of 4IR and green entrepreneurship can be implemented with a focus on the protection of intellectual property (IP), as in South Africa, the patenting and protection of IP are not widely implemented. 4IR tools to sort waste and ensure people are protected working on waste and wastewater can be encouraged. The training, implementation, awareness, and economic viability within those mentioned above can serve as a starting point in ensuring that the green entrepreneurship technology is optimally used by knowing when and how and what tools and resources to exploit for profit generation and job creation. The creation of digital networks, cyber security, and additional tools within green entrepreneurship is further recommended to create jobs and contribute to sustainable development and the green economy with the lenses of 4IR.

However, in the South African context, there are challenges of a lack of enough research, support from the community stance, and capabilities to implement the 4IR framework effectively and thoroughly. In The South African context, 3D scanning, additive manufacturing, and augmented reality are the leading 4IR tools implemented by the Centre of 4IR and CSIR [43]. Additional 4IR tools that are mainly gaining momentum and are still in their infancy are the internet of things, virtual banking, e-commerce, virtual reality, and robotics. However, with less attention to the 4IR tools within the green entrepreneurship space, for instance, technology to ensure e-agriculture, wastewater treatment plants, minimising waste and at the same time ensuring that profit and social welfare are maintained. The current study further contributes through simulation and optimisation to minimise the gap between 4IR, system engineering and optimisation through scoping review and scenarios. The scenarios are discussed below to be tested and validated.

5.1 Simulation through the lenses of optimisation through visual digitalisation

Testing and simulation of the results mentioned above with the software are recommended. The simulation can be in the form of virtually demarcating boundaries, leveraging the philosophy behind optimisation in building the parameters and key drivers of the green entrepreneurship ecosystem. The testing can be done in Figure 3 below. Huge waste happens in engineering [44-45] because contaminants or risks identified are discarded. The green economy as a focus or cornerstone is a tool and better sees how to best reserve the resources and other ways of using the discarded information, which fulfils the sustainable development goals. Probable waste that could pose environmental challenges is a chemical waste [44]. Environmental challenges from system engineering may be that more water or energy may be needed during manufacturing to produce or manufacture a system effectively and efficiently to optimise the system.

Systems engineering could be implemented in green entrepreneurship through the following: a reference to waste as an example may mean precisely orientation or capabilities to identify natural resources and use waste or collect waste to generate income, for instance, ensuring the logistics and the methods, or criteria used to check how waste was received and will be used as an end product; its efficiency and effectiveness, and to investigate whether these entrepreneurs able to identify opportunities tiny scale to medium scale enterprises in support of motives to green entrepreneurship, as well as the sustainability of this enterprises, especially in the period of sustaining resources. Systems engineering or process can also be checked, verified, or investigated whether the small-scale enterprises can convert waste into finished products; or whether emerging green entrepreneurs can start their enterprises or manage the process or not. Furthermore, the process of investigating the challenges in engaging in green entrepreneurship and remedies needs to be determined by green entrepreneurship and can receive coaching in the current mechanism.

The relevant solution process in engineering terms is optimisation. In echoing the optimisation, the linked process uses an engineering design process. The engineering design process is causal, related to one another in a closed circular relationship, and reiterative.

The field of systems engineering always thrives on ensuring efficiency and quality because the best or most successful systems engineering focuses on providing the system or model that meets the objectives and requirements set prior, whether it works optimally and its life span or longevity [46]. When translating the latter idea into the current context, in this process, one will find out what are the type of competencies green entrepreneurs need to possess; the challenges imposed by the environmental conditions or markets; the attitudes, motives and experiences to succeed within green entrepreneurship; the success factors, and support mechanisms. Furthermore, an investigation of contingency plans must be implemented if the initial goals do not work out or meet the objective or criteria. The systems engineering model within green entrepreneurship needs to investigate and serve as sustainable or have a longer life span that adds to human capital. System engineering models focus on innovation by capitalising on technological advances to ensure complexity and longevity. Flexibility, adaptability, and problem-solving are traits supporting the field of system engineering. One needs to disregard information or process if risks are identified that outweighs the benefits, idea, or opportunities in the process.

Systems engineering takes into consideration the process indicated in the above figure. However, it is not limited to only this process as the underpinning process requires that there needs to be flexibility in model design, trying alternatives if the initial process did not work and contextualising the process to a given environment. The systems mentioned above engineering sphere is the most applicable to the definition of 4IR, as the 4IR considers the social, biological, technological, and human perspectives.

5.2 Policy implications and contribution from the engineering processes for SMEs

An awareness and investigation of whether entrepreneurs within the green economy can identify green customers, financial and non-financial support concerning green opportunities, or survive in and after COVID-19. The operational environment can be assessed where green entrepreneurs operate to validate whether green entrepreneurs demonstrate good leadership or can grow and transfer knowledge or train others. Furthermore, the assessment can be broadened to the societal level on whether society can identify entrepreneurial gaps within green economy thematic areas, capitalising on capabilities to act as a catalyst on the personnel type of systems engineering.

As part of a coaching session, the use of industry 4.0 introduces and adds industry 5.0 elements of artificial intelligence as part of engineering. Industry 5.0 considers the people side or social side beyond the process [47]. They are using artificial intelligence in eco-design to accelerate the green economy and cope with external challenges such as pandemics. This aids in managing time, reducing costs, identifying hazards, and preserving resources [47]. On the other hand, the nature of artificial intelligence or industry 4.0 in South Africa is still in its infancy. The significant obstacles and delays in adopting the mechanism are infrastructure development and training and development.

We believe that optimisation can also be advanced by steering towards using technology, software, and simulation to manage workload and reduce the stress of green entrepreneurs [48]. Green entrepreneurs are facing double or even triple jeopardy of the ability to pursue markets, venturing into a sometimes-unpopular field of "green", and having to survive in challenging times such as the impact of the COVID-19 pandemic. However, venturing into green entrepreneurship puts them at a competitive advantage. It is important to note that as much as optimisation is part of the industrial engineering side, awareness of working effectively and efficiently can guide green entrepreneurs especially post-COVID-19. It is essential to balance those mentioned above behavioural and psychological perspectives and industrial engineering perspectives to humanise the process at the same time, have efficient and effective.

Policy implications summarising the results mentioned above and discussion can be seen in the Microsoft 3D simulation below.

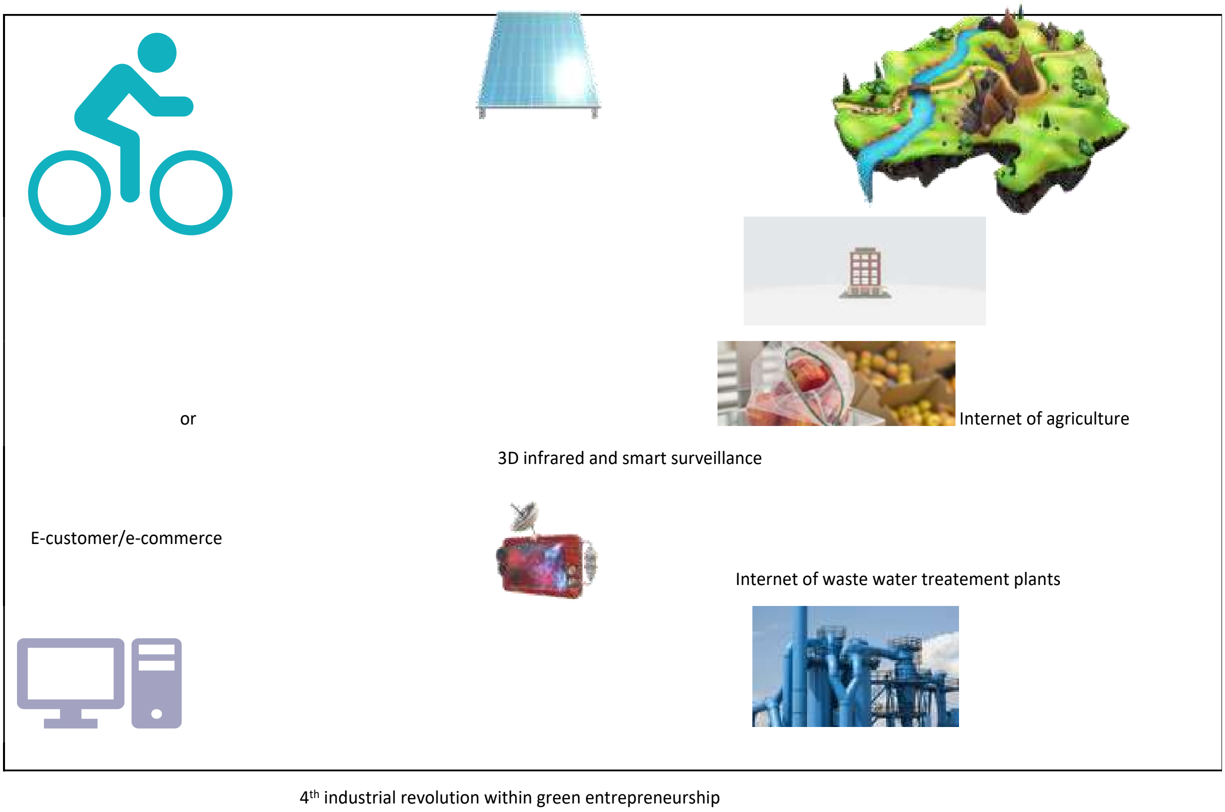

Figure 3: 4th Industrial Revolution within green entrepreneurship

The overall contribution that the current paper makes is through the integrated 4IR onto green entrepreneurship, with the following scenario, to promote sustainable living, individuals can cycle to the store or get basic needs such as nutritional food for well-being and low carbon emissions at the same time contributing to the economy, for individuals who cannot cycle electric bikes or online e-commerce shopping could take place. Solar heating or maintaining its average temperature is recommended giving emergence to the internet of agriculture or e-agriculture. Sustainable agriculture can be further maintained by a min tool or internet of the wastewater treatment plant. With 24-hour surveillance or robot to promote smart surveillance in protecting people, infrastructure is suggested as part of the collective system. We believe it will take integration and simulation of the 4IR framework and integration onto green entrepreneurship to ensure optimisation and survival amidst or post covid. Some efforts have been to integrate energy, water, and agriculture [49-53]. The integration of energy, agriculture and water was explored in a different context and environment in a different setting other than enterprises, e-commerce, mobility or with a lack of focus on 4IR, simulation or optimisation.

6 CONCLUSION AND RECOMMENDATION

The study reviewed the literature on environmental challenges, green economy, and green entrepreneurship through the lenses of 4IR, followed by the results and discussions on the theme. In answering the research question, How can 4th industrial revolution be utilised to accelerate green entrepreneurship theoretically, is through the 3D, additive devices, mathematical modelling, time series, monitoring tools for water, energy usage, water management, transport and mobility, socio technical and economic impact as well societal awareness in South Africa to be broadened to green entrepreneurship. The socio-technological education introduced by government entities could be green entrepreneurship for beginners and established businesses. The education can include mindfulness, green entrepreneurial alertness, blockchain, coding and automation of the day-to-day task of a green entrepreneur.

The leading municipalities in the green economy, such as Cape town, the city of Tshwane, the City of Joburg and eThekwini municipalities, can pilot the training mentioned above and set best practices for other regions in South Africa.

How can system engineering and optimisation be utilised to accelerate the green entrepreneurship culture theoretical through the system engineering system of modelling design and trying alternatives as well as simulations and 3D modelling. The system engineering process which can be integrated onto green entrepreneurship is through identifying green customer needs, the green system operational environmental, interfacing green systems, logistics and support requirements, capabilities of personnel inclusive community members, tribal kings, priests, entrepreneurs, aspiring entrepreneurs, politicians and policymakers Future recommendations are for the theoretical framework and contribution to be validated through observations for enhanced effectiveness and efficiency. The limitation of the study is the limited research on entrepreneurship and 4IR with non-existent research on green entrepreneurship, 4IR, and system engineering optimisation. However, the latter limitation is a contribution to the current study. Optimisation can be instilled through disrupting norms and introducing a new culture of doing business through change management, highlighting the benefits and disadvantages of introducing optimisation and rewarding the organisations that engage in optimisation and system engineering. However, tax incentives, for example, and additional skills levies act for giving back to society through what the authors term *entrepreneurial digitalised green skills citizenship*.

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UTILIZATION OF ARTIFICIAL INTELLIGENCE IN OPTIMIZING PRODUCTION PROCESSES WITHIN THE GREEN ECONOMY: A LITERATURE REVIEW

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ABSTRACT

Over the years, artificial intelligence has become a profound potent and practical tool for overcoming difficult problems in different sectors where complex problems are required to be resolved. The urgent need to review various research conducted before and during COVID-19 to ascertain the application of artificial intelligence within energy production processes. The literature-based research study targeted journal papers covering topics such as fourth industrial revolution, smart manufacturing, the influence of information technology within the green economy. The findings of the study revealed how companies resisted technology integration suffered to improvise their production systems to contain pressures exerted by the market demands. On the other hand, companies which embraced the application of the artificial intelligence (AI) benefitted due to the reduction emissions while satisfying the markets' needs, whereby N=32 articles met the criteria.

Keywords: Artifcicial intelligence, Industry 4.0 technologies, Fourth indusrial revolution, manufacuturing processes, green economy

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1 INTRODUCTION

The green economy production systems need to be geared towards sustainability to reduce the emissions of harmful gases. The current study is birthed from the Sustainable Development Goals (SDGs), adopted by the United Nations in 2015 as a universal call to action to end poverty, protect the planet, and ensure that by 2030 all people enjoy peace and prosperity [1]. However, this study took an angle of mitigation of air pollution with respect to engineering manufacturing processes. This requires technologies that would limit the operation of traditional equipment with the recent automated equipment. For the South African context, transition towards green economy comes with variety of challenges and opportunities. The notion of green economies has become an important topic world-wide in both developed and developing countries [2]. It has now become a responsibility for South Africa to make sure that all industrial activities contribute directly to the production of greenhouse gases while reducing unemployment, poverty, and inequality. South Africa remained focussed in reorientation of its economy towards low-carbon growth path for both domestic and continental agenda. It is interesting to note that the current policies are very impressive in directing the country towards low carbon economic growth, however its realities on the ground point to the opposite direction. Other authors believe that understanding the implications of green economy remains crucial for sustainable development and for determining the degree of being sustainable for economies [3]. Green economy is more about economic growth and improvement of economic life conditions when reducing the environmental harm [4]. The coordination of economic, social, and environmental responsibilities is found to be key on the success of sustainable development. It has been discovered that over the years, governments strive to keep green economy for sustainable development by developing new strategies and plans through green economy, but unfortunately their indicators of being green economy cannot provide sufficient results for governments [3]. On the other hand, water treatment was found to be an important step for pollutant reduction and the promotion of water environment quality. As such, Artificial intelligence has become a powerful tool for minimizing the complexities and complications in environmental challenges [5].

Difficult problems in various fields and solving complex problems in real life were managed by means of Artificial intelligence. The nature of AI of being ease of use, high speed operation, and acceptable accuracy without the need to understand physical issues made other researchers to show some interests on it [6]. In the field of medicine, AI technology is used for disease prevention, diagnosis, and treatment [7]. In the financial sector, AI is a topic gaining increasing attention [8] and used to predict the flow of financial capital [9]. It is used in supply chain risk management to weigh risks and develop contingency plans to strengthen against major shifts in the supply chain and potentially prevent significant losses [10]. AI has been used in a variety of engineering disciplines because of its ability to solve practical problems, such as the wastewater treatment [11]. Equally important, the solution was recognized through artificial intelligence to enhance sustainability and efficiency of the sector within the green building [12].

Smart production systems depended upon innovative solutions in enhancing quality and sustainability of manufacturing activities while reducing costs [3]. The emergence of AI technologies such as Internet of Things, advanced embedded systems, cloud computing, big data, cognitive systems, virtual and augmented reality) made way for new industrial paradigms [13].

McCarthy [14], defined artificial intelligence as the science and engineering of making intelligent machines, especially intelligent computer programs. Gupta [13] postulates that AI becomes more visible when machine stimulates functions that humans associate with other human minds such as learning and problem solving. AI is found to be useful in solving critical matters for sustainable manufacturing in areas such as optimization of energy resources, logistics, supply chain management, waste manangent, etc. [3]. Various authors discovered that AI has been incorporated into green manufacturing processes for the enhancement of environmental policies smart production [15].

2 LITERATURE REVIEW

As indicated earlier that the current study seeks to unravel the research undertaken within utilising AI to replace manual processes that led into harmful gasses in the area of green economy. In various sectors, the improvement of manufacturing processes depended mainly on industry 4.0 facilities [16] which in a way restricted the use of manual processes that might have involved emissions related systems.

In the predictive maintenance space, data mining was found to be implementable for multilevel alerting systems [17]. Zhang [8], argues that artificial neural networks was also utilised in the context of predictive maintenance. These studies prove that different technologies can be applied to optimize production processes [16]. Some important topics of Industry 4.0 are Internet of Things (IoT) Industrial Internet, Smart Manufacturing, and Cloud based Manufacturing [18]. The transition towards industry 4.0 made it possible for the accessibility of the industry-specific solutions for optimizing production processes [19]. Additionally, the introduction of the digital twins allows the use of the Internet of Things and big data to simulate the alternative operation strategies without compromising current operation. The introduced digital twin in Denmark used big data and the Internet of Things as means to optimize the greenhouse production process and communicate with other digital twins representing essential areas in the greenhouse [19].

Environment 14.0 aid in decision to be made about production processes before the actual production is physically developed as it eliminates failure of structure, prevent bottlenecks in the production process, methods of optimization of production processes. It means that costs and production cycle times can be minimized [20]. Environment 14.0 works well with augmented reality (AR) and virtual reality (VR) as they allow employees not to repeat tasks that might pose risks during operations and hazardous substances that might cause injury at work. In this environment, employees are afforded opportunities to be creative and innovative in performing complex business operation more easily regarding production program, adjustment of products while improving the real environment [21].

The study conducted by Ahmad [40], further strengthened that the emergence of industry 4.0 technologies (Internet of Things (IoT), cloud and big data analytics, Artificial Intelligence (AI) has become an important innovative tool for digital transformation and technological upgrading of global manufacturing. Simulation results show that, under increasing AI investment, semiconductor output will be 10.34% higher than the baseline, and employment demand will be 24.61% lower than the baseline in 2025. It emerged that the new technological developments are also created unwanted results of unemployment and the uneven income distribution.

Ralph [23], in their study on 'Digitalization and digital transformation in metal forming' concurred that the birth of Industry 4.0 in 2011 unleashed the new dispensation of industrial manufacturing where data-driven decision making and smart networks under the influence of artificial intelligence awakened a new dawn of continuous change in working environments in production. However. The study further acknowledged other manufacturing companies lagging in exploiting the potential of the fourth industrial revolution due to low level of automation. Interestingly. Other manufacturing companies purposefully delayed the transition due to the fear of job losses.

Redchuk [24] conducted a case study on the adoption of machine learning in a steel manufacturing process through a platform provided by a novel Canadian startup, Canvass Analytics. The intention of the company was to optimize the blast furnace process. As results, the steel company could satisfactorily optimize the process in a blast furnace. Whereby, AI facilitated traditional industries to obtain better operational outcome and effective use of resources. In the advancement of the sustainable manufacturing, smart production AI was found to be appropriate tool within the field of AI. Authors canocur that the introduction of the Industry 4.0, artificial intelligence and machine learning remain considerate as the driving force of smart factory revolution [25]. The study put more emphasis on the cotributions due to the impact AI is bringing in the manufacturing environment.

Cioffi [26] presented four different case studies on technology upgrading involving Industry 4.0 technologies and artificial intelligence. The four case studies concentrated on manufacturing process of kitchen, tank production, pasta production, and electronic welding check. All the cases of study concerned the analysis of engineered processes and the inline implementation of image vision techniques. The research study eventually proved that the combination of image processing techniques, data mining approaches, process simulation, chart process modelling, and process reengineering can constitute a scientific research project in industry research. Andronie [27] collated a yearlong review study on sustainable cyber-physical production systems by showing that the technological and operations management features of cyber-physical systems constitute the components of data-driven sustainable smart manufacturing. Credible databases such as Web of Science, Scopus, and ProQuest were used to decide on the 119 articles regarding the importance of industry 4.0 manufacturing technologies. The study reveal how much work is currently happening due to the advancement of industry 4.0 with relevant to manufacturing proceses.

Yuldoshev [28] conducted a literature review study on safe and efficient methods of food production using AI. The findings of the study depicted that the computer vision solutions combined with artificial intelligence algorithms achieved important results in the detection of patterns in images. From the results of the systematic review, it is possible to identify great opportunities, such as the exploitation of Graphics Processing Unit and advanced artificial intelligence techniques, such as Deep Belief Networks in the construction of robust methods of computer vision applied to precision agriculture. Numerous authors examined the intrinsic mechanism of the impact of internet development on green economic growth and provided empirical support for cities and regions in China to increase internet construction in 269 prefecture-level cities China from 2004 to 2019 [29]. The statistical results revealed that internet development has contributed significantly to green economic growth. When the internet development level increased by 1 unit, the green economic growth level increased by an average of 5.0372 units. Internet accessibility makes it possible for technological advancements particularly in green economies.

Numerous authors in the systematic literature study from 2018 to 2021 indicated the need to comprehend sustainable, smart, and sensing technologies underpinning data-driven decision-making processes [27]. The findings of the study also reported previous previous findings were cumulated showing that cyber-physical production networks operate automatically and smoothly with artificial intelligence-based decision-making algorithms in a sustainable manner and contribute to the literature by indicating that sustainable Internet of Things-based manufacturing systems function in an automated, robust, and flexible manner. Out of 426 articles only 174 empirical sources highlighted how cyber-physical production networks and Internet of Things-based real-time production logistics, by use of cognitive decision-making algorithms, enable the advancement of data-driven sustainable smart manufacturing.

The implementation of AI in agri-food supply chains pushed down the boundaries of manual traditional production processes [30]. The study investigated eighteen papers within the agri-food supply chain using bibliometric analysis. The study findings indicated the need to expand the introduction of AI implementation in order to estimate production need that matches the demand uncertainty and personalise needs of customers inline with the storage optimization, waste reduction in the post-production phase. There is tremendous potential for AI utilisation in agri-food especially from the start-ups.

Bag [31], established that big data analytics-powered artificial intelligence is capable to enhance supply chain performance. The study employed institutional theory and resource based view theory to explain the way in which automotive firms configure tangible resources and workforce skills to drive technological enablement and sustainable improvement of manufacturing practices. The study provided the role of institutional pressures on resources and their effects on the adoption of big data analytics-powered artificial intelligence, and its effects on sustainable manufacturing.

Li [32], explored a data panel of 277 cities in China from between 2011 to 2018 where digital economy index and green economy efficiency index were constructed. The findings revealed that digital economy significantly improved the efficiency of the green economy in various regions from the eastern, central, and western regions and in both small and large cities in China. Industry 4.0 technologies are found to be valuable in improving economies in various countries.

A comprehensive reviewing of the application of artificial intelligence (AI) in hybrid renewable energy systems covering solar photovoltaic and wind energy that are integrated with fuel cells [33]. The outcome of the paper showed the massive improvement of AI-based, and data-driven modelling in identifying the conditions required for maximum power production. AI integration within hybrid renewable energy systems enabled the prediction of unexpected load peaks as well as intermittent energy production.

The implementation of Artificial Intelligence (AI) as a means of improving industrial production impacted positively within climate change [34]. It is noted that the significant advancements in the ecological performance of manufacturing companies accredited to resource efficiency. The findings of the study indicated that AI applications are described with a focus on predictive maintenance, production planning, fault detection and predictive quality, as well as the increase in energy efficiency. The authors concurred that the need for further research in considering sustainability in the development of AI solutions, including Green AI. Predictive maintance, production planning and other manufacturing activities keep on improving with the involvement of AI.

In the views of Liao [35], Artificial intelligence (AI) has emerged a technology potential in the reduction of energy consumption, environmental burdens, and operational risks of chemical production. The study highlighted limited implementations of AI related tools within the numerous literature reviews conducted over the years in the sustainable development of the chemical industry. AI continues to play a fundamental role in various engineering processes to make things better.

A systematic literature review study was conducted by Jamwal [36] to ascertain the extent impact of industry 4.0 technologies on manufacturing sustainability. The findings revealed that Industry 4.0 technologies was found useful in achieving sustainability in business practices. It goes without saying that the manufacturing processes are improving with times due to the emergence of industry 4.0 technologies.

Artificial intelligence (AI) is seen as a driving force in the productivity and efficiency of global supply chains over the next decade [37]. Equally important, AI is accelerating natural resource extraction and the distancing of waste, casting dark shadows of harm across marginalized communities, fragile ecosystems, and future generations. These findings also allude that the theoretical understanding in the field of international political economy of the hidden dangers of relying on technology and corporate governance to resolve the deep unsustainability of the contemporary world order [37]. It is clear that AI has a tremendous role in easing production processes during this technological dispenasation.

Green processes remain key in the implementation of green technologies in production to achieve positive sustainability outcomes in the Industry 4.0 era [38]. The authors reviewed Twentynine papers on conventional green processes as a part of Industry 4.0 in provision of sustainability outcomes in manufacturing. The study highlighted preferred technologies such as big data, cyber-physical systems, Industrial Internet of Things and smart systems and green processes (logistics, manufacturing and product design) as of vital importance in achieving a higher level of sustainability. This study demonstrate how impactful technologies are within the green economy.

Numerous authors through a systematic literature review investigated challenges for the implementation of artificial intelligence (AI) in agriculture [39]. AI technologies gained tremendous memontum in supporting farm level, monitoring conditions and optimizing production to allow farmers to apply the optimal number of inputs for each crop while reducing water use and greenhouse gas emissions. The study demonstrated how useful are AI technologies in improving processes in the farming environment. Hence, its inclusion in the current study as it enhances the green economy.

The introduction of Digital technology in the form of (AI) technology was utilised to integrate energy supply, demand, and renewable sources into the power grid controlled autonomously by smart software that optimizes decision-making and operations [40]. The study merged three major aspects, including the use of AI in solar and hydrogen power generation: the use of AI in supply and demand management control and recent advances in AI technology. The study concluded that AI has become an enabler of a key magic tool to increase operational performance and efficiency in an increasingly cut-throat environment. The study further revealed that AI continue to dominate the technological fraternity.

In a comparative study conducted by Dudnik [41], in the implementation of AI within the energy sector of two energy companies from Russian and French. The study focussed on readiness level indicators of these companies using the Fibonacci sequence, Student's t-test, and the method of fuzzy sets were empirically determined. The results of the study depicted that companies in Russia were behind regarding implementation of AI technologies. This development of AI implementations in the energy sector proved a point of most companies continue to put their trust on technology as a way forward safe operational activities.

The data colleacted through systematic literature offered the authors some ground to see how impactful industry 4.0 technologies have been towards manufacturing processes in relation to the green economy. Accessibility of technologies in various spaces in different countries conviced many people to adopt technological route. More details of the research methodology is covered on the below section to indicate the depth of the literature covered.

3 RESEARCH METHODOLOGY

A literature review method was used, targeting the credible data bases such as Scopus, Knovel and Web of Sciences based on their astuteness regarding the the subject of industry 4.0 and its applicability around the production in the manufacturing sector. The study also leveraged from previous reviews conducted from 2010 until recent where similar databases were preferred also. The study also took into consideration the influence of COVID-19 in 2019. The search engines hovered around *artificial intelligence* and *green economy*; *industry 4.0* and *green economy*; artificial intelligence and manufacturing production processes*. Literature depicted that previous studies on the subject of industry 4.0 technologies preferred SCOPUS, Knovel and Web of Sciences databases. The sentiment is also true that the institution prefers to use these data bases as criteria to select all manuscricpts that qualify for Department of higher education and training (DHET) subcidy. These databases are found to be credible because they allow scruitiny of all papers through three blind reviews for quality assurance point of view.

3.1 Data collection

The data collection for the current study focussed more on Scopus, Knovel and Web of Sciences databases. However, google scholar was initially utilised for general searches for scoping purposes. Figure 1 below, according to Moher, Liberati, Tetzlaf, Altman, and The PRISMA

Group 942 [42], a total 787 resources were consulted including additional resouvres. After a thorough screening and the exclusion of 180 articles, a total of 607 articles were retained. Articles that were not available from the three identified databases were also left out. The inclusion criteria focussed on articles from 2010 until 2022 and written in English. As a result, 32 articles were selected for further analysis and extraction of reliable data.

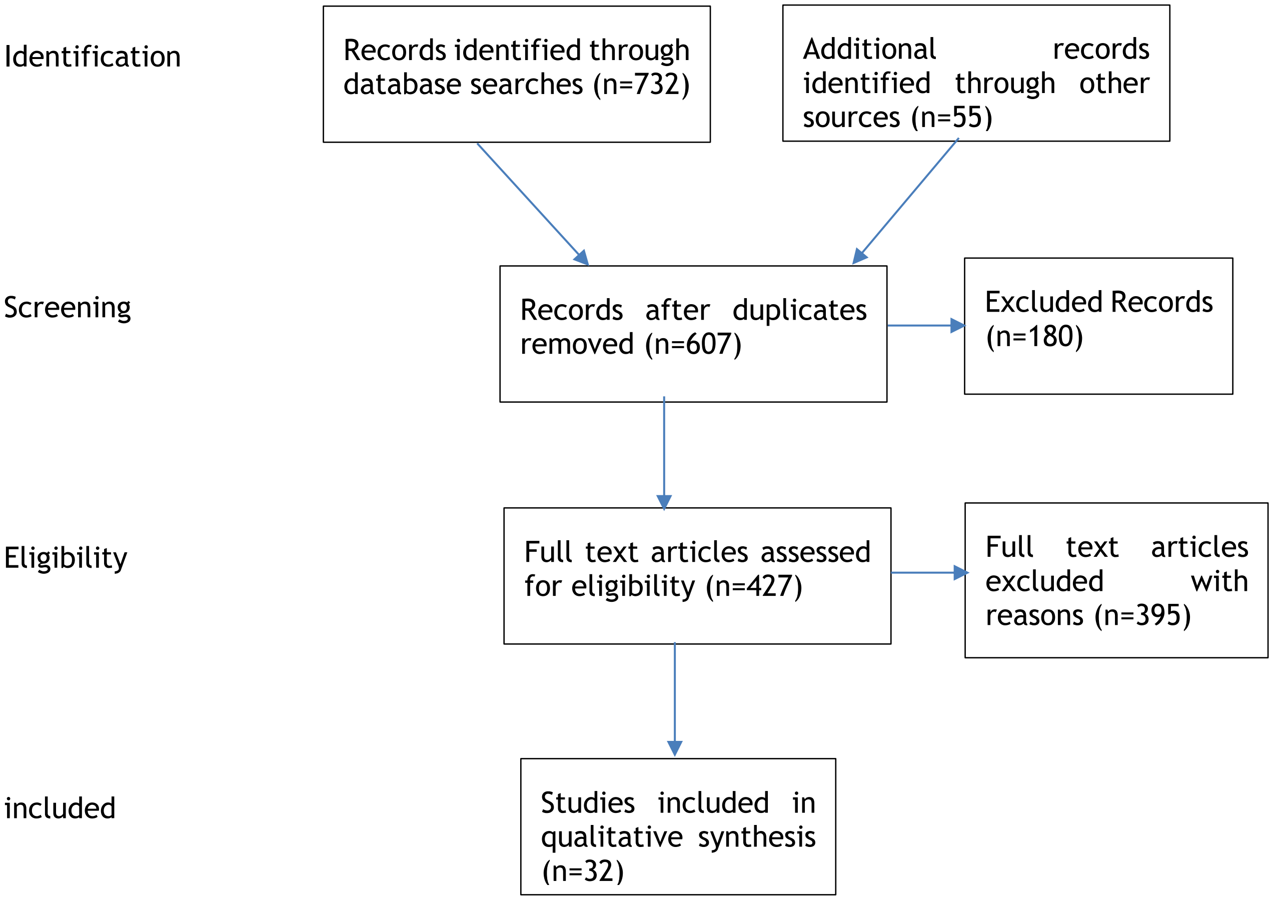

Figure 1: Systematic literature review system [42]

The preferred systematic literature review method played a tremendous role in the extraction of the current data to be discussed above.

4 DISCUSSION OF THE RESULTS

As indicated earlier that the purpose of the current study was to assess the utilization of artificial intelligence in optimizing production processes within the Green economy to show how much work has been done around this area. The data on both table 1 and and figure 2 clearly indicate that few studies were conducted before 2014 on the topic of artificial intelligence within the production processes in relation to the green economy. It is clear that many economies of the world were mindful of the need to reduce any production system responsible for the emissions of the dangerous gasses as is evidence on the work done by authors such as [8],[16],[17],[21],[23],[27],[32]. Other authors continue to show the importance of companies paying attention to the emergence of technological dispensation on how productions processes evolved over time. It was also discovered that more pollutions were experienced during traditional or manual production processes. Green economy slowly emerged with technological advances as seen on the work conducted by authors such as [25], [26], [29]-[31], [33]-[41]. The technological advances manifested as Neural network, Artificial Intelligence, Industry 4.0, Smart production and Industry 4.0 context, Digitalization and digital transformation, Big Data, Digital economy and green economic, Sustainable, smart.

Table 1: Evidence of technological transition of production processes

Period published	Number of published articles	Authors	Research theme
2010 - 2014	1	[17]	Application of data mining
2015 - 2018	8	[16]	Application of enabling technologies
		[8]	Neural network
		[6]	Artificial Intelligence
		[7]	Application of artificial intelligence
		[18]	Application of artificial neural networks
		[18]	Industry 4.0
		[21]	Industry 4.0
		[28]	Artificial intelligence
2019 -2022	20	[20]	Smart production and Industry 4.0 context
		[23]	Digitalization and digital transformation
		[5]	Application of artificial intelligence
		[25]	Artificial intelligence
		[27]	Big Data
		[26]	Artificial intelligence and machine learning applications
		[32]	Digital economy and green economic
		[29]	Smart framework
		[27]	Sustainable, smart,
		[30]	Artificial Intelligence
		[31]	Adoption of big data and Artificial intelligence,
		[40]	Artificial intelligence
		[41]	Artificial intelligence technologies
		[39]	Data-driven artificial intelligence applications
		[38]	Industry 4.0
		[37]	Artificial intelligence
		[36]	Industry 4.0 technologies

		[35]	Sustainability implications of artificial intelligence
		[34]	Artificial Intelligence Applications
		[33]	Artificial intelligence and numerical models

Technological viability within the manufacturing and production processes were experienced heavily between 2016 and until recent. Figure 2, clearly indicates that there have been a drastic increase in technological dominance towards industry 4.0 technologies until 2021. The drop was however, experienced in 2022 due to the lack of additional data. It could be assumed that as the year progresses, the picture can change drastically.

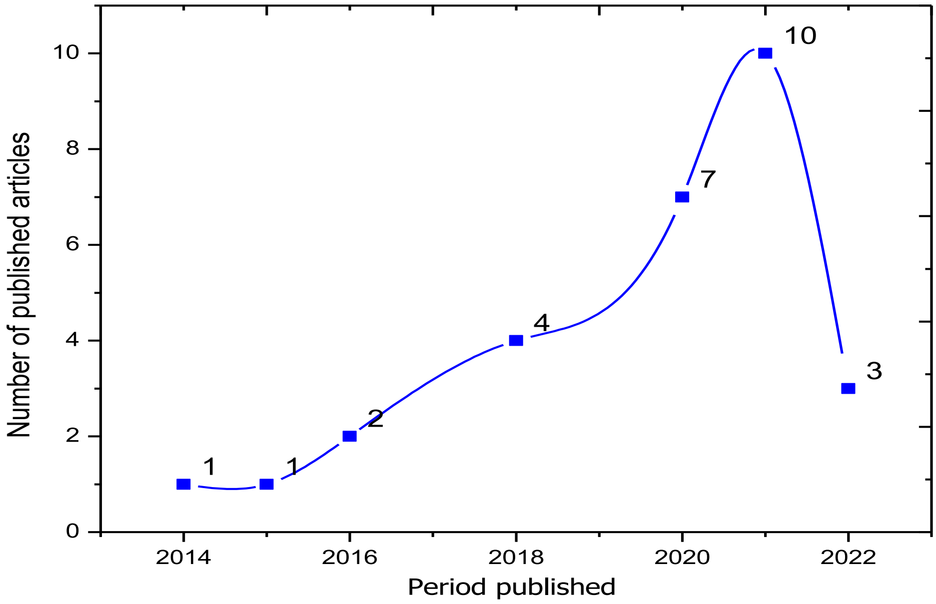

Figure 2: Dynamics of research trends regarding green economy

The results also depicted that the technological transition over the years began to move towards the dependence of internet connectivity. Hence, more technological advancements are experienced in the developing and developed settlements.

5 CONCLUSION

It is of vital importance to indicate that the current study focuccesd on technological advances from 2010 until recent but also noting the influence of COVID-19 in determing the state of the green economy. It took its roots from the SDGs to demonstrate the impact of technology within the manufacturing processes towards green economy. Many companies used to justify why they preferred traditional production processes as to technological means. Many companies showed interest in the technological dispensation before 2010, but others were reluctant but conformatble on their traditional ways. However, the emergence of COVID-19 made many companies to stop in their traditional tracks and were compelled to transit towards technology in order to stay in business.

The systematic review conducted revealed the technological trends in various industries involved in manufacturing processes. The results clearly indicates that before technological practices, many companies were comfortable to pollute the environment through their manufacturing processes as their only means of doing business. However, the emergence of technology over the years brought another reality of the green economy where people are concerned about augmented reality the optimization of product assembly processes, Artificial intelligence for defect prediction, production data storage and mapping, CNC production process, digital production traceability, production process levels improved by digitized information etc. The study further demonstrated that from 2016 until recent, people are now awaken to the reality of technology to continue with modern manufacturing without producing harmful gasses causing the depletion of the ozne layer. The current system literature review indicated that the more people of the world are aware of the technological capabilities regarding manufacturing processes, the green economy would become a reality. It is therefore a recommendation that future study be conducted in various manufacturing small and medium enterprises in South Africa to test how much work has been done already regarding green economy.

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OVERVIEW OF AGRICULTURAL WASTE MANAGEMENT PRACTICES IN NIGERIA

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ABSTRACT

Increased population, rapid industrial growth, economic development, and the need for food security have led to increased activities in the agricultural sector, and consequently generation of more agricultural wastes (AWs) in recent years. In Nigeria, the management of AWs in the form of crop residues, animal wastes, agro-industrial wastes, and hazardous wastes has become problematic despite efforts by various stakeholders to curtail it. The current intervention presents an overview of the strategies for the management of AWs toward evolving an innovative and environmentally sustainable approach to solving the intractable problem. Management practices aimed at converting AWs into heat, biofuels, composting, fertilizers, adsorbents, enzymes, and organic acids are highlighted. Intelligent technologies should be introduced into the monitoring, control, and management of AWs. Going forward, governments should enact laws and offer incentives capable of encouraging the rural population to adopt and participate in systematic management practices in the short and long terms to obviate the imminent environmental misfortunes.

Keywords: agricultural wastes, recycling, biofuel, waste conversion, waste utilization, agro-industrial wastes

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1 INTRODUCTION

Management of wastes has become one of the major challenges of the modern world. The problem is more pronounced in major cities in developing countries. Nigeria has had its share of waste management problems. With uncontrolled population growth, rapid urbanization, inadequate financial resources, unhelpful lifestyles, and a lack of political will to implement waste management laws, waste management has continued to militate against clean communities. Nigeria is the most populous country in Africa with climatic conditions ranging from arid to humid equatorial. The average annual precipitation is 1,165 mm. Nigeria experiences rainfall almost throughout the year but majorly during the rainy season between April and October and minimal precipitations between November to March. However, states in the South South, South East, and South West geopolitical zones receive more rainfall than their counterpart in the North East, North West, and North Central regions. Figure 1 shows the mean annual rainfall (mm) in each state of Nigeria, across geopolitical zones, in 2018 [1]. Huge funds are being pumped to the northern region for irrigation to ensure agricultural productivity. With enough rainfall and pleasant weather conditions, agricultural activities go on almost throughout the year.

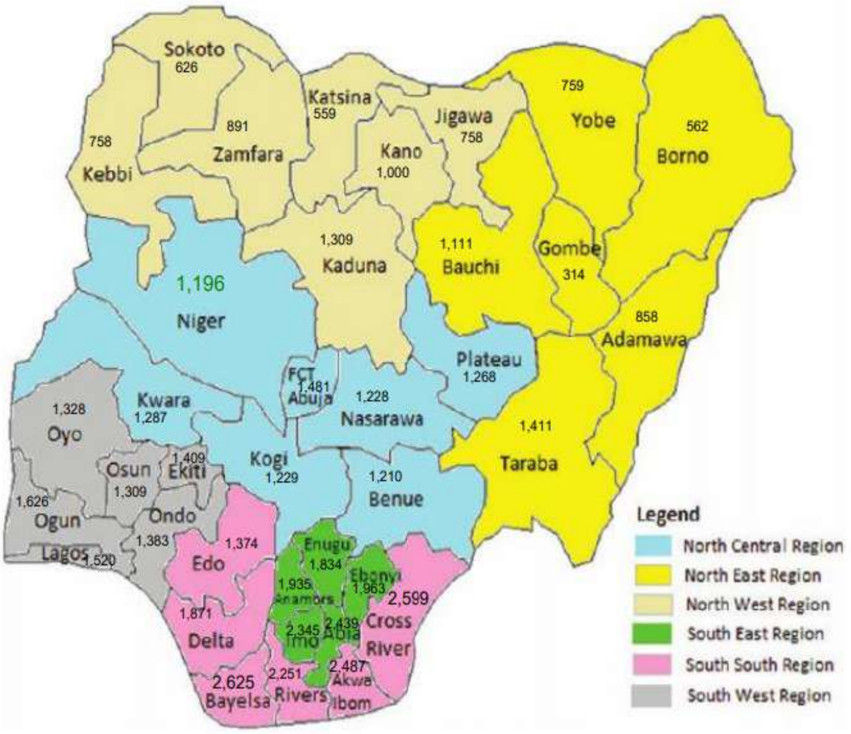

Figure 1: Nigeria's annual rainfall in 2018 [1]

In 2021, the Nigeria National Bureau of Statistics (NBC), indicated that the population of Nigeria is about 166.2 million while the United Nations reports that the current population of Nigeria is over 215 million. Nigeria's population has been projected to exceed 400 million by 2050 going by the current growth rate [2]. Table 1 shows major Nigerian population data. With average global waste generation put at 0.74 kg per person per day, it is noticeable that huge wastes are generated daily in Nigeria. According to the Food and Agricultural Organization, agriculture contributed about 22.35 % to the total Gross Domestic Product in 2021 with over 70 % of Nigerians engaging in subsistence agriculture [3]. Nigeria's agile population and arable land support continuous agricultural activities all year-round. With renewed efforts to produce food to feed the ever-growing human population and meet industrial needs, more activities are expected in the agricultural sector.

Table 1: Nigeria population data

Parameter	Data
Current population (March 2022)	214,657,300
Percentage of the world population	2.64%
Population density	226 per km^2
Total land area	910, 770 km^2 (351, 650 sq. miles)
Urban population	52 %
Median age	18.1 years

Compiled by authors from [2].

Agricultural wastes are the unwanted items/parts generated during agricultural activities [4]. They include crop residues, leftover fruits, and vegetables, wastes from poultry and slaughterhouses, unused fertilizers, pesticides, herbicides, veterinary medicines, packaging materials, horticultural plastics, etc. because they are no longer needed, they are discarded. The agricultural sector is one of the largest generators of solid waste [4], [5]. This is so because wastes are generated at every stage of the agricultural activities from bush clearing, weeding, planting, processing, harvesting, processing, to consumption. These wastes, if not well managed, are disposed of indiscriminately and inappropriately thereby constituting a nuisance to environmental sustainability, and animal and human health [4]. Globally, about 998 million tonnes of agricultural waste (AWs) are generated annually. Annually in Nigeria, the palm oil sector generates about 0.9 million tonnes, with 4.34 million tonnes from rice husk, and 90 million tonnes from rice straw [5].

In most parts of Nigeria, AWs are dumped indiscriminately in unauthorized places and allowed to decay or subjected to open burning thereby leading to environmental pollution, defilement of air quality, generation of smoke, and contamination of aquatic and terrestrial habitats [4], [5]. When wastes are burnt, it often leads to bush burning, and the residues are washed into rivers and other water bodies thus contaminating water bodies and underground water. Indiscriminate disposal of AWs in farms and communities distorts the aesthetic scenery of communities, allows the breeding of diseases causing vectors, and oozes unpleasant odours [6]. However, if well managed, AWs can serve as a source of fuel, and raw material for a circular bioeconomy, contributing to the reduction of greenhouse gas emissions, job creation, and production of animal feeds.

In recent years, Awogbemi et al. [4], Capanoglu et al. [7], Adebisi et al. [8], and Koul et al. [9] have propounded waste reduction, utilization, and recycling as viable strategies for the management of AWs towards ensuring a sustainable environment. They were unanimous in their reportage that AWs can be converted to heterogeneous catalysts for biofuel production, bioenergy, building materials, industrial enzymes, fertilizers, and other valuable products. Other studies have equally been conducted to highlight practicable strategies for managing AWs in various countries [10], [11]. However, there has been a death of research and information on the management of AWs in the Nigerian environment. The motivation for this work is to expose avenues for the management of wastes from the agricultural sector such as farming, livestock, and aquaculture and to further expand the work of Awogbemi et al. [4] but with emphasis on Nigeria's environment. This current study, therefore, aims to give an overview of the management of AWs in Nigeria to bring to the fore the enormous potential inherent in this neglected sector. The outcome of this research will unveil various cost-effective and environmentally sustainable pathways for managing AWs. The current effort is limited to the management of wastes generated from farming, livestock, and aquaculture from the perspective of waste conversion and utilization. Environmental experts, energy producers and consumers, policymakers, and indeed governments at various levels will benefit from the outcome of this study.

2 CLASSIFICATION OF AGRICULTURAL WASTE

AWs can be classified based on the state (solid, liquid/slurries, or gaseous), biodegradability (biodegradable or non-biodegradable), toxicity (hazardous or non-hazardous) [9]. These wastes are generated along the agriculture value chain from production to consumption in various proportions and forms, depending on the nature and types of agricultural activities. For this study, AWs are categorized into crop residues, animal wastes, industrial processing wastes, and hazardous wastes (Figure 2) [4], [9], [12]. This novel classification is based on the type of agricultural waste generated in the Nigerian environment.

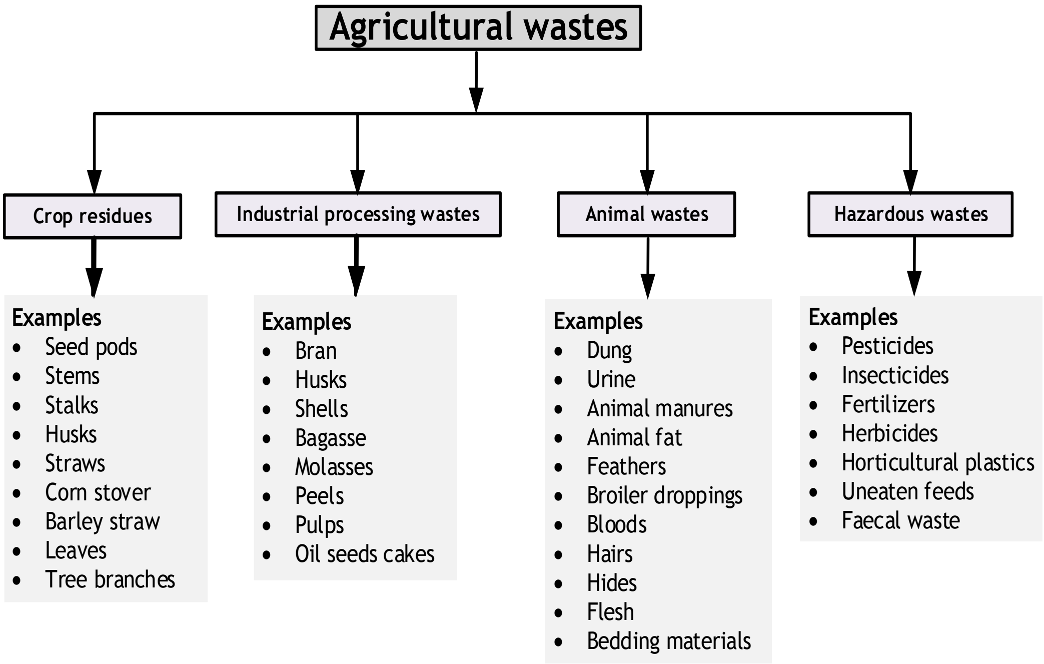

Figure 2: Classification of agricultural waste [4], [9], [12]

Crop residues are generated because of land preparation for farming activities, trimming of flowers and horticultural plants, gardening, crop harvesting, etc. Some of these wastes are biodegradable and non-hazardous. Industrial processing wastes which include banana peels, sugarcane bagasse, and eggshells, are produced as by-products of industrial processing of agricultural products or after household consumption of foods. These classes of waste attract flies, cockroaches, and other diseases that cause vectors to homes as well as ooze unpleasant odours. They can be hazardous and are mainly nonbiodegradable. Waste generated from poultry farms, slaughterhouses, and general animal husbandry is classified as animal waste. They include feathers, animal fats, cow dung, broiler droppings, animal bones, horns, etc. They attract flies, are non-biodegradable, and are not easily destroyed by open burning. Chemical wastes such as leftover fertilizers, unused herbicides, pesticides, and plastic containers, packaging materials, etc. form a major part of wastes from the agricultural sector, especially where commercial or mechanized agriculture is practiced. These are mainly non-biodegradable, poisonous, and dangerous to aquatic and terrestrial habitats when there is no immediate and effective remediation process [4], [9], [12].

3 MANAGEMENT OF AGRICULTURAL WASTE

Over the years, a huge quantity of AWs has been generated in various countries around the world, and Nigeria's situation is not an exception. Though there are no data on the quantity of AWs generated in Nigeria annually, with the high activity in the Nigerian agricultural sector, it is believed that thousands of tonnes of such wastes are generated annually. Adequate planning, resources, and innovative policies are required to evolve workable strategies for the management of this class of waste. The customary method of managing AWs in Nigeria is to discard the wastes indiscriminately into the environment.

For the crop residues and animal wastes, they are usually left on the farms where they are generated and allowed to decay. Industrial processing wastes, on the other hand, are evacuated from the kitchens, restaurants, and industries where they are generated and discarded into dumpsites and water bodies. The leftover and unused chemicals and their containers are thrown away indiscriminately into drainages where they are washed into rivers. When rain falls, these non-biodegradable and hazardous chemicals percolate into the soil to contaminate the underground water while some are washed into rivers to pollute the aquatic animals. Though some AWs are easily decomposed and provide essential nutrients for plants to grow, most of them, lead to increased soil degradation and negatively impact the environment [9].

To ameliorate the danger of inappropriate disposal AWs, there is a need to strategically handle and convert AWs to value-added products to achieve optimal resource usability and environmental sustainability. The deployment of novel management skills, effective policies, targeted incentives, environmentally friendly attitudes, and intelligent technologies are key in this regard. According to Obi et al. [13], an effective agricultural waste management system (AWMS) consists of six components of managing wastes at the generation, collection, storage, treatment, transfer, and utilization stages.

Waste generation is an integral part of an effective AWMS. A complete analysis of AWs generation must entail information on the type, volume, location, timing, and regularity of generation. AWs collection system involves identifying the strategies for collection, designation of collection points, schedule, or frequency of collection, as well as labour, financial, and infrastructural requirements for effective collection. During the sorting and temporary storage stage, the AWMS must answer the question relating to the type, size, location, cost, and capacity of the storage facility. There must be adequate information on the inflow and outflow of wastes as well as the assessment of the environmental impact of the storage facility.

AWs treatment as a management function is a way of reducing the toxicity or harmful potentials of the collected wastes. Physical, biological, chemical, and physicochemical pre-treatment techniques are used to convert AWs from their original unsafe and unusable state into a harmless and beneficial usage. The pre-treatment techniques must be carefully selected and must take cognizance of the type and form of wastes (solid, slurries), size, location, water content, cost and operation of pre-treatment, expected product, and potential usage [14]. The last AWMS function, which is the transfer function involves the movement of the AWs from the point of generation to utilization, bearing in mind the ecological effects of such use. Waste utilization is the deployment of AWs for productive and beneficial purposes after it has been converted into safe form. This is achieved through the conversion and recycling of AWs into reusable products through technology-driven routes [11], [13]. The six essential tasks of AWMS can be combined, duplicated, repeated, and restructured toward achieving the desired target.

4 APPROACH TO AGRICULTURAL WASTE MANAGEMENT

The three approaches that contribute toward the effective management of AWs are called the 3R approach to strategic AWMS [9]. They are ‘reduce’, ‘reuse’, and ‘recycle’. AWs reduction, reuse, and recycling are proven methods that contribute to the management of AWs. They are referred to as waste hierarchy, since they are arranged in order of importance, for the categorization of waste management strategies based on their desirability.

The concept of waste reduction encapsulates the painstaking treatment of wastes to reduce the quantity and the adverse effects of the generation of unnecessary wastes. Notable AWs reduction strategies include improved farming methods, reduced application of herbicides, insecticides, fertilizers, and other chemicals, increased funds allocation to the agricultural sector, and increased deployment of good agricultural practices that promote environmental sustainability. In animal husbandry, the use of poultry droppings as manure to improve soil fertility is also part of methods aimed at ensuring waste reduction and minimization [9], [13],

[15]. The application of waste reduction will ensure cost-effectiveness, reduction of greenhouse gas (CHG) emission, environmental hygiene, and elimination of underground water contamination [4], [14].

Waste reuse involves the re-channelling of discarded material to another use with little or no treatment or processing. In this case, wastes generated from farming activities, animal husbandry, and the agro-industrial sector are reutilized in another sector. This practice is simple, low-cost, and requires no technical expertise or special infrastructure. Notable examples of waste reuse include the application of rice husks as mulch, reuse of plant wastes and poultry droppings as organic fertilizer, reuse of cow dung to generate biogas, reuse of cattle manure as fish food, etc. This prevents the emission of smoke and other CHGs that usually occurs during burning, ensures plants benefit from nitrogen, potassium, calcium, boron, and other nutrients found in poultry droppings, and increases soil fertility. Also, slurries from anaerobic digestion (AD) can be reused as fish meal, food for phytoplankton and other aquatic animals, and nutrients for algae and aquatic plants to achieve a balanced ecosystem [9], [16].

Recycling of AWs involves a series of complex activities aimed at recovering and retrieving usable resources from waste. During this process, wastes such as straw, leaves, dungs, peels, shells, pulps, bagasse, molasses, feathers, animal fats, etc. are transformed into fertilizers, biocatalysts, adsorbents, biofuels, animal feed, and other biomaterials. Notable examples include the conversion of organic wastes into biochar, eggshells into heterogeneous catalysts, animal dung into biogas, and food wastes into adsorbents for water purification, among others [4], [17]-[19]. Unlike waste reduction, waste recycling requires time, effort, resources, energy, technical expertise, and technologies to process and convert AWs into useful products and recycle these AWs into usable products. Recycling of AWs improves the economy, produces renewable energy, ensures optimal utilization of materials, reduces greenhouse gas emissions, and contributes to Nigerian environmental sustainability. However, for this study, we shall focus on an in-depth analysis of recycling, as one of the 3Rs.

5 AVENUES FOR UTILIZATION OF AGRICULTURAL WASTE

Waste recycling is the best strategy for the management of AW [9]. In this context, AWs are processed and converted to usable products. Various innovative technologies and techniques have been adopted and deployed to prevent spoilage and ensure the recycling and optimal utilization of AWs. The products, benefits, and drawbacks of some AWMS are compiled in Table 2. The avenues for utilization of AWs analyzed in this study is by no means exhaustive but what is currently obtainable in Nigeria.

5.1 Direct combustion

Direct combustion, also known as burning, is the oldest method of managing AWs. During the process, AWs are subjected to a rapid chemical reaction in the presence of oxygen (open-air) and the process is accompanied by the release of energy, carbon dioxide, and water. The energy released is in the form of radiant and thermal energy. The energy released is used for cooking, heating, drying, charcoal production, steam, and electricity generation. AWs such as leaves, tree branches, wood chips, maize stalks, husks, and other crop residues are always subjected to open burning in the farms, households, and communities.

In Nigeria, more than 90 % of AWs are managed by open burning [20]. According to NBC, more than 68.3 % of households in Nigeria rely on firewood for cooking and source of heat energy. This has led to various environmental and health challenges resulting in the death of an estimated 93,000 Nigerians, mainly women and children, annually, according to the International Centre for Energy, Environment, and Development [20]. Though direct combustion as a waste reduction strategy for managing AWs is easy and requires no technology, it is a crude and unhygienic method of heat generation. Direct combustion of AWs also leads to deforestation, emission of smoke, and other dangerous gases thereby endangering lives and polluting the environment.

5.2 Pyrolysis

Pyrolysis, as AWMS involves subjecting wastes to thermal degradation at about 400 – 600 °C in the absence of oxygen, usually in special-purpose reactors or kilns [13]. During the process, the moisture in the waste material vaporizes, and products including char, pyrolyzed oil, and gas are obtained. Compared with direct combustion, pyrolysis is considered a cleaner and more technologically advanced waste conversion and utilization pathway for the generation of chemicals and energy recovery. Factors such as temperature, heating rate, residence time, type of waste, reactor type, etc plays important role in determining the success of the pyrolysis process [7], [13].

5.3 Composting

Composting is a natural waste management process during which organic wastes such as leaves, lawn cuttings, straws, cobs, stovers, rotted hay, husks, animal manure, and other crop residues are converted into fertilizer. During the aerobic process, complex molecules in AWs are broken down and transformed into simple organic and inorganic by-products by bacteria and fungi [4], [21]. Composting has become an attractive technique for the recycling of AWs owing to its simplicity in operation, safety, environmental friendliness, and cost-effectiveness. Products of AWS composting are used as biofertilizers, bioremediation, soil amendments, weed control, pollution prevention, plant disease control, landscaping, and wetland restoration. However, composting AWS is time-consuming, emits an unpleasant odour, has a long mineralization duration, may breed some pathogens, and poses some health hazards [21], [22]. In Nigeria, composting is used as a waste reduction management strategy to produce fertilizers, landscaping, and horticultural practices.

5.4 Anaerobic Digestion

Anaerobic digestion (AD) is a sequence of processes where the organic matter in AWs is decomposed by microorganisms in the absence of oxygen to produce a methane-rich gas called biogas [9], [23]. The process usually takes place in an airtight reactor called a digester. AWs such as rice straws, banana peels, potato peels, cow dungs, poultry droppings, stover, wheat straws, animal manures, etc have been effectively used as feedstock for the generation of biogas. The generated methane-rich gas is used for space heating, cooking, boiler operation, grain drying, electricity generation, etc. AD offers a simple, safe, low-cost, effective, and environmentally friendly pathway for the treatment, disposal, conversion, and management of AWs. Through AD, the management of poultry, swine, and dairy wastes becomes easy and without unpleasant odour. Other benefits of AD as a waste management strategy include its low energy usage, utilization of slurry as fertilizer, operational flexibility, and serving as additional sources of income to farmers. However, the major disadvantages of AD include the high cost of some modern digesters, difficulties in maintaining an airtight reactor, and the likelihood of explosion of the methane gas.

In Nigeria, various farm holders and households use AD as a strategy for managing AWs mainly for the generation of biogas and biofertilizers. While biogas is used mainly for cooking and other industrial applications, the fertilizer is used to grow vegetables and other horticultural purposes. Wastes generated from poultry farms, abattoirs, and slaughterhouses are collected and sold to vegetable growers and horticulturists. Ngumah et al. [23] reported that about 542 million tonnes of livestock wastes and crop residues are generated with the potential to produce over 25 billion m^3 of biogas (169 541 MWh) and 88 million tonnes of biofertilizer with a conservative combined market value of USD 29.29 billion, annually. Getting these wastes off the streets generates additional income for farmers, contributes to youth and women employment, promotes environmental cleanliness, and contributes to the renewable energy utilization drive.

5.5 Fermentation

Fermentation is the chemical breakdown of wastes by bacteria, yeasts, or other microorganisms for the generation of biofuels, bioactive compounds, bioplastics, heat, and other value-added products [24]. Several AWs including crop residues, animal dungs, and livestock manures are used as fermented, a form of biological treatment technique, for the generation of biofuels. The use of AWs as a replacement for maize and cassava is to reduce the cost of feedstock and avoid the food-fuel debate. Fermentation of crop residue, waste vegetables, and residues from food processing industries are used to generate biohydrogen, biobutanol, bioethanol, and other value-added products.

In Nigeria, for example, bagasse and cornhusk have been used to produce ethanol, wheat straw, corn stalks, and potato peels for hydrogen production, as well as while livestock wastes have been fermented into biohydrogen as part of AWMS [13]. This is to take the advantage of waste recycling techniques for energy production, reduction of landfill wastes, and environmental sustainability [24], [25]. Though fermentation is easy, cost-effective, requires low energy, and eco-friendly process, the process can be plagued with the high cost of enzymes, low yield of some materials, low purity of products, and difficulty in the purification of products [26].

5.6 Adsorbent production

The rate of soil and water contamination has increased in Nigeria over the past decades. This can be urbanization, industrialization, youth restiveness, poverty, and agitations for resource control. In the oil-rich South South region of the country youth restiveness and quest for resource control always result in oil spillages and pipeline vandalization thereby polluting aquatic and terrestrial habitats. During the process, heavy metal ions like copper, lead, cadmium, zinc, mercury, etc., and non-biodegradable materials are released into the environment. The use of synthetic materials as adsorbents for the removal of these contaminants is huge and unsustainable. This has led to the search for low-cost adsorbents for the removal of these heavy metals from groundwater and other water sources.

AWs such as bagasse, rice husk, sawdust, wood back, coconut husks, oil palm shells, eggshells, potato peels, banana peels, and other crop residues have been found to have a strong adsorption affinity for heavy metals [25]. Also, these AWs are readily available at low cost, ecologically friendly, as well as possess antimicrobial and antioxidant abilities, and therefore can act as adsorbents. The deployment of these AWs as eco-friendly adsorbents is a viable AWMS for water purification and environmental clean-up strategy.

5.7 Enzyme production

Enzymes are the biological macromolecules that are formed by living organisms that act as a catalyst to facilitate specific biochemical processes [4], [25]. They are usually used to speed up reactions in the pharmaceuticals, chemical production, biofuels, food, and beverages industries. There has been increased demand for cellulases, amylases, hemicellulases, pectinases, xylanases, lignases, phytases, pectinases, lipases, laccases, proteases, and other industrial enzymes in recent years. Getting these enzymes from commercial sources is not only costly and challenging, but the production processes also exacerbate environmental degradation. Conservatively, Nigeria spends more than USD 3 billion on the importation of industrial enzymes, annually [27]. Efforts are being intensified to produce some of these enzymes locally using AWs as feedstocks.

Lignocellulosic biomass-derived AWs are cost-effective and sustainable raw materials for the large-scale production of enzymes. In Nigeria, AWs such as spent grain, rice straw, banana peels, rice bran, wheat bran, sorghum bagasse, rice husk, sugarcane bagasse, soya bean hulls, and other crop residues have been tested and found effective for the production of enzymes [9], [28]. Research institutes, Universities, industrialists, and other stakeholders are collaborating to ensure the continuous production of enzymes from locally available AWs.

Local production of enzymes from these AWs will relieve the pressure on the foreign exchange, reduce food inflation, create employment, and accelerate industrial growth. Enzymes produced from AWS are cheaper and with less CO_2 footprint.

5.8 Organic acids production

Organic acids are organic compounds that possessed acidic properties and are usually derived from plants, animals, and other microbial sources. They are mostly used in the beverage, food, and feed production industries as preservatives, acidifying agents, seasoners, and to slow down food spoilage. Commercial production of organic acids (carboxylic acid, citric acid, malic acid, ascorbic acid, acetic acid, lactic acid, oxalic acid, succinic acid, and formic acid) from chemical sources has become expensive and challenging. The use of fruits as feedstock conflicts with food security and has sparked up the food versus chemical debate. This has necessitated the use of lignocellulosic biomass and other renewable materials for its production.

Nigerian researchers have started the use of some crop residues (cotton waste, pomace, cobs, sugarcane bagasse, cassava peel, banana peel, rice straw, orange peel, and husk), livestock waste (chicken feather) as a low-cost feedstock for the commercial production of organic acids [4]. Documented evidence revealed that sugarcane bagasse, sweet sorghum bagasse, and banana peel have been successfully bio-converted into levulinic acid, succinic acid, and citric acid, respectively [9], [29]. Edewor-Kuponiyi and Amuda [30] produced oxalic acid from cocoa pods, palm bunches, and plantain peels while Nwokoro [31] converted cassava peel into lactic acid. The use of AWs to produce organic acids is safe, cost-effective, and contributes to environmental sustainability. Farmers also derive additional income from the sale of these crop residues to local producers of organic acids. More investigations are still needed on the practicability and socioeconomic viability of some of these AWs to produce organic acids.

6 IMPLICATIONS AND FUTURE PERSPECTIVES

To an average Nigerian farmer, AWs are seen and handled as dangerous and unwanted. Across communities and various social groups, there are social, cultural, and religious beliefs that abhor the prolonged handling and utilization of waste. These have immensely affected AWs management practices in Nigeria. Successive governments have not been successful in changing these narratives. But with more enlightenment, education, and the influence of information and communication technology which has turned the world into a global village,

Table 2: The products, benefits, and drawbacks of some AWMS.

Agricultural wastes	Management strategy	Method	Products	Benefits	Drawbacks
Crop residues, wood offcuts	Waste reduction	Direct combustion	Charcoal, ashes, heat, and radiant energy	• Simple and low-cost • No technical infrastructure needed	• Crude and unhygienic • Leads to deforestation and bush burning • Emission of smoke and other toxic gases • Environmental pollution,
Crop residues, animal manures, livestock droppings,	Waste reduction	Pyrolysis	Biochar, biooil	• Easily to operate • Useful products are generated • Affordable cost of operation • Less pollution	• Requires technical knowhow • High cost of the reactor and other infrastructure • Environmental pollution and degradation
Crop residues leaves, lawn cuttings, straws, cobs, stovers rotted hay, husks, animal manures,	Waste reduction	Composting	Biofertilizers,	• Safe and Simple operation • Environmental friendliness and cost-effectiveness • Production of biofertilizers, soil bioremediation, and amendments. • Assist in weed control, pollution prevention, and wetland restoration	• The process is time-consuming • Generation of unpleasant odour • Constitute health hazards
Crop residues, livestock manures. animal excreta,	Waste reduction, waste recycling	Anaerobic Digestion	Biogas, biofertilizers	• Simple, odourless, and safe process • Promotes environmental hygiene and sustainability • low energy usage • Operational flexibility • Production of biogas and fertilizer • Avenue for additional income to farmers. • Promotes youth and women employment	• High cost of modern digester. • Challenges in handling methane. • Methane contributes to global warming.
crop residues, waste vegetables, livestock wastes	Waste recycling	Fermentation	Hydrogen, biohydrogen, ethanol, bioethanol, biobutanol	• Easy and cost-effective • low energy consumption • Safe and eco-friendly process • Production of biofuels • Generation of other value-added products	• High cost of enzymes • Low yield of some substrate • Low purity of products • The cost of setting up biofuel production is expensive • High cost of product purification

Agricultural wastes	Management strategy	Method	Products	Benefits	Drawbacks
Crop residues	Waste recycling	Adsorption	Water purification, pollution control and	• Easy and eco-friendly • Cost-effectiveness • CO_2 neutral • Readily available	• Some of the wastes are not fully tested • Scarcity of waste in some location • Some wastes are seasonal
Crop residues	Waste recycling	Enzyme production	Cellulase, xylanases, lignases, pectinase, proteases	• Cost-effective production • Readily available raw material • Employment creation • Safe foreign exchange	• Season wastes • Uncertainty in the efficacy of some AWs • Some of the AWs require more study • Lengthy process
Crop residues	Waste recycling	Organic acids production	Acetic acid, lactic acid, levulinic acid, succinic acid, citric acid	• Safe and cost-effective process • Contributes to environmental sustainability • An additional source of income to farmers	• Social and cultural biases • The process requires more investigations • Lengthy process

Compiled by the authors.

some of these beliefs and practices are changing, though slowly. Burning of wastes and allowing the wastes to decay which are the traditional waste management strategies are fast giving way to more scientific and result-oriented AWs management practices. The way out of these scenarios is the development of innovative strategies and unwavering implementation of policies and programs that favour waste recycling and resource recovery from the agricultural sector.

More than at any other time in human history, there is a dearth of materials to run the industrial sector. Manufacturers and industrialists are daily confronted with getting raw and semi-finished materials to meet contemporary material demand with the capability to meet global specifications. With inadequate materials to meet up with the demand for raw materials for the 4th industrial revolution, more attention is now focused on resource recovery since virgin materials are now scarce. From the economic and performance perspectives, it is more advantageous to use recovered materials than freshly developed materials. Nigeria, as a country, comes up with novel, cost-effective, and ecologically malleable materials to produce state-of-the-art components and machines.

With the various agricultural initiatives and programmes of the federal and state governments, activities in the agricultural sector (farming and animal husbandry) are expected to increase considerably. For example, the establishment of cattle colonies or cattle ranches across the country is anticipated to generate more cattle manures, animal fats, bones, etc. Also, with increased funding for local farmers [30] for accelerated local rice production, it is projected that more rice straws, husks, and other related wastes will be generated along the value chain. The Nigerian government can do very little to slow down the rate of AWs generation across the country, renewed efforts are needed to ensure the conversion of the generated wastes from the various agricultural activities. Since the condition of our environment is intricately linked with the quality of our lives, it is best that practice activities that promote good sanitation and environmental sustainability. One of the avenues to achieve that is the implementation and enforcement of workable AWMS.

Though there has been an increase in research and development in the utilization, recycling, and management of AWs in Nigeria and globally. There are compelling necessities for the scaling up of the existing AWs reduction, conversion, and recycling avenues while new pathways for the unearthing of advanced materials from AWs be developed. Furthermore, to fully explore and derive maximum benefits from AWs, innovative treatment and conversion pathways should be adopted for the conversion and utilization of AWs. Ground-breaking research should be commissioned to establish the commercial feasibility, life-cycle analysis, and techno-economic dynamics for the effective and sustainable management of AWs. Smart technologies like artificial intelligence, machine learning, big data, Internet of Things, wireless sensor networks, robots, cloud computing, cyber-physical systems, and other intelligent monitoring systems should be deployed in the study, monitoring, and metering of products derived from AWs [32]-[34].

7 CONCLUSION

The agricultural sector generates huge quantities of wastes at each stage of the process, and along the value chain from land preparation, production, processing, and consumption. The AWs are classified into crop residues (husks, stalks, straws, leaves), industrial processing wastes (peels, shells, pulps, bagasse), animal wastes (dungs, animal fats, animal manures, livestock droppings), and hazardous wastes (pesticides, fertilizers, horticultural plastic, leftover feeds). Inappropriate disposal and management of AWs leads to a dirty environment, generates offensive odours, attracts flies, cockroaches, and other pathogens, constitutes an environmental eyesore, and exacerbates environmental degradation. Untreated hazardous AWs can pollute both aquatic and terrestrial habitats as well as endanger animal and human health. To prevent these unpalatable consequences, a practicable, carefully planned, and sustainable AWMS is sacrosanct.

In the current study, the waste management approach has been presented to entail strategies to 'reduce', 'reuse', and 'recycle'. The concept of waste reduction is the use of improved farming techniques and innovative agricultural practices to minimize the negative impacts of AWs on humanity. Waste reuse is the utilization of the generated wastes with little or no treatments to produce other products or render services with less grievous consequences while waste recycling involves the use of technologies to recover useful resources from the AWs. Recycling is the conversion or the modification of waste into useful forms. Regarding the Nigerian environment, avenues for utilization of AWs include direct combustion for the generation of heat and charcoal, pyrolysis for the conversion of crop residues to biochar and biooil, and composting for the conversion of crop residues and animal manures to biofertilizer. AWs are also reduced, recycled, and bio-converted into biofuels, industrial enzymes, and organic acids through AD, fermentation, and other processes.

To stem the harmful effects of the huge waste generated in the farming, livestock, and aquaculture sectors, the following recommendation should ensure a sustainable environment and healthy citizens. Going forward, governments at various levels must update existing policies on AWS management for effective waste management in the 21st century. Policymakers, environmentalists, and civil society organizations should partner with legislators to enact and pass practicable and enforceable laws for the effective management of AWs. Law enforcement agencies must be firm and impartial in enforcing environmental laws. There should be incentives like tax holidays, access to interest-free loans, and mentoring to encourage entrepreneurs to venture into waste recycling. More research is required to develop innovative techniques and technologies for the conversion of AWs into useful products. There should be regular awareness and enlightenment campaigns to remove the social, cultural, and religious beliefs against the conversion of waste into a useful resource. To inculcate the concept of waste management in the coming generations, waste management should become part of the educational curriculum at the secondary and tertiary educational levels across Nigeria.

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INDUSTRIAL APPLICATION OF AGRICULTURAL WASTES

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ABSTRACT

Continuous depletion of natural resources, rising population, and environmental concerns have increased the attention for the identification, development, and utilization of wastes for diverse industrial applications to meet the shortage of needed raw materials. Agricultural wastes (AWs) are the unusable materials generated from agricultural activities and, are, therefore, discarded. This study highlights the application of agricultural wastes as raw materials for the production of enzymes, polysaccharides, organic acids, bioactive compounds, and other value-added chemical products. The conversion of AWs into useful industrial products offers cost-effective and environmental advantages for the commercial production of various products. With renewed interest and funding of research initiatives, it is anticipated that novel, affordable, and ecologically friendly routes for the conversion of AWs into useful industrial products will be developed. Appropriate policies, targeted subsidies, and an encouraging business environment should be created to ensure the development of more useful materials for industrial growth.

Keywords: Agricultural wastes, enzymes, waste conversion, industrial applications, waste utilization, eco-friendly.

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1 INTRODUCTION

Arising from the recent industrial revolutions, there has been an increased shortage of materials to feed the ever-increasing number of industries. With sustained population growth, urbanization, and change in consumer satisfaction, there is a need for a sustained supply of raw materials to keep the production sector running. The manufacturing and production sector remains a significantly important source of income, improved living standards, growth, and development of both the developed and developing economies. It remains a major source of employment, production of goods, innovation and competitiveness, exports, foreign exchange earner, and productivity growth. The share of gross domestic product (GDP) to the global economy which was 27.51 % in 2010 became 26.81 %, 27.1%, and 26 % in 2015, 2018, and 2020 respectively [1]. The contribution of the industrial sector to the global economy rose from USD 17.17 Trillion in 2010 to become USD 20.136 Trillion, USD 22.81 Trillion, and USD 22.081 Trillion in 2015, 2018, and 2020 respectively [2]. In an International Labour Organization report published by the World bank, it was reported that the percentage of the global working population engaged by the industrial sector that was 22.49 % in 2010 became 23.17 %, 22.95 %, and 20 % in 2015, 2018, and 2020 [3]. Figure 1 shows the share of contribution of the industrial sector to the global economy, value-added, and employment from 2010 to 2020.

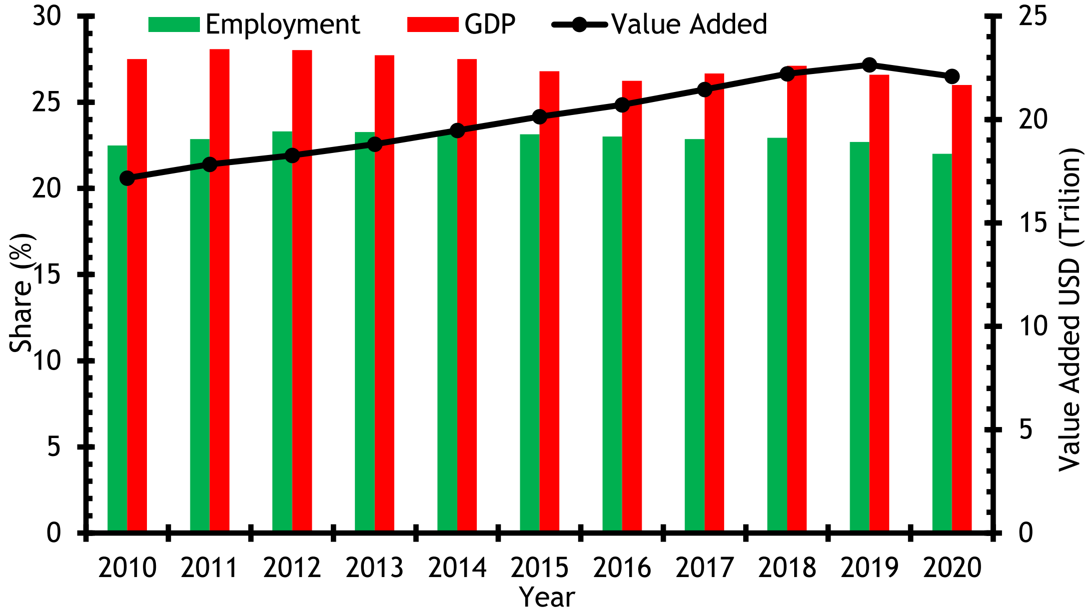

Figure 1: Contribution of the industrial sector to employment, GDP, and value-added to the economy. Compiled from [1-3].

Agricultural wastes (AWs) are defined as materials generated from agricultural activities whose economic values are less than the cost of collection, sorting, transportation, and processing. AWs are the residues and remainders from farming activities, production, and processing of fruits, food crops, vegetables, cash crops, livestock and animal production, and the agro-industrial sector [4]. Globally, about 998 million tonnes of waste are generated from various agricultural activities every year [5]. Most of these wastes are untreated and disposed of indiscriminately in drainages and unplanned dumpsites thereby becoming an eyesore and constituting environmental hazards. Inappropriate disposal of AWs impacts climate change and exacerbates the emission of greenhouse gases (GHGs). Untreated AWs are breeding grounds for disease-causing pathogens, natural habitats for flies, cockroaches, and other rodents, and sources of pollution for terrestrial and aquatic animals. Also, when AWs are inappropriately disposed of, they create an unpleasant atmosphere, generate offensive odours, and are detrimental to animal and human health. Recent studies have revealed that AWS can serve as a source of heat and radiant energy, utilized as feedstocks for biofuels, converted into catalysts for biofuels production, and low-cost materials for building and construction industries. Economically, farmers can earn excess income from the selling of AWs while employment opportunities can be created for youths and women groups in the society. AWs, if well managed, can be converted to fertilizers and animal feeds, contribute to environmental sustainability, and become a veritable source of vital raw materials for the industrial sector.

1.1 Review of Literature

In a recent study, Awogbemi et al. [4] exposed the latest routes in the conversion and utilization of AWs into heterogeneous catalysts or biodiesel production. They concluded that AWs are readily available, low-cost, and easily converted raw materials for catalytic biodiesel production. Also, Ibrahim et al. [6] and Gupta et al.[7] studied the application of AWs for the production of biofuel and other products and reported that applications conserve renewable resources and economically benefit the farmers. In another research, Boudali et al. [8], Dharek et al. [9], and Liuzzi et al. [10] investigated and reported that the utilization of AWs in the building and construction industries is one of the waste minimization and management strategies. Wastes from the agricultural sector contribute to the bioeconomy and offer economic, environmental, and sustainable pathways for the biosynthesis of value-added products [11, 12]. The outcomes of these investigations revealed the practicality and viability of the conversion of AW for bioeconomy, biorefinery, and other industrial applications.

The application of AWs in material recovery and utilization has been investigated. Horue et al. [13], Mostafa et al. [14], and Ravindran et al. [15] experimented with the conversion and recovery of hybrid biopolymers, biodegradable plastics, and industrial enzymes, respectively from AWs. They asserted that wastes from agricultural sectors offer low-cost, abundant, and sustainable raw materials for the effective production of high-value products. Across various countries, including Nigeria [16], South Africa, [17], Greece and China [18], Taiwan [19], and India [20], pathways for the conversion and effective utilization of various AWs have been studied with encouraging outcomes. These confirmed the benefits derivable from the conversion of AW to chemicals and other value-added products. Despite these interventions, noticeable research gaps still exist in the industrial application of AWs, hence this intervention.

1.2 Aim and Objectives of Study

It is no gainsaying that untreated and inappropriately disposed AWs portends an enormous threat to man and animal wellbeing, economic development, and environmental sustainability. Also, it has been established that enormous valuable materials can be recovered from AWs, the relevant question to ask, therefore, is what the avenues for the application of these AWs for are the much-needed industrial development. This is the motivation for the current study which is a review of the various industrial application of AW. The research methodology involves mining recent and relevant published articles on the conversion and utilization of various forms of AW for paper and pulp production, food and beverage industries, wastewater purification, medical, cosmeceutical, pharmaceutical, as well as building and construction. The aim is to expose the various pathways for the conversion of AWs into useful raw materials for the modern industrial sector. There is an exhaustive discussion of the usefulness of the various products that can be recovered from AWs. The current intervention is limited to the use of desktop review strategy as a basis for informed discussion on the material recovery from AWs and their utilization in the industrial sector.

The outcomes of this study will enrich scholarship, expand the frontiers of knowledge, and stimulate further investigation into the conversion of AWs into raw materials for industrial applications. Researchers, environmentalists, material experts, and industrialists will be equipped with low-cost and innovative avenues for the derivation and utilization of AWs in the industries. Governments, civil society organizations, and other stakeholders across various jurisdictions should collaborate to evolve Implementable policies and laws to encourage and incentivize the conversion of AWs to useful products.

2 COMPOSITION AND CLASSIFICATION OF AWS

Various authors have classified AWs according to different criteria. But for the purpose of this study, AWs are broadly categorized into farming and crop residues, agro-industrial residues, animal and livestock wastes, and chemical residues. Some of these wastes are biodegradable and can decay if left for a long time. Common examples of biodegradable AWs are leaves, tree branches, peels, animal dungs, livestock droppings. Nonbiodegradable AWs do not decay or disintegrate on their own but remain a nuisance in the environment and they include shells, bones, hairs, plastics, animal fats, pesticides. Some of these wastes are dangerous to man, animals, and the environment. Examples of hazardous AWs include shells, herbicides, pesticides, medications while non-poisonous AWs include peels, cobs, feathers, cobs, etc [13].

Agricultural wastes are easily generated, renewable, abundant, and can be converted into many products depending on their composition. Also, it is necessary to carry out biochemical analysis on any AWs to be able to determine the pre-treatment process, conversion route, and the utilization avenues for such wastes. Generally, the proximate, ultimate, and lignocellulosic analyses of any AWs will reveal their composition and help us to decipher the available conversion, recycling, and utilization routes. The proximate analysis reveals the moisture, ash, total volatiles, and fixed carbon contents of the wastes while the ultimate analysis shows the carbon (C), hydrogen (H), nitrogen (N), sulphur (S), and oxygen (O) contents of the wastes. The lignocellulosic analysis shows the cellulose, hemicellulose, and lignin compositions of the waste. The heating value or calorific value is the amount of heat released when 1 Kg of waste is combusted [15, 20]. Table 1 shows the proximate, ultimate, heating value, and lignocellulosic compositions of common AWs.

2.1 Farming residues

Farming residues are the wastes generated during farming activities like bush clearing, weeding, harvesting, and horticultural activities. Traditionally, they are burnt to generate heat for cooking and heating. Common examples include leaves, trees, garden shrubs, stalks, stems, bamboo, etc. They can be composted to generate manures, gasified into fuels, and for building construction. For example, barley straw with heating value of 16.42 MJ/kg, and total volatile, carbon, and oxygen contents of 76.20 %, 49.40 %, and 43.60 % is a viable feedstock for biofuel, heat generation, and building construction [15, 20].

2.2 Crop residues

Crop residues are the waste generated from the actual agricultural production processes including harvesting, processing, and consumption of food crops. They are generated in huge quantities around the year. Notable examples include cobs, pods, bagasse, peels, husks, molasses, etc. Crop residues are the commonest and most abundant AWS which are easily converted into useful forms. For example, the global annual production of crop residues is put at about 2 802 million tons while 731 million tons and 354.34 million tons of rice straw and wheat straws are generated annually [21]. With a carbon content of 59.31 %, heating value of 12.76 MJ/kg, and cellulose content of 37.90 %, cassava peel can be fermented to biogas and converted to animal feed. Crop residues are commonly used as feedstocks for bioethanol production, catalysts, adsorbents, and other value-added products.

2.3 Agro-industrial wastes

Agro-industrial wastes are the byproducts and leftovers from the processing of agricultural products. They are produced in large quantities from food processing industries, starch manufacturing industries, slaughterhouses and abattoirs, meat processing industries, and palm oil processing industries. For example, about 279 million metric tons of sugarcane bagasse are produced globally, worldwide [22]. Notable example includes shells, peels, oilcakes, pods, bagasse, molasses, oilseed cakes, etc. Inappropriate disposal of this category of AWs can cause the breeding of flies and pathogens, unpleasant odour, and environmental pollution.

2.4 Animal and Livestock wastes

These are the categories of wastes generated from animals and livestock. They can be in liquid form (urine, blood, animal fats, wastewater) or solid form (dungs, animal manure, bones, feathers, beddings, poultry droppings). The cattle manure has heating value of 17.21 MJ/kg and total volatiles, carbon, and oxygen contents of 70.49 %, 40.02 %, and 32.45 % respectively. This explains why it is biogas for heat generation. These types of wastes can be converted into biofuels, fertilizers, or heat energy. Untreated animal and livestock wastes can cause air and water pollution, contamination of surface and underground water, and emission of carbon dioxide (CO_2), methane (CH_4), and other GHGs.

2.5 Chemical wastes

Chemical residues are generated from the agricultural sector during pest control, weed control, feeding of animals and livestock, from plastic containers and other packaging materials. They include pesticides, herbicides, unconsumed poultry feeds, fertilizers, plastic containers, and medications.

Table 1: Composition of some agricultural wastes [21, 23, 24]

AWs	Proximate Analysis (% w/w)			Ultimate Analysis (% w/w)					Lignocellulosic Composition (% w/w)			HV (MJ/kg)
	Moisture	Ash	TV	C	H	N	S	O	Cel	HCel	Lig	
CP	14.00	4.50	59.40	59.31	9.78	2.06	0.11	28.74	37.90	23.90	7.50	12.76
EFB	15.01	4.48	82.98	43.89	5.33	0.52	0.10	54.32	42.00	18.90	11.70	17.85
RH	6.34	16.70	67.50	36.52	4.82	0.86	na	41.10	30.42	28.03	36.02	2.93
SBG	8.61	4.05	86.02	47.30	6.20	0.27	na	44.15	42.16	36.00	19.30	18.75
CS	8.21	0.80	77.82	49.62	7.31	0.22	0.10	42.75	14.00	32.00	46.00	17.40
BS	19.79	5.30-9.80	76.20	49.40	6.20	0.70	0.13	43.60	29.20-48.60	35.80-29.70	6.70-21.70	16.42
RS	4.20-6.00	8.20-16.00	71.60-92.80	34.00-41.50	4.60-6.70	0.20-0.80	0.10-0.20	32.80-41.20	30.30-52.30	19.80-31.60	7.20-12.80	14.50-15.50
CM	12.01	18.81	70.49	40.02	5.83	1.44	1.45	32.45	32.70	24.50	42.80	17.21
ODC	na	2.8	62.10	53.70	6.70	0.60	na	36.20	22.00	18.20	50.00	21.60

C= carbon, H= hydrogen, N= nitrogen, S= sulphur, O= oxygen, CP= cassava peel, CS= coconut shell, SBG= sugarcane bagasse, EFB= empty fruit bunch, BS= barley straw, RH= rice husk, RS= rice straw, CM= cattle manure, ODC= olive deoiled cake HV= heating value, Cel= cellulose, HCel= hemicellulose, Lig= lignin, TV= total volatiles, na= not available

3 APPLICATIONS OF AW IN THE INDUSTRIES

Over the years, materials recovered from AWs have been used as raw materials to manufacture many products. This is due to the high cost, infrastructural deficits, and environmental challenges involved in the extraction and development of virgin materials for industrial processes. Food, cosmeceutical, and pharmaceutical industries, building and construction industries, paper and pulp industries, chemical and paint industries, biomedical industries, electrical and electronic industries, among others, have benefited from materials recovered from AWs. Table 2 contains the highlights of the industrial applications of AWs.

3.1 Food, Beverage, Cosmeceutical, and Pharmaceutical industries

The food, beverage, cosmeceutical, and pharmaceutical industries are very strategic to the well-being of citizens of the world and global development. The contributions of these industries to global employment and GDP are enormous and cannot be overemphasized. For example, the global pharmaceutical market which was USD 1,073 billion in 2015 became USD 1,228 billion in 2020 and is projected to reach USD 1,700 in 2025 [25]. Also, the global cosmetic market size rose from about USD 326 billion in 2015 to become USD 345 billion in 2020 and is estimated to reach USD 758.4 billion in 2025 [26]. Similarly, the food and beverage market size are expected to grow from USD 5,838.8 billion in 2020 to about USD 8,163.61 billion in 2025 [27]. Due to the crucial roles these industries play and the importance of their products, great efforts are justifiably placed on meeting the raw materials demand to ensure production. Concerted efforts are also expended to guarantee that raw materials meet the cost and environmental requirements so that products can be affordable to the majority of consumers. The use of AWs is one of the strategies to ensure ceaseless, low-cost, readily available, and ecologically sustainable feedstocks towards continuous production.

Wastes from the agricultural sector such as woody biomass, peels, bamboo, shells, husks, bagasse, oilseed cake, leaves, straws, etc. are used as a replacement for some of the raw materials in the food, beverage, cosmeceutical, and pharmaceutical industries. For example, woody biomass, sugarcane bagasse, rice straw, rice bran, and other lignocellulosic wastes from the agricultural sector contain cellulose (35–50%), hemicellulose (20–35%), and lignin (15–25%). Cellulases, hemicellulases, lignins, and amylases are major ingredients for major foods, beverages, cosmetics, and drugs. Also, major enzymes such as amylase, tannase, xylanase, protease, and laccase are synthesized from AWs and used for various industrial applications [28, 29]. Banana peels, corncob, oil palm empty fruit bunches, wheat straw, and other AWs are converted to cellulose and emulsions which serve as valuable raw materials in the food and cosmetic industries [30]. The antioxidant and antimicrobial properties of bamboo shoots, leaves, and lignins are useful in the food and pharmaceutical industries. Due to its nutritive and therapeutic properties, cellulose and enzymes are extracted from bamboo shoots, leaves, and lignins for the fortification of crackers, snacks, cookies, chips, biscuits, cakes, and yogurt [31]. Also, consumption of bamboo shoot fiber reduces serum total cholesterol, atherogenic index, and is a good source of potassium. The high silica content of bamboo shoots helps in maintaining the structural integrity and permeability of the arteries and regulation of the blood pressure [32]. The deployment of AWs in the food, beverage, cosmetic, and pharmaceutical industries has led to a low-cost, ecofriendly, and environmentally sustainable pathway for material recovery, waste recycling, and utilization.

3.2 Pulp and Paper industry

The pulp and paper industry, like other productive industries, is witnessing increased patronage, use of energy-efficient processes, cleaner and intelligent technologies, and ecofriendly process. These changes are being driven by increased population, increased in global literacy, meeting consumers' satisfaction, and the need for a zero-emissions production process. As to be expected, the global market value for the paper and pulp industry which was USD 349.18 billion in 2020 became USD 351.51 billion in 2021 and is expected to grow to USD 370.12 billion in 2028 [33]. Due to rising environmental challenges on the use of plastic bags as packaging material, producers and consumers of food, cosmetics, and fast-moving consumer goods have adopted paper as a sustainable and recyclable packaging material. Increased deforestation and water crisis have necessitated the search for low-cost, ecofriendly, and environmentally sustainable materials to replace the traditional cotton fiber, cellulose fiber, and wood pulp for paper production.

The use of AWs such as bagasse, rice straw, cotton stalks, and other non-wood wastes. Therefore, bagasse and various crop residues have become ecofriendly and readily available raw materials to make pulp and paper. In separate research, Sharma et al. [34], Gonzalo et al. [35], and Fasake and Dashora [36] used palm oil EFB, six agricultural residues (stems of bell pepper, chili pepper, broad bean, asparagus, pea, and okra), and cow dung, respectively, to produce pulp and paper. There is unanimity of opinions that crop residue, animal dung, and other wastes from the agricultural sector are ecofriendly, low-cost, easily convertible, and environmentally sustainable raw materials for paper and pulp production and in meeting the increased demand for paper and paper products.

3.3 Textile industry

There has been an increase in demand for textile materials in recent years due partly to population growth, urbanization, and growth in the fashion world. Also increased industrial growth and other professional services have boosted demand for beddings, apparel, special clothing for construction, medical, transportation, armed forces, as well as other specialized and protective clothing. Consequently, the global textile market valued at USD 1,005 billion in 2020 has been predicted to become USD 1,032 billion in 2022 and USD 1,522 billion by 2027 [37]. The need to reduce the cost of raw materials and mitigate environmental impacts of the production process has led to the adaptation of cost-effective and natural feedstocks to produce textiles for household, technical, fashion, and other specialized applications. Due to increasing environmental concerns, stringent waste emission regulation, and the rapid consumers' shift toward sustainable products, the demand for natural cellulose fibers (cotton, silk, jute, wool, and polyester) has continued to rise. Cellulose fibers are synthesized from bagasse, peels, straw, oil cakes, husks, shells, and other crop residues.

Teli and Pandit [38] developed cotton fabric from coconut shell extract while Hazarika et al. [39] generated lignocellulosic fiber from pineapple leaf for textile application. The extract from these crop residues contains the requisite properties of thread and is found suitable for making high-quality cloth. The use of AWs as a replacement for synthetic fibers is not only cost-effective but also ecofriendly and a dependable pathway for the conversion of wastes to useful products. Textile grade dye for good coloration and functional finishing of cotton, wool, silk, and other textile materials were also extracted from was extracted from chickpea husk. Terpenoids, glycosides, flavonoids, saponins, phenols, tannins, and other organic compounds were extracted from chickpea husk to add colour to the fabric and improve its aesthetic value [40]. The processing was ecofriendly, low-cost, reduced environmental pollution, and generates additional income for cowpea farmers.

3.4 Building and Construction industry

Global population growth, rising urbanization, and increased socioeconomic activities have led to demand for more construction materials in the ever-growing building and construction industries. Cement, thermal, and acoustic insulation materials are needed regularly in the building and construction industries. For example, the global cement consumption that was about 4 billion metric tons in 2019 has been projected to become 4.7 billion metric tons in 2025 [41]. The production of these construction materials aggravates GHG emissions, exacerbates environmental degradation, and impacts human health. Investigations have been conducted to find sustainable alternatives for petrochemical and synthetic raw materials for the manufacturing of cement and insulation materials.

According to Thomas et al. [42] and He et al. [43] silica-rich ash is derived from bamboo leaf, elephant grass banana leaf, plantain peel, rice straw, wheat straw, corn cob, and bagasse ash are used as pozzolans for cement and mineral filler in asphalt mixtures. Balador et al. [44] experimented with the use of sugarcane bagasse, corn cob, rice straw, and coconut fiber as natural fibers for the production of thermal and acoustic insulators in buildings. The insulators produced from recycled agricultural residues were found to be more attractive, cost-effective, and ecofriendly. The deployment of raw materials derived from AWs to replace the synthetic materials for the production of cement, thermal and acoustic insulators in the building and construction industries is economically and ecologically beneficial. It helps in waste disposal, material recovery, and utilization of wastes for industrial development.

3.5 Wastewater treatment

Effluents from human and industrial processes are released into our surroundings daily resulting in contamination of the atmosphere and geosphere. These toxic and poisonous chemicals, dyes, and heavy metals are mostly non-biodegradable and remains in the soil, water bodies, and underground waters for a long time. The pollutants contaminate the water bodies and cause severe environmental issues and impair human and animal health. There has been increased study of the cost-effective and safe removal of metallic elements such as chromium, cadmium, nickel, zinc, mercury, lead and copper, and dyes from industrial effluents and wastewater. The use of adsorbents such as zeolites, graphene, activated carbon, activated alumina, and carbon nanotubes to remove pollutants from wastewaters has been effective and generally accepted. However, rising environmental concerns and the cost of these chemical adsorbents have opened the window for the use of alternative and sustainable adsorbents. Studies have shown that crop residues with high cellulose contents have high biosorption capacity and therefore offer a low-cost, ecofriendly, and sustainable alternative to chemical adsorbents [45].

Syeda et al. [46] reported the conversion of sugarcane bagasse, orange peel, banana peels, lemon peel, pineapple peel, corn cob, walnut shell, rice husk, and other crop residues into bioadsorbents for the treatment of wastewater. The bioadsorbents derived from AWs were ecofriendly and highly efficient in chromium, lead, zinc, copper, mercury, cadmium, arsenic, and nickel. The AWs-derived bioadsorbents are significantly cheaper than commercial adsorbents, regenerated, and reused for more than 10 cycles. In similar research, Al-Gheethi et al. [47] investigated sustainable pathways for the removal of rhodamine B, methylene blue, congo red, direct red 12B, indigo carmine, and other pollutants from wastewater. They utilized rice husk, banana peel, garlic peel, orange peel, tea waste, coconut coir, and other crop residues as bioadsorbents. The outcome of their studies revealed that adsorbents derived from AWs are highly effective and efficient in removing these dyes from waste and contaminated water. The bioadsorbents removed up to 98 % of pollutants in the wastewater, displayed high adsorption capacity, and superior reusability of more than 15 runs. Though more studies should be commissioned to ascertain the chemical composition of each waste in the locality, adsorbate dose, and other parameters, the use of AWs as bioadsorbents is highly advantageous and mitigate environmental degradation.

Table 2: Highlights of industrial applications of AWs

AWs	Conversion technique	Byproducts	Industry	Applications	Merits	Demerits	Ref.
Peels, bagasse, woody biomass	Enzymatic hydrolysis	Cellulose, enzymes	Food and beverages	• Production of enzymes, polysaccharides, and organic acids. • aroma, colouring, and flavor compounds • Food fortification	• Ecofriendly • Economic advantage • Stability and adaptability to most environment • Natural antioxidants	Risk of contamination	[28]
Watermelon seeds, sugarcane bagasse, pineapple peels, grape peel, apple pomace	Enzymatic hydrolysis, Fermentation	Flours, colorants, and enzymes	Food and beverage	• Additive and natural coloring in pastry and confectionery • Source of vitamin A • Baked goods and pasta • Biscuit, cereal bars, and pancakes • Oat, rice, sorghum, and corn extrudates • Colouring and flavoring	• Low cost • Easy processing	Risk of food poisoning from wastes	[29]
Oat shell, grapeseed, coffee waste, shells	Fermentation, microwave - assisted extraction	Antioxidants and enzymes	Cosmetic	• Serves as deodorants, cleansing foams, and soaps • Production of antioxidant soaps • Used for hair dyes, eye, and face makeup • Serves as sunscreen, moisturizers, and lubricants • As lighteners, epilators, depigmented	• Low cost • Readily available • Low energy consumption processes	Risk of viral diseases from fruit peels	[29]
Orange peel, pineapple peels, mango seed, grapefruit peel, kafir lime peel, and leaves	Fermentation	Antibacterial. Anticancer, antivirals, enzymes	pharmaceutical	• Antibacterial • Cancer prevention and treatment • Inhibitory effect of respiratory pathogens • Reduce viral loads • Boost the immune system	• Low cost • Easy processing	Needs more investigations on the appropriate dosage	[29]
Banana peels, CC, oil palm EFB, wheat straw	Extraction, microwave treatment and salting out	Emulsions, cellulose	Food and cosmeceutical	As stabilizers, pickering emulsions	• Low cost and ready availability • Environmentally friendly • Less toxic than conventional emulsions with surfactants	• Can be toxic if used excessively • Potential health risks	[30]

AWs	Conversion technique	Byproducts	Industry	Applications	Merits	Demerits	Ref.
Bamboo, bamboo shoot, bamboo leaves	Enzymatic hydrolysis	Lignin, enzyme, cellulose	Food	• Promotes and maintains skin tissues • Hair, nail, ligament, tendon, bone, skin supplement • Antiaging, anti-obesity, and anti-inflammatory. • Strengthens the arteries, joints, nails, hair, skin, and bones • Food fortification	• Low cost • Low energy processing • Environmentally friendly	• Can be antinutrients. • Harvest of bamboo can lead to deforestation	[31]
	Enzymatic hydrolysis	Phytosterol, phenol, and dietary fiber	Pharmaceutical	• Anticancer, antibacterial, antiviral, antidiabetic, anti-inflammatory and anti-obesity • Reduces cholesterol • Promotes digestion • Protects neurons from oxidative stress	• Low cost • Natural products with no side effects	• Deforestation • More investigations are needed for standardization	[31]
Bamboo shoots, leaves, and lignin	Fermentation	Phenols, vitamin C, vitamin E, trace mineral elements	Food and pharmaceutical	• Food fortification • Good antioxidant and bioactive compounds • Rich in phenols, flavonoids, vitamin C and E, and other antioxidants • Contains selenium, zinc, copper, iron, manganese, potassium • Prolong the shelf life of foods, beverages, cosmetics, and drugs	• Rich in antioxidant and nutrient • Low cost and ecofriendly • Readily available • waste conversion and material recovery channels	• threat of deforestation	[32]
palm oil EFB	Supercritical fluid extraction	Pulp fiber	Pulp and paper	• Writing and printing grade pulp and paper	• Easy conversion process • Energy efficient process • Ecofriendly and low-cost • Low water consumption • Crop residues are available annually	• Inadequate raw materials to meet production rate • Unpredictable product quality and yield	[34]
Agricultural residues	Ultrasound and microwave extraction	Pulps, Fibers, Hemicelluloses, and Lignin	Pulp and paper	• Paper for writing • Packaging paper • Cardboard production	• Effective raw material • Easily converted • Green raw materials • Cheap and easy availability • Prevents deforestation	• Collection and sorting of wastes • Cultural barriers	[35]

AWs	Conversion technique	Byproducts	Industry	Applications	Merits	Demerits	Ref.
Cow dung	Supercritical fluid extraction	Fibers	Pulp and paper	• Paper • Packaging and laminating materials	• Improved physiochemical properties • Animal wastes are available yearly • Eliminates deforestation • Protects the environment • Encourage waste recycling • Inexpensive and effective method	• Sociocultural barriers • Unpredictable products quality and yield	[36]
Coconut shell	Carbonization	Natural cellulose fiber	Textile	• Cloth • Sofa cover and curtains • Protective materials for making tents	• Cost effective • Readily available • Better thermal stability • Good antibacterial property	• Long processing	[38]
Pineapple leaf	Hydrolysis	Natural cellulose fiber	Textile	• Apparel • Cotton • Cords and ropes • Home furnishing fabric	• Low cost • Ecofriendly • Products of good mechanical properties	• Underdeveloped technology	[39]
Chickpea husk	Hydrolysis	Dye	Textile	• Textile colouration • Apparel finishing	• Ecofriendly • Low cost • Reduce environmental pollution • Additional income generation	• Economics and quality of the product	[40]
Bamboo leaf, RH, elephant grass, banana and plantain peels	Pyrolysis, gasification, and combustion	Cementitious materials, pozzolans,	Building and construction	• Cement • Geopolymer	• Ecofriendly • Environmentally friendly • Reduction in CO_2 emissions • Replacement for Portland cement	• Reduced workability • Lower strength activity index	[42]
Sugar cane bagasse, RH, sugar cane straw	Pyrolysis, gasification, and combustion	Mineral filler	Building and Construction	• Agro-cement	• Sustainable materials • Strong and durable concrete • Eco-efficient	• Concrete susceptible to scaling • Slow drying process	[43]
Sugarcane bagasse, RS, CC, coconut fibers,	Hydrolysis	Natural fibers	Building	• Thermal and acoustic insulation	• More attractive and durable insulators • Cost-effective, and ecofriendly • Better mechanical properties	• Concerns about availability and security of supply of wastes • Cost of storage	[44]
Sugarcane bagasse, orange peel, banana	Microwave pyrolysis,	Bioadsorbents	Wastewater	• Bioadsorbents	• Ecofriendly and highly efficient • Low-cost and easy to process	• More techno-economic analysis needed	[46]

AWs	Conversion technique	Byproducts	Industry	Applications	Merits	Demerits	Ref.
peel, pineapple peels, CC	carbonization		purification		• Can be regenerated and reused multiple times	• Modification needed to improve efficiency	
RH, banana peel, garlic peel, orange peel, tea waste, coconut coir	Microwave pyrolysis, carbonization	Bioadsorbents	Contaminated water	• Dye removal	• Low cost and ecofriendly • High reusability • Minimum energy consumption • Superior adsorption capacity	• More investigation on the chemical composition, adsorbate dose, and optimal reaction parameters needed	[47]

EFB= empty fruit bunch, RH= rice husk, RS= rice straw, CC= corn cob.

4 IMPLICATIONS AND FUTURE PERSPECTIVES

Huge wastes are generated from agricultural activities, crop residues, animal husbandry, and livestock daily. These wastes are converted to useful forms for various applications including the industrial sector where valuable materials have been recovered from wastes. The implication of these recovery and conversion strategies for global industrial growth and development cannot be overemphasized. For one, many valuable and useful by-products from wastes and raw materials for the industrial sector are recovered from AWs. These represent a low-cost and ecofriendly route for accessing raw materials for the needed productive sector. Raw materials for the food and beverage industries as well as cosmetic and pharmaceutical industries which must meet stringent standards are equally sought from AWs. These contribute to food security, welfare, health, and wellbeing of the people.

The use of agricultural residues helps to meet the increased demand for raw materials for the ever-growing paper and pulp industries without aggravating deforestation and depletion the forest resources. Production of agro-cement from crop residues to replace fine aggregates reduces the carbon footprint and mitigates the emission of GHGs arising from the Portland cement production process. Further studies are needed on the process and modalities for incorporating additives, ensuring durability and functionality, optimal mix of multiple natural fibers towards getting the cementitious matrix [48]. Low-cost and highly effective thermal and acoustic insulators derived from AWs not only reduce the cost of building construction but also ensures attractive and durable insulators that meet environmental sustainability criteria are produced. Agricultural residues such as sugarcane bagasse, banana peel, orange peel, pineapple peel, rice husks, rice straw, coconut fibers, and corn pods are converted into bioadsorbents for the removal of pollutants in industrial, surface, and groundwater. Pollutants such as heavy metal (chromium, cadmium, lead, copper) and dyes (rhodamine B, methylene blue, congo red, direct red 12B, indigo carmine) are removed from contaminated water. The use of AWs has become an effective, low-cost, and environmentally benign adsorbent for treating contaminated water towards ensuring good water quality and water security.

To further deepen the use of AWs, more investigations are needed to evolve innovative conversion techniques to ensure quality material recovery and utilization. The quest for Appropriate and novel agricultural waste management policies is needed to address the growing waste generation problem. Government should intensify enlightenment and education for both rural and urban dwellers on the short, medium, and long terms benefits of waste recovery and recycling strategies. Also, there must concerted efforts to refine and fine-tune existing policies, laws, and regulations guiding waste generation, waste disposal, waste management, and utilization [49].

The utilization of AWs in the industrial sector should be tailored towards achieving optimal material recovery for the circular economy. Concerted efforts should be geared towards promoting intelligent technologies, innovative research, and extension services in AWs conversion and utilization for speedy industrialization. Currently, the lack of established AWs supply chain, technical knowledge, and infrastructure is hampering waste collecting and processing. There is an urgent need for upgrading of knowledge and infrastructure among practitioners and stakeholders to ensure a resilient framework for rapid implementation of updated policies, laws, and regulations [50].

5 CONCLUSIONS

The application of crop residues, animal wastes, livestock beddings and droppings, and other agricultural residues have been presented in the current study. It has been shown that industrial sector such as food and beverage, cosmetic and pharmaceuticals, paper and pulp, building and construction, and wastewater treatment have been unveiled as consumers of materials recovered from AWs. Wastes derived from agricultural activities offer low-cost, ecofriendly, easily convertible, and environmentally sustainable raw materials for the productive industries. The conversion of AWs and utilization of waste-derived materials are part of the effective routes for waste management and toward meeting the material needs of the industrial sector. Conversion and utilization of AWs promote environmental sanitation, ensure materials recovery under low carbon footprint, mitigate GHGs emissions, contribute to the circular economy and environmental sustainability.

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STATE OF WASTEWATER INFRASTRUCTURE IN SOUTH AFRICA

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ABSTRACT

Wastewater infrastructure includes a network of sewers and pipes that collect and carry household, business, and industrial effluents to wastewater treatment systems — onsite or centralized facilities. The deteriorating state of municipal wastewater and sewage treatment management in South Africa is one of the largest contributing factors to the numerous pollution problems experienced in most parts of the country and a major contributor to environmental and human health problems. South Africa is currently facing many challenges in the area of wastewater infrastructure. Effluent and sludge quality compliance; the environmental, technical management, financial provision for operations and maintenance of the infrastructure are some of the challenges that need immediate intervention. The infrastructure funded by the government often collapses due to poor operations and maintenance. Ineffective maintenance often results in sewer blockages, which has terrible negative health effects for residents and the environment. An exponential population growth which causes growth in waste volumes has accompanied this trend, but appears to have been inadequately catered for by those entities responsible for its management. It is, in fact, estimated that during 2015, eighty percent (80%) of South Africa's fresh water resources were badly polluted. This paper provides an overview of wastewater mismanagement on the one hand, and the enviro-social impact thereof on the other. Different wastewater infrastructure were visited and evaluated. The current stat shows that there is a lot of improvement that needs to be done and continuous maintenance and research and development is required.

Keywords: wastewater, pollution, South Africa, governance, management, conserving crime

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1 INTRODUCTION

Since 1956, South African water Act (Act 54 of 1956) prioritised the need for more comprehensive water infrastructure and acceptable standard of drinking water and Maintainable access to clean and safe water is a constitutional right of all South Africans [1].The population growth rate in South Africa is high which creates pressure on the demand of clean water that is best for human consumption. This is also adding pressure on the available wastewater treatment infrastructure and systems. Regarding the improvement of water and sanitation services, South African government has introduced and implemented many solutions such as Reconstruction and Development programmes (RDP) to improve service delivery. These government solutions have made progress, however, sustainability and improvement of wastewater infrastructure remains a challenge. South Africa has 9 provinces with an approximately 824 treatment plants, with only 60 treatment plants that are operational [2]. Many health complications in South Africa are caused by the declining state of wastewater infrastructure [3]. The poorly untreated water that is discharged to the communities for human consumption contains microbial pathogens, nutrient loads, heavy metals and some organic chemicals [4]. Effective sanitation services will not only improve health of South Africans but will also protect the environment. 380 cases of diarrhoea and 9 confirmed cases of typhoid fever were reported in Demas, Mpumalanga province by the Mail and Guardian (2004). Also the outbreak of typhoid fever was found in many parts of the country including Limpopo, Kwazulu-Natal, Mpumalanga and the Eastern Cape [5]. This outbreak was recognized by the UKhahlamba District Municipality to be attributed to microbiological water quality caused by sewage spills [5].

In Gauteng province water from the Vaal Dam is pumped to 13 Municipalities, 40 Mines, and 926 Industries, however it has been reported that since 2014 untreated sewage has been flowing to Vaal river from the surrounding inoperative wastewater treatment plant [6]. The ongoing sewage spill to Vaal dam started with many faults in the sewage system, until it has reached the breaking point. While the sewage crisis continues engineers are doing their best to keep the old infrastructure working, however, one manhole cover gets stolen and immediately the sewage flows to the nearest river. Crime is also a challenge in order to maintain wastewater infrastructure.

The spilling sewage is discouraging investment in tourism which has an impact on creation of jobs. Johannesburg water has a problem with people who do not pay for water distribution services which affect budget for infrastructure development [7]. Waste management of used nappies, old infrastructure, old plastics, illegal storm water connections and others remains major challenge to many Municipalities in South Africa. This paper provides underlying causes of wastewater infrastructure mismanagement by reviewing the stat of the top 4 big Cities in South Africa and propose solutions.

2 THE CURRENT SITUATION IN SOUTH AFRICA

The biggest cities in South Africa as determined by population Johannesburg, Cape Town, Durban and Pretoria. The South African government made a commitment to sustain certain standards for water and sanitation. This commitment is accompanied by both challenges and achievement. Mail and guardian of 6th April 2022 has reported that in South Africa hundreds of wastewater treatment works are in a dismal state. The decline is shown in both sewer collection level and wastewater treatment [8]. Due to poor maintenance of the wastewater treatment plants it is normal to see overflowing sewage at nearby residents in the streets of Johannesburg. Exposure to wastewater can lead to many health complications. Figure 1 shows what seems like a river of sewage flowing in the Streets of Alexandra, township in Johannesburg that is not far from Sandton. Filthy streets littered, sewage runoff and sewage odour are everyday life realities in the township of Alexandra.

Figure 1: Sewage Runoff in the street of Alexandra [9]

Municipal workers are doing their best to fix the blockages on time but struggle with regular pipe bursts. Being exposed to sewage can cause Gastro intestine illness, ear, nose or threat infections which is noticeable after a 24-hour incubation period. The effect of the exposure to sewage is ignored by authorities. South Africa is facing water crisis due to poor water treatment infrastructure, persistent draught that is accompanied by the variation in climate change, poor water quality and lack of water engineers. The sewage crisis is affecting the economic growth and also the well-being of everyone. The spilling sewage is an epidemic that needs urgent intervention. In Cape Town the spilling manhole which is located at the Rietvlei section of Table bay nature reserve is causing lot of bad smell which affect the tourist visits. Figure 2. It is the responsibility of the local government to provide basic sanitation services related to domestic wastewater and the safe sewage disposal. Hygiene, disposal of human excreta, collection and treatment of domestic wastewater and sewage from households are the prescribes minimum standard of basic sanitation services that government need to maintain. At the same time, it is the responsibility of Municipalities to ensure that wastewater treatment works are maintained and monitor any corroded infrastructure that is degrading and upgrade the treatment system to accommodate the increasing population.

Figure 2: Sewage Spill at the Rievlei Section of the Table Bay Nature Reserve [10]

In Cape Town because of sewage spill, the three major recreational venues were closed for months. The smell of sewage in Townships of South Africa is a daily challenge, like in Khayelitsha and Philipi two of Cape Town's Townships residents live with sewage in their streets [11]. It was found by South Africa's national water quality sewage standards that 5 Municipalities in Southern and northern Gauteng do not comply [12]. Every South African has a right to stay in an environment that is not harmful to their wellbeing and the environment that protect the future generations. The sewage crisis has raised lots of blames on government, some blame corruption, lack of expertise, poor financial management, crime, Waster water mismanagement among others. Whatever the case may be, this situation needs immediate intervention and proper investigation. It is evident that South Africans can no longer rely on the current wastewater system. Government needs to invest in water engineers and infrastructure that accommodate new technologies. Platforms or processes for sharing information about waste management needs to be set up and be accessessible to all South Africans, every citizen need to be educated about the dangers of sewage exposure and be informed of the guidelines for conservation of environment.

3 WASTEWATER MISMANAGEMENT IN SOUTH AFRICA

The responsibility of each Municipality in South Africa is to maintain and manage wastewater infrastructure on daily basis to protect the citizens of South Africa and the environment. National and provincial authorities or gate keepers manage the finances and resources. Their role is to enforce principles of wastewater management among government departments and spheres of government, like the implementation of Green drop programme. Green drop programme is a monitoring reporting system that is designed to improve the performance of wastewater treatments plants. The Green drop programme has released a worrying state of wastewater treatment plants in South Africa [13]. The report states that the status of wastewater Treatment plants in South Africa is worsening from an excellent to very poor. The Green drop prioritize intervention where poor performance and failure is witnessed [14]. This programme continues to work with government by providing information and data to plan for continuous Improvement.

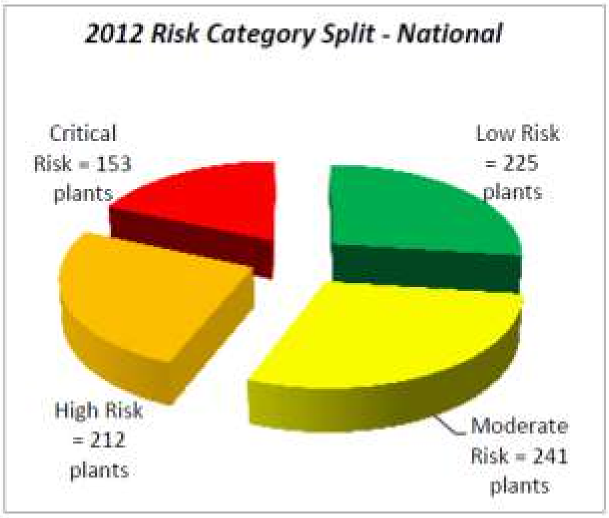

Figure 3: Green Drop Report Regarding Status of Wastewater Infrastructure in South Africa [14]

Figure 3 clearly shows that almost 75% of wastewater treatment plants are at risk, only 25% of plants are at low risk. The department of water and sanitation seeks to protect citizens of South Africa from any dangers that are caused by poor quality of drinking water, however the current situation of wastewater requires regulations, research and development, commitment and support.

4 WASTEWATER MISMANAGEMENT POTENTIAL SOLUTIONS

There is a need for a system to micro manage Municipalities. Existing environmental legislation is not strong enough to force Municipalities to comply [15] . Rapidly aging water infrastructure, rapid population growth, and increasing climate change are some of the challenges that add strain to South Africa's wastewater infrastructure. The key challenges of Municipalities are [16]:

- Many wastewater treatment plants are operating above their capacity with no emergency overflow dam, when the plant overflows the sewage flows straight to the streams, rivers and communities. There is supposed to be a technical monitoring systems that shut off the plant once it has reached its maximum capacity.
- Poor operation and maintenance. Most of the plants are old with no operational manuals and maintenance manuals. The old infrastructure has old parts that are no longer available in the market, thus new technologies need to be introduced.
- Lack of skilled staff, with no strategy to retain the current engineers and to attract the best engineers. Municipalities need to start investing in skilled people whether the worker is an operator or the engineer.
- Poor budgeting and finances. There is no accurate expenditure, citizens have no say when it comes to finances. There must be procedures and guidelines that enforce transparency regarding finances.
- Corruption and poor management. Poor staff management, employees not performing their responsibility due to lack of training. Set of criteria need to be established to ensure that people who hold high positions have business mind and leadership skills so as to improve service delivery.

The reuse of water projects needs to be implemented, these challenges are not only affecting the citizens of South Africa but also affect the economy [17]. Table 1 sammarizes the current state of waste water is South Africa and the proposed Solutions. The introduction of new technologies makes the waste water management complicated and complex, which makes it more difficult to manage.

Table 1: Summarized solutions of the current state of waste water

CURRENT STATE	SOLUTION
Sewage leaking to rivers	Repair leaking faucets or pipes immediately. Install monitoring technology, this technology will need to activate an alarm to inform technicians of any leaks or brocken pipes in the system.
Poor maintenance of wastewater treatment plants.	Scheduled preventative maintenance need to be communicated with all Stakeholders. If there are no enough resources to focus on maintenance this can be outsourced to the maintenance contractor.
Shortage of spairs when repairing wastewater equipment.	Investing to the storage or the availability of critical spares will improve the efficiency of the plant. The list of critical spares

CURRENT STATE	SOLUTION
	needs to be prioritized and their availability needs to be check regularly.
Lack of skilled staff	Invest in training, it is easier to train existing staff than to take on new employees. Skilled staff will be able to lay down solutions that will address the rest of the other problems.
Limited maintenance budget	Focus on staff retention, create culture that encourages people to stay

Government need to give special attention when it comes to funding water maintenance project. Purchasing higher quality components or investing more in repairs will go a longer way in ensuring longer-term sustainability.

5 ANALYSING THE CAUSES OF THE DECLINING WASTEWATER INFRASTRUCTURE

The declining state of municipal wastewater and sewage treatment management in South Africa is one of the largest paying factors to the several pollution problems experienced in most parts of the country and a major supplier to environmental and human health problems. The severe decline of the availability of funds to improve wastewater infrastructure, has led those in authorities to compromise the quality of wastewater treatment infrastructure. Their decision is focused on affordability not on the quality they receive, such that those that are appointed to improve the infrastructure supply poor quality. The state continues to increase the regulatory standard for consumer safety, which that increases cost for upgrading the equipment. A rapid increase in population growth has caused exponential growth in waste volumes which causes a strain to the infrastructure [12].

6 CONCLUSION

Water service delivery negatively affect the economy and the livelihood of the people of South Africa. There is a need to improve water sector financial viability. In most cases these wastewater treatments plants need full rehabilitation, government needs to work closely with private sector to improve plant operations and adoption of more innovations. People needs to be educated about the importance of water conservation. The legislation of environmental Health and safety clearly states that those who pollute the environment must pay, however, this legislation is not practised by our Municipalities. If this legislation can be enforced and be implemented with heavy fines this will serve as a deer ant and provide as a source of funding.

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TESTABILITY: AN IOT SYSTEM PERSPECTIVE

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ABSTRACT

The paradigm shift brought about by the Internet of Things (IoT) environment has challenged traditional system analysis and design perspectives. One of the perspectives that has been changed, but may have not received sufficient review, is the way a system and its elements are tested. On the traditional end, testability focuses on test and verification of individual components, their interfaces, and integrated testing in isolated environments. However, the availability of interconnectivity allows testability to cross boundaries, which in turn requires the engineering scientist to revisit the philosophy of testing to highlight the advantages of interconnectivity in system testability. The recent focus of IoT testability has shifted towards software testing using the concept of digital twins, with the assumption that hardware and interconnection components have been tested during development and fabrication. An important challenge that we will address, is thus the concept of an abstract system model that is a real-time reflection of the underlying system state at a point in time. This relies on the availability of the status of all system elements on a continuous basis, where status includes all life cycle information in a multi-agent, multi-disciplinary system. The traditional definition of testability is thus revisited and adjusted to reflect the true intention of testing namely, to acquire the system status in terms of all its elements, and to compare the observed status against a set of desired values that may be defined using a variety of analysis methods over a full system life cycle. A real-world case study and structured literature study are used to show the value of a system perspective on testing in an interconnected (IoT) system.

Keywords: IoT, testability, full life cycle

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1 INTRODUCTION

In the past few decades, the development in Industry 4.0 has had large impact on the application of the Internet of Things (IoT) and the Industrial Internet of Things (IIoT) in modern day systems. Testing has become more complex with the development of more advanced IoT systems and networks. This paper analyses the impact of IoT on testability over the full product life cycle.

During the development of IoT systems, a design process is followed that typically has phases including concept, preliminary, and detail design, followed by implementation and testing, and ending in production, operation and maintenance before being phased out (full life cycle [18]). Testability of IoT systems up to this point has proven difficult with no definitive method or mutually agreed upon definition of testing in these types of systems [1],[2],[3].

Testing of IoT systems is typically done to verify the functionality of the system during and after development, during production, at field commissioning, and during operation for performance and availability assurance. In order to revisit the concept of IoT system testability, it is necessary to analyse testing of IoT systems and to learn from analysis, literature, and a case study *where* and *how* the testability of IoT systems is affected.

2 RESEARCH CONTEXTUALIZATION AND METHOD

2.1 Problem definition

The research challenge is to understand the effects of IoT on system testability from a full life cycle perspective, and to propose a method for ensuring testability during operations.

From a real-world perspective, the context is an agricultural irrigation pivot system that has been automated using IoT technology. A number of these systems have been deployed nationally and internationally by the client (owner of the IoT system) for whom this research was conducted.

2.2 Research process / steps

The research process was approached as follows:

1. Understand the impact of IoT on testability (practice-inspired research):
    a. Perform an analysis of testing over a full life cycle from a systems perspective;
    b. Do a systematic literature review on IoT system testability from existing literature; and
    c. Conduct a real-world case study on an irrigation pivot system in the context of agricultural IoT;
2. Reflect and learn from the above impact study (guided emergence):
    a. Identify ***where*** IoT will add value in the client's system life cycle, with the focus on operation and maintenance;
    b. Define ***how*** IoT will affect testability by learning from the literature review and case study;
3. Derive a method to ensure testability for the client's real-world system:
    a. Identify areas in the client's maintenance system where IoT will add value from a testability perspective;
    b. Provide a method that will support testability based on the research and bring the method into context.

2.3 Formal research methods

In light of the above process, the following research methods were used to ensure the research obtained a balance between real-world application and theory, as defined in the list below.

1) <u>**Research paradigm and alignment with real world:**</u>
   a) Artefact definition using design science research (DSR) - design science research [11] was used to ensure a recognized paradigm links the real world agricultural IoT system to a grounded theoretical base;
   b) Systems engineering (SE) to identify *where* IoT impacts testability - the client uses systems engineering full life cycle processes for system and product acquisition and utilization [10]. Thus, to align the research with the client process, a full life cycle approach was followed to analyse the areas where IoT testability would be present in the life cycle;
   c) Alignment using quality research management (QRM) - quality research management [12] provided structure to align client requirements and research outputs by listening to “the voice of the customer”. This was done inside the DSR paradigm and provided goal-driven research challenges and solutions;
2) <u>**Case study research:**</u>
   a) Case study research to understand how IoT impacts testability - due to the complexity of IoT systems, and since the boundaries between the abstract (logical) representation of the system and the real-life context are not clear, it was necessary to use a case study. Observations from case studies were used to indicate *where* and *how* IoT principles will affect testability [24];
   b) Elaborated Action Design Research (eADR) to support action research - elaborated action design research [13],[14],[15] allowed real-world activities to inform the case study in a structured manner. The case study allowed analysis and reflection of the implementation and evolution eADR cycles with an artefact as outcome (the resulting method derived from findings).

3 LITERATURE STUDY

3.1 Testability in the systems engineering full life cycle

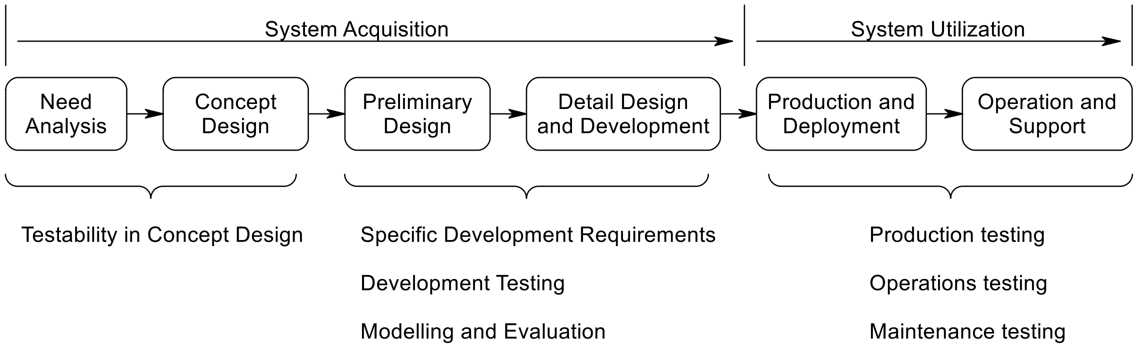

Figure 1: Testability in the Full Life Cycle [18]

From the above process [18], it is evident that testability forms part of the overall life cycle, and it is thus important to understand the impact of testability downstream in order to specify correctly in the first phases above. With production testing mostly contained and defined in a controlled environment, the focus of this research shifts to the high-level Operation and Support where testing is used in the utilization life cycle phase. Requirements, design references, model evaluation, and detail system testing are all verified in the systems engineering process, which is also a form of testing.

Specifically, testing in the Operation and Support high-level task is important since a real-time view of the overall system status is important for timely failure monitoring, reactive and preventive maintenance, and system performance management.

3.2 Testing during maintenance and operation

The corrective maintenance cycle can be reduced to six phases as indicated in Figure 2 [18].

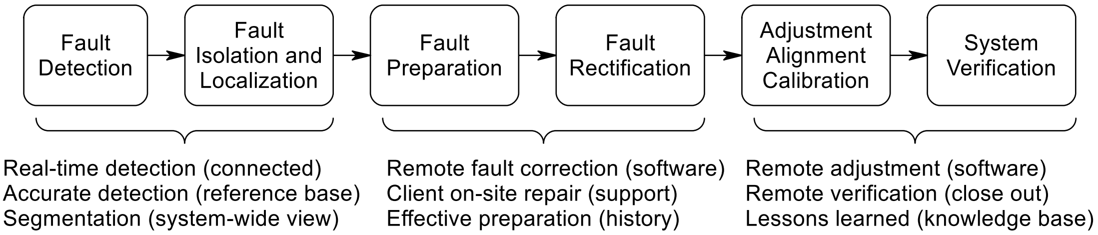

Figure 2: Corrective Maintenance and IoT-Related Activities (adapted from [18])

In terms of testability, the IoT system will provide the ability to:

1. Perform fault detection either reactively (functional capability failure) or proactively (deviation from expected value) using remotely obtained system status data. Historical data will be available to (i) identify a predefined fault (pattern recognition), or (ii) to report on exceptions (anomaly detection);
2. Support fault isolation from a system view (as opposed to a limited view) by using data from nodes and interconnections. Historical data from system logs will support this effort as actionable information;
3. Preparation for repair can be done using historical data to derive system characteristics. Failure types, inferred from IoT status data, will prepare the workforce for a site visit;
4. Fault rectification can be done either remotely, by a person on the client site, or by means of a dedicated site visit from a service technician. IoT will enable and support the prior two options;
5. Adjustment may be done reactively or proactively based on real-time system status data. Verification is done in a similar manner.

When testability is considered as the ability to obtain system status data and to compare this data against a valid reference, it becomes possible to perform performance (functional capability) testing and condition (resource integrity) testing.

Without IoT, a minimum of 2 site visits will be required. At the first visit the fault would need to be identified (testing), and required tools and components be acquired, followed by a second site visit. If unsuccessful, a third visit may be required. With IoT, a single planned site visit may be sufficient using historical and real-time status data.

The same argument holds for preventive maintenance, where the availability of system status will support workforce management (effort and cost) by having available relevant system status data.

Similarly, performance testing (doing installation and operating the system) is equally supported by having performance data available for quality management purposes. That is, to obtain relevant, real-time performance data for comparison with valid desired performance values.

3.3 Testability in an IoT system

Testability is the extent to which a system or unit supports fault detection and fault isolation in a confident, timely and cost-effective manner [9]. In general, testability is the ability to run an experiment to test a hypothesis or theory [8]. Thus, testability implies the ability to (i) define the desired state of a system, (ii) obtain the status of a system, (iii) compare the obtained status against the desired status, and (iv) make available actionable information.

From the research, the scope of testing was limited to device testing – a system view was not provided, as such.

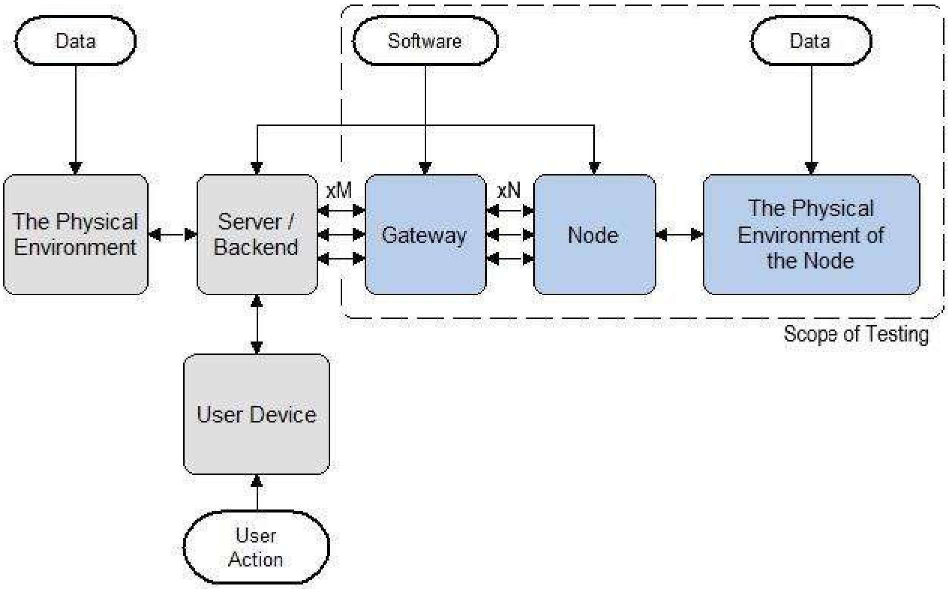

Figure 3: Scope of Testability in Terms of IoT (adapted from [1])

Full testing in an IoT system is similar to fully testing large sections of the internet. While the possibility of fully testing the internet is unlikely, it is sensible to create sub-networks within the greater IoT network. Sub-networks, defined as Networks-of-Things, are bounded components of the IoT network that support realistic testing [3].

A question of interest concerns how the size of the network affects testability. With large-scale networks, large amounts of data will be produced. The data, after processing, is likely to be used in making decisions and taking different actions [3].

Physically, a large IoT network will rely heavily on simulations when testing sub-systems. Large networks will by definition have larger numbers of nodes that cannot be all individually tested. With the difficulties in the testing of smaller-scale IoT networks already discussed, the reliance of large IoT networks on well-modelled simulations for hardware testing is clear.

3.4 Systematic literature review

As part of the research process, a systematic literature review was done on IoT system testability [16],[17]. Inclusion and exclusion criteria are provided in Table 1 below:

Table 1: Criteria for source inclusion or exclusion

	Criteria (Code)	**Criteria Description**
Inclusion	Closely Related (CR)	The text relates to general testability or testing of IoT systems
	Application Relevance (AR)	The application type used for IoT, or testability provides insight into the research problem
Exclusion	Duplication (DP)	The text appears multiple times within the same criterion
	Language Compatibility (LP)	The full text is not accessible in English
	Text Length (TL)	The full text is not available or accessible
	Context (C)	The context wherein IoT or testability is used differs too much from the context of the study
	Casual Use (CU)	The terms IoT and testability are not discussed or investigated in depth to provide relevant information

3.4.1 Text selection process

The text selection followed a four-stage process with two exclusion stages as indicated in Figure 4. In the first exclusion stage, the texts were removed if found to be duplicates (DP), not available in full English (LP), or the full length of the text was not available (TL). Having passed the first exclusion stage, the texts were removed in the second exclusion stage if the research topic was found to be in a non-applicable context (C), or the text used the terms testability and IoT in a casual way (CU) without providing any in-depth definitions or discussions on the topic.

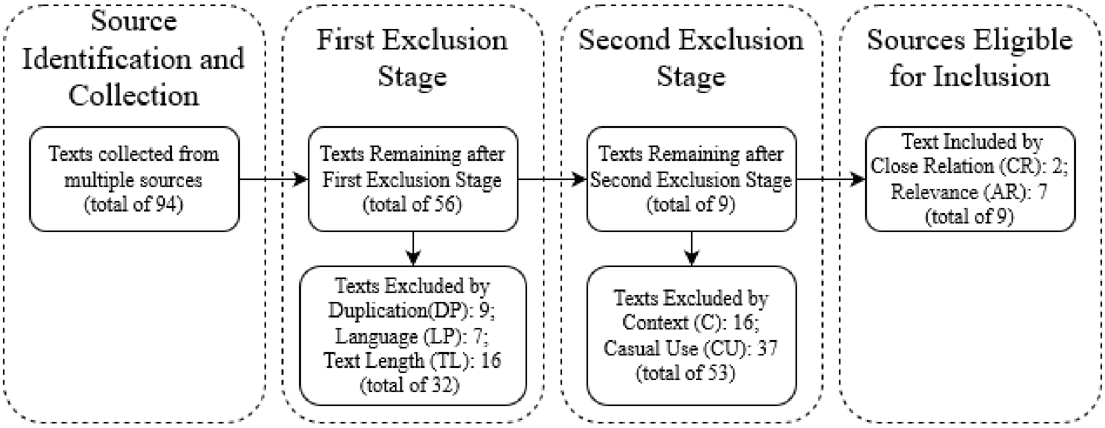

Figure 4: Four-Stage Systematic Text Selection Process (adapted from [25])

Four main focus areas emerged from the search, namely:

- Testing of IoT systems and related test challenges;
- Scope of testing in terms of IoT;
- Unique characteristics of an IoT system;
- Testability in the general and IoT context.

The limited scope of IoT testability was confirmed from the above (mainly considering testing within the scope of Figure 3, the device itself). There was no literature specifically on the impact of IoT from a system full life cycle perspective as shown in Figure 1. It was found that there is limited in-depth research specifically on testability in the IoT space, and how it differs from conventional system testing.

The following was found from the systematic literature review:

- Testing of IoT systems and related test challenges [1],[2],[3] – A significant challenge is the size of IoT networks [1],[3]. Each node on such an IoT network is linked to multiple sub-systems/nodes to handle communication, control, data capturing, and processing. The status of each node must be available, as well as communication links between nodes. Critical communications links were not specifically addressed in the literature that was reviewed, but must be considered in real-world systems (for failure mode effect analysis);
- Scope of testing in terms of IoT [1],[3] - The scope of testing in an IoT environment is limited mostly to functional testing of devices and their features. This limited perspective means that testability will not take a full life cycle system view (a product as opposed to a system view), which will result in less-than-optimal system status information being available for life cycle intelligence;
- Unique characteristics of an IoT system [4],[5],[6],[7] - An IoT system is characterized as a large network of multiple different hardware, software, and human elements implemented with the goal of generating, collecting, and processing data. Characteristics of IoT systems include the following, namely: interconnectivity (massive); heterogeneity; dynamic nature; enormous scale; and data security;
- Testability in the general and IoT context [8],[9] - Testability in the general context is mostly limited to test processes, procedures and methods in detail design, production testing, and diagnostic testing (in general) in the system full life cycle. Reference to full life cycle testing was not found in the review. This limited view prevents operations testing issues from being used as cases in the system acquisition phase.

In summary, the concept of testability as a system life cycle consideration was not explicitly found in the literature review. Test methods were limited in scope and mostly to functional testing of a node or “thing”. In general, the definition of testability relies heavily on the concepts of controllability and observability testing as stated in [9],[22],[23],[24],[25]. It can therefore be concluded that testability can be described as the ability to establish the status of a system and to compare that status against a desired reference state.

3.5 The concept of an IoT agent in a multilayer system

In a general IoT system, the concept of a multilayer system as well as the concept of an agent are important as these form part of the testability analysis and the definition of a method (or framework) to be provided [23]. The layers include:

1. Layer 1 - Perception layer: Devices, sensors and actuators are present. In the case of the client’s agricultural IoT system, this layer includes a controller connected to local devices via local wireless and copper networks;
2. Layer 2 - Network layer: Short-range, long-range cellular and fibre networks are typically used, with a proprietary ad-hoc local wireless network, copper network, and a cellular gateway being the main components at client sites;
3. Layer 3 - Middleware layer: This cloud-based layer is used for management of devices, connectivity, data, and service. In case of the client site, this layer is important as this is where testability will be ensured (as a quality management function);
4. Layer 4 - Application layer: Consumer and business applications appear in this layer. In the client’s case, this layer includes web applications for smartphones and computers, as well as business applications for management of enterprise farm systems.

An agent is defined as a physical or virtual entity that is sufficiently resourced, and being (i) autonomous, (ii) flexible in terms of being reactive, proactive, and socially connected, (iii) situationally aware, (iv) capable of reasoning, and (v) adaptive [23].

All the characteristics above are not always present in an agent, depending on the need. At the onset of this research study, the presence of agents (as such) in higher layers did not exist. The client system had need for a method to ensure testability, with an agent being a candidate option to implement a method to ensure testability. The case for both proactive and reactive approaches is made as historical and real-time data is available.

4 CASE STUDY

The case study was used to obtain insight into the impact of testability in the real world. Observations from the case study were used to augment the findings from the analysis and the systematic review.

4.1 Case study design

This is an exploratory study to answer the questions: “where”, “how”, and “how much” IoT capability will impact the overall system testability [24]. The focus is on the utilization phase of the irrigation system, with specific focus on scheduled and unscheduled maintenance and general system support.

The proposition is to use this case study in the Operation and Support task to evaluate the effects of IoT capability on test effort and cost. System repair may take place either remotely (software or configuration) or on-site (hardware or irrecoverable software failure).

The units of analysis will thus be work effort and associated cost (for example, site visit travel cost). The outcome of effective testing is thus that the system down-time and cost of testing are reduced.

A representation of an agricultural irrigation pivot point system and sub-systems of this case study is provided in Figure 5 (below). Note that central to the system is an IoT Master unit that acts as a gateway. In this system, the water supply, electrical supply, and weather sub-systems are connected to the IoT Master by means of a local ad hoc wireless network. The interfaces between the Master and sub-systems provide additional information to a local digital agent.

4.2 Participants

The research team comprised the following participants, as outlined in the list below.

- Primary researcher: Participant-observer doing (pre-)installation testing, testing as part of corrective maintenance, and recording and analysis of observations;
- Research leader: Observer assisting with data analysis and case study design;
- Technical team: Client team doing on-site installation, testing, and system status monitoring during operations and for maintenance tasks;
- Cloud development team: Client team doing development in the Middleware layer (layer 3);
- End-user team: Farmer (or representative) performing inspection, on-site repair, and minor service.

SAIIE 4.3 Case study system context

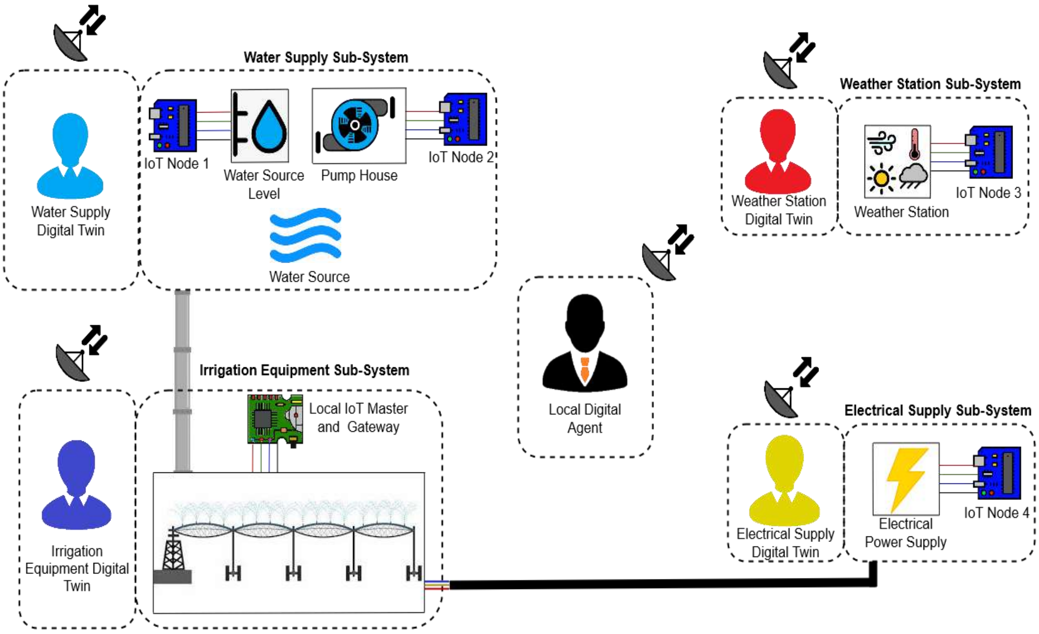

Figure 5: Irrigation Pivot IoT Field System Architecture

4.4 Data collection

Data collected in the study was in the form of observations during the installation, operation, and maintenance phases of the life cycle (that is, the utilization phase). The intrinsic nature of the data resulted in some system elements being less informative.

Specifically, the following process was followed for test analysis:

- For each system task, observations relating to testing were made and recorded. These tasks include installation and repair testing;
- System status measurement (IoT) was observed and noted. For example, 3-phase power presence, fluctuation, and failure;
- Root-cause analyses of underlying faults were done. Observations were linked to measured data to find the role of IoT functionality in the test effort;
- Failure modes were identified, and associated cause-effect analysis provided information on the actual failure, its diagnostic data, and the impact of each failure;
- Operations data was also obtained to describe the effects of human-system interaction on site, as well as measurements relating to sub-system performance;
- Directly measured data on system status was used to report and rectify faults, while in other cases, inferences were made from measurements, their dynamics, and their trends.

4.5 Case study results and analysis

In the data collection phase, the impact that IoT has on such a system was identified on an operational level. A comparison was made for the field system with and without on-site IoT equipment. A summary of incident types and their root causes is presented below:

Primary failures

- Electrical supply failure: Incorrect wiring (phases not connected, phase sequences incorrect), Eskom supply failure, load-shedding, power fluctuation, short circuits, lightning strikes. Observed using IoT status on power line monitoring that required a site visit. Loss of system communication was due to a lightning strike. Required site visits by an electrical contractor;

- Water system failure: Incorrect system design, pump system failure, valve failure, blockages in the water line, pressure drops due to losses. Observed using power flow and pressure monitoring. Required extensive system audit (design), pump equipment replacement (failure), and on-site removal of obstructions. Obstructions could be removed by the end-user without a dedicated site visit;
- Pivot structure failure: Tower motor drive failure, safety system failure, wet condition failures (wheels losing traction), and structural failure. Observed using dynamic anomalies from measuring rotation angle, speed, and safety signals. Could be rectified using end-user team without a dedicated site visit;
- Pivot controller failure: Configuration error, equipment module failure, communication failure (not a critical failure by design), and software failures. Observed using system configuration and operational status monitoring, and event logs. Configuration changes did not require site visits, but equipment failure required a dedicated site visit;
- Communication failure: In the Network layer, failure to communicate, slow speed on network, and power failure. Observed using network layer monitoring software. On-site power failures resulted in communication failure, while slow networks were characterised, and changes were made to antennas based on link quality. Required site visits for installation failures but reduced future visits upon fault rectification;
- Operator failure: End-user errors, system tamper, and incorrect system configuration. Observed using Middleware software and Application layer software to detect system status change and consequent failures. Could be resolved remotely by providing client support;
- System performance: Irrigation performance, total operating hours (up-time) and down-time, and failure frequency. Observed using operational performance status monitoring and comparing against desired set values. Did not require site visits for support, but notifications could be provided to end users;
- Configuration and reconfiguration: After installation or after fault rectification, the system could be reconfigured remotely without a site visit specifically to this end. Configurations could be verified against historical configurations or defined set values as a form of testing.

The inclusion of IoT thus, in general, increased the efficacy of corrective maintenance by reducing the number of site visits typically to a single visit in the case of a hardware fault, and none in the case of a recoverable software fault. IoT functionality decreased the total system down-time and time required to detect, isolate, and prepare for fault rectification.

IoT provided system performance and technical logs that supported preparation for scheduled maintenance as all performance data was available in the Middleware layer before a site visit. Performance data could be used to identify anomalies, while technical logs provided maintenance history.

4.6 Cost and time impact

The case study was conducted over a limited period of time (1 year), and time and cost savings can be illustrated for single visits. Distances to sites varied significantly, from 50km to 400km from the depot, hence the cost saving becomes a major consideration for remote sites. In a single visit, the time and cost spent on the road as well as on-site work effort (cost and time) can be estimated fairly accurately based on actual site visits.

The following values were used for time and cost estimation (for a specific site close to the depot – for simplicity, set at 50km):

- Fuel price: R 21.61 (at the time of the study)
- Average fuel consumption of vehicle: 10-15 km/l
- Labour fees per technician: R 105 per hour (two technicians per site visit)
- Average duration of site visit: 6 hours
- Travel time: 1 hour
- Distance to site: 50 km
- Cost of single site visit: R 1,509.06 – R 1,581.10

For a site located at 400km, the following applies:

- Average duration of site visit: 6 hours
- Travel time: 10 hours
- Overnight cost: R 850 (total for both technicians)
- Distance to site: 400 km
- Cost of single site visit: R 4,312.52 – R 4,888.80

The cost and time savings per annum was estimated for sites located 50km and 400km from the depot. From site visits in 2021, the following average estimates can be made:

- Site visits per annum without IoT: 6 visits including fault isolation and delays
- Site visits per annum with IoT: 2 where planning is done in advance
- Mechanical lifetime of mechanical structure: 20 years

With the above values, it can be estimated that the system maintenance costs would be as follows over the system lifetime:

- 50km from depot:
  - Without IoT enabled, the cost would be R 181,087 – R 189,732. In comparison, with IoT the cost would be R 60,362 – R 63,244;
  - Time spent on repairs for a site close to the depot would be 35 person-days without IoT, and 12 with IoT.
- 400km from depot:
  - Without IoT enabled, the cost would be R 517,502.40 – R 586,656 in 2021 terms. An IoT enabled system would be R 172,500.80 – R 195,552 for a system with IoT;
  - The time spent on repairs would be 80 person-days without IoT, and 27 days with IoT.

Production down-time and other losses were not considered. Also, costs will increase significantly as travel costs (cost to service provider) will increase. Travel costs to the end-user will be at a higher rate, and repeat visits were not considered (wastage and spillage were not considered).

The saving is thus a factor 3 based on site visit statistics from 2021. This is an estimate as sites often required more on-site work not directly related to testing, and an estimation was made for work done specifically on testing.

It is thus evident "where" IoT testability affects the system life cycle most, namely in the Operation and Support phase of the life cycle. More specifically, testing is mostly done in corrective and preventive maintenance tasks, although performance is also measured and verified.

4.7 Reflection

Based on the system life cycle analysis, systematic literature review, and the case study results, a generalized conclusion can be drawn as shown in Table 2:

Table 2: "How" of IoT on testability

With IoT Implemented	Physical Action	With IoT Not Implemented
Requires no site visits unless the system is offline. Data can be retrieved remotely at any point in time at very low cost.	***Long-term monitoring***	Requires multiple scheduled site visits. Requires hardware capable of storing data until the following data retrieval.
Site visits are reduced unless the system is offline. Faults are identified and restored remotely, or with a single site visit. Time on site is reduced as the fault is known.	***Fault identification and restoration***	Requires site visit. Multiple site visits may be required if the identified fault requires specialised equipment to be restored.
Requires no site visits unless fault cannot be detected or reported by the system. The system can automatically report any faults and notify the relevant parties. This also results in minimal system downtime.	***Fault detection***	Impossible to detect possible fault immediately. Fault detection done after the system has halted operation. Site visit is required in some cases
Requires no site visit unless an in-depth reconfiguration is needed, or the system is offline. The system can be configured in any way remotely at any time at low cost.	***System configuration***	Requires site visit at every configuration. Configurations can occur at any point in time depending on the site. Changes in environmental conditions, for example, could require a system reconfiguration.
Requires no site visit or physical human interaction with the equipment unless the system is offline. The user can fully access, control and monitor the system remotely.	***User operation***	Monitoring and control are only possible when on site, which requires travel and time. No status available remotely, leading to losses and effort.

It is evident that the availability of a reliable network is critical, but also that a system must be designed to function without such a connection. In such instances, testability will be affected as system status data will be delayed.

5 ENSURING TESTABILITY

To ensure testability, it is necessary to measure system status and performance in different layers. From a logical perspective, a digital agent may be employed to acquire system status and performance data from different sources [23]. Its main purpose is to monitor system element status and operational performance, to compare status and performance data against desired set values and provide actionable information as an output. Figure 6 indicates the application space of the digital agent within the context of this study, whereas Figure 7 shows the functional structure of the agent.

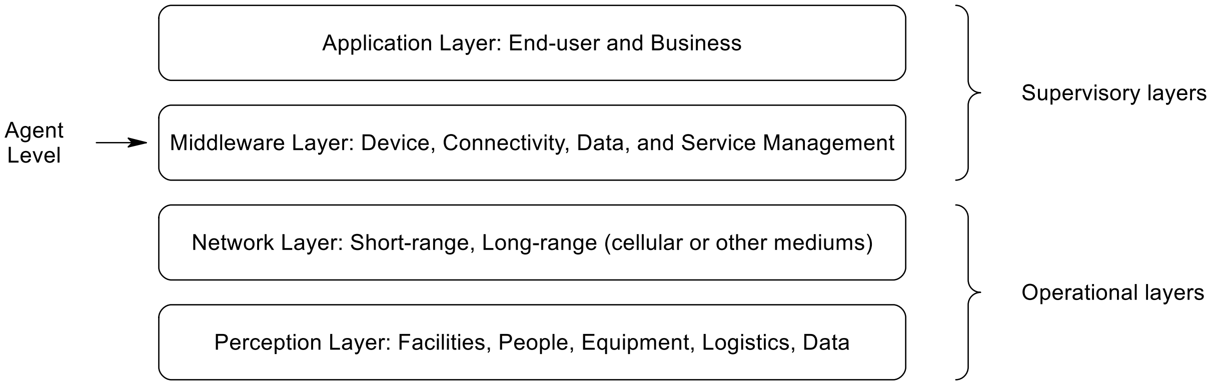

Figure 6: Digital Agent in the Middleware Layer

A Digital Test Agent is thus introduced as a software implementation of an autonomous entity to ensure focus on testability. The importance of testability in an IoT system has been identified from the study and the application of a Digital Test Agent will allow a single entity to charaterize a complete installation on site, with all its metadata, historical data, desired and expected reference values, with actionable information (intelligence) as output to the system Middleware and Application (management) layers.

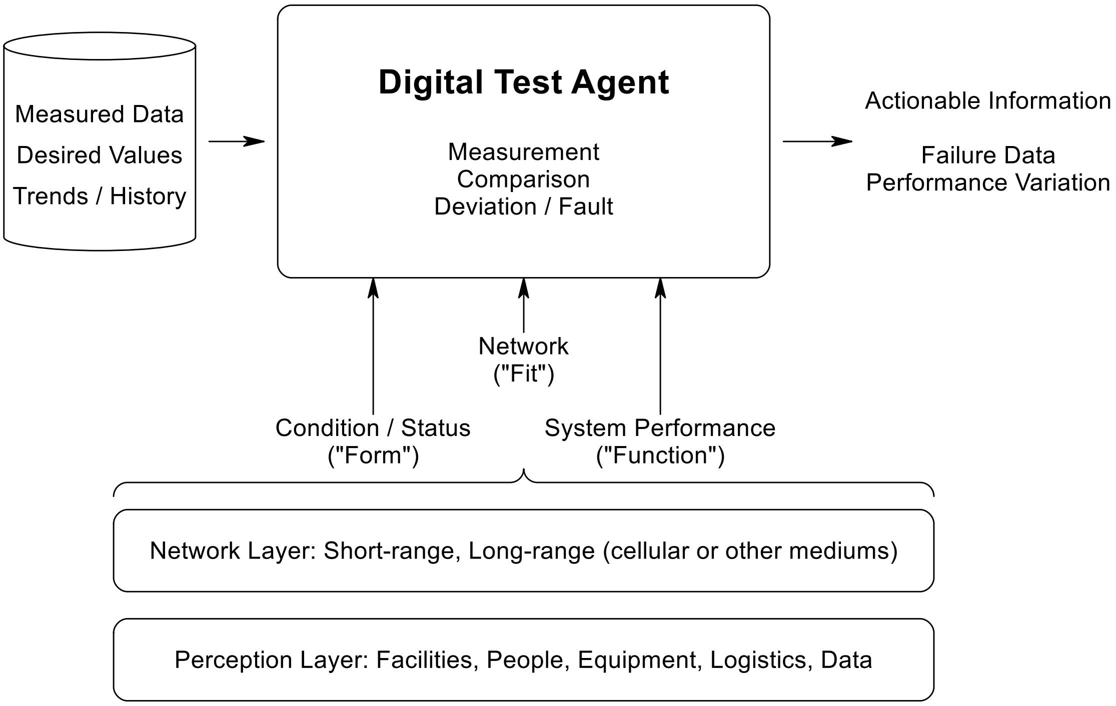

Figure 7: The Structure of a Digital Test Agent

6 CONCLUSION

It is concluded that testability, in this context, is the ability to establish the performance and resource condition status of a system, and to compare that status against a desired reference state or expected trend.

Usability becomes important when considering what a testable system looks like. In basic terms, a system that is usable is not always testable, but usability in the form of "ease of access" to status information is important.

From a full life cycle perspective, a system's testability is designed by assuming connectivity and the critical dependency on an available network. This must be stressed as the system's overall performance will become increasingly dependent on data availability. In the case study, the system was designed to also function without access to data (with limited efficacy).

IoT supports remote status data acquisition in real-time, resulting in significant advantages in system characterisation, availability assurance, and workforce management and planning. Effort and costs are saved, and centralised monitoring and control are utilised to ensure system operational availability. Remote access to data provided an opportunity to perform timely fault and variance detection since most processing was done centrally. This type of status data would not be available without a reliable IoT network, underlining the need for a robust, stable IoT network.

In the case study, remote availability of system status data and metadata reduced site visits for both the end user and technical staff, reducing lifetime cost by a factor of around 3. Operational loss reduction is achieved from timely and focused repairs but may be as much as the loss of a total production unit due to lack of irrigation.

The concept of a Digital Agent was identified to ensure testability is supported by measuring system performance and status data. Such an agent will be present in the Middleware layer and will focus on an installation as a whole. Its purpose is to measure status and performance data, compare against trends and desired values, and provide actionable information.

The IoT system is heavily reliant on interconnectivity, which remains a challenge in an environment with less-than-optimal available resources (failing electricity), but its value is evident from the analysis and case study.

Future work will include analysis of additional case study analyses and refinement of the concept to include advanced intelligence.

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A SYSTEMS PERSPECTIVE ON DATABASE MODELLING AND DESIGN

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ABSTRACT

The traditional approach for database modelling and design is based on Peter Chen's entity relational methodology. A firm separation exists between application design and database modelling, which leads to challenges as a system's environment and requirements change. The scalability and flexibility of a data model are typically not considered during the design phase due to the disconnect between the processes of the application design and data modelling. This paper will present an alternative paradigm regarding database and application design, by making use of the systems engineering methodology. A systems approach provides a holistic view of a database system, its functional units and its interfaces. By embedding database design and modelling into the systems paradigm, a generalized approach to data modelling is obtained. A systems engineering paradigm leads to a closer-knit relationship between application and database development, which allows scalability and agility when an environment changes.

Keywords: Database modelling, systems paradigm, holistic perspective

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1 INTRODUCTION

Peter Chen established the *de facto* standard for database modelling as early as 1976, when the entity relational (ER) data modelling approach was defined. It is based on the following four data-related tasks [1]:

1. Identification of data entities and relationships of interest;
2. Identification of semantic information, such as relational cardinality;
3. Definition of values and attributes;
4. Organization of data into relations and primary key decisions.

The above tasks form conceptual modelling in the traditional data modelling process. Typically, the artefact of this model is a collection of entity-relationship diagrams or UML class models. Logical modelling is the process of producing a database schema, usually table-based, from the conceptual model. Finally, physical modelling is the process of defining the physical storage structures of a database, mainly automated by database management systems [2].

This process is often uncoupled from application design requirements and primarily considers the data and its relationships. ER could therefore be defined as a middle-out design approach. This separation subsequently leads to difficulty when application requirements cannot be met due to rigid database design methodologies leading to a lack of flexibility and poor scalability. The situation becomes increasingly problematic when a system's environment or requirements change [3].

Considering modern database technologies such as NoSQL, or hybrid approaches, solving the problems mentioned above becomes even more convoluted due to the vast array of modelling and deployment options with no hard-and-fast rules [4], [5].

This article submits that by employing systems engineering (SE) principles with a holistic view of the system, the problems mentioned above become manageable and will produce scalable and flexible systems. In contrast to ER, SE follows a top-down design approach [6].

Figure 1 shows an IDEF0 function diagram. A functional unit consists of inputs, outputs, controls, and resources that govern the function's design and parameters. Inputs could be, for example, system requirements. Resources include human resources, tools, and capabilities. Controls and constraints could be technical or financial, for example [6]. These inputs weigh in on the function and must be considered during its design phase.

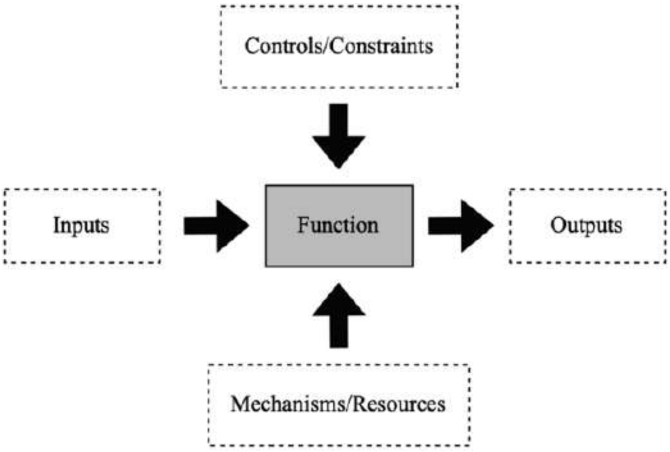

Figure 1: Resource allocation [6]

Moreover, a system consists of many such functions interconnected with interfaces that must be considered during the design, which further advances the need for a holistic database modelling and design paradigm [2], [3], [7].

This article reviews the literature on database modelling and application development *status quo*. Experimental analysis of the impact of modelling parameters on the performance of traditional and modern databases is performed and discussed. These results guide the development of a methodology based on a holistic systems paradigm to aid in the design and modelling of database systems. This methodology, in the form of a decision support framework, is tested against a traditional approach to database modelling and design using a standardised benchmark.

2 LITERATURE REVIEW

This section presents a review of typical database modelling techniques and tasks. Application development and design concepts in a cloud context are presented. Finally, the systems engineering approach is reviewed and applied to database design.

2.1 Database modelling

Typical database design and modelling are based on the following three phases [8], [9]:

- Conceptual modelling;
- Logical modelling;
- Physical modelling.

2.1.1 Conceptual modelling

Traditionally, the first step in database modelling is gathering requirements and developing a specification relating to the database and management system [2].

From the requirements, one elicits a set of entities, their attributes, relationships between them, and actors acting on the database. This elicitation includes cardinalities, that is, how many relations may exist between entity instances [10].

UML class diagrams have become a viable alternative to the traditional ER diagram used to model entities and relationships. Each entity shows its attributes, basic attribute types and relations with basic cardinalities to other entities [11].

Traditionally relationships are grouped into one of the following kinds [12]:

- One-to-one (a person and their spouse);
- One-to-many (a department and its employees);
- Many-to-many (student(s) and class(es)).

Recent developments have provided two additional relationships: one-to-few (less than a few hundred, for example) and one-to-squillions (an unlimited number). These distinctions are essential in modern database development, especially during logical modelling [13].

2.1.2 Logical modelling

After conceptual modelling has been completed, logical modelling transforms the entities and relationships to fit a specific database system, typically a relational table-based database such as PostgreSQL. Logical modelling, traditionally, has the following steps [8]:

- Definition of tables, columns, relationships, and constraints;
- Normalization of tables;
- Ensure integrity constraints are defined.

Tables represent relationships by making use of primary keys and foreign keys. Each entity is assigned a primary key which uniquely identifies that entity. In establishing a relationship between tables, the unique primary key of one entity is placed in another, serving as a reference. Depending on the situation and nature of the relationship, it could be included on both ends. Foreign keys are therefore used to reference a primary key from a different entity uniquely [8].

Many-to-many relationships are typically substituted with a JOIN table, which serves as a one-to-many and many-to-one mediator between the two sides of the relationship [10].

Normalization, typically the third normal form, organizes data into stable structures to minimize update anomalies and maximize data accessibility. This process is a standard step during traditional logical modelling [14].

Traditional rigid normalization strategies, though supported, have been challenged by the modern NoSQL concept of embedding and denormalization [15].

With the prevalence of NoSQL, and especially document-based databases such as MongoDB, a new paradigm of data modelling has emerged. Tables, or rows of data, have been replaced by collections of documents. The rigidity of columnar, normalized data has been replaced by rich, hierarchical data structures and the ability to have flexible schemas [16].

The divergence from a normalized approach has enabled NoSQL-like approaches to achieve higher scalability and performance, even with traditional technologies [14], [17].

Although the same modelling techniques and principles apply to modern approaches, it is not as clear-cut as the rigid normative approach: improving design flexibility while adversely increasing complexity during the modelling process [16], [18], [19].

2.1.3 Physical modelling

Each database system has specific physical model formats, features, requirements, and constraints [20], [21].

Though indexing, especially concerning integrity, is defined and specified during logical modelling, it manifests in the physical model. Views, partitioning, access control, availability and performance measures are defined in the physical model [8].

Many essential physical modelling tasks can be automated, but performance tuning is frequently delayed until problems arise, often due to poor decisions or lack of foresight during previous modelling phases [2].

2.2 Application design and development

Application development, from the perspective of database roles, happens after database design. Applications interact with databases, though very rarely dictate or influence the design process [2], [10], [22].

Traditionally applications have the following life cycle phases [23], [24], namely, requirements, analysis, design, implementation, post-delivery maintenance, and retirement.

Post-delivery maintenance manifests when specification changes or enhancements are required, often entailing changes in database models or designs [23].

2.2.1 Cloud development

Three specific requirements for cloud applications exist [25], [26]:

- Elasticity – the ability to scale horizontally;
- Flexibility – being adaptable (including data models and schemas);
- Fault tolerance - being highly available.

The underlying database design greatly influences a system's ability to adhere to the above requirements [27], especially when the needs for an application change or schema evolution takes place. In these cases, schema migration has to occur on relational databases, while NoSQL databases are flexible when changes to a model are required [28], [29].

2.2.2 Unified Modelling Language

Unified modelling language (UML) is often used for software and database development. It is an industry-standard suite of notations, primarily in the object-oriented domain. UML's essential diagram tools support conceptual database modelling and application design, including use-case diagrams, activity diagrams, sequence diagrams and class diagrams [30].

2.3 Systems engineering

Systems engineering, as a methodology, focuses on form, fit, and function. It defines various tools and methods for specifying, designing, creating, operating, and maintaining functions [31].

The systems engineering process is divided into the following two main life cycle phases and activities [6]:

- System acquisition:
    - System design;
    - Implementation;
    - Test and integration;
    - Construction or production;
- System utilization:
    - Operation;
    - Maintenance and support;
    - Upgrade;
    - Retirement.

Figure 2 juxtaposes system development activities (system acquisition phase) in the systems engineering and entity relational design approaches. It is of note that there are similarities between the two approaches.

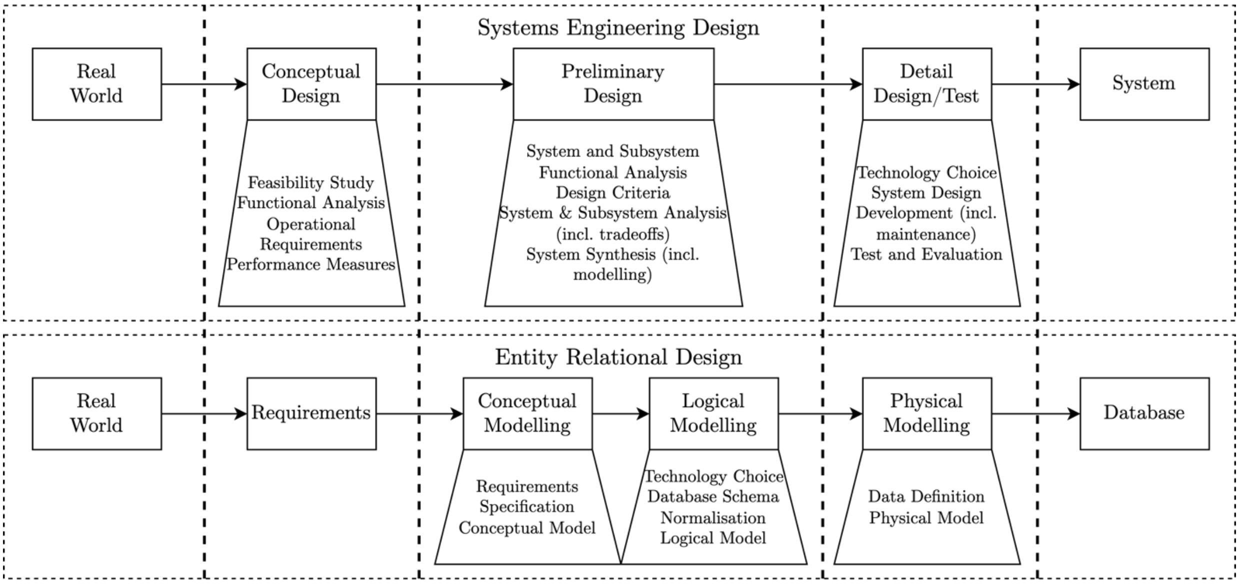

Figure 2: Systems engineering [6] vs entity relational design [2], [22]

A significant distinction is that systems engineering prescribes the modelling activity during the preliminary design phase, whereas ER performs it early on during the conceptual modelling phase. Furthermore, technology choices are made during the detail design phase, whereas ER chooses a database technology during the logical modelling phase.

Essential to the rationale of this article, the ER process delivers as artefact a documented database, whereas systems engineering delivers a documented functional system, including a database and application as well as all interfaces, subsystems and functions involved [1], [6].

Critically important is that system modelling, evaluation and development specification are the main activities of preliminary design, where the proposed decision support framework delivers the most significant contribution.

3 RESEARCH METHODOLOGY

Two sets of experiments were conducted to solve the problem facing most database designers: Which design considerations are the most important when developing a new data-based application? Two design philosophies must be considered: (i) database technology as the primary determinant or (ii) design methodology as an equalising (technology agnostic) approach.

The first set of experiments focused only on the primary database operations, create, read update, and delete, to determine the performance of two different database technologies not specific to any application test standard or design methodologies. That is, technology options MongoDB and PostgreSQL were objectively compared on a "technology only" test bed.

The second set of experiments evaluates (i) the performance of MongoDB and PostgreSQL after applying a traditional entity relational design process and (ii) the performance of Mongo and PostgreSQL after applying a SE-based design methodology.

The experiments will show that the most significant performance determinant lies in the preliminary design phase (logical database modelling) and not in technology choice. This finding may seem counterintuitive and unexpected, but the experiments followed a systems engineering approach instead of a naïve technology selection process.

Design choices for the second set of experiments were informed by the results from the first set of experiments. Specifically, design parameters such as the number of indexes, fields, and batch sizes were adjusted to obtain optimal performance, regardless of the database technology.

For the second set of experiments, an e-commerce system (based on the TPC-C benchmark [32]) was used as an application benchmark. The benchmark incorporates both the application and database design, and results will therefore holistically reflect the impact of the design methodology on the system's performance and scalability.

Emphasis is placed on performance engineering because it impacts a system's quality, reliability, maintainability, and sustainability [33].

3.1 First set: Empirical experiments

3.1.1 Purpose

Determine the performance characteristics of two database technologies (MongoDB and PostgreSQL) to identify design parameters for the logical database design activity in the preliminary design phase of the life cycle process.

Create, read, update, and delete operations are empirical functions that are used in all database operations and were used in this set of experiments.

3.1.2 Parameters and setup

The parameters that were varied in experiments include the following: number of read and write indexes, fields projected, stored and queried, number of threads used, the row limit of results, and batch sizes.

The parameter setups for create, read, update, and delete experiments were comprehensively run through relevant permutations. All tests varied the number of threads (from 1 through 8) to measure the local scalability of the database system. Each combination was run on MongoDB 4.4 and PostgreSQL 13 on a controlled commodity machine with default configurations. MongoDB is a popular NoSQL database, while PostgreSQL is a popular relational database with the ability to model complex columns and therefore allows for embedding [20], [21].

To investigate the impact of each parameter, the whole result set was taken into account, and each parameter change was tested for interdependence with other parameters. Each iteration was timed and repeated a sufficient number of times to obtain statistical significance.

3.1.3 Tests

The experimental tests are described below:

1) Test 1 – inserts: This test measures the impact of batch size, number of fields and indexes on insert performance. Documents/rows are generated randomly and inserted based on the parameters.
2) Test 2 – standard queries: This test measures the impact of fields queried, fields returned, fields indexed, and query limit on read performance. The database is pre-populated as described above, and indexes are created or dropped as required by the parameter set.
3) Test 3 – updates: Since updates have both a read and write component, the database is populated with rows of two sets of fields, one used for querying exclusively and one used exclusively for writing. This is done to isolate the impact of each type of index on the measurements. The parameters tested are the number of fields used to query, the number of fields updated, the number of indexes used in a query and the number of unqueried write-only indexes. An increment with random magnitude was used as the operation.
4) Test 4 – deletes: This test measures the impact of fields queried and the number of indexes on delete performance. Like updates, delete operations have a query and a write component, in this case, complete removal of the row/document. The deleted rows are re-inserted after every iteration as it is a necessary step to keep the database pristine for each iteration and set of parameters.

3.1.4 *Results and findings*

Even though MongoDB generally performed better at write operations and PostgreSQL at read operations, the impacts of the parameters indicated that both database technologies behave in a similar way and with similar magnitudes to changes in these parameters.

In summary, the following observations were made:

1. Indexes significantly improve read performance; exponential gain with > 10^2 on the 6th index
2. Indexes significantly improve sorting performance; exponential gain with > 10^2 on the 6th index
3. Indexes reduce write performance:
    a. Adding more indexes always reduces write performance; logarithmic decay in insert and update tests with between 36% and 50% loss on the 6th index.
    b. If the index helps reduce database scanning, the net effect is positive; exponential gain with > 10^2 on the 6th index
4. High limits reduce the number of operations per second, though inversely increase the number of rows/documents per second;
5. Batching is beneficial for writes in general; logarithmic gain > 10^1 on batches of 4096 versus single inserts
6. Multiple threads/connections are always beneficial; near-linear improvement across all tests (60% improvement per thread)
7. Inserting more fields per row/document decreases write performance; linear decay of around 3%-9% per additional field
8. Projecting more fields reduces read performance; near-linear decay based on the number of rows/documents returned (between 1.5% and 2.5% per field).
9. Updating fewer fields improves write performance; similar behaviour to inserts when unindexed (between 1% and 6% per field) and greater when indexed (between 4% and 12% per field)
10. Querying with fewer fields improves read performance, even when indexed; near-linear decay of 2% per additional field
11. Write operations are far more expensive than reading operations. Ranging from 10^1 to 10^3 times slower for the same number of documents processed.

These findings play a vital role in defining the design choices for the logical database modelling methodology as part of the preliminary design activities. These design choices are typically not applied in traditional database design, and this is because, in traditional database design, strict normalization is the *de facto* philosophy [2].

3.2 Second set: TPC-C experiment

3.2.1 *Purpose*

This set of experiments aims to evaluate the value of design choices obtained from the first set of experiments in a standard data-based application benchmark (TPC-C).

The TPC-C benchmark is a standard set of functions implemented by a defined set of transactions. Furthermore, the TPC-C benchmark is a standardized database management system and cloud performance benchmark based on complex online-transactional processing (OLTP) workloads. It measures the business throughput: the number of new order transactions processed per minute (TpmC) [32].

The workload is typically modelled for relational databases, but adaptations to fit the benchmark to MongoDB have been successful. The premise of these adaptations is to measure the effect of embedding data rather than relying on strict normalized paradigms [34].

The rationale of using an SE approach is to first characterize the information system, with all its interfaces and interdependencies, before allocating the system requirements to the database subsystem. With the TPC-C benchmark, there is lenience in the design and implementation of the database and application – this was used to demonstrate the effects of allocating system requirements on the database design and performance.

Therefore, this experiment compared (i) a traditional normalized TPC-C application without the value of system requirements analysis and (ii) the SE-based designed database on the TPC-C application after the application of system requirements analysis.

3.2.2 Parameters and setup

The same test system was used as in the first set of experiments. The application was benchmarked against a series of transactions shown below [35]:

- New order – mid-weight read-write transaction;
- Payment – light-weight read-write transaction;
- Order status – mid-weight read-only transaction;
- Delivery – mid-weight read-write transaction;
- Stock level – heavy read-only transaction.

The above transactions were performed and measured (in the application) on both traditional (ER) and SE design paradigms for PostgreSQL and MongoDB to validate that a SE design approach on both technologies scales and performs better, even for more complex transactions. The results were validated against the MongoDB results in [34].

3.2.3 Results and findings

The results of the PostgreSQL experiment are shown in

Figure **3** and MongoDB in Figure 4. An average increase of 20% in TpmC (new-order transactions per minute) for the modern approach on PostgreSQL and 15% for MongoDB correlates with the results found in [34].

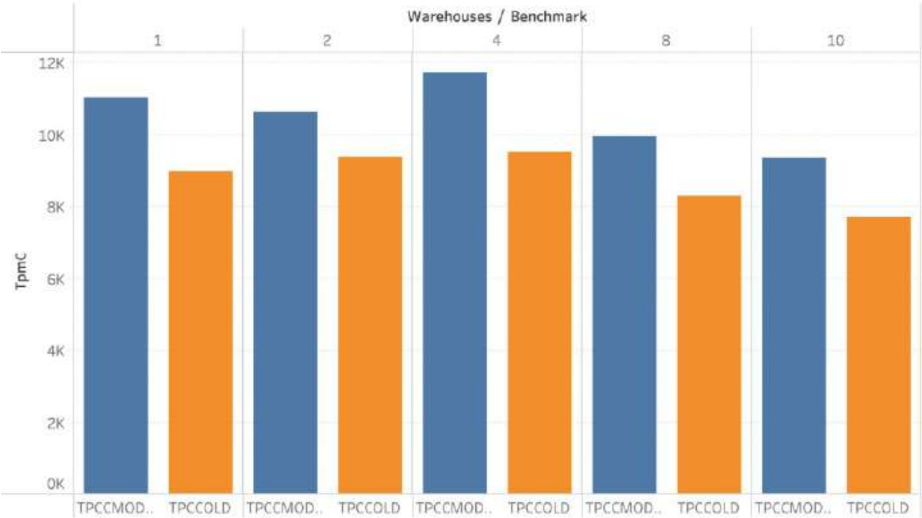

Figure 3: TPC-C PostgreSQL results

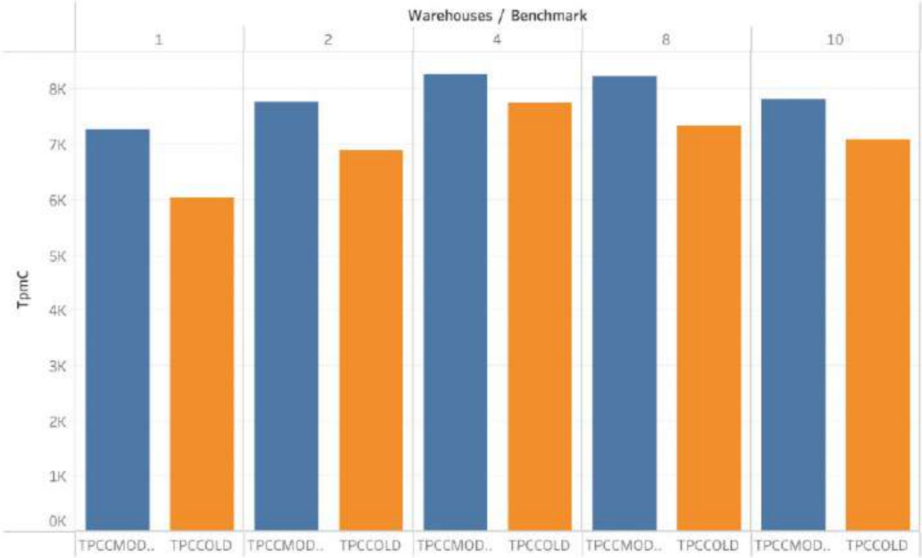

Figure 4: TPC-C MongoDB results

The original model was modified by embedding the order lines entity within an order, the exact change made in [34]. This change is because order and order lines have a composition relationship (orders are composed of order lines), so embedding is preferred.

This observation was made during the preliminary design when inspecting the relationships and directly impacted the design choice. Moreover, since the application interface requires fewer round trips to the database (no JOINS required), scalability was improved (contribution from the empirical experiments). This impact was envisioned during the preliminary design (SE) by inspecting the interface between the database and the application.

This result validates that both databases behave similarly to changes in the underlying model, even with complex transactions. Therefore, a thorough preliminary design, more specifically the allocation of requirements to data-based design as derived from application level, results in improved scalability, regardless of the technology. This is a very important finding.

4 PROPOSED SE-BASED DATABASE DESIGN METHODOLOGY

The design methodology is based on the systems engineering phases, as shown in Figure 2. The sections will focus on the database-specific design aspects while incorporating essential factors relating to how the system interfaces with the database. While the process is very similar to an ER approach at times, the focus and end result is very different.

4.1 Real-world problem/Input

It is critical to establish all actors that will manipulate and use the system (where data is concerned) either directly or indirectly. In other words, it should be noted if an action must be persisted in some way, cause a change in persisted data, or request data directly or indirectly. For each actor, all interactions must be elicited [8], [10].

The above is typically extracted during the requirements elicitation process at the system level [6], and it is vital to elicit requirements relating to the whole life cycle of the system as-is, to-be, and might-be.

4.2 Conceptual design

After requirements elicitation, a high-level/operational-level functional analysis is performed. From this analysis, it is crucial to identify the business rules relating to technical performance measures (TPMs) and high-level functions and interfaces. Detail on the frequency at which functions will be executed and any relationships and cardinalities that may pertain to data-related design on a conceptual level must be made visible and documented [6].

It is essential to point out that no database technology selection or modelling had been made up to this point. This is different from current methods that follow a middle-out approach.

4.3 Preliminary design

The preliminary design phase mostly coincides with the typical tasks associated with the ER approach, conceptual and logical modelling. However, it is still to be done agnostic of the database technology.

In the SE approach, one performs a refined functional analysis on a subsystem level. As the design progresses, the documentation has to be expanded to include new requirements or constraints that may arise from other subsystems (such as the application) or functions that interface with the database [6].

At this stage, the high-level data entities that have to be persisted, their relationships and cardinalities and some data fields or attributes should be known (from requirements and functional analysis).

Each relationship has to be defined as one of (from weakest to strongest in terms of dependence for existence) [16], [36]:

- Association - any logical relationship with no dependence on existence;
- Aggregation - parts of a whole but can exist separately;
- Composition - parts of a whole but cannot exist separately;
- Inheritance - specialization of an entity.

Given the relationships of a data entity, one can determine whether an entity is strong or weak. A strong entity's existence is not dependent on its relationships.

Cardinalities are often expressed vaguely, such as one-to-many and many-to-many, but it is more instructive to have specific descriptions such as one-to-fifty.

Closely related to cardinality is the rate at which entities (and by extension relations) are inserted into or removed from the database and updated or read. This rate can be derived from related functions and interfaces (application, for instance) and their specifications [7].

To support multi-tenancy, which enables a single system to service multiple tenants, annotate entities or relationships that may aid segregation. For example, the entity "account" could be used to segregate all other entities based on which account they belong to.

The entities and relationships can be modelled and refined in UML class diagrams with all the metadata and documentation gathered during the above steps. This process must be iterative to address all the requirements as described below.

4.3.1 Entities

Firstly, all data entities and their attributes are rendered into a UML class diagram, followed by their relationships and cardinalities.

When modelling and refining entities, the decision has to be made whether to embed or reference an entity.

As a first step, entities that grow boundless should always be strong standalone entities, and these entities will serve as anchors for other entities based on their relationships. One exception is weak entities that grow boundless, and these can use a special bucket pattern for embedding or remain a top-level entity [37].

4.3.2 Attributes

All attributes garnered from previous steps are annotated in the UML class diagrams. These should use simple types and allow for some special types, such as arrays of simple values initially. Attributes typically assigned as relational data (addresses or phone numbers, for example) should remain intact until further decomposition is required.

Imbue each entity with a unique identifier, if not already inherent. Here it is important to introduce any multi-tenancy attributes that may be used for discrimination.

4.3.3 Relationships

Any relationship is inherently bi-directional, but, in the context of a database system, some relationships can be considered single-ended or uni-directional, such as when the system only accesses the data in one direction.

Firstly, simplex relationships will be handled. These are defined as relationships between entities which do not have more than one strong relationship with other entities.

One-to-one relationships are typically embedded into the stronger of the entities, and these are also typically single-ended. Annotate a new field to denote the relation, but type it with the type of the entity embedded.

One-to-few relationships embed or reference the "few" entities into the "one" entity. The rule of thumb is based on the strength of the relation, and deciding which side to embed/refer to is based on the entities' strength. Composition or inheritance relations should usually embed, while it is not as clear for weaker relations. It is also possible to reference the entity but embed some data that changes rarely and is frequently required.

One-to-many typically only reference each other but optionally embeds data locally that is often required and rarely changing. Typically one would refer to the "one" from the "many" side, though it is possible with a bucket pattern to have it the other way around. Use the latter approach if the directionality of operations would benefit from such an approach.

Many-to-many can be grouped into the following varieties: many-to-many, many-to-few and few-to-few.

Pure many-to-many cannot consider full embedding. Often, a new JOIN entity that references the left and right-hand entities is required.

Many-to-few can be handled similarly to a one-to-many relationship, where the "few" are embedded or referenced on the "many" side. JOIN entities are not required.

Like many-to-few, few-to-few relationships can embed or reference on both ends, depending on the association type.

Only simplex situations have been considered up to now. When more complex relationships exist where entities have different cardinalities and association types with more than one entity, one should carefully consider how to render each entity optimally. The above process should be followed recursively, rendering the stronger relationships first until only simplex relationships remain. Considering that boundless entities serve as anchors, start with these and render each association with them accordingly.

The primary decision to be made when modelling entities is whether to embed, reference or follow a hybrid approach. It is here where application query patterns play a vital role in determining the necessary trade-offs to consider.

When considering embedding in complex cases, the following questions have a bearing on the design choice [13]:

- How often is the embedded data changed?
- How often is the embedded data required in a query?

The answer to these questions will determine whether embedding is ideal. When embedded data changes often, it must be fanned out to all other entities that embed this entity on change. If the ratio to writes versus reads is skewed to the write-heavy side, referencing might prove more performant and maintain a stricter level of consistency. However, if the ratio is skewed towards the read-heavy side, embedding might prove more performant by removing the need to join the entities during a query [13]

Referencing is typically better for scaling writes for complex cases primarily by avoiding the fan-out discussed earlier. Embedding, in contrast, is better for read performance. A third option is to utilize both models, following an eventual consistency approach to embedded data. Attributes typically required in queries should be noted as possible candidates for partial embedding for this approach. A fourth option could be to utilize the bucket pattern, which creates buckets of references or embeddings.

The experiments showed that writes are more costly on a database system than reads and should be prioritised when designing complex relationships.

4.4 Detail design

Following the preliminary design, a detail design requires technology choices. The database management system (DBMS) should be chosen based on the system's constraints, controls, resources, inputs, and outputs. Form follows function; therefore, the database chosen should have a form and fit to meet the function [38].

The UML class diagrams must be synthesized into the DBMS of choice during detail design.

Indexes must be designed, which was seen as the most impactful parameter in the empirical tests. To successfully design the indexes, one has to consider the frequency at which queries will be performed. It may be more desirable to allow longer query times than to suffer lower write throughput for all inserts/updates. However, if a query is performed frequently, and especially if the collection/table grows significantly large, it cannot be helped but to add an index [29].

The rule of thumb for indexing multiple columns – start with the most selective column first, then work toward the least selective column, superseded by the clause that the left-most columns have to be fully specified to benefit from the right-most columns [9].

For scalability, one may have to consider sharding. Both databases can partition (or shard) based on a range of keys (similar to an index) or by hash. Sharding, in addition to regular partitioning, migrates a partition to a different server altogether. Not only is disk performance scaled, but also reads, writes and CPU-bound work [20], [39].

To obtain high availability (on the database layer), the database layer requires replication to serve as live backup and recovery [20], [21].

4.5 Artefact/Output

After the processes described above, the design of the database subsystem is complete. All interfaces and functions interacting with the database are defined and documented; thus, the application could be developed and implemented in parallel.

Considering the empirical results as a guide to database operations design in the application, one can make the best use of the underlying database system. For example, one can improve the system's performance by employing multiple threads and batch operations.

5 CONCLUSION

This paper has demonstrated that traditional database design methodologies lack a holistic system-wide approach. Although similarities between the phases of ER and SE exist, they are significantly different in nature, purpose, and execution. As alluded to earlier, ER follows a middle-out approach while SE follows a top-down approach.

The most challenging yet impactful decisions must be made during the preliminary design phase, which is a phase typically not included in traditional database design. In SE, a conceptual design closely represents the real world and its requirements, while preliminary designs represent the abstract database system more closely. Translation between concept requirements (Type A) and preliminary (Type B) is critical to ensure requirements are fully managed. Detail design progresses to closely represent the physical database system and, ultimately, the application’s structures. In other words, the conceptual design closely resembles the use cases and actors in the system, while the preliminary design, prudently so, more closely resembles the application and system.

Empirical database tests were performed on PostgreSQL and MongoDB to determine the databases’ characteristic performance with respect to parameter changes. From the results, literature, and systems engineering principles, a new methodology was developed in the form of a decision support framework encapsulated in the development method.

To validate that the empirical results apply to complex transactions and a modern modelling paradigm applies to PostgreSQL and MongoDB, a TPC-C benchmark was performed on traditionally modelled and modern approaches. A similar experiment was done by [34] for MongoDB. In both cases, the modern approach achieved up to 20% improvement in transactions per minute.

These results demonstrate that following a system-oriented design and modelling within a modern paradigm delivers better scalability and design flexibility, whether applied to MongoDB or PostgreSQL. For this reason, the SE preliminary design phase can and must be completed before choosing a database technology. Moreover, considering surrounding functions and interfaces in the design (such as the application), a complete solution with the correct form and fit is obtained.

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PHYSICAL SECURITY IN THE SOUTH AFRICAN BANKING SECTOR

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ABSTRACT

Provisioning of physical security in the banking sector has become critically important in South Africa and abroad. In the banking industry, physical assets under protection (AUP) are highly attractive and are protected using a complex system of processes, people, technology, information, and interfaces. As a result, physical security system complexity must be managed in a high-risk environment using a structured approach - this is critical to prevent harm to people and significant material loss. In a case study, the value of security engineering management and model-based security engineering at a local bank is demonstrated. From a risk management perspective, it is instructive to define the system that actively manages controls to reduce reputational risk and material loss. Successes in this space can be evidenced and are ascribed to innovative technology and its impact on physical security. Important elements of physical security engineering are identified and presented as critical focus areas.

Keywords: Physical security, risk management, model-based engineering

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1 INTRODUCTION

Physical security plays a critical role in banking and has become more sophisticated and complex over the last few decades. Assets under protection (AUP) are highly attractive, and methods and tools available to attackers have become equally sophisticated and available. As a result, physical security systems in the banking sector are constantly evolving to stay ahead of criminals.

Crime is never fully terminated but deflected to targets that are more rewarding or less risky in terms of benefit-risk (from the criminal's perspective). The reputation of a bank or entity that receives, stores, transports, processes, and provides cash and other valuable assets is of cardinal importance. Reputation translates to ease or difficulty of access, and a bank with a good reputation will deflect crime more effectively.

An ever-changing environment forces a bank to adapt its physical security system continuously. Therefore, political, economic, social, technological, and regulatory changes in the environment must be strategically analysed and converted into solutions that mitigate physical security risks. Similarly, the crime landscape changes in reaction to environmental change, for example, in protest actions, ATM and vault attacks, robberies, and other criminal activities.

Technology changes follow a change control process. The unique ontology of physical security makes this environment particularly challenging as it constitutes a multi-disciplinary system in a very high-risk environment. Therefore, sound engineering principles must be applied to ensure effective mitigation of risk, sustainable operations, and accelerated change.

In this action design research (ADR) project, the authors played vital roles in creating a physical security management framework for a local bank. This was achieved using engineering principles and an adapted capability maturity model (CMM) to define a management structure with clear focus areas. The project started in 2013 and has progressed to high maturity levels with evidenced sustained success.

This case study followed a structured approach to create and implement an effective, sustainable physical security framework over five years. The method and resulting successes are discussed in this article.

2 RESEARCH CONTEXT

Physical security can generally be defined as the application of available controls (processes, procedures, people, technology, information (data), logistics, facilities, and environmental controls) to provide physical protection of physical assets and people. The risks against which protection must be provided determine the mitigation methods' form, fit, and function. The environment plays a significant role in the prevalence of criminal activities, and the interplay between offender, victim or targets, and the law is essential [1]. Socio-economic determinants of crime are important in this context, and it is known that unemployment, income levels, and the level of inequality must be considered in the crime landscape [2].

Due to its history, South Africa is characterised by being an ecosystem with significant socio-economic division between first world and third world that has, in essence, not changed over the past two decades [3] [4]. In this ecosystem, physical assets, including facilities, people, money, equipment, and other assets are at risk for being attractive rewards. This challenging situation will not be resolved in the short term, and whilst waiting on socio-economic reform, action must be taken to protect these physical assets in an effective manner.

2.1 Physical bank security in South Africa

Violent crime in South Africa has increased with robberies that increased around 30% over the decade up to 2021 [5]. The South African Banking Risk Information Center (SABRIC) reported an increase in bank burglaries (12%), attacks at ATM facilities (9%), and a significant increase in robberies (42%) across the industry over two years from 2019 - 2021 [6]. Physical security, accordingly, had to become more effective in terms of its controls. These include civil structures (walls, doors, barriers, etc.), electronic detection and reactive measures (alarm systems and reaction), surveillance mechanisms (e.g., CCTV, body-worn cameras and drones), access control and prevention (card, biometrics, turnstiles, etc.), and most importantly the element of personal integrity.

Specifically, the storage, transport, hand-off, processing, and dispensing of cash are important activities in banking. In addition, protection of people assets in the form of bank personnel and clients, facilities in the form of publicly accessible retail branches and ATM structures, equipment in the form of computers and other valuable assets, and physical prevention of access to information (data) are focal areas. From 2019 to 2021, the bank in this study experienced 9237 protest actions, handled 2201 incidents, made 168 arrests and prevented losses of up to R5b from attacks.

Multi-disciplinary security methods are employed to protect assets under protection (AUPs) commensurate with the physical threat profile obtained from risk analyses. This approach requires sophisticated engineering and operations reliant on a critical element in the system, namely crime intelligence, that will provide the threat intelligence [7].

2.2 The need for structure and standards

Physical security management is an essential consideration in security standards, and national and international bodies exist to ensure analysis of threats is conducted, solutions are created, and standardisation is achieved [8] [7]. However, these bodies focus primarily on security management, leaving the details of solutions to security architects as security subject matter experts (SMEs).

In South Africa, the South African Banking Risk Information Centre (SABRIC) was created to combat financial and banking-related crime and ensure the general safety and security of the banking environment [9]. The objectives of SABRIC include information exchange, provision of technical services, and coordination of bank-related security projects. As part of its activities, SABRIC enables the creation of standards in the banking sector through the collaboration of its financial industry partners.

Internationally, organisations such as the American Society for Industrial Security (ASIS – USA-based, with 240 global members) and the Security Institute (UK-based organisation) exist to create security information platforms and forums for their members [10] [11]. Like South Africa, international organisations develop standards to govern risk management, security technology, methods, and security professionals. Partners of these organisations are primarily vendors from the industry.

The South African bureau of standards (SABS) used to develop local security standards through dedicated work groups. However, this situation has vastly changed, and SABS decided to adopt and adjust international standards under the SANS umbrella mainly. International standards organisations, such as ISO, provide physical security standards for different environments. ISO18788, for example, provides a security management framework for private security companies – this is an essential standard in the context of security engineering management as it speaks directly to management standards (as opposed to technology standards, of which there are many).

Specifically, standards relating to risk are in the ISO31000 range, relating to risk in general. In addition, standards for contextualisation, assessment, and treatment are provided [7]. These standards will overlap with security standards as both have the same objective: to reduce and maintain risk at acceptable levels. Thus, different standards exist, but these had to be aligned for application in the South African banking sector.

2.3 Culture in physical security

In an environment where the focus is on physical activities and where high risk is present, it is necessary to utilise relevant and robust resources. As a result, trained personnel from the military and police services are employed, facilities and other civil structures are specialised, and equipment is robust and technologically advanced.

Due to the specialised nature of security-specific resources, there is a reliance on subject matter experts (SMEs) that are typically trained and supported by service and product providers. And although standards are used, the standards are not always based on systems engineering and maturity methods, as had been observed in the case study discussed in this research. Legacy methods for risk assessment, design, implementation, and operation are often based on the experience of SMEs that may not be trained in engineering management or systems engineering.

The physical security environment, as with any other environment, has a specific culture that is difficult to challenge that has historically been successful. This culture has a particular ontology that does not align with engineering principles (for example, using terms such as “minimum standards” as opposed to “security requirements” may not make immediate sense in the requirements management process). These cultures must be considered when translating physical security and engineering ontologies.

3 RELEVANT LITERATURE

In addition to security management standards, namely ISO18788 [8], two literature focus areas are important, namely Systems Engineering (SE) and Capability Maturity (CM), with specific reference to CMMI (Capability Maturity Model Integration) [12]. These will be discussed below as they form part of the overall security engineering management system (framework) that resulted from the research, also informed by work done on security science [7].

3.1 ISO18788

This standard uses a “plan-do-check-act” approach to provide a framework for organisations conducting or contracting security operations to demonstrate:

- Business and risk management capacity to meet security requirements;
- Awareness of the impact of activities on local communities;
- Accountability concerning human rights and the law;
- Consistency with the ISO codes and principles.

The standard ensures (not an exhaustive list):

- Contextualisation of the security environment and organisation: External, internal contexts, risk criteria, sub-contracting, stakeholder need analyses, and scope;
- The leadership of the organisation: Commitment, policies, roles and responsibilities, and conformance;
- Security operations planning: Risk management and control methods, regulatory compliance, and communication;
- Support for security operations: Resource assurance, financial support, competency, recording, and communication;
- Security operation: Planning, event and incident handling, application of security resources, personnel-related processes, and compliance;
- Performance evaluation: Compliance, test and evaluation, management reviews;
- Improvement: Non-conformity assessment and change management.

Although the standard is a good standard for security management, analysis and comparison of the 18788 standard against engineering management best practices ([13] [14]) revealed possible improvements, including the following:

- The addition of specific levels of measurement may be provided, as opposed to leaving the client of an audit with a binary decision and findings to address [12];
- Improved focus on engineering principles and associated activities that will add significant value, as will be discussed below [13];
- Modernisation of the standard from a traditional security view (that excludes modern aspects of security) to also focus on intelligence and technology [15].

As discussed, improvements to the above standard will be considered in the sections below. These improvements will be considered to ensure a comprehensive framework for security engineering management is created.

3.2 Systems engineering and management

In our research, specific references in security standards to the critical aspects of SE and its management could not be readily found. However, reference is made to the importance of standards and engineering functions in security [7]. Nevertheless, these crucial aspects must be considered as any security risk mitigation solution will follow a life cycle and will use most engineering processes and activities as defined in the SE ontology [13]. Specifically, the following were used in the case study, as discussed below.

3.2.1 Full life cycles

Different life cycles must be considered as they coincide in the operations phase of an asset under protection, as is evident in a security environment.

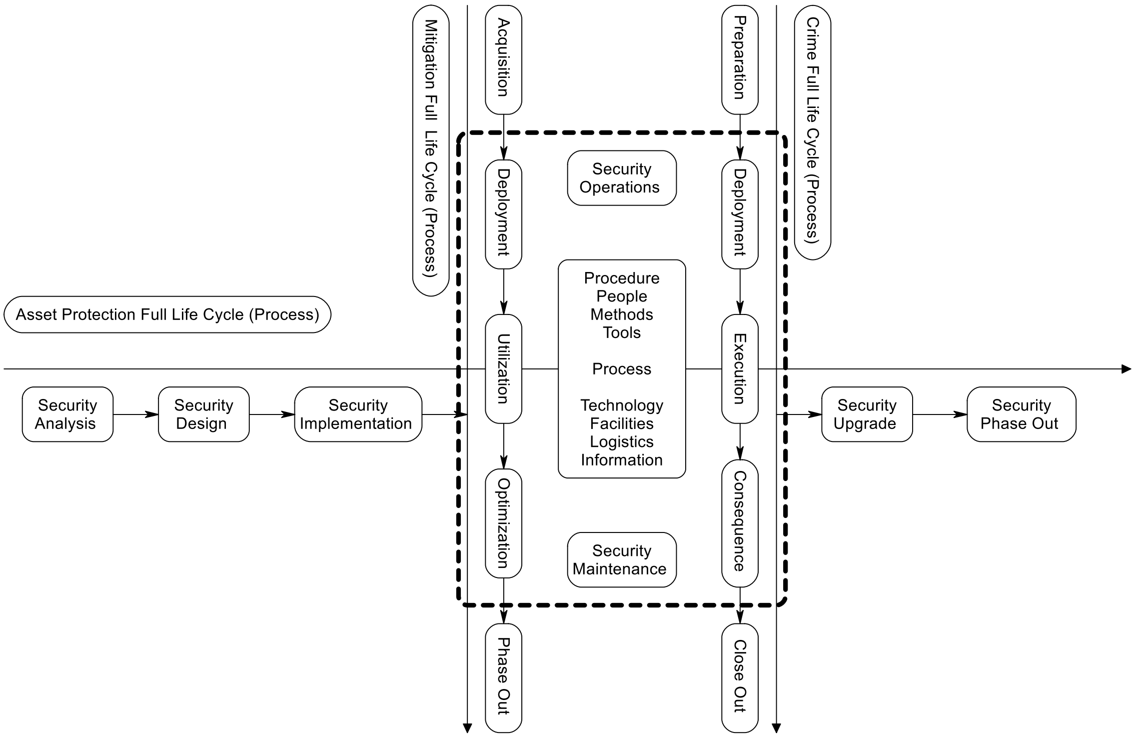

Figure 1 Security life cycles (derived from literature and case study).

The life cycle diagram above was derived from SE principles [13] [14], security literature [7], and observations made as participants in a case study as described in Section 5 below. The role of security engineering management is to ensure risk is adequately managed in two respects, namely:

- **Crime risk (threats)**: Originating from threats emanating from the environment and its role players (criminals) as defined by the Crime Full Life Cycle shown above. The Asset Protection Full Life Cycle ensures each asset is considered entirely in the process. The Mitigation Full Life Cycle ensures risk controls are defined and standardised;
- **Operational risk (vulnerabilities)**: Risks originate from failures associated with security resources. Failures of security resources (controls) are, in fact, operational risk events that translate to crime risk events when these resources are not available when an attack on an asset is executed.

It is clear from the analysis above that the SE perspective allows a single view of all security engineering management (SEM) in a general environment but also applicable to a bank.

3.2.2 Valuable SE tools in Security Engineering Management

Important methods and tools from systems engineering that apply to the security environment include the following [13] [14]:

- Verification and validation: All security resources must be validated from duly performed threat analyses and fit-for-purpose test and evaluation activities;
- Configuration management: Change management (as referenced in ISO18788) is a formal process in SE and engineering management;
- Requirements management: Not only security requirements but also business requirements must be included to ensure all stakeholders receive value (e.g., CCTV);
- Security design: Model-based SE should be used to design security solutions based on security models for facilities (and other assets) according to crime risk profiles;
- Integration: Security standards referred to individual equipment, but integration and interoperability were not explicitly covered – this is a critical aspect;
- Maintenance and support: Resource availability must be ensured to mitigate operational risk by using well-designed maintenance systems;
- Reliability/availability: Equipment reliability data must be used to reduce operational risk and cost, where this data feeds into maintenance planning;
- Performance management: Performance is measured and controlled as part of system analysis, a critical systems engineering activity.

From an analysis of standards (ISO 18788), it became evident that the vital link between operational availability and crime risk was not explicitly made in standards, although reference was made to equipment maintenance. However, this critical link is made by considering the probability of an operational failure leading to an attack when left unattended, considering the impact of such a failure based on the consequence of a successful attack that results in a material loss [7].

3.2.3 Engineering management methods and tools

From an engineering management perspective, the following methods and tools apply:

- Technology management: Specific focus must be given to technology management, including normalisation, life cycle economics and management. A normalised base reduces variability, which is critical to reducing operational risk;
- Project management: Security projects are complex and require proper project management methods, not referenced in detail in standards. This is critical as timely

execution will prevent the risk of an attack. A model-based approach simplified the project process;

- Value engineering: In a cost-constrained environment, security controls cannot simply be “removed” when attacks become less frequent, and a cost-effectiveness balance must be found and maintained;
- Engineering economics: Although also a tool in SE, the security engineering manager must understand the full cost of ownership as this cost must be visible to executive management (security is a “grudge expense” [7]).

3.3 Capability maturity models

From a historical perspective, capability maturity had not been used in the security industry, with recent efforts focused on this topic (in progress) [16] [17]. Capability Maturity (CM) will form an interface between governance and security management [18].

3.3.1 Capability Maturity Model Integration

The Capability Maturity Model Integration (CMMI) V2.0 framework [12] is a long-standing framework that originated from the need for a service capability maturity model in software systems [19]. Over time, the model has been adjusted to meet general service system requirements and has been adapted to environments other than routine software services, including different cybersecurity systems [15], [20]. CMMI recently evolved from V1.3 to V2.0 due to the constant improvement of the model as supported by the CMMI Institute. In addition, the CMMI Institute actively improves its knowledge base based on industry feedback, making these models relevant and pragmatic.

In CMMI V2.0, three primary CMMI standards overlap, namely (i) CMMI for Development, (ii) CMMI for Supplier Management, and (iii) CMMI for Services. Some elements of acquisition and development are present in the Services standard as new systems are always integrated into a service environment. The focus of security, however, is not on development or acquisition, and the relevant process areas will become evident in full life cycle analyses that define the core physical security functions.

CMMI V2.0 has 25 Practice Areas of importance in a service system environment, grouped into 10 Capability Areas. The Capability Areas are grouped at a higher level to give 4 Categories, namely (i) Doing, (ii) Managing, (iii) Enabling, and (iv) Improving. These are briefly discussed in the paragraphs that follow, with their relevance and importance discussed in the context of Physical Security. In the discussions that follow, it is important to refer to the CMMI Process Areas as these are comprehensive, and additions or omissions can be highlighted and considered.

The different Capability Areas are (adapted to suit a physical security perspective):

1. Delivering and Managing Services: In the security environment, this entails all security services provided in a specific functional area, including Physical Security, Executive Protection, and Forensic Investigations;
2. Engineering and Developing Products: In the security services context, this is done when new services are provided to clients in the organisation. These include new areas of protection or investigation;
3. Ensuring Quality: This implies quality assurance of security-related processes, management of requirements (of all stakeholders), and verification and validation of all requirements to ensure client satisfaction;
4. Selecting and Managing Suppliers: As security units use different suppliers, a formal process for selecting suppliers is required. This is similar to the recent Project Paramount process. In addition, supplier agreements must be defined and managed;

5. Managing Business Resilience: For a security unit, it is imperative to align with organisational policy to ensure business continuity, perform incident resolution and prevention, and manage risk (and opportunity);
6. Managing the Workforce: As a matter of high importance, and because humans are causing most failures in an organisation, organisational training is required, including all aspects of training across supplier resources;
7. Planning and Managing Work: It is critical to perform work estimation, planning and monitoring in control in an environment that is cost sensitive – this is also true for security units inside the organisational context;
8. Supporting Implementation: For all services across their life cycles, it is critical to perform continued causal analysis and resolution, configuration management, and decision analysis and resolution. These are crucial functions that flow over to operations as well as the development of service systems;
9. Improving Performance: At a high level, process performance must be measured and managed, new process assets developed on a continuous basis, and processes managed by using measured data. This is applicable as needs and services continuously change;
10. Sustaining Habit and Persistence: Governance is required (as is also required from an organisational perspective), and that infrastructure is used in a persistent way, where reference to infrastructure implies process descriptions, resource availability, funding, training, and process evaluation.

Each Capability Area, linked to Practice Areas, is measured by considering individual Practice Areas and their maximum achievable capability level. CMMI V2.0 uses the term “evolutionary level” as a replacement for “capability level” since V2.0 explicitly allows the evolution of an organisation to meet individual and combined maturity levels. The evolutionary levels are described below as:

1. Level 1 – Initial: Processes are executed, poorly controlled, and reactive.
2. Level 2 – Managed: Processes are often reactive and specific to functional units.
3. Level 3 – Defined: Processes implemented across all functional units are proactive.
4. Level 4 – Quantitatively Managed: Processes are measured and controlled
5. Level 5 – Optimising: The focus is on continuous process improvement.

Of specific importance is that the Service Practice Areas are defined by the specific functional area/business unit that delivers such functions, which implies that different business units will implement their own Services. This allows the CMMI V2.0 framework to be customised to become a “model” specific to each functional unit. Still, it is possible to generalise CMMI across all business functions by using the general Process Areas (excluding Service Process Areas).

3.3.2 ANSI/ASIS PSC.3-2013 Maturity Model

The ANSI PSC.3 American National Standard is a maturity model for the phased implementation of a quality assurance management system for private security service providers [17]. This model proposes six phases of maturity “from no process in place for quality assurance management, to going beyond the requirements of the Standard”, as from the standards document. The model is based on the core elements of the ANSI/ASIS PSC.1-2012 American National Standard: “Management System for Quality of Private Security Company Operations – Requirements with Guidance”.

The following stages/phases are present in the model [17], [21]:

- Phase One: Pre-awareness – Ad hoc quality assurance, no process currently in place, quality assurance is absent, and management does not recognise the benefits of quality assurance management;
- Phase Two: Project Approach – Awareness phase, where management is willing to test the concept and establish a trial period for evaluation of quality assurance;
- Phase Three: Program Approach – A transition is made from specific issues to addressing division- or organisation-wide issues by implementing the core elements of the base standard;
- Phase Four: Systems Approach – Implementation of ANSI/ASIS PSC.1-2012 core elements. Proactive quality assurance management is implemented using the PDCA (plan-do-check-act) model;
- Phase Five: All elements of PSC.1 have been implemented and validated to ensure all core elements are in full conformance;
- Phase Six: Holistic Management – A quality assurance management culture is established and is considered an inseparable part of decision-making.

A generic model is defined for maturity is provided in PSC.3. The model describes the characteristics of each phase based on the PSC.1 standard. No specific, quantifiable measures are available in the PSC.3 standard, and the maturity model actually performs a “conformance check” due to the lack of defined capability levels. As both standards are based on PSC.1-specific clauses (principles), the application of this maturity model is limited and cannot be easily generalised.

The ANSI PSC.3 maturity model security-specific functions are aligned with security quality management implementation stages. Since ISO 18788 is used in the physical security space, the corresponding clauses in 18788 and PSC.1 may be aligned.

4 A CUSTOMISED SECURITY ENGINEERING MANAGEMENT FRAMEWORK

From the analysis conducted above, the framework for security engineering management framework has emerged. The framework must address two aspects of a system: (i) the core and enabling security operations processes as obtained from a full life cycle analysis using Security Management (ISO 18788), and (ii) the capability maturity processes required to ensure a sustainable, mature business entity [12]. By encapsulating the security operations inside the maturity model, it is possible to define a framework for security engineering management as an original contribution.

From Figure 2, the following should be evident:

- A security engineering management framework can utilise practice areas of a maturity model as customised from the CMMI V2.0 framework. The 25 Process Areas will be adapted to fit the physical security environment and used for maturity measurement and gap analysis;
- Systems engineering and engineering management activities and tasks will be added to the adjusted process areas of the CMMI V2.0 framework to provide a unified framework that addresses all aspects of security engineering management as identified in the analysis above.
- The life cycle processes, which are simply the highest-level processes of interest, will provide the following:
    - Identification of all relevant tasks (activities) that form core security functions;
    - Performance measurement as obtained from system analysis will be used in a capability maturity assessment;

  - Allocated resources, interfaces and other related derivatives will describe the security system architecture;
  - Functions may cross organisational boundaries and can be integrated using SE principles.
- Functions are assigned to all core and support security-related processes as process assets of the bank's security management entity and are governed mainly by external standards (ISO18788) and internal bank standards and policies.

The above framework was defined and applied in an actual bank security environment where its effectiveness is evidenced by the resulting decrease in losses, as discussed below.

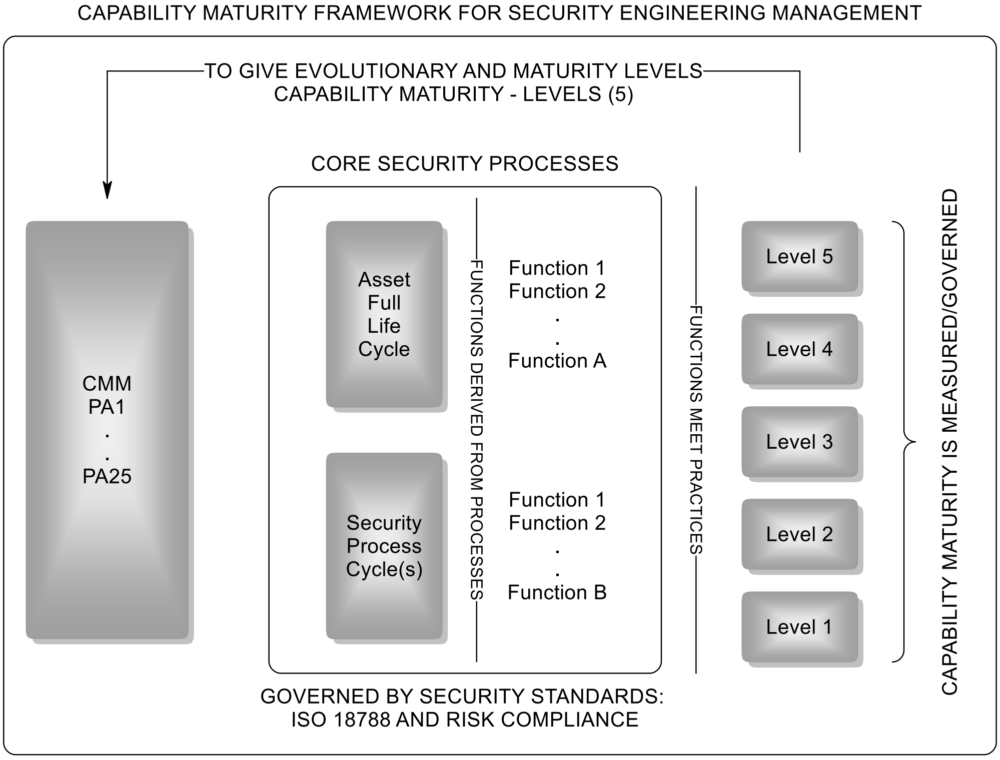

Figure 2 Physical security engineering management framework (own contribution)

5 CASE STUDY – PHYSICAL SECURITY IN A LOCAL BANK

A local bank security project was miniated in 2014 and is still in progress as a managed program. The case study reports on the implementation of the above security engineering management framework and its effects on the actual system losses (material losses).

5.1 Objectives

In the case study, a security engineering management framework was designed and implemented. Observations were made on the actual implementation and the areas where the initially created security framework did not address the need. These areas of improvement were identified and will be included in a future framework.

5.2 Case study context

The South African bank is a major bank in the local financial banking sector, with a significant number of facilities, people, cash, and equipment assets under protection. Facilities include cash centres, retail outlets, ATM facilities, corporate buildings, and data centres. For this study, the retail outlets and ATM facilities were considered.

Research participants in the study conducted research on different management paradigms and frameworks, participated in the implementation, and conducted self-assessments according to the maturity scales based on measured and verified records and inspections. The study is thus action design research (ADR) as the artefact from the study is a security engineering management framework.

5.3 Research Methodology

5.3.1 Problem formulation

The research challenge addressed in this case study is to find the relevance of the proposed security engineering management framework as a primary objective. In addition, gaps in the proposed framework had to be identified and included in an updated framework.

The participants in the study include the security engineering team at the bank, with the security manager and independent contractor acting as active participants in the research process.

From the practice-inspired research, knowledge is created firstly in the form of research that informed the initial security engineering management framework as well as knowledge created from a gap analysis after implementation. Observations from implementation are used to improve the initial framework.

The theory used to create the initial artefact includes existing standards, specifically ISO18788, CMMI, systems engineering, and research on security governance. This was used to define and authenticate the framework used as the theoretically grounded artefact. The primary informant for the artefact is the knowledge base that existed at the onset of the study [4]. Note that, at the time, CMMI V1.3 was used and later updated with CMMI V2.0.

5.3.2 Building, intervention, and evaluation (BIE)

From ADR, two endpoints are defined: *the creation of an innovative technological design* in the form of a framework and *the generation of design knowledge* in the form of an updated framework with "lessons learned".

The ADR team used reciprocal shaping to improve both the knowledge base and the artefact, with the result being an artefact validated in practice. The underlying problems became better understood, and the resources became more specialised as the research process advanced (e.g., CMMI V1.3 became CMMI V2.0).

The mutual influence was evident from observations, internal audits, and the ISO 18788 certification audit. Continuous learning and information sharing among all relevant project participants were implemented and encouraged. All role players in the process, namely the project teams, contractors, and managers, had been influenced to change the organisational culture.

The authentic and concurrent evaluation took place with the CMM measurement, successful implementation of the ISO18788 standard, and reduction of material losses used to validate the process. The actual, real-world success evidenced the result.

5.3.3 Reflection and learning

The main objective here is to show how the artefact was built and which *lessons learnt* are relevant. In this case, *guided emergence* was evident in that the initial framework was incomplete, and additional information emerged during the implementation and reflection. The artefact was thus shaped to result in a more robust framework that addresses a more comprehensive set of practice areas.

5.3.4 Formalisation of learning

Researchers have formalised learning by outlining the accomplishments of the artefact and describing the organisational outcomes. From a generalisation perspective, lessons learned were included in a security engineering management framework that allows for maturity measurement.

Thus, the bank security problem, which was specific and unique, was generalised to define a generic and abstract outcome.

5.4 Implementation method

The actual implementation method for defining and evaluating a pragmatic security engineering management framework included the following steps:

1. An “AS IS” analysis was conducted: The system was assessed in 2013 to provide a baseline in terms of existing system records and performance data. This was done to ensure a reference was created against which to measure;
2. A “TO BE” and project were defined: Important project phases were determined to ensure a methodical method was used to implement necessary changes. The project included the following stages:
    a. Risk review: Perform threat analysis and review external security threats based on crime data and statistics. Crime statistics as obtained from a crime intelligence platform were used. Define facility risk models;
    b. Mitigation analysis: Conduct an internal risk mitigation analysis and identify shortfalls in the controls by performing an effectiveness analysis. This was done as a research project between different banks and SABRIC;
    c. Define framework: Define a methodology/framework for security engineering management and ensure all stakeholders are involved. Ensure the risk mitigation analyses are shared;
    d. Implement structure: The security engineering management framework was implemented based on CMMI V1.3, model-based systems engineering, and engineering management principles;
    e. Apply security engineering management: Processes, resources, and standards were reviewed, gaps addressed using the principles as in step 2d, ontology differences were addressed, and security/mitigation models applied;
    f. Assess capability maturity: A self-assessment was done to show that capability maturity was achieved to an acceptable level, specifically in the business areas identified above (retail branches and ATMs) – this was done in 2016/17;
    g. Implement ISO18788: As part of the growth path, to become certified and as a means to assess the bank’s capability, ISO18788 implementation and an audit were done – this was done in 2019;
    h. Perform continuous improvement: In line with level 5 of the capability maturity model, the bank is currently optimising effectiveness and reducing cost (value engineering);
3. Reflect and review: With reference to ISO18788 and the adapted capability maturity framework (based on CMMI V.13), gaps in the security engineering framework were identified and addressed (as discussed in Section 5.6). These improvements resulted from active participation in the security project.

Figure 3 shows the timeline applicable to the study. Initially, the overall security system was stabilised, followed by standardisation, and achieved at least level 3 of maturity. Having achieved level 3, services could be outsourced due to the mature nature of the business which simplified contracting. Also, more advanced technologies could be implemented as there was good performance measurement to allow service and system optimisation and the use of advanced information analysis to provide intelligence for risk prediction and mitigation.

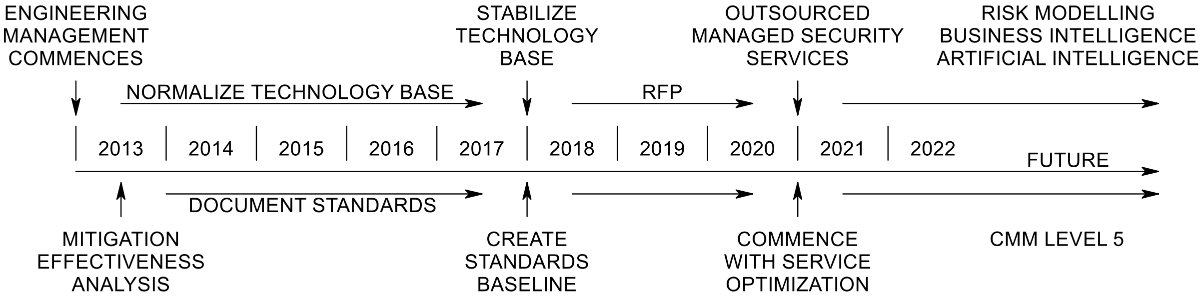

Figure 3 Timeline for the case study (Source: Absa)

5.5 Experiences and findings

From observations, the following became evident, as described below. The need for a security engineering management structure was identified and addressed as part of the process.

5.5.1 Initial phase

The initial phase was mainly to determine the “AS IS” situation and to define the way forward based on a security engineering management framework.

1. Processes: System processes were documented for compliance purposes, but the lack of engineering management resulted in significantly less than optimal resource allocation;
2. Technology: The existing technology base was unstable and uninformative, making management nearly impossible due to the lack of reliable performance data. The lack of uniformity made maintenance very difficult (if not impossible);
3. People: SMEs acted as security experts, internal personnel required more specialised training, and performance management was done on available data;
4. Information: Management information was limited, which caused underlying risks to be hidden. Maintenance data was unreliable as obtained from service providers;
5. Risk management: A risk-mitigation analysis was conducted to assess the relevance, importance, and effectiveness of different technologies. From this analysis, apparent shortfalls were identified to be addressed.

5.5.2 Improvement and optimisation phases

In these phases, a security engineering management structure was designed to ensure stakeholder involvement, provide structure, revise security operation standards, and define security engineering management. Figure 4 shows the security engineering management structure that involves all organisational stakeholders and security contractors.

1. Processes: Full life cycle processes were introduced and used to identify tasks and activities. The life cycles ensured a comprehensive set of functions was defined and linked to resources. Security engineering management processes were introduced;
2. Technology: An engineering committee was introduced to manage technology with all stakeholders forming part of this committee. Threats and technology failures were reviewed as part of the crime and operational risk management processes;

3. People: Stakeholders were included as part of the solution, training programmes were introduced, and internal SMEs were used to protect the bank's interests. A centralised workflow management system was introduced;
4. Information: A central intelligence database was created to ensure both crime and operational intelligence are available to inform security and technology decisions;
5. Risk management: Risk management was based on timely and relevant risk information of high integrity, and the performance of systems was measured accordingly.

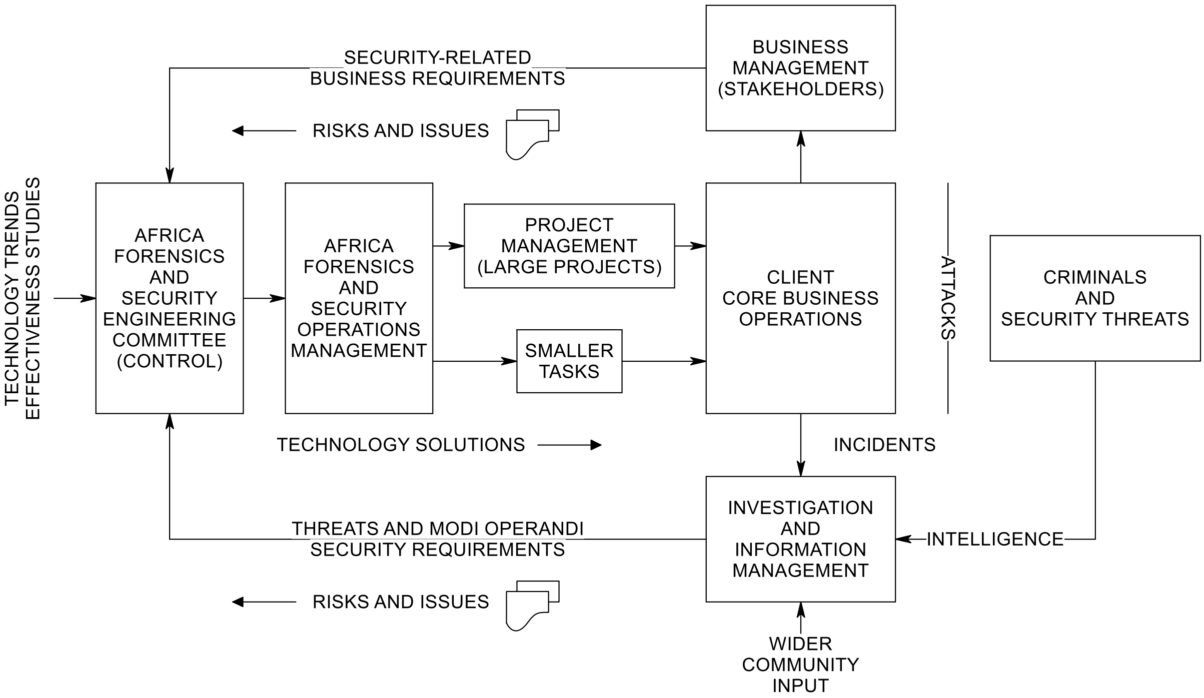

Figure 4 Security engineering management structure (own contribution)

5.6 Results

5.6.1 Capability maturity and ISO certification

In 2016/17, an internal capability maturity (CM) assessment was made against the CM framework available at the time. From the assessment, a level of 3 was reached where applicable, with the potential to improve in terms of measurement and optimisation across the relevant practice areas.

The bank achieved ISO 18788 certification following the security engineering and management efforts of the business unit and its partners (2019). The bank's internal risk and compliance functions supported the standards process to meet requirements very effectively.

Consequently, the following additional CM practice areas were identified from the study to be included in the future security engineering management framework:

- Value engineering and management – based on the absence of resource optimisation in the prior CM model in an economic climate that does not support excessive cost;
- Personal integrity management – prior CM models did not support testing, vetting, and associated risk controls applied to human resources, including contractors;
- Technology asset integrity management – the condition of resources, in terms of their physical ability/state to perform their function, must be managed;

- Information and knowledge management – risk information management (including knowledge and intelligence) was found to be critically important;
- Enabling safety – current CM models do not support this measurement as an OHS function, but this function must be included in future models;
- Regulatory compliance and standards – in addition to security, compliance was also required for the broader regulatory framework (including technology standards).

5.6.2 Material losses

From Figure 5 below, the annual losses from 2013 onwards were significantly reduced after (i) implementing risk controls based on an "AS IS" focused risk analysis in 2013, (ii) security engineering management methods identified and replaced ineffective technologies in 2014 to 2016, (iii) a comprehensive security engineering management structure was implemented in 2014, and eventually, (iv) sustainability was achieved by application of security engineering management and reducing security cost (using value engineering).

A loss reduction is evident due to the introduction of effective technology classes (shown in Figure 5) that mitigated risks identified from the mitigation-effectiveness analysis (also refer to Figure 3). Risk intelligence was vital and supported these decisions, and it was found to be a critically important success factor. The reduction in incidents at this specific bank is ascribed to its good security reputation that caused a deflection of attacks to other targets.

The organisational structures supported the security engineering management effort as the security business unit has to comply with internal risk and compliance requirements (tested against audits). As noted, all organisational role players (including contractors) had been directed by the security management team to change the security culture by accepting and implementing standards. The ISO 18788 certification evidenced this commitment (the first organisation in South Africa to receive this certification).

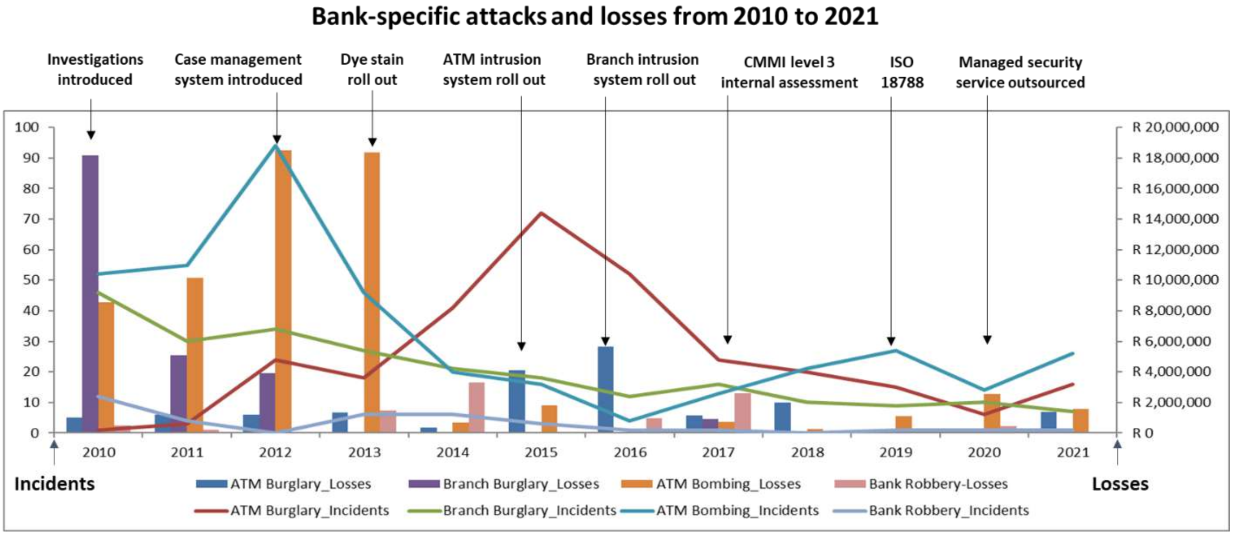

Figure 5 Incident and loss reduction since 2010 (Source: Absa)

6 CONCLUSION

The traditional technology-driven physical security approach can significantly improve by applying engineering management principles [7]. Differences in ontologies must be considered, and a combination of systems engineering, capability maturity, and ISO standards may be used to define a security engineering management framework [8] [12] [13] [14].

In addition to the 25 adjusted practice areas of CMMI, six additional areas were identified that relate specifically to security organisations, as informed by the ADR research method.

Although ISO18788 is highly relevant, the new security engineering management framework does not depend on additional standards, but security organisations will gain from using these good standards. Accordingly, ISO18788 will benefit from this framework as the framework addresses gaps in the standard.

The evidence of success ultimately lies in the sustained prevention of losses, as evidenced by real-world data. The framework is effective and sustainable, and security businesses will benefit by applying this security engineering management framework in practice.

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AN EMPIRICAL STUDY IN EXPLORING THE RELATIONSHIPS AMONG DESIGN THINKING TEAM DIVERSITY, TEAM INTEGRATION AND TEAM PERFORMANCE

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ABSTRACT

This study aimed at exploring the relationships among four concepts: Design Thinking, team diversity, team integration and team performance. An online survey was used to collect 90 valid responses from Design Thinking process participants and practitioners from the case chosen. The results from the hierarchical regression analysis show significant positive relationships between all the concepts; however, team integration did not moderate the relationship between team diversity and team performance as originally postulated in the study hypothesis. The three design thinking processes of setting multiple frames, reflection and practical reasoning were analysed in relation to team diversity and team integration. Setting multiple frames has the strongest significant relationship with both team diversity and team integration, followed by practical reasoning. This study recommends that a greater understanding of the impact of Design Thinking on diverse teams can foster deeper understanding and support wider application of DT within diverse teams' settings.

Keywords: Innovation Process, Design Thinking, Team Diversity, Team Integration, Team Performance

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1 INTRODUCTION

The application of design thinking is becoming more popular as a co-creative innovation process to enhance business competitiveness [1]. This concept is echoed by Liedtka [2] when stating that design thinking is an ideal problem-solution process appropriate for businesses intending to mitigate complex challenges, stimulate growth and innovation as well as differentiate themselves from their competitors. However, in the research study by Wattanasupachoke [1] he ultimately found that direct matching of design thinking to team performance was difficult due to the indirect relationship between design thinking and team performance. He argued that design thinking directly impacted on creativity and innovativeness of businesses and in turn innovativeness directly impacted on team performance.

In an effort to corroborate the strategic and management appreciation of design thinking with academic research Liedtka [3] went one step beyond by only consider team performance to evaluate the impact of design thinking. She explored the emergent benefits of design thinking applied within diverse teams, as described in her earlier research [2]. The study of cognitive bias literature concluded that unexpected emergent benefits presented themselves when design thinking was applied within diverse teams [3]. These emergent benefits include overcoming individual team member bias and reducing the perceived distance between members, thereby creating improved team integration and enhanced team performance. The study concluded that this aspect of design thinking, however, needed deeper academic understanding to enhance management implementation and outcomes, as well as expand on the existing body of knowledge on design thinking.

O'Brien et al.[4] found that some businesses were actively pursuing team diversity in their work force. This is either by desire, necessity or both. They also found that enhancing team diversity within teams required constant positive reinforcement and intervention from management. This is to overcome inclusivity challenges within the diverse team. One can therefore argue that team diversity is of importance for some businesses and requires processes and tools that integrate the diverse teams to be beneficial to the organisation. Such processes and tools may include design thinking.

Based on the previous arguments, it is reasoned that the innovation process of design thinking and the business elements of team diversity, team integration and team performance can possibly impact each other within organisations. It is also reasoned that these elements are independently and collectively of strategic importance to businesses. Liedtka [3] posits that more academic research is required to understand the impacts of the elements on design thinking and the impact of design thinking on the elements.

This research study is therefore aimed at exploring the relationship between design thinking (DT) and team diversity (TD) through developing an understanding of team integration (TI) and team performance (TP), within this context, as well as to explore the interrelated connection between the four topics. In order to address this problem, a research project with the following objective is proposed: "The study and evaluation of the impact of design thinking on diverse teams, through team integration, in order to achieve the team's desired outcomes."

This study asks the following research questions:

1. Which TD-attributes result in the successful implementation of the DT-process?
2. Which DT-processes and tools lead to the successful integration of diverse teams?
3. To what extent does TD impact TP?
4. To what extent does the TI achieved through applying DT-processes and tools moderate the relationship between TD and TP?

2 LITERATURE REVIEW

The literature review is structured around four theoretical relationships that are elaborated further in this paper: the TD-DT relationship, the TD-TP relationship, the TD-TI-TP relationship and finally the DT-TD-TI relationship.

2.1. Design Thinking (DT)

Greater understanding of DT-processes and tools is required to assess the interaction of DT with TD, TP and TI. The initial literature review established the development of DT over the last decades into the distinct practice applied today [3]. The historic development of DT will not be explored in further detail in this study. This research study will focus on the processes applied and tools used when practicing DT, to understand how they interact with TD and impact on TI and TP.

2.1.1 Design thinking (DT) processes and tools

DT is an innovation process studied and implemented by various academic institutions and businesses today. Despite the fact that the various schools have differing terminology for the DT-processes and tools, they all agree that DT has three basic steps or stages [3]. The stages include the primary data gathering stage, the secondary idea generation stage and the third and final testing stage. The schools similarly agree that there are DT-tools to be applied for all three stages of the process, which include: visualisation, ethnography, structured collaborative sense-making, assumption surfacing, prototyping, co-creation and field experiments.

One of the schools that extensively study DT is the Darden Business School at the University of Virginia. They define the DT stages as the questions of “What is?”, “What if?”, “What wows?” and “What works?”, as discussed in depth in the book *The designing for growth field book*, by Liedtka et al. [5]. The authors further explain that the four DT-questions align with the three generic stages of the DT-process. Figure 1 below illustrates the sequencing of DT-stages, and when the tools can and should be applied.

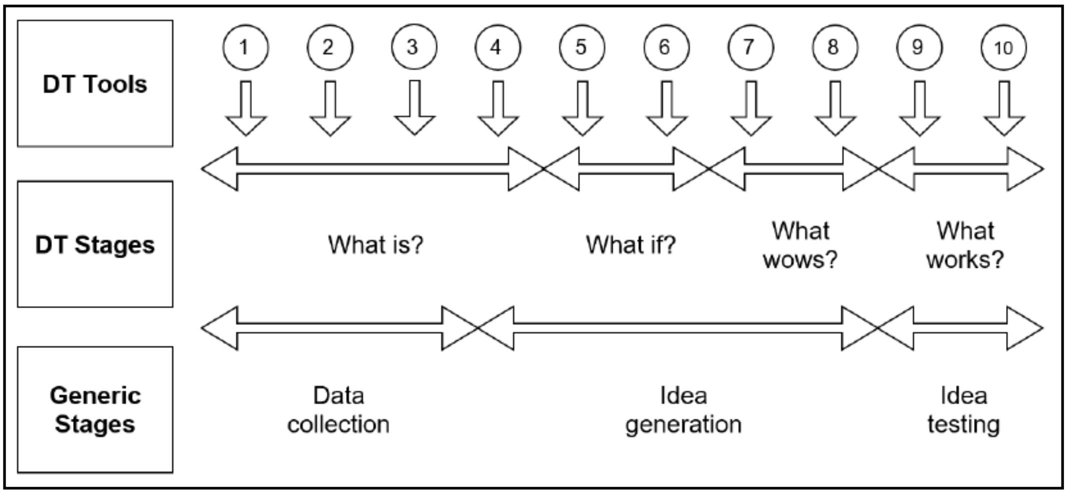

Figure 1: Design Thinking (DT) Process and Tools

Adopted from Liedtka [5] and Liedtka et al. [4]

The tools correlating with the numbered items in Figure 1 are briefly defined as follows [1]:

1. Visualisation: using imagery to reflect envisaged possibilities and outcomes.
2. Journey mapping: assessing and representing the end-users’ experience from their perspective through building story boards.

3. Value chain analysis: assessing the current value chain from the end-user's perspective.
4. Mind mapping: a commonly used exploration activity and tool, applied to create the design criteria and start working towards defining the desired outcome.
5. Brainstorming: collectively generating new possibilities and new alternative business models for consideration.
6. Concept development: accumulating innovative elements into a coherent alternative solution to the current state defined in the "What is?" stage, that can be explored and evaluated.
7. Assumption testing: segregating and challenging the key assumptions that will drive the success or failure of a concept.
8. Rapid prototyping: expressing a new concept in a perceptible form for investigation, testing and improvement.
9. Customer co-creation: enrolling customers (also referred to as end-users) to participate in development of the solution that satisfies end-users' needs.
10. Learning launch: producing an affordable field trial that lets the end-user experience the preferred solution over an extended period, to test key assumptions with actual market data.

Benson and Dresdow [7] conducted quantitative research on how Design Thinking is applied within an innovation project at undergraduate level, compared to general liberal learning methods. They state that undergraduate learning is generally focused on analytical thinking to solve problems, whereas the DT-process applied in the same setting allows for several complimentary thinking processes that consist of combinations of DT-processes and tools as illustrated and described above. They group these thinking processes into three categories, namely: setting multiple frames, reflective thinking and practical reasoning. Their research concluded that DT-processes and tools enhanced the learning process for the undergraduate students, augmenting the traditional analytical thinking and finally recommending frequent and wider use of DT.

2.1.2 Design Thinking (DT) application

As described above, DT provides integrative processes and tools applied within a team context [6]. Team selection and facilitation of the process are fundamentals that are carefully managed during the process. Liedtka [3] describes the process as a human-centric, problem solving approach that is possibilities-driven and iterative. The process combines creative and analytical modes of reasoning. This implies careful planning and preparation by the DT-facilitator before the cross-functional team is selected and teamed up with the end-user.

2.2. Team Diversity (TD) in context of Design Thinking (DT)

Up to this point the review of literature has related to the DT-process, tools and their facilitated application point to TD as one of the key elements when selecting co-creative DT teams. The initial literature review indicated that two groups of TD-dimensions are arguably found [8,9]. For purposes of this research study these groups are referred to as tangible and intangible dimensions of TD. In the context of DT, TD refers to the diversity that is created by team members who "think differently" due to their cross-functional composition which includes different functions within the design organisation, as well as that of the end-users making up the team. Liedtka [2] states that diversity of perspectives, talents and experiences is the most reliable source of new thinking for the DT-process which in turn enhances the TP. This is argued to point towards the TD-DT-relationship. Liedtka [2] explained that diverse thinking and viewpoints lead to robust engagement within the team which in turn fuels the DT process. The more diverse the thinking, the more care must be taken to avoid never-ending debates or compromise – which is not desirable. But if correctly applied, the end result is far more rewarding in terms of creativity and success.

Wattanasupachoke [1] explored the relationship between DT and TP and found that measuring the direct impact was challenging. The observation was made that there was an indirect relationship. The argument was made that DT influenced creativity and innovation, and this in turn influenced performance. To understand this relation better, the TD-TP-relationship needs to be examined as well.

2.3. Relationship between Team Diversity (TD) and Team Performance (TP)

Extensive literature exists on the relationship between TD and TP, ranging across tangible and intangible dimensions of TD. It is argued that a review of the relations of all forms of diversity and TP will assist to understand the wide-ranging impact of TD on TP. However, the DT-literature indicates that functional diversity and diversity in thinking play a major role in the DT-process. Therefore, the TD-TP link will now be discussed in groups with common diversity traits, grouped into non-functional diversity and functional diversity. Functional diversity refers to the role or function of an individual within an organisation or group. Functional diversity falls within the intangible group of diversity dimensions as the cannot be distinguished through visual or physical methods. Non-functional diversity on the other hand, falls within the tangible and non-tangible diversity groups. The non-functional diversity attributes are discussed in more detail below, however, all reside within the tangible diversity groups.

Non-functional diversity includes age/generation diversity [10, 11], cultural diversity [12, 13, 14] and gender diversity [15] to name some of the diversity attributes that are distinguished. Functional diversity falls within the intangible group of diversity attributes and skill and task diversity are deemed to refer to functional diversity. Garcia Martinez et al. [16] conducted research to study the impact of surface and deep-level team diversity within research and development teams on innovation performance. Their study found that that an inverse U-shape relationship exist when gender and skill diversity were plotted against performance.

Horwitz and Horwitz [8] conducted a meta-analytical study regarding the impact of team diversity on team performance through which they identified 35 peer-reviewed articles collectively resulting in 78 correlations. They distinguished between task-related team diversity and bio-demographic team diversity. The first was aligned with underlying themes such as functional role, education, experience and tenure in the team. The latter was determined by visible attributes such as race, gender, age, etc. They developed several propositions around the impact (positive or negative) and strength (strong or weak) between the two diversity types and several performance attributes. This include the quality and quantity of diverse team performance as well as social integration between team members. The outcome of the meta-analytical study was that only task-related team diversity had a clear impact on team performance. No correlation was found between bio-demographic team diversity and team performance. Neither types of diversity could be linked to social integration of the teams.

Joshi and Roh [9] embarked on a meta-analytical study which included 8575 teams surveyed and interviewed in 39 independent studies. As with the 2007-study, the 2009-study differentiated between task-orientated and relations-orientated diversity, with the first limited to the attributes of role, qualification and tenure. Similar to the bio-demographic diversity of the earlier study, the relations-orientated diversity consisted of ethnicity, gender and age. However, that was where the similarity in method ended. Joshi and Roh [9] considered the context within which the teams functioned and looked into more detail at the operating environment of the teams in the study. They also studied industry type (high-technology, services and manufacturing) and interdependency (low, medium and high) to understand if there were significant differences in correlation. The outcome of the meta-analytical study is that there is a context dependence and influence when it comes to understanding team diversity in relation to team performance.

A study was conducted by Kakarika [17] to understand entrepreneurial/new ventures team diversity in terms of three parameters: diversity in opinion, diversity in expertise/skills and diversity in power. The study concluded that moderate differences in opinion, high diversity in expertise or skills and low diversity in power created optimal diversity metrics for enhanced team performance within entrepreneurial teams.

2.4. Relationships among Team Integration (TI), Team Diversity (TD) and Team Performance (TP)

Co-design is usually applied early in the life cycle of service or product development by pairing the user or customer with the service provider or manufacturer to develop new service or product offerings. Co-design is an innovation process applied to generate new concepts and ideas by bringing the end-user and creator together. Trischler et al. [18] conducted a mixed method study amongst 45 co-design teams that found that the right mix of diversity in co-design teams created optimal results in terms of innovative new ideas. They concluded that minimal diversity in separation (power), maximum variety (function, expertise and experience) and moderate disparity (gender, age and nationality) created the optimal diversity mix for innovative co-design.

Baiden and Price [19] conducted research into the effect of integration on the project team effectiveness. Construction teams are by nature cross-functional with each team member having a different role, task, need and desired outcome. They concluded that although integration within construction teams was desirable, other factors also needed consideration to provide context to the team's performance.

The impact of trust on the performance of cross-functional teams has been contemplated by various researchers. In their research study Buvik and Tvedt [20] found that trust directly and indirectly impacted the performance of cross-functional teams. Their findings indicate that project commitment and team agreement on the level of trust between the individual members, are indications of the level of performance of the team. Their final argument is that interventions to enhance trust within the cross-functional teams' context will improve team performance.

Daspit et al. [21] examined the factors that impacted on cross-functional team effectiveness and performance. They concluded that the integration of the team indirectly influenced the team performance through shared leadership and cohesion amongst the cross-functional team members. They also found that team effectiveness did not influence the team's performance and that shared leadership did not impact on cohesion amongst the team members.

In exploring the impact of tangible (in this case demographic diversity) and intangible diversity (deep level skill diversity) on team performance, Liang et al. [22], concluded that not all diversity dimensions equally impact on the performance of the team. This research was based on the similarity-attraction theory and found that the perspective might be too broad to explain or predict the impact of team diversity on team performance.

The moderating effect of team functional diversity on team performance was explored by Tekleab et al. [23]. They conducted a longitudinal study on 45 teams over a six-month period. The study examined when and why team cohesion and team learning assisted to negate the impact of functional diversity on team performance. The conclusion was that behavioural integration promoted team learning which in turn assisted to create more cohesion amongst diverse team members over time, leading to improved performance.

2.5. Relationships among Design Thinking (DT), Team Diversity, Team Integration (TI) and Team Performance

Up to this point DT, TD, TI and TP have all been reviewed in some detail. In this section literature related to the combined relationship between the four concepts will be reviewed.

Plattner et al. [24] edited several DT-related research papers into a single compilation titled "*Design thinking research: making design thinking foundational*". One of the research papers by Schmiedgen et al. [25], was aimed at understanding how the impact of design thinking can and should be measured. Their multi-method study started with quantitative surveys, supported by qualitative interviews with numerous design thinking practitioners. The conclusion was that traditional measurements were ill-suited for design thinking and needed to be supported by story-based measures to understand the full impact. Another research paper within the same compilation was aimed at developing such tool kits to assist practitioners in understanding the value of the DT-process.

In 2014, ten firms who had been implementing design thinking processes and tools were interviewed [2]. Surprisingly enough, the outcome of the interviews was not so much focused on the new designs, processes or products that emerged from the innovation process, but rather some unexpected add-on benefits that enriched the ways that these firm operated and functioned. The emergent benefits included: Design thinking processes helped to improve the way that diverse teams functioned; Design thinking processes and tools allowed for diverse teams to leverage differences in positive ways; Keeping end-users and stakeholders in mind, helped to focus on the larger problems and overcome internal constraints (just to name a few).

Liedtka [3] extensively reviewed literature on the topic of DT, TD, TI and TP to develop some understanding on how DT impacted on the cognitive processing flaws of the individual team members within the DT-teams. The study concluded that the DT processes and tools assisted in overcoming several cognitive and perception biases of the individual team members within the diverse DT-team to achieve the desired TP. The individuals' biases studied included self-projection of bias onto others, over positive attitudes, confidence in one's own solutions/predictions, avoidance of uncomfortable data/input, hasty/shallow solution development and superficial testing. Overcoming the cognitive and perception bias and building better teams were deemed part of TI and the study concluded that further research was required to fully understand this phenomenon.

Based on the in-depth review of the available literature on DT, TD, TP and TI, some conclusions can be made. The first conclusion is that there is evidence that DT is positively enhanced by the right TD-mix. This includes the intangible diversity dimensions of cross-functional teaming, enhanced by collaboration with the end-user. The assumption is made that the resulting team is made up of team members who "think differently".

The second conclusion is that the assumption may be made that DT can lead to effective TI of diverse teams. TI may be achieved through following DT-processes and applying DT-tools. Process facilitation by training facilitators enhances the impact of the process and tools in respect of TI. Meta-analytical surveys indicate that the application of DT can lead to the reduction of cognitive and perception bias between team members [3], leading to effective TI and improved TP in terms of the desired outcomes.

The third conclusion is that supporting literature indicates that there are relationships between DT, TD, TP and TI. The extent to which these relationships impact upon each other varies and needs to be further considered within the context that they interact with each other.

3 CONCEPTUAL MODEL

The literature reviewed indicated that there were several existing theoretical relationships that encompassed the elements of DT, TD, TI and TP. The literature review equally indicates that DT, as an innovation process, is enhanced by the right mix of TD. The most important being the right mix of functional diversity created by teaming up cross-functional design team members with the end-user [2]. This is referred to as the theoretical TD-DT-relationship.

The literature also indicated that TD moderated TP through an inverse U-shape relationship [17] . This was found to be applicable for both functional and non-functional diversity attributes [19, 26]. The moderation occurs through a process referred to as TI. This reflects the theoretical TD-TI-TP-relationship. It was also revealed that some information and understanding existed regarding the emergent benefits of DT-processes and tools applied within these cross-functional and diverse teams in order to achieve the desired TP. These emergent benefits are associated with overcoming individual team member bias and reducing the perceived distance between members, thereby achieving TI of the diverse team. Liedtka [3] goes as far as to state that DT can help to “build better teams”. Exploring this phenomenon is at the centre of this research study.

It is argued that greater understanding of the impact of DT on diverse teams will foster deeper understanding and possibly encourage wider application of DT within diverse teams and team settings. This might assist organisations for which DT, TD, TP and TI are of importance, by testing whether DT is an applicable process and tool to moderate the impacts of these business elements on each another.

This research study explores the moderating effect that DT has on integrating (TI) diverse teams (TD) to achieve the desired outcomes (TP). To explore this notion, better understanding will be developed on the process and tools of DT, as well as the elements of TD, TI and TP, subsequently exploring how the individual team members, within the co-design teams, perceive TI within the DT team context.

In support of the arguments made earlier, the following theoretical framework is proposed, as illustrated in Figure 2 below.

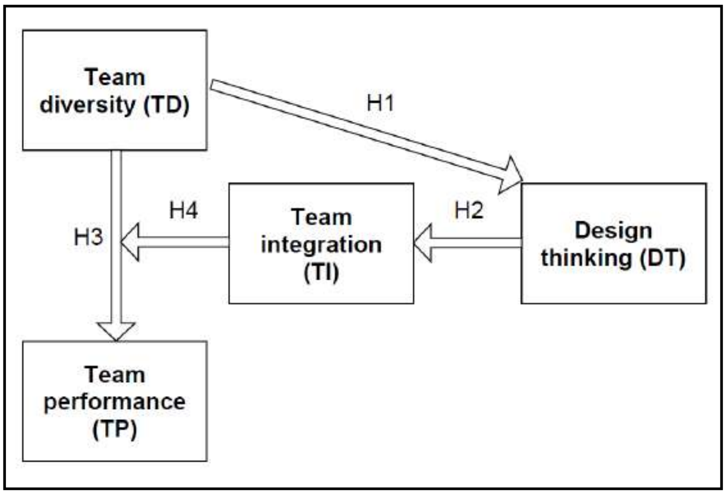

Figure 2: Research Conceptual Model

Given the above, the following research hypotheses are stated for further testing:

Hypothesis 1: The right mix of functional diversity attributes, reflective of TD, influences the DT-process. Functional diversity refers to team members having different roles, qualifications, experiences, viewpoints and expectations of one another.

Hypothesis 2: The DT-process, through the application of its tools and processes, impacts on the integration and collaboration within the DT-team, indicating effective TI.

Hypothesis 3: The right mix of functional diversity attributes, reflective of TD, influences TP. Functional diversity refers to team members having different roles, qualifications, experiences, viewpoints and expectations of one another and TP refers to the achievement of desired outcomes by the DT-team within the DT-process.

Hypothesis 4: Effective TI, influenced by the DT-processes and tools moderates the impact of TD on TP, thereby leading to the desired TP.

4 RESEARCH METHOD

4.1. Research Approach and Strategy

Previous studies conducted were executed through meta-analytical and qualitative methods and did not extend to quantifiable data collection [3]. It is therefore argued that quantified data will assist to test the DT-TD-TP-TI-connection. The assumption is made that such quantitative data will assist to understand if the proposition that DT can integrate diverse teams whilst achieving the desired outcomes, is true and to what extent. This study used quantitative research approach.

Given the research approach described in the previous section, the research strategy is aimed at sourcing quantitative data from people that practice DT and participate in DT-workshops, preferably based in various locations around the world. The best suited data collection method identified was a web-hosted (SurveyMonkey.com) and the participants were invited through invitation letters emailed to them.

Participation in the online survey was voluntary and all data kept confidential. The questionnaire was developed by adopting existing questions and instruments from similar studies identified during the literature review and research design development. Internal consistency and reliability was taken into consideration in selecting the most appropriate questions for the questionnaire design [27]. There are various methods for calculating internal consistency, which include the commonly used Cronbach's alpha, which is indicative of the consistency in responses relevant to a set of questions that are combined as a scale.

4.2. Sampling Technique

Purposive sampling is applied as the participants for the online survey are individuals that attend, participate or facilitate DT-workshops and have understanding and experience of the D-processes and tools. The participants are based in a wide geographical spread in Africa, the Middle East, Asia, Australia and New Zealand and are all working for one organisation. The targeted population is 270 people. The participants are deemed to form random teams to participate in DT-workshops applied on a project to project basis. Therefore, the unit of analysis will be the individual level, as the team grouping is re-arranged for each DT-workshop.

To achieve statistical confidence and accuracy for the statistical analysis of the data, the highest possible response rate was targeted. According to Saunders et al. [27], the expected response rate for a web-based questionnaire sent out within one organisation is 30-50%. A 30% response rate would mean at least 81 valid responses might be received. Sample size calculation indicates that a response rate of between 80 to 170 successful questionnaires will result in a confidence range of 90% to 95%, with a 5% degree of accuracy.

4.3. Data Collection Methods and Analysis Tools

The quantitative data was collected through an online questionnaire developed by applying existing research questions and instruments adopted by other researchers in similar studies. The questionnaire is appended to this paper, including all sources, variable descriptions and coding for analysis. The questionnaire included control, dependant and independent variables as well as one moderator. The selected survey instruments were all confirmed to have high internal consistency by checking if the Cronbach's Alpha of the questions were more than 0.7. A value of more than 0.7 means that the questions can be combined as a scale and are measuring the same variable. The variables covered by the questions include TD, DT, TI and TP in line with the theoretical model covered in the previous section. The questionnaire was sent to 270 pre-selected participants.

SPSS-statistics analysis software was used to conduct descriptive and inferential statistical analysis on the data. The statistical methods applied for this research study interrogate the quantitative data collected through online survey methods to reflect possible correlation and causation between the different elements of DT-TD-TP-TI. Statistical methods include reliability and correlation testing, factor and regression analysis.

5 RESULTS

5.1. Response Rate and Completion Ratio

A total of 270 survey invitations were sent out using the online SurveyMonkey.com survey tool. 90 fully completed and valid responses were received and used for data analysis. This results in a 33.33% response rate, falling within the expected response rate parameters of 30% to 50% and therefore suitable for further analysis. The response rate translates into a margin of error of 8% at a confidence level of 95%. Data was checked for errors, corrected if required and variables coded for further descriptive and hierarchical regression analysis. Reference should be made to Appendix A, where the full questionnaire and coded variables are provided. Results for questions with high internal consistency where average as further discussed in Section 5.3 below. The averaged variables are indicated as "variable name_ave" in the following sections.

5.2. Descriptive Statistics

The mean and standard deviations were calculated for all the metric items (scale and ordinal measures). The metric items were all tested against an ordinal scale using a 5-point Likert scale where 1 indicates "strongly disagree" and 5 indicates "strongly agree". Table 1 summarises the mean and standard deviation for the averaged results for each variable (see Appendix A).

Table 1: Summary: descriptive statistics - mean and standard deviation

		TP_ave	TD_ave	DT_ave	TI_ave	DT_Frames	DT_Reflect	DT_PracReas
N	**Valid**	88	89	85	85	89	86	88
	Missing	2	1	5	5	1	4	2
Mean		3.9123	3.6348	4.0965	3.9205	4.2725	3.8973	4.1148
Mode		4.00	4.00	4.32	3.79	4.42	3.92	4.00
Std. deviation		0.46679	0.81451	0.39469	0.32778	0.40994	0.49104	0.42441

5.3. Reliability Analysis

To determine the internal consistency of the questions related to a specific variable, Cronbach's Alpha (CA) was calculated for all scale and ordinal metrics (Saunders et al., 2016).

Table 2: Cronbach's alpha for averaged variables (see Appendix A)

Construct	Cronbach's Alpha	N of Items	Valid	Excluded[a]
DT_ave	0.925	34	85	5
TI_ave	0.878	29	85	5
TD_ave	0.723	2	89	1
TP_ave	0.866	7	88	2
DT_Frames	0.843	12	89	1
DT_Reflect	0.859	12	86	4
DT_PracReas	0.768	10	88	2

a. Listwise deletion based on all variables in the procedure.

A CA of 0.7 or more indicates that the questions have a high internal consistency and therefore offer reliable data for further evaluation. Before the CA was calculated, all metrics were tested for positivity and reverse coded if required. The cut-off value for reliability was set at a CA of 0.7. All metrics were tested and found to meet or exceed the CA-threshold of 0.7 for the specific variable they were testing. This allowed for averaged result for all items related to a variable to be used to simplify the metrics for further analysis, as indicated in Table 2 above .Refer to Figure 3 below for the questions, variables and averaged variables (see Appendix A) in relation to the theoretical model discussed earlier.

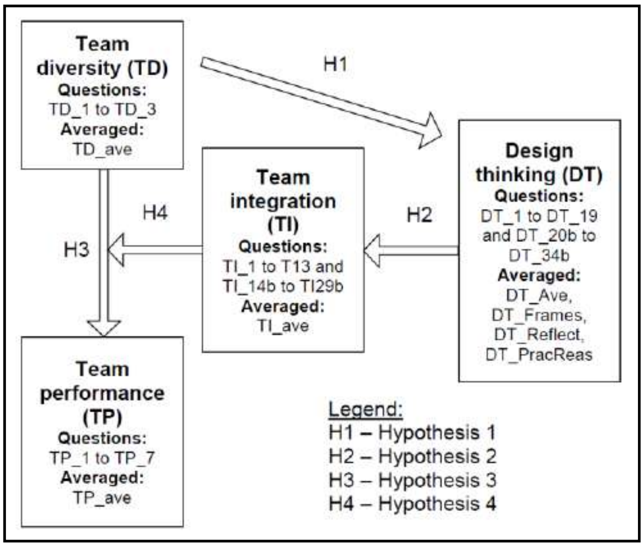

Figure 3: Questions, Variables and Averaged Variables as Provided in Appendix A Related to the Theoretical Model

5.4. Correlation analysis

The strength of the relationships between the paired variables associated with the four hypotheses was tested trough correlation coefficient tests. The data collected through the survey is ranked, and therefore the Spearman's rank correlation coefficient test was selected.

Because the data set is numerical, but not normally distributed, non-parametric statistics apply. Table 3 summarises the non-parametric results using Spearman's ρ to test the strength of the correlation between the relevant averaged variables.

Table 3: Correlation analysis using Spearman's ρ

	1	2	3	4	5	6	7	8	9	10
1. Gender	**1.000**									
2.	0.003	**1.000**								
3. DT_freq	0.097	-0.041	**1.000**							
4. DT_role	-0.058	0.061	-0.388	**1.000**						
5. TP_ave	0.037	-0.183	0.212*	-0.034	**1.000**					
6. TD_ave	-0.007	-0.124	-0.021	0.037	0.459**	**1.000**				
7. TI_ave	0.085	-0.070	0.151	0.130	0.711**	0.443**	**1.000**			
8.	0.054	-.0261*	0.140	-0.022	0.637**	0.367**	0.519**	**1.000**		
9.	0.104	-0.130	0.237*	-0.145	0.502**	0.304**	0.362**	0.658**	**1.000**	
10.	0.098	-0.116	0.150	-0.082	0.558**	0.311**	0.533**	0.685**	0.670**	**1.000**

* Correlation is significant at the 0.05 level (2-tailed).

** Correlation is significant at the 0.01 level (2-tailed).

5.5. Hierarchical Regression Analysis

To test each of the four hypotheses, three tests were developed. Each test applies two to three models in steps that consist of regression equations comprising of the Independent Variables (IV), Dependent Variables (DV), Control Variables (CV) and Moderating Variables (MV)

5.5.1 Results of Test 1 for Hypothesis 1 and Test 2 for Hypothesis 2

The first regression analysis test was conducted to test the hypothesis that TD impacts on DT. The results for the hierarchical regression analyses are summarised in **Error! Not a valid bookmark self-reference.**.

The results indicate that VIF was less than 10 for both Model 1 and 2, therefore collinearity was not a concern. Model 1 indicated that the control variables are statistically insignificant with a low R^2 value of 8.1%. Model 2 shows an improved R^2 value 13.6%, but still within the low range. The relationship between "DT_ave" and "TD_ave" is significant given that F = 3.520 with a ρ of less than 0.01. There is a statistically significant moderate positive correlation between "TD_ave" and "DT_ave" with a Beta (the Greek symbol ß) of 0.330 and a ρ of less than 0.01, supporting Hypothesis 1.

Table 4: Test 1 and Test 2 regression analysis results

Variables	DV$_1$: Design Thinking (DT_ave)		Variables	DV$_2$: Team Integration (TI_ave)	
	Model 1	**Model 2**		**Model 1**	**Model 2**
Constant	4.023	3.374	**Constant**	3.622	1.811
CV$_1$: Gender	0.121	0.112	**CV$_1$**: Gender	0.047	-0.022
CV$_2$: Qualification	-0.151	-0.096	**CV$_2$**: Qualification	0.001	0.081
CV$_3$: DT_freq	0.158	0.185*	**CV$_3$**: DT_freq	0.202	0.093
CV$_4$: DT_role	-0.075	-0.078	**CV$_4$**: DT_role	0.222*	0.262**
IV$_1$: Team Diversity (TD_ave)		0.330***	**IV$_1$:** Team Diversity (TD_ave)		0.554***
R^2	8.1%	18.6%	R^2	5.7%	33.5%
ΔR^2	3.3%	13.3%	ΔR^2	5.7%	27.7%
F-value	1.709	3.520***	F-value	1.144	7.452***
ΔF-value	1.709	9.978***	ΔF-value	1.144	30.863***
VIF range	1.002-1.191	1.006-1.198	VIF range	1.001-1.213	1.024-1.255

* $\rho<0.1$; ** $\rho<0.05$; *** $\rho<0.01$ Significant (2-tailed)

The second regression analysis was to test the hypothesis that DT has an impact on TI. The results for the hierarchical regression analyses are summarised in Table 5. The results indicate that VIF was less than 10 for both Model 1 and 2, therefore collinearity was not a concern. Model 1 indicated that the control variables are statistically insignificant with a low R^2 value of 5.7%. Model 2 shows an improved R^2 value 33.6%. The relationship between “DT_ave” and “TI_ave” is significant given that F = 7.452 with a ρ of less than 0.01. There is a statistically significant moderate positive correlation between “DT_ave” and “TI_ave” with a ß of 0.554 and a ρ of less than 0.01. There is also a statistically significant weak positive correlation between “DT_role” and “TI_ave” with a ß of 0.262 and a ρ of less than 0.05. The results of the second test indicate that Hypothesis 2 is supported.

5.5.2 The results of Test 3 for Hypothesis 3 and 4

The third regression analysis test was to examine the hypothesis that TD affects TP and that the relationship is moderated by TI. The results for the hierarchical regression analyses are summarised in Table 5. In the first run of the third test, VIF-values for Model 1 and 2 were found to be well below 10, but Model 3 had a VIF of 196.712, which is over 10. This indicated multicollinearity between variables. To solve this problem, the mean centred values were calculated for “TI_ave” and “TD_ave” and used for the regression analysis. This adequately solved the multicollinearity problem as indicated by the results tabled above. The VIF-range is well below 10 for the mean centred variables and multicollinearity avoided.

Table 5: Test 3 regression analysis results

Variables	**DV$_3$: Team Performance (TP_ave)**		
	Model 1	**Model 2**	**Model 3**
Constant	3.782	-0.033	-0.039
CV$_1$: Gender	-0.052	-0.064	-0.064
CV$_2$: Qualification	-0.150	-0.094	-0.094
CV$_3$: DT_freq	0.306	0.171**	0.171**
CV$_4$: DT_role	0.176	0.034	0.034
IV$_1$: Team Diversity (TD_ave)		0.139	0.140*
IV$_2$: Design Thinking (DT_ave)		0.658***	0.659***
M$_1$: Team Integration (TI_ave)			
IV$_1$ x **M$_1$**			-0.005
R^2	9.7%	59.5%	59.5%
ΔR^2	5.1%	56.3%	55.7%
F-value	2.094*	18.627***	15.758***
ΔF-value	2.094*	46.778***	0.005
VIF range	1.003-1.260	1.012-1.320	1.014-1.330

* $\rho<0.1$; ** $\rho<0.05$; *** $\rho<0.01$ Significant (2-tailed)

Model 1 indicated that the control variables are statistically insignificant with a low R^2 value of 9.7%. Model 2 and 3 both show an improved R^2 value 59.5%. The relationship between "TD_ave" and "TP_ave" is significant for both Model 2 and 3, given that F is 18.627 and 15.758 respectively (ρ of less than 0.01 for both models). There is a statistically significant strong positive correlation between "TP_ave" and "TI_ave" with a ß of 0.658 and 0.659 for Model 2 and 3 respectively (ρ of less than 0.01 for both models). There is also a statistically significant weak positive correlation between "DT_freq" and "TP_ave" with a ß of 0.171 and a ρ of less than 0.05 for both Model 2 and 3. The results of the third test indicate that Hypothesis 3 is supported.

For Hypothesis 4 to be true, the multiplication factor between "DT_ave" and the mean centred "TI_ave" should have a significant relationship with "TP_ave". This was, however, found not to be the case with a ß of -0.005 and a ρ of 0.943. Hypothesis 4 is therefore proven not to be supported by the data.

5.5.3 Additional tests conducted for testing Hypotheses 1 and 2

The first three tests indicated that Hypotheses 1, 2 and 3 were proven to be substantiated, but Hypothesis 4 was not. It was therefore decided to explore the impact of the three DT-processes, explored by Benson and Dresdow (2015), on TD and TI. The DT-processes include the setting of multiple frames ("DT_Frames"), reflection ("DT_Reflect") and practical reasoning ("DT_PracReas"). This was analysed through six additional tests, that helped to understand which of the three DT processes have the greater or lesser impact on TD and TI respectively.

The results of the additional regression analysis are provided in

Table 6 and The results for Tests 7 to 9 indicate that the VIF-ranges for all three tests and both models were less than 10, therefore collinearity was not a concern for any of the tests. All three DT processes have significant weak to moderate positive relationships with TD. "DT_Frames" with a β of 0.561 and a ρ of less than 0.01 has the strongest positive relationship with "TI_ave", followed by "DT_PracReas" with a β of 0.525 and a ρ of less than 0.01 as well. Similar to Test 2, "DT_role" is proven to have a significant weak positive relationship with "TI_ave" across all tests, with β ranging between 0.204 and 0.223, for a ρ of between 0.05 and 0.1.

Table 7. The results indicate that the VIF-ranges for all three tests and both models were less than 10, therefore collinearity was not a concern for any of the tests. Tests 4 to 6 indicate that all three DT processes have significant weak to moderate positive relationships with "TD_ave". "DT_Frames" with a β of 0.347 and a ρ of less than 0.01 has the strongest positive relationship with TD, followed by "DT_PracReas" with a β of 0.318 and a ρ of less than 0.01 as well.

For all three tests, Model 1 indicated that the control variables are statistically insignificant with low R^2-values ranging between 6.7% and 8.7%. The R^2-ranges do improve to be between 16.0% and 19.1%, but this remains a weak to moderate result. The F-values indicate that the relationships between all three DT-processes and "TD_ave" are significant. Similar to the β values, "DT_Frames" has the highest F value of 3.828, followed by "DT_PracReas" with 3.210 and in the last position "DT_Reflect" with 2.968. The above results support the outcome of Test 1 that substantiated Hypothesis 1 that TD does impact on DT. Tests 4 to 6 in fact indicate that TD has the strongest relationship with setting multiple frames, followed by practical reasoning within the DT-process.

Table 6: Test 4 to 6 regression analysis results

Variables	Test 4: DV_1: DT_Fames		Test 5: DV_2: DT_Reflect		Test 6: DV_3: DT_PracReas	
	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2
Constant	4.368	3.652	3.727	3.083	3.952	3.304
CV_1: Gender	0.030	0.025	0.114	0.113	0.129	0.130
CV_2: Qualification	-0.220**	-0.167	-0.100	-0.063	-0.052	-0.016
CV_3: DT_freq	0.142	0.164	0.197*	0.211*	0.138	0.151
CV_4: DT_role	-0.005	-0.010	-0.092	-0.094	-0.111	-0.116
IV_1 : Team Diversity (TD_ave)		0.347***		0.272*		0.318***
R^2	7.4%	19.1%	8.7%	16.0%	6.7%	16.7%
ΔR^2	7.4%	11.%7	8.7%	7.3%	6.7%	10.0%
F-value	1.630	3.828***	1.887	2.968**	1.460	3.210**
ΔF-value	1.630	11.765***	1.887	6.742**	1.460	9.590***
VIF range	1.004-1.220	1.005-1.225	1.004-1.192	1.004-1.194	1.001-1.202	1.005-1.198

* $\rho<0.1$; ** $\rho<0.05$; *** $\rho<0.01$ Significant (2-tailed)

The results for Tests 7 to 9 indicate that the VIF-ranges for all three tests and both models were less than 10, therefore collinearity was not a concern for any of the tests. All three DT processes have significant weak to moderate positive relationships with TD. "DT_Frames" with a β of 0.561 and a ρ of less than 0.01 has the strongest positive relationship with "TI_ave", followed by "DT_PracReas" with a β of 0.525 and a ρ of less than 0.01 as well. Similar to Test 2, "DT_role" is proven to have a significant weak positive relationship with "TI_ave" across all tests, with β ranging between 0.204 and 0.223, for a ρ of between 0.05 and 0.1.

Table 7: Test 7 to 9 regression analysis results

Variables	Test 7: DV$_1$: TI_ave		Test 8: DV$_1$: TI_ave		Test 9: DV$_1$: TI_ave	
	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2
Constant	3.696	1.752	3.624	2.682	3.651	2.105
CV$_1$: Gender	0.026	0.008	0.050	0.010	0.059	-0.019
CV$_2$: Qualification	-0.053	0.073	-0.002	0.034	-0.034	-0.015
CV$_3$: DT_freq	0.211	0.113	0.200	0.103	0.183	0.110
CV$_4$: DT_role	0.204*	0.204**	0.223*	0.248**	0.215**	0.284***
IV$_1$: Design Thinking (DT_Frames)		0.561***				
IV$_2$: Design Thinking (DT_Reflect)				0.388***		
IV$_3$: Design Thinking (DT_PracReas)						0.525***
R^2	5.3%	34.1%	5.7%	19.2%	5.2%	30.6%
ΔR^2	5.3%	28.8%	5.7%	13.5%	5.2%	25.3%
F-value	1.091	7.970***	1.153	3.564***	1.076	6.780***
ΔF-value	1.091	33.660***	1.153	12.508***	1.076	28.099***
VIF range	1.003-1.229	1.007-1.264	1.000-1.214	1.010-1.284	1.002-1.220	1.003-1.246

* $\rho<0.1$; ** $\rho<0.05$; *** $\rho<0.01$ Significant (2-tailed)

For all three tests, Model 1 indicated that the control variables were statistically insignificant with low R^2-values ranging between 5.2% and 5.7%. The R^2-ranges do improve to be between 19.2% and 34.1%, but this remains a weak to moderate result. The F-values indicate that the relationship between all three DT-processes and "TI_ave" are significant. Like the ß values, "DT_Frames" has the highest F value of 7.970, followed by "DT_PracReas" with 6.780 and in the last position "DT_Reflect" with 3.564. The above results support the outcome of Test 2 that substantiated Hypothesis 2 that DT-processes do impact on TI. Tests 7 to 9 in fact, indicate that setting multiple frames and practical reasons have significant impacts on TI. Of all three DT-processes, Reflection is found to have the weakest relationship with TI.

6 CONCLUSIONS AND RECOMMENDATIONS

To achieve the objective of "exploring the impact of design thinking on diverse teams, through team integration, in order to achieve the team's desired outcomes", a conceptual model with four hypotheses for each relationship proposed were developed from theory. To test these hypotheses the data collected from 90 Design Thinking practitioners went through quantitative statistical analyses. The summary below shows the extent how the objective was achieved.

The results from the statistical analyses and specifically the correlation analyses, indicate that there are significant correlations between TD and DT, DT and TI and TD and TP, as well as between TI and TP. These were further explored through hierarchical regression analyses to test the four hypotheses and in particular if TI moderated the relationship between TD and TP. Although it was found that there were correlations and causation between the variables of each of the four hypotheses, it was found that no moderation took place in the relationships between the variables of the fourth hypothesis. To summarise, Hypothesis 1 was found to be valid and that TD had a significant positive relationship with DT, meaning that an increase in TD enhanced the DT-processes. Hypothesis 2 and Hypothesis 3 were both found to be valid as well. DT was found to enhance TI and TD was found to improve TP. Both these relationships were found to have significant positive relationships. Hypothesis 4 was developed under the proviso that TI moderated the relationship between TD and TP. This was, however, not substantiated by the results. Correlation was found between TD and TP as well as TI and TP, but TI was found to have no influence on the relationship between TD and TP.

The three DT-processes of setting multiple frames, reflection and practical reasoning [7] were further analysed with regard to their relationships with TD and TI respectively. It was concluded that setting multiple frames has the strongest significant relationship with both TD and TI, followed by practical reasoning. The findings are useful from a DT-application point of view. It broadens the field of knowledge on the topic of DT created by researchers such as Liedtka [2] and Lockwood [28], Schmiedgen et al. [25] and Wattanasupachoke [1]. Previous studies assisted to indicate qualitative perspectives on the DT-TD-TI-TP-relationship, which was now found to be validated from a quantitative perspective.

The research sampling was limited to DT-practitioners from one organisation willing to participate in the research study. It would be valuable to obtain data from more firms that apply DT as an innovation process to test if the results found can be generalised. From that perspective, this remains a limitation. This research study measured TP based on the perception of the participants regarding the outcomes of the DT-workshops and processes. No end-user surveys or measurements were done to confirm if the DT-processes resulted in the desired outcomes. Inclusion of the end-users of DT-processes in future quantitative data collection will assist to test the achievement of the desired outcomes of the DT-processes explicitly and would be of value to understand which of DT-tools and processes influence TP more, from the end-user’s perspectives.

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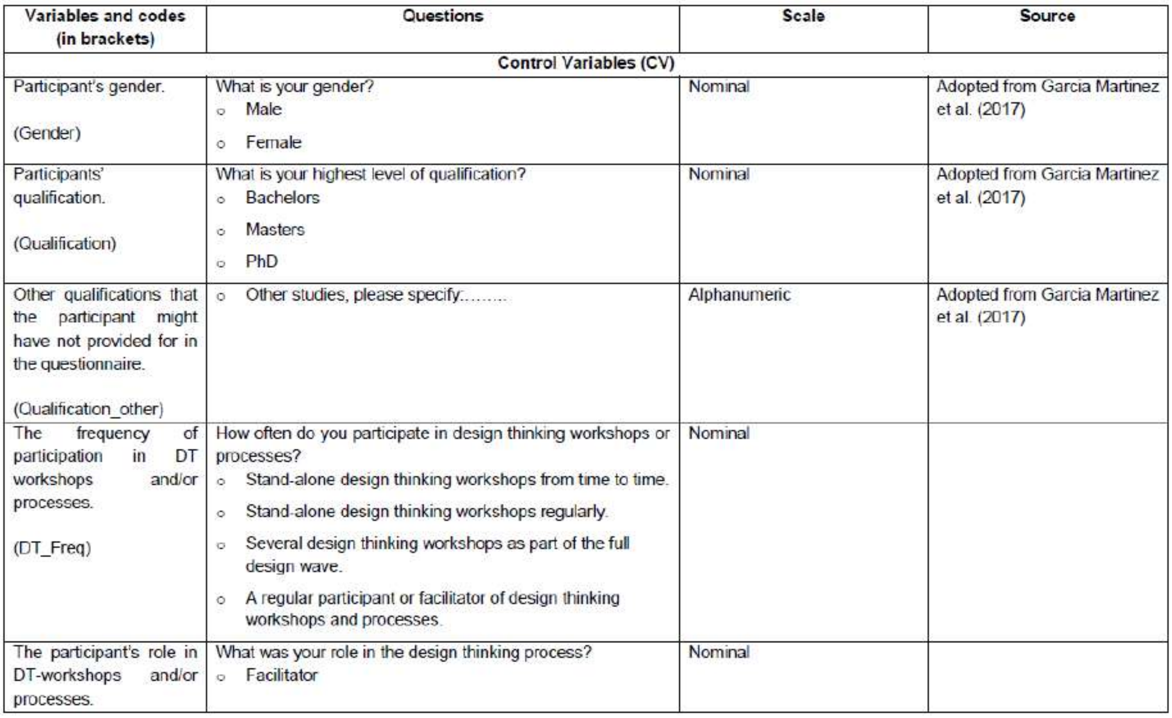
APPENDIX A – QUESTIONAIRE DESIGN, VARIABLES AND CODING



Variables and codes (in brackets)	Questions	Scale	Source
	Control Variables (CV)		
Participant's gender. (Gender)	What is your gender? ○ Male ○ Female	Nominal	Adopted from Garcia Martinez et al. (2017)
Participants' qualification. (Qualification)	What is your highest level of qualification? ○ Bachelors ○ Masters ○ PhD	Nominal	Adopted from Garcia Martinez et al. (2017)
Other qualifications that the participant might have not provided for in the questionnaire. (Qualification_other)	○ Other studies, please specify:........	Alphanumeric	Adopted from Garcia Martinez et al. (2017)
The frequency of participation in DT workshops and/or processes. (DT_Freq)	How often do you participate in design thinking workshops or processes? ○ Stand-alone design thinking workshops from time to time. ○ Stand-alone design thinking workshops regularly. ○ Several design thinking workshops as part of the full design wave. ○ A regular participant or facilitator of design thinking workshops and processes.	Nominal	
The participant's role in DT-workshops and/or processes.	What was your role in the design thinking process? ○ Facilitator	Nominal	

(DT_Role)	○ Researcher ○ Technical expert ○ Support staff ○ Client ○ End-user		
The average size of DT-workshops attended by the participant. (DT_People)	How many people were involved in the design thinking process? No: …………………	Alphanumeric	
Independent Variables (IV)			
Team Diversity (TD) (TD_1 to TD_3) TD_2 reverse coded as TD_2RC. Averaged as TD_ave.	1. Members of the team are too dissimilar to work together well. 2. The team does not have a broad enough range of experiences and perspectives to accomplish its purposes. 3. The team has a nearly ideal "mix" of members - a diverse set of people who bring different perspectives and experiences to the work.	Ordinal Likert scale 1. Strongly disagree 2. Disagree 3. Neutral 4. Agree 5. Strongly agree Note: Question 2 was reverse coded for analysis purposes to align with the positive scales of the other questions.	Adopted from Gevers et al. (2015).
Dependent Variables (DV)			
Design Thinking (DT) (DT_1 to DT_19 and DT_20b to DT_34B)	The following questions are related to the design thinking methods and tools applied in the workshop/s: 1. The process avoided focusing on a single point of view.	Ordinal Likert scale 1. Strongly disagree	Adopted from Benson and Dresdow (2015): Question 1 to 12 related to "multiple frames".
Averaged as DT_ave Sub-variables averaged as: DT_Frames DT_Reflect DT_PracReas	2. The process deals with questions that require judgment to develop multiple solutions. 3. The process engages in discovery through observations. 4. "Why not" questions are asked. 5. Ideas are generated through free-flowing actions. 6. "Why" questions are asked. 7. Main and opposing aspect of the problem is explored. 8. Issues are viewed from multiple perspectives. 9. Various opportunities are explored. 10. The team observes behaviour and/or relationships to enrich decisions. 11. Identifying connections between several ideas was possible. 12. The process combines ideas and insights. 13. The best answer/solution was achieved given the team's skills, time availability and resource availability. 14. Ambiguous questions are explored. 15. Assumptions and bias are challenged. 16. Two or more ideas are combined to form a new idea. 17. "What if"-scenarios are explored. 18. "How"-questions are asked to define the larger decision context. 19. Prototyping activities are applied 20. Issue are restructure and redefined. 21. Small or field experiments are conducted.	2. Disagree 3. Neutral 4. Agree 5. Strongly agree	Question 13 to 24 related to "reflective thinking". Question 25 to 34 related to "practical reasoning".

	22. Unrelated ideas are connected. 23. Decision and impact analysis is done. 24. The process requires thinking of future scenarios. 25. New and different ideas are generated. 26. Incomplete information is used to facilitate progress. 27. Visual tools were applied. 28. The process is solution-orientated. 29. Future possibilities are developed. 30. The process requires collaboration between team members. 31. Solutions are revised based on new insights. 32. Solutions can be justified. 33. Good connections are found between seemingly unrelated issues. 34. The process creates new knowledge.		
Dependent Variables (DV) and Moderator (M)			
Team integration (TI) (TI_1 to TI_13 and TI_14b to TI29b) The following were reverse coded: TI_2RC TI_7RC TI_9RC TI_11RC	How did you feel about fellow design thinking team workshop team members? 1. I trust them. 2. I believe they are dishonest. 3. I am willing to rely on their work-related judgements 4. I am willing to depend on them to support me in difficult situations. 5. They work hard. 6. I respect them.	Ordinal Likert scale 1. Strongly disagree 2. Disagree 3. Neutral 4. Agree 5. Strongly agree Note:	Overall adopted from Liang et al. (2015), with reference to other studies: Adopted from Weingart et al. (2008): Questions 1 to 9 are related to "effective team integration". Questions 10 to 13 are related to "cognitive team integration".
TI_13RC TI_14RC Averaged as TI_ave	7. Some of them are unprofessional. 8. I think they have a good work ethic 9. I have little faith in the things they say 10. I understand their ideas 11. I tend to dismiss what they say 12. Their ideas are difficult to build on 13. It is hard to build their ideas in with my own 14. If there were a chance, most of the members of this team would join other teams or not participate. 15. The members of this team can cooperate with each other. 16. Members of the team will defend each other toward critiques from outside parties. 17. Members of the team really feel like a part of the team. 18. The members of the team look forward to meeting each other every day. 19. Members of the team usually are notable to cooperate with each other. 20. Members of the team enjoy being members because they have many friends in the team. 21. I would continue working together with these team members even if I could choose not to. 22. I would willingly accept offers to collaborate on a team task.	Questions 2, 7, 9, 11, 13 and 14 were reverse coded for analysis purposes to align with the positive scales of the other questions.	Adopted from Dobbins & Zaccaro. (1986): Questions 14 to 20 are related to "team cohesiveness". Adopted from Lee, Stajkovic, & Cho. (2011): Question 21 to 24 are related to "team cooperation". Adopted from Podsakoff etal. (1997): Question 25 to 29 related to "team helping behaviour".

	23. If I work together with these team members, we will achieve more than we could independently in terms of performance. 24. I am willing to share new ideas, information, and resources with these team members. 25. Our team members help each other out if someone falls behind in his/her work. 26. Our team members "touch base" with other teammates before initiating actions that might affect them. 27. Our team members encourage other teammates when someone is down. 28. Our team members willingly share their expertise with other teammates of the store. 29. Our team members take steps to try to prevent problems with other teammates.		
Dependent Variables (DV)			
Team performance (TP) (TP_1 to TP_7) Averaged as TP_ave	1. The team can achieve the desired outcomes. 2. The team operates efficiently within the workshop and afterwards. 3. The work quality is high 4. The ideas generated achieve excellence. 5. The team is able to meet the end-user's requirements. 6. The ideas/solutions developed adhere to budget and schedule requirements. 7. The new ideas and innovations were produced efficiently.	Ordinal Likert scale 1. Strongly disagree 2. Disagree 3. Neutral 4. Agree 5. Strongly agree	Overall adopted from Lee et al. (2010), with references to: Question 1 to 4 adopted from Faraj and Sproull (2000) Questions 5 to 7 adopted from Ancona and Caldwell (1992)

PRIORITISING BOILER MACHINE TRIPS USING A COST-DRIVEN PARETO CHART

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ABSTRACT

The stoppage of the operation of boiler machines responsible for energy generation in the South African Power Plant can be attributed to its machine components tripping owing to their faulty working conditions. In order to establish sustainable boiler machine maintenance solutions, this study deployed the Pareto Chart scheme to ascertain the critical boiler turbine trips, whose preventative maintenance solutions need to be given attention to improve the reliability of these machines. To achieve this, the trips exhibited by three (3) boiler machines from the year 2018 to the year 2020 were identified and ranked using the Pareto computation algorithm. A cost-driven Pareto Chart was developed using the result of the former exercise. This exercise revealed that super-heater spray water system trips, reheater spray water system trips, draught group trips, furnace trips and milling plant trips are the critical boiler machine trips. This study serves as an eye-opener to ascertain the core boiler machine trips, which cause the disconnection of the electricity supply to the grid.

Keywords: Boiler Machine, Trip, Energy Generation, Pareto Chart, Downtime Cost

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1 INTRODUCTION

Eskom plays a critical role in the economy since it generates roughly 95% of the electricity used in the country [1]. It is no longer a secret that Eskom power plants are faced with operational instability resulting in insufficient electricity, which destructively upsets South African people. For example, the study by McCann [2] revealed that the reliability of boiler and turbine machines used at Kusile and Medupi Power Stations is valued at 40%. This unsatisfactory performance was pinpointed as the core driver of insufficient power generation within the organisation, thus resulting in load shedding in South African communities. The study of Anjorin et al. [3] indicated that the low reliability experienced by the boiler and turbine machines used at Eskom Power Plants is caused by myriads of trips, which emanates owing to faulty operating conditions.

A machine trip can be defined as a safety action triggered by the machine components to prevent damage and catastrophic events [4]. The boiler and turbines will trip if the various machine components are operated outside desired functional specifications, leading to the electricity supply disconnection to the national grid.

On the one hand, the study of Walport [5] revealed that insufficient energy generation owing to myriads of boiler and turbine machine trips, which result in load-shedding, could spring up the stoppage of various business operations, thereby reducing the profit made in various organisations. On the other hand, this author and other authors such as Ndaguba [6] and Steenkamp et al. [7] revealed that the load-shedding phenomenon could result in the loss of lives of premature babies and loss of patients that require steady electricity for oxygen therapy and dialysis. Furthermore, the study of Amadi [8] unveiled that the load shedding phenomenon owing to boiler and turbine trips could trigger criminal activities as well as results in the non-functioning of lifts, safety systems, and remote doors in commercial and residential buildings. Therefore, these aforementioned assertions unveil the negative impacts of boiler and turbine trips at Eskom Power Plants, which result in load-shedding. Hence, it is crucial for Eskom Power Plants to critically analyse the boiler and machine trips generated in their plants to ascertain the vital few trips contributing the most to the disconnection of electricity supply to the national grid.

The problems of ascertaining the vital few factors that could influence the performance of a system, which is solved using the Pareto Charting technique, are quite enormous. To mention a few, Chen et al. [9] and Abubakar [10] deployed the Pareto Chart to ascertain the core failures contributing to the non-functioning of the Numeric Control Lathe Machine and pumps. The study of Ngoma et al. [11] deployed the Pareto technique to ascertain the core faults that occur when using pumps in a precious metal processing plant. The study of Tayal et al. [12] deployed Pareto Chart to ascertain the core categories of product losses that lower an organisation's Overall Equipment Effectiveness (OEE. Zeferino et al. [13] deployed Pareto Chart to ascertain the core categories of product losses that need to be considered by the community decision makers when selecting a quarantine facility location for isolating COVID-19 patients. From the previous discourse, it could be ascertained that the Pareto technique is a useful prioritisation tool that stimulates the generation of cost-effective solutions for addressing myriads of problems in various organisations. The authors observed that critical analysis of boiler trips within the South African context had received little attention in the literature. In light of this, this paper, on the one hand, unveil a cost-driven Pareto computation algorithm that ascertains the major and minor trips boiler trips that emanate from myriads of this machine components failure. On the other hand, it pinpoints the vital trips that contribute to the high total downtime cost experienced by a South African Power Plant owing to the occurrence of boiler trips. The result of this study will serve as an eye-opener for Eskom Management towards developing sustainable maintenance strategies for its various Power Plants in the country.

The remaining sections of the paper are highlighted as follows: section 2 presents the methodology used for this study, while section 3 presents and discusses the results obtained. The last section concludes based on this study's results and presents future research works that could emanate from this study.

2 METHODOLOGY

A quantitative research approach was used in this study. Three boiler machines used at a South African Power Plant were considered in this study. Historical data of the various categories of trips experienced for the past three (3) years on these boiler machines were extracted from the Trip Log Book of the South African Power Plant considered in this study. Thereafter, this data was sorted on Microsoft Excel with a view to categorise the various boiler machine trips, systematically note the frequency of the trips generated by each boiler machine trip category, and note the starting time and the ending time for each boiler machine trip category. The boiler machine trip downtime was computed using equation 1.

$$Trip\ Downtime = Trip\ Investigation\ Time + Trip\ Fixing\ Time \quad (1)$$

Thereafter, a cost-driven Pareto Charting algorithm was deployed in this study to ascertain the core trips contributing to the non-operation of the boiler machines as well as the total downtime cost experienced at the South African Power Plant considered in this study.

The cost-driven Pareto Charting algorithmic steps are highlighted as follows:

- Itemise each boiler trip category as well as the frequency of the occurrence of each boiler machine trip category.
- Rearrange in descending order the frequency of the occurrence of each boiler machine trip category.
- Cumulate the frequency of these boiler machine trip categories obtained in step 2.
- Develop the Pareto Chart to show the vital few trips contributing to the non-operation of the boiler machines.
- Calculate the cost of downtime for each boiler machine trip category using equation 2.

  $$Downtime\ Cost\ (R) = Downtime\ (MWh)\ X\ Power\ Production\ Cost\ per\ hour\ (R/MWh) \quad (2)$$

- Rearrange in descending order the cost of downtime for each boiler machine trip category.
- Develop the cost-driven Pareto Chart to show the vital few trips contributing to the high downtime cost of the South African Power Plant considered in this study.

In order to ensure that the study was credible and valid, the authors confirmed with the boiler machine maintenance operators that the trip information captured in the Trip Log Book is a true reflection of the trip issues experienced by the boiler machines for the past three (3) years. Furthermore, boiler machine trip events with incomplete information, such as the unnamed boiler machine trip category and unavailable downtime for a documented boiler machine trip category, were removed from the data utilised in the study.

3 RESULTS AND DISCUSSION

3.1 Categories of Boiler Machine Trips

Information about the various categories of boiler machine trips sourced from the Trip Log Book of a South African Power Plant is explained as follows:

a) Super-heater spray water system trip: the super-heater spray water system, which comprises spray water system valves responsible for controlling and maintaining the steam temperatures from the desired boiler outlet to the high pressure (HP) turbine, trips when the spray water valves are defective, i.e. fail to open and close.

b) Reheater spray water system trip: the reheater spray water system, which comprises spray water valves responsible for controlling and maintaining the steam temperatures from the desired boiler outlet to the Intermediate pressure (IP) turbine, trips when the spray water valves are defective, i.e. fail to open and close. The tripping of this system prevents further overheating of the boiler machine, which could cause tube leaks.

c) Draught group trip: the draught group system, which is the air delivery system responsible for supplying air at the desired pressure, temperature and flow rate for the combustion process of the boiler machine, trips, when the Induced Draught (ID) fan or Forced Draught (FD) fan or Pulverized Air (PA) fan is faulty.

d) Furnace trip: the furnace which is a compartment area where the combustion of fuel takes place for preheating of water and steam to create superheated steam, trips when the burners of the furnace are faulty, which could result in incomplete combustion.

e) Milling plant trips: the milling plant, which is responsible for receiving raw coal for grinding, drying and transportation of the finer particles or pulverised fuel through the classifier to the burners for combustion in the furnace, trips when there is a low airflow from the transportation media of the fine coal particles or when the grinding rollers of the milling plant are faulty. This system can also trip when the valves of the hydraulic system responsible for operating and controlling the roller are faulty or when the hydraulic oil used for lifting or lowering the rollers is contaminated.

f) Evaporator System trip: the evaporator system is responsible for further heating of water in the boiler, and trips, when there is insufficient water fed into the boiler by the feed pump.

g) Feed water system pump trip: the feed water responsible for feeding water to the boiler trip when the feed pumps are defective.

h) Sub-merger scrapper conveyor trip: the sub-merger scrapper conveyor is responsible for removing and transporting wet ash from the boiler, trips when the chain in the flight belt of the conveyor is broken or when the flight belt of the conveyor itself is damaged.

i) Reheater safety system trip: reheater safety system, which is responsible for releasing excess pressure from the boiler to the atmosphere, trips when the valves of this system fail to open and close.

j) Final steam flow trip: this trip occurs when there is an insufficient flow of the final steam to be conveyed from the final stage of the boiler of the turbine in order to turn the turbine. This act could occur owing to the inadequate firing of the steam in the boiler.

3.2 Result of the Boiler Machine Trips Analysis

The result of boiler trip occurrence analysis for the South African Power Plant considered in this study is depicted in Figure 1.

This result revealed that the three boiler machines coded as M4, M5 and M6 experienced 14 super-heater spray water system trips, 8 super-heater spray water system trips and 30 super-heater spray water system trips, respectively, which resulted in a total of 52 super-heater spray water system trips generated by these boiler machines. This category of the trip was the highest contributor of trips experienced by these boiler machines considered in this study. The three boiler machines experienced 8 reheater spray water system trips, 9 reheater spray water system trips and 24 reheater spray water system trips, respectively, which resulted in a total of 41 reheater spray water system trips generated by these boiler machines. The three boiler machines experienced 10 draught group trips, 6 draught group trips and 24 draught group trips, respectively, which resulted in a total of 40 reheater spray water system trips generated by these boiler machines. This category of the trip was the third highest contributed of trips experienced by the boiler machines considered in this study.

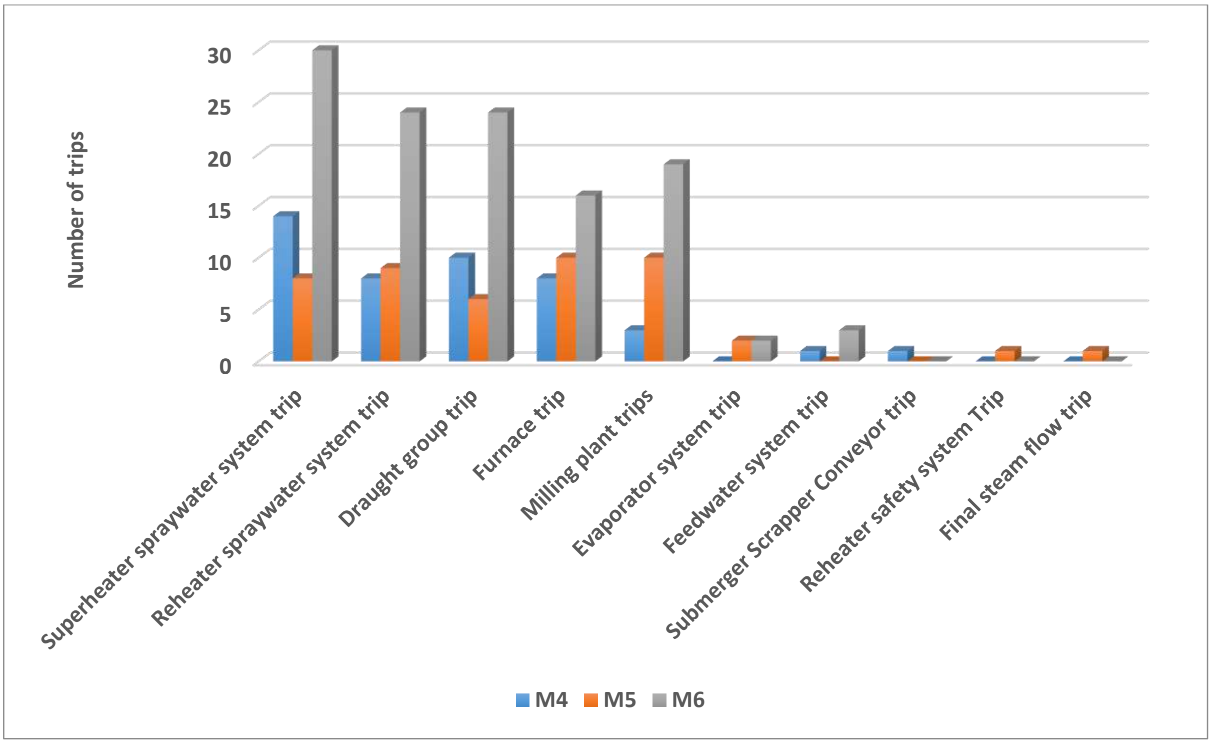

Figure 1: Boiler trips analysis per machine

The fourth highest boiler machine trip contributor known as the furnace trip, comprises 8 furnace trips experienced on the first boiler machine, 10 furnace trips experienced on the second boiler machine and 16 furnace trips experienced on the third boiler machine. Milling plant trip, evaporator system trip, feed water system trip, sub-merger scrapper conveyor trip, reheater safety system trip and final steam flow trip experienced by the three boiler machines considered in this study contributed a total of 32 trips, 4 trips, 4 trips, 1 trip, 1 trip and 1 trip respectively.

Further analysis of the boiler trips occurrence, on the one hand, revealed that 90% of these boiler machine tripping events emanate from mechanical failure or faulty working conditions of the various subsystems of these machines, while 5% of these boiler machine tripping events emanate from control and instrumentation failure or faulty working conditions of some subsystems of these machines. On the other hand, this analysis revealed that 3% of these boiler machine tripping events emanate from electrical failure or faulty working conditions of some subsystems of these machines, while 2% of these boiler tripping events emanate from human error during the operation of these machines (see Figure 2).

This result implies that the establishment and usage of suitable preventative maintenance strategies for proactive management of various mechanical subsystems in the boiler machines used at the South African Power Station considered in this study will exponentially improve the availability and reliability of boiler machines used in this organisation.

3.3 Result of the Pareto Trip Count Analysis for the Boiler Machines

The result of the Pareto Trip Count analysis for the boiler machines used at a South African Power Plant, obtained using steps 1 to 4 of the Pareto computation algorithm presented in the methodology section, is depicted in Figure 3.

This result revealed that the critical boiler machine trips are the super-heater spray water system trip, reheater spray water system trip, draught group trip and furnace trip since they contribute 80% of the trip experienced by the boiler machines considered in this study. Hence, boiler machine maintenance managers should focus their management efforts on establishing proactive maintenance strategies that will minimise or eradicate unforeseen boiler machine subsystem failure or faulty working operating conditions that cause these critical tripping events.

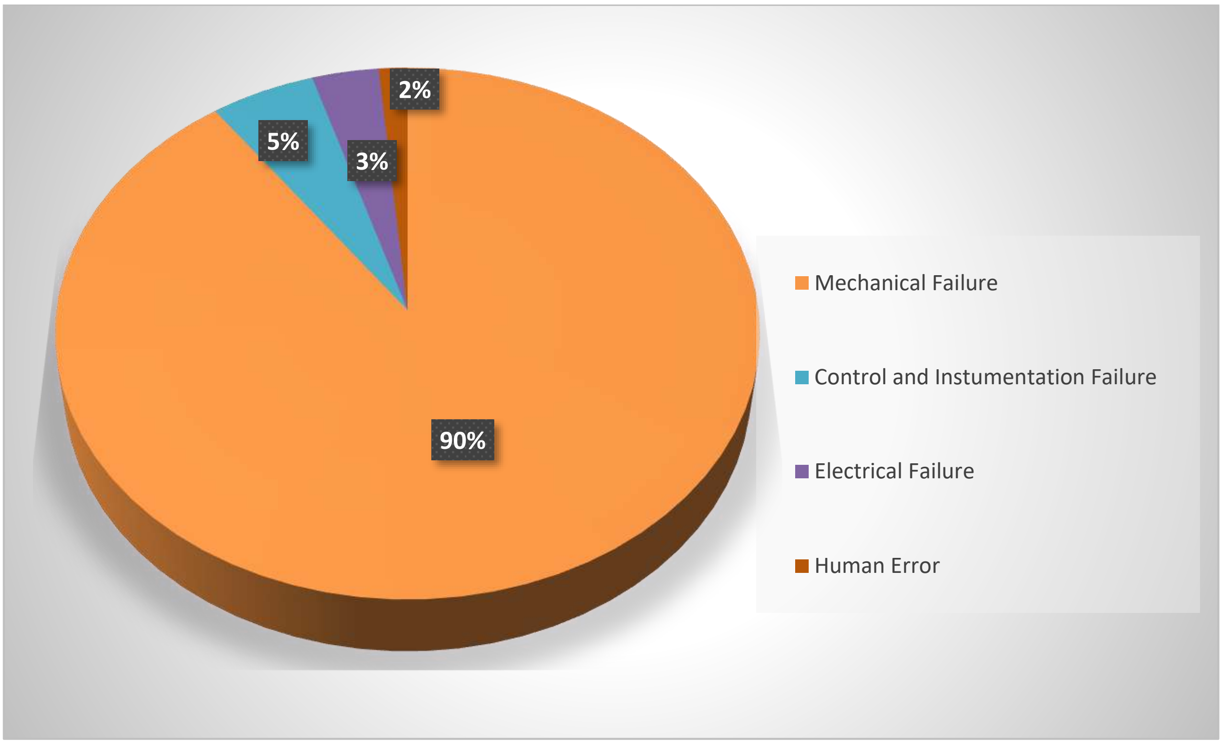

Figure 2: Categories of failures causing Boiler Trips

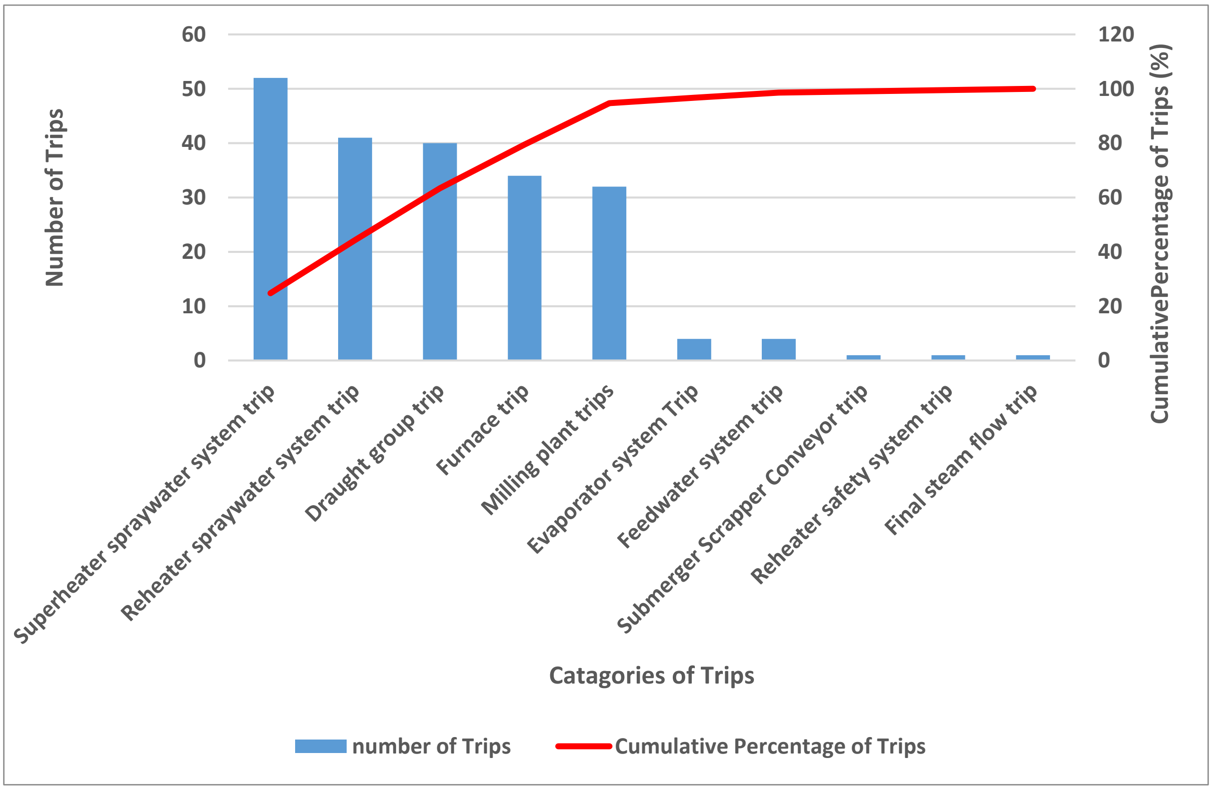

Figure 3: Pareto Chart for trips experienced by the boiler machines

3.4 Result of the Cost-Driven Pareto Analysis of the Boiler Machines

The result of the cost-driven Pareto analysis for the boiler machines obtained using steps 5 to 8 of the Pareto computation algorithm presented in the methodology section is depicted in Figure 4.

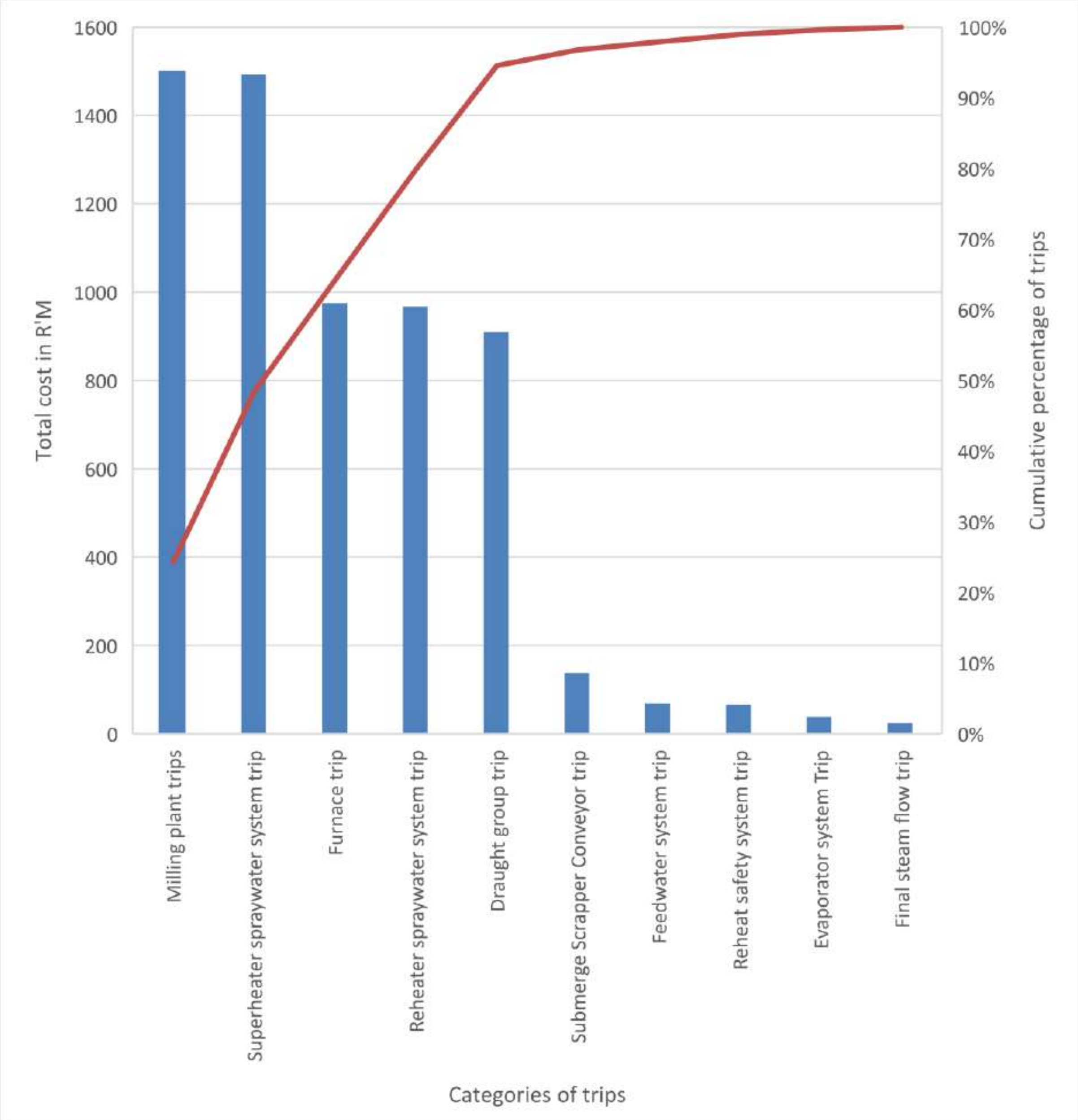

Figure 4: Cost-driven Pareto Chart for trips experienced by the boiler machines

This result revealed that the milling plant trip, super-heater spray water system trip, furnace trip and reheater spray water system trip are the core boiler trips that contributed to the majority of the downtime cost (i.e. a total of R4.9 billion) experienced by the South African power plant considered in this study. Hence, this South African Power Plant need to establish suitable strategies that will minimise downtime cost that emanates owing to boiler trip occurrence.

4 CONCLUSIONS

In this study, we deployed the Pareto prioritisation technique to critically analyse various categories of trips generated by the boiler machines used in a South African Power Plant. This exercise unveiled the Pareto algorithm, the Pareto Trip Count Chart, and the cost-driven Pareto Chart. The Pareto algorithm used in this study played a vital role in ensuring the ease of identification of various boiler machine trips, while the Pareto Chart unveiled the core boiler trips contributing the most to the trip occurrence and high downtime cost experienced at a South African Power Plant. The cost-driven Pareto computation technique has given clearly unveiled the core trips contributing to the production loss experienced at the South African Power Plant considered in this study. On the one hand, future research work needs to focus on the establishment of the intensity weight scores of each boiler machine trip based on the influence of one trip category on other trip categories, to conduct further prioritisation of the boiler trips from systems thinking perspective. On the other hand, future studies should look at ascertaining the root causes of these boiler machine trips and establishing suitable strategies to eradicate these root causes. Since this study only focused on boiler machine trips, future studies should also focus on carrying out the afore-discussed work on the turbine machines in order to ensure sustainable machine maintenance management at Eskom Power Plants.

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EXAMINING THE PROSPECTS AND CHALLENGES OF QUALITY IMPROVEMENT IN EDUCATION, RESEARCH, EXCHANGE, AND CAPACITY BUILDING

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ABSTRACT

This study examined the opportunities and difficulties in education, research, exchange, and capacity building with a focus on quality enhancement and a special emphasis on Nigerian Higher Education Institutions (HEIs). Emphasis on quality improvement in education is growing. The lack of a thorough analysis of acceptability and practicality of capacity building, student exchange, and total quality management in higher education institutions in Nigeria gave rise to the problem statement. Because of the circumstances, adopting Total Quality Management (TQM) in Nigerian HEIs, student exchange, and capacity building continue to be a big challenge, leading to several insufficient quality and operational standards. The implication is that TQM is a crucial prerequisite for high-caliber HEIs. Higher Education Administrators (HEAs) should continuously re-evaluate and enhance management operations through a culture of enhanced quality control. The conclusion is that TQM has evolved into a required framework approach, a very critical precondition for high-quality in HEIs.

Keywords: education, capacity building, quality improvement

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1. INTRODUCTION

Administrators of Higher Education Institutions (HEIs) are persistently confronted with monumental challenges of demands for consistent academic quality standards and the challenge to meet all the needs and yearnings of most of the stakeholders, which consists of regional agencies and policymakers, Higher Education Administrators (HEAs), teachers, and students. According to the works of Ganguli and Roy [1]; Gil, Berenguer and Cervera [2]; Pizam, Shapoval and Ellis[3]; Vavra [4], it was discovered from the conceptual framework in quality management that stakeholder (or customer) satisfaction is the pivotal criterion for guaranteeing the quality of the product/ service offered. Kotler [5] posited in the same vein that quality science, just like marketing science, laid bare the need to clearly define and understand the needs of the customer or stakeholder as a fundamental prerequisite for any management philosophy. Conversely, Jacobsen [6] and Oluwafemi and Laseinde [7] posits that there is no research-based undisputable definition for a customer in HEIs and its administration. Incidentally, the different customer groups or major stakeholders in HEIs have diverse and sometimes conflicting needs, goals, and expectations. The concept of quality in higher education is indeed extremely diverse, and it is not surprising that most studies have not attempted to measure it directly and have instead taken educational attainment as an acceptable proxy measure. Defining quality in terms of HEIs elucidate many arguments as quality is influenced by various factors, such as teaching and learning processes, outcomes of learning, the students, global economy, and advantages of education Pharm and Starkey [8]. Elassy [9] and Udam and Heidmets [10] both opined that perceptions of quality influence the approach adopted to assure quality, and those who have a vested interest in the quality of education think about quality in different ways. This research aims at assessing possibilities of HEAs using Total Quality Management (TQM) to achieve optimal quality output at the least cost. This study will utilise Philip Crosby's Quality Zero Defects approaches to initiate an approach to assess the extent to which stakeholders' quality enhancement culture expectations are achievable in HEIs, and how research, student exchange and capacity are met and build consensus in quality standardisation. Driessen and Hillebrand [11], on the other hand, lament the deficiency of published findings on the convergence of stakeholders' preferences of higher education quality. A highly accurate, minimally burdensome psychometric tool measuring the factors that lead to quality and barriers is needed to better understand the major stakeholder perceptions about quality in higher education [12]. This research will contribute immensely through a broad review of the literature and invariably deploy the use of Philip Crosby's Quality Zero Defects theory to make a critical evaluation of the extent to which quality expectations are met by HEAs.

1.1 Statement of the problem

The problem statement arose from the fact that the acceptability and practicality of TQM in HEIs, student exchange, and capacity building in Nigeria has not been thoroughly examined. As a result of the circumstances, adopting TQM continues to be a severe challenge in HEIs, student exchange, and capacity building in Nigeria, resulting in several poor quality and operational standards. Due to ambiguous approaches to service quality and a misunderstanding of the idea of quality in Management, which is only implemented in the productive sector, applying it in HEIs, student exchange, and capacity building, remain a source of contention among various schools of thought. So, according to Aluko, Odugbesan, Gadamosi, and Osuagwu [13], a primary worry of this research work is some people's unwillingness to adapt to TQM culture as some individuals see quality as a costless solution. Cole, Bacdayan and White [14] identified resource waste and managements' failure to move away from unprogressive-result-focused management operations approaches as factors impeding growth of TQM culture in HEIs, student exchange, and capacity building in Nigeria. This study is strategised to solve some of the inadequate TQM practices and knowledge to substantiate the shortcomings of TQM culture, which are not widely visible in Nigeria's education sector. This has hampered the establishment of a quality culture in HEIs, research, student exchange, and capacity building, or the Nigerian education sector.

1.2 Objective of the study

The objective of the study is to examine the opportunities and challenges in education, research, exchange, and capacity building through quality enhancement in Nigerian HEIs. The study will assist HEAs in making policy decisions. Academics will benefit from this study as well. This research would be helpful in the Nigerian government as part of her current strategy on her reform program in the quality educational field. The public would benefit because the comprehensive introduction of a complete quality improvement culture in HEIs will then be applied to all other areas of societal activity management, which can be used to provide quality services to increase citizens' quality of life.

2 LITERATURE REVIEW

It has been difficult to define excellence in a university context. "Education quality is a somewhat perplexing and controversial idea," according to Cheng and Tam [15], although Pounder [16] says it is a "notoriously vague expression." Quality evaluation has been problematic due to the difficulties in defining quality. However, according to Cruickshank [17], TQM is the most widely used tool on a global scale, which is defined as: a management approach of an organisation centred on quality, based on the participation of all its members, and aiming at long-term success through customer satisfaction and benefits to all members of the organisation and society [18].

Adoption is supported by the fact that TQM can bring together the quality viewpoints of external and internal stakeholders, enabling a holistic approach to quality management that assures quality while also promoting change and innovation. However, significant impediments to widespread TQM adoption in university education have been found. While industry has only a few quality indicators, higher education has many more which, and they are more complex and more difficult to measure.

It has also been suggested that TQM practice in higher education is devolving towards managerialism due to a misalignment between TQM methodology and educational processes, as well as a lack of a shared vision across institutions or educational sectors as opined by Srikanthan and Dalrymple [19]. As a result of this discussion, they proposed developing a model of educational excellence that is distinct from, but connected to, commercial models. “A new viewpoint on higher education quality is required," write Srikanthan and Dalrymple [19]. A comprehensive examination of present procedures to identify the extent to which various definitions of quality and stakeholder viewpoints might be a useful beginning point for this strategy. A new framework for a quality audit tool was developed to analyses existing quality management practices in higher education, drawing on relevant literature from both education and industry.

Many university stakeholders' perceptions of "quality of education" are becoming increasingly problematic. Customers' dissatisfaction and low employee morale have been identified as important concerns in institutions. According to Pfeffer and Salancik [20], the flaws of today's university education systems are inadequate teaching, outmoded programmes, incoherent curriculum, expensive tuition, and increasing and ineffective administrative bureaucracies. Many individuals believe that TQM offers immense promise for issue solving. It could boost student/staff morale, increase productivity, and provide better services to both internal and external clients.

Difficulties in recognising consumer wants, as well as a diverse set of stakeholders (e.g., students, parents, employers, faculty members, government, and the public), add to the complication. This feature of a university education system, however, must not be allowed to take precedence over the requirement for an operational definition of excellence that allows for continuous growth. Quality and market concerns are inextricably linked; better quality may be achieved by recruiting more competent students, hiring more capable personnel, and absorbing more industry money, all of which are market related. This demonstrates that institutions may use financially motivated approaches to quality management.

Although many TQM concepts may be applied in university education, it is realistic to anticipate certain issues when applying them to an organisational structure different than that of the commercial sector. The challenge is that there will be a direct link between the higher education strategy adopted, the concept of quality employed, and the performance metrics chosen to assess quality as posited by Tam [21].

2.1 Theoretical framework

Philip Crosby's Quality Zero Defects laid the foundation for this analysis. Crosby [22] identifies Zero Defects as to the idea that TQM will unquestionably be dealing with reducing variation in the production process to absolute zero. To achieve zero defects, Crosby's theory emphasises the importance of increasing overall quality visibility and gaining sponsorship. He said that the pursuit of quality in the service marketing industry is never-ending. Crosby's 14 TQM points are management commitment, quality assurance departments, evaluation, quality cost, quality detection, corrective action, zero-defects planning, zero-defects day, goal setting, error cause avoidance, recognition, quality groups, and repeating the process.

2.2 The concept of total quality management

TQM is defined by Cherkasky [23] as a pioneering problem-solving way of regulating quality in an organisation to optimise its goods, services, and operations. Notably, [24] Zikmund defined TQM as a business strategy that necessitates strategy design to instil the notion of customer-driven quality in an organisation. He emphasises the need of continuing to enhance the quality of products and services.

According to Martin [25], total quality control/management is the use of quantitative methodologies and human resources to enhance the goods and services offered by an organisation, all operations inside an organisation, and the amount to which the consumer's expectations are satisfied now and in the future. TQM, according to Stahl [26], is a management system approach that strives to benefit customers via the deployment and continual improvement of organisational processes and systems. According to Hellstein and Klefsjo [27], TQM is an ever-changing management system comprising of concepts, procedures, and strategies for improving internal and externally generated product quality with less resources. Stahl discusses several facets of quality, including compliance to standards, efficiency, quick reaction, rapid change, experience, features, dependability, durability, serviceability, aesthetics, perceived quality, and humanism [26].

The acceptance of the TQM definition in service marketing, according to Aluko et al. [13], should be treated with caution. Furthermore, Aluko et al. said that Nigerian executives should be aware that implementing a TQM approach involves careful calculation. They further stated that continual TQM growth necessitates management allowing its people to participate in problem-solving activities that are free of red tape. TQM is defined by Milakovich [28] as a theory-based alternative that enables public managers to inspire excellent individual production by applying the TQM approach. He went on to explain that the government's inability to implement reform programmes to improve service quality has prompted calls for a total rethink of management systems. Several authors (Dotchin and Oakland [29], Teryima et al. [30], Lewis [31] and Boaden [32]), especially in the context of comprehensive quality management systems, believe concepts, procedures, and techniques to be fundamental for the theory.

According to Talib et al. [33], financial organisations will only grow more resilient and efficient if they enhance their customer service, performance, costs, and innovation. As a result, service quality, according to them, plays a strategic function and is a crucial determinant in a service provider's performance in the worldwide market. However, because this notion is universal to all service industries and has directly contributed to the formulation of TQM in service delivery, the emphasis is now mostly on surpassing customers' demands. Tribus [34] claims:

> *"For an organisation to be truly effective, each part of it must work properly together towards the same goals, recognising that each person and each activity effects and in turn, is affected by each other's…. the methods and techniques used in Total Quality Management can be applied throughout any organisation".*

According to Swiss [35], TQM is based on a highly well-established organisational culture with a clear focus on and respect for quality. "The Total Quality Management ideology is based on a culture of employee empowerment and teamwork," Swiss added. According to Shiba [36], total quality control is an emerging model consisting of practices, strategies, and training approaches for managing organisation in a rapidly changing operations management practice.

According to Ovretveil [37], service quality makes the most vulnerable people's needs accessible with limited resources and at the lowest possible cost. He went on to say that quality components involve things like timeliness, precision, legality, and others.

2.3 The need for TQM process

According to Spaulding et al. [38], quality management should be applied to processes rather than goods. Companies would benefit, according to [39] Ewurum, from focusing on business processes through TQM rather than being focused on results and final outcomes that can be evaluated against metrics to assess success or failure. Similarly, Chopping [40] asserted that focusing on the process could assist organisation in making the cultural changes needed by TQM since the process's ability to work is required to meet the customer's needs and desires.

2.4 Service quality

According to Ugonwenyi [41], service companies need high-quality goods to resolve the constraints imposed by competition. Similarly, Palmer [42] describes quality as a service's ability to meet explicit or implied needs. It refers to a service's ability to fulfil its needs or wishes. Customers use service quality to compare one organisation's services to others. Palmer considers the level of quality with which a facility is designed to be a vital component of the overall service provided. Since quality is described as the apparent performance level, TQM is critical in-service marketing. Palmer contends that assessing the quality of services is more complex than assessing the quality of tangible goods. He claimed that a service deemed to be of high technical quality by the manufacturer might be regarded very differently by a particular customer with a different set of quality evaluation standards. Palmer went on to say that while services are intangible, conventional quantification problems make it even more difficult for an organisation to track and sustain a consistently high quality of service. According to Palmer, customer expectations are an integral component of quality. Palmer claims that any service that fails to meet the needs of one customer is of low quality.

In contrast, another customer who receives an equivalent service but does not have such high expectations may consider the service high quality [42]. Palmer argued that, given the importance of quality in the overall value proposition, the application of TQM in service marketing has become crucial. Professionals and analysts, according to Palmer, have been even more interested in the concept of service quality as a way of gaining a competitive advantage. According to Palmer, quantifying quality parameters and defining customer esteem quality variables are complex tasks. Furthermore, Palmer argued that the intangibility and inseparability of most services result in a series of one-of-a-kind buyer-seller transactions, with no comparable services provided in the same way [42].

3 METHODOLOGY

Since educational cooperation is moving toward evidence-based practices to improve educational quality, a realistic model that aims at practical, workable solutions for TQM in

HEIs has been adopted, and for this study to effectively gather, analyse, and justify data for the information asserted, a sequential mixed approach was chosen as a research method. The expected benefits include the development of a road map in educational research showing methodological possibilities for brand new expertise statements. This mixed-method design methodology aided in concentrating primarily on the conceptual premises of this research, in developing research questions, promoting data collection and analysis, ethical problems, quality of inference, and theoretical formulation to substantiate and validate the study's findings.

The descriptive description is also subject to social science research methods, and the rationale for using a mixed approach to perform this research stems from the unique nature of this analysis. Hypotheses were developed and checked, necessitating the use of quantitative methods. Both the qualitative and quantitative mixed methods are plausible since they are both experimental and are widely used in survey research for many social science studies focused on rational processes such as problem formulation, data collection, and analysis to support or refute a hypothesis.

The population of the study was drawn from one Federal University, one State University, one Private University, one Polytechnic, and one College of Education. The sample of the study population used in this research was 100 respondents; this sample was obtained through the random sampling technique from five Higher Education Institutions (one Federal University, one State University, one Private University, one Polytechnic and one College of Education) in Nigeria. This method was chosen because the research could not have been able to contain all the 170 Universities comprising of 79 Private Universities, 48 State Universities and 43 Federal Universities, the 17 Federal Polytechnics and 26 State-owned Polytechnics totalling 43 Polytechnics (United States embassy 2020) and 152 Colleges of Education consisting of 21 Federal, 82 private and 49 State Colleges of Education. Administrators/management of HEIs, academic/non-academic staff, present and past students were the respondents. Of the sample used, 90 respondents were given a questionnaire while ten were interviewed, consisting of 45 males and 35 females. The ten respondents that were interviewed comprised of three Administrators/Management cadres, three Academic/non-academic staff and two current students and two past students.

The methods used in collecting data were very productive as the responses to the questions were expressed in findings that are easy for identification and comparison. A total of 100 questionnaires were carefully counted out and recorded as necessary. After counting the respondents that are under each category, percentages were counted out, and figures were constructed for the presentation and analysis of the data.

4 RESEARCH GAP

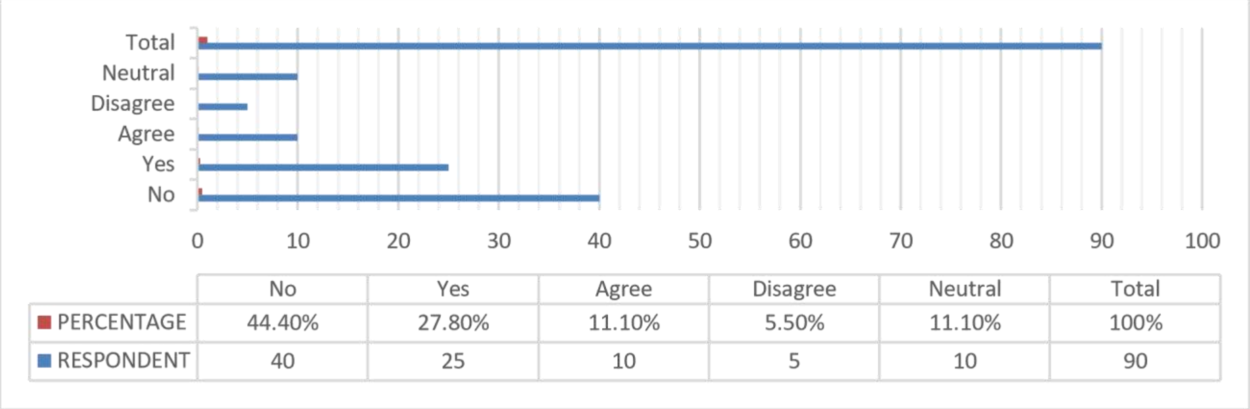
In order to determine how TQM procedures, affect organisational performance, this study aims to analyse their influence in HEIs. Several Business Excellence Awards (Corredor and Goñi [43], Amin et al. [44], Foster and Ganguly [45], Harrison and New [46], Miguel and Cauchick [47], Samson and Singh [48] and Talwar [49]) were used to measure the effectiveness of quality management implementation. The factors in this study also concentrated on TQM techniques that enhance quality, leadership commitment, employee and stakeholder happiness, enhanced stakeholder interactions, and its effect on organizational performance. The following frameworks' criteria, which serve as the foundation for implementing TQM, are also covered in the study:

The successful implementation of TQM enhancement cultures in developed nations was found to depend on meeting the criteria for achieving various excellence awards, such as the Malcolm Baldrige National Quality Award (MBNQA), Deming Prize (DP), European Foundation for Quality Management (EFQM), Canadian Quality Award (CQA), Australian Business Excellence Award (ABEA), and South African Excellence Model (SAEM). All of these point out characteristics that have been emphasised in research done by prior studies. Therefore, the definitive contribution of this study has been determined to be Nigeria's HEIs' lack of well-defined criteria for winning excellence awards as such quality objectives are not taken cognisance of by HEAs in Nigeria. These awards are essential for performance and organisational excellence to enable the implementation of successful TQM procedures. Since there is little to no understanding of strategy to establish the aims and attain excellence, which was the research gap that had been discovered through a survey of the literature. In Nigerian HEIs, there is zero motivation to strive for excellence in developing, implementing, and evaluating TQM components.

5 RESULTS AND DISCUSSION

A total of 100 respondents were approached, including 37.5% from management and 62.5% from academic and non-academic staff. An attempt was made to find out from the respondent if there was adequate awareness created by the management in terms of seminars, workshops, or conferences on TQM and its adoption by management and staff. The answers given vary from one respondent to another. These include a lack of awareness of the inability of TQM to enhance the performance of the HEAs.

Figure 1 presents the awareness created by the management in terms of seminars, workshops or conferences on TQM and its adoption by management and staff. Of the 90 respondents sampled, the result shows that 40 (44.50%), being the highest in the study, strongly disagree that the management created awareness seminars, workshops, or conferences on TQM and its adoption. Twenty-five respondents (27.80%) strongly agreed, and five respondents (5.50%) agreed. Ten respondents (11.10%) were neutral.

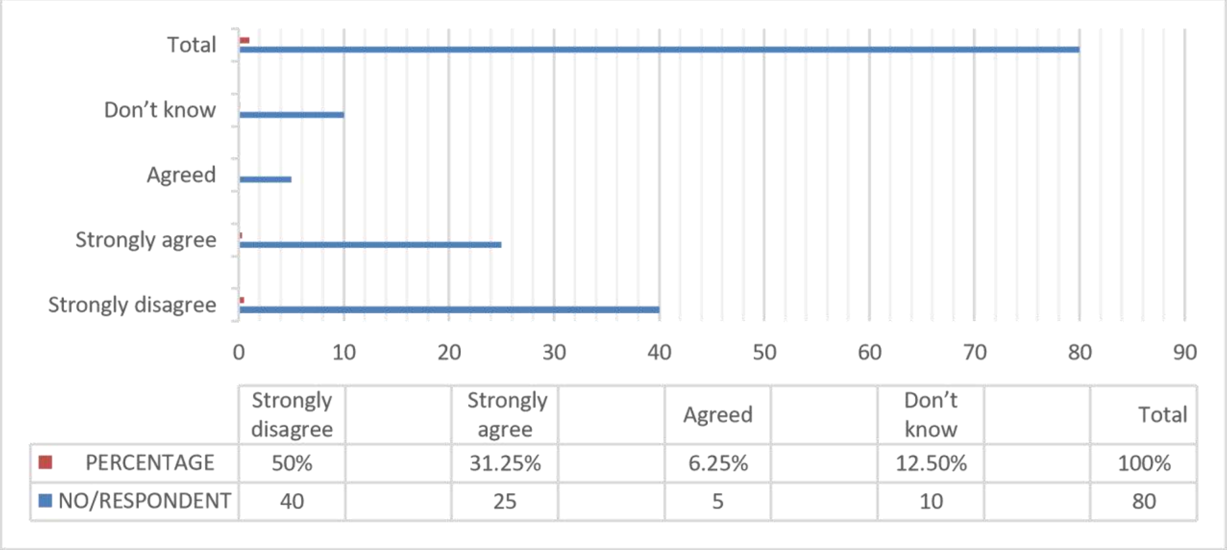


	No	Yes	Agree	Disagree	Neutral	Total
🟥 PERCENTAGE	44.40%	27.80%	11.10%	5.50%	11.10%	100%
🟦 RESPONDENT	40	25	10	5	10	90

Figure 1: Respondents' awareness of TQM created by the Management in terms of seminars, workshops, or conferences on TQM

The study also made some statistical distribution asking along years of experience in HEIs' administration service with a view to the level of awareness in HEI administration and the possibility of adoption of TQM performance enhancement culture in the operations of Nigerian HEIs. The analysis revealed that 50% of administrators/academic staff have 5-26 years of working experience while 31.25% of non-academic staff have 5-26 years of working experience. The implication is that not sufficient awareness is demonstrated among a significant number (62.5%) of HEAs who happen to be decision-makers. This accounts for the reason why TQM culture is non-existent.

Figure 2 presents the years of experience of HEAs. Out of the 80 respondents sampled, the result shows that 40 (50.0%), which is the highest result, strongly disagreed that TQM influences the administration of HEIs. Twenty-five (31.25%) of the HEAs strongly agreed that TQM influences the administration of HEIs. Only five respondents agreed, while ten (12.50%) do not know if the operational services of HEIs are influenced by TQM. The result indicates that most operations of HEIs are majorly lacking in TQM adoption and implementation.



	Strongly disagree		Strongly agree		Agreed		Don’t know		Total
🟥 PERCENTAGE	50%		31.25%		6.25%		12.50%		100%
🟦 NO/RESPONDENT	40		25		5		10		80

Figure 2: Years of practice and experience in HEIs administration Service influenced by TQM

6 CONCLUSION AND RECOMMENDATIONS

The study revealed there were everyday challenges for HEIs and exchange and capacity building on TQM practice in Nigeria. For starters, it was discovered that HEAs and policymakers made no substantial efforts to raise awareness about adopting the TQM culture in Nigeria. Secondly, this study also revealed that there is no significant adoption of TQM in HEIs in Nigeria. Thirdly, this research also reveals that there are many obstacles inhibiting the adoption of a pragmatic quality culture in Nigeria.

The aim of this study was to investigate the opportunities and challenges of education, research, exchange, and capacity building in Nigerian HEIs, with a focus on quality improvement. The six-week study included participants from one Federal University, one State University, one Private University, one Polytechnic, and one College of Education. The survey was completed by 100 participants. TQM is characterised as the application of quantitative methods and human resources to enhance the provision of services rendered and promoted by organisations, as well as the degree to which anticipated customer needs are met now and in the future.

The study's results indicate the following recommendations for enhancing the effectiveness of TQM culture and performance enhancement in HEIs, as well as increasing stakeholder satisfaction: (i) more training sessions are needed to raise TQM awareness among HEIs’ administrators and management; (ii) ongoing synergies among stakeholders are required; (iii) strengthen and expand working standards for academic and non-academic workers at Nigerian HEIs; and (iv) capacity development for administrators/management, academic and non-academic personnel. It is recommended that TQM ought to be the operational framework with an approach that aims at the importance of quality to HEAs and other service providers, which should be done by redesigning and continuously enhancing management operations, quality control culture, and general operating systems. TQM should be prioritised by implementing TQM in the HEIs sector, conducting research, and building capacity as this would lay the groundwork for more sensitive and robust quality service delivery in Nigeria TQM's effectiveness in HEIs service operations; in general, it will be a panacea for increased organisational effectiveness, reliability, competitiveness, maximum stakeholders’ loyalty, and quality service operations. For all stakeholders to achieve the best results, they are encouraged to collaborate. This will facilitate the acceptance, adoption, and implementation of TQM in the administration of HEIs in Nigeria and beyond.

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A TECHNO-ENVIRONMENTAL AND ECONOMIC ASSESSMENT FOR PRODUCING 10 TONS/DAY OF BLENDED VERMICOMPOST AND COAL BASED FLY ASH BIO FERTILIZER

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ABSTRACT

This study evaluated the technical, environmental and economic feasibility of setting up a plant producing 10 tons/day of blended bio fertilizer from vermicompost and fly ash as a waste management initiative and also as an alternative to chemical fertilizers. The fertilizer based nutrients in the fly ash were leached out using *Thyobacillus ferrooxidans* as a bio catalyst at 10 hour intervals. The vermicompost rich with fly ash leachate was dried in a 6.28 m2 fluidized bed reactor continually to produce the bio fertilizer. All materials were made from steel and specific process controls were on pressure, temperature and flow. At total capital equipment investment of USD 260 400.00 is required and the selling price of the vermicompost is USD 0.54/kg. A payback period of 3.0 years and a return on investment of 33.3% was realized during economic assessment for this study.

Keywords: Bio fertilizer, fly ash, techno-economic assessment, vermicompost, waste management

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1 INTRODUCTION

The production of environmentally friendly bio fertilizers such as vermicompost is becoming popular as an alternative to chemical fertilizers [1]. Chemical fertilizers have a disadvantage of high costs and can also result in acid rain due to high presence of chemicals such as nitrogen and sulphur. Vermicompost is generated from the decomposition of any organic matter using earthworms under standard conditions and is rich in nitrogen, phosphorous and potassium nutrients [2]. On the other hand, in countries like Zimbabwe, where thermal coal is used in the power plants, a lot of fly ash is generated as a waste product. This fly ash has potential to cause landfilling problems [3]. Fly ash is rich in nutrients such as Al, Fe, Ca, C, Mg, K, Na, S, Ti, P, Mn, Mo, Se, Cd and Zn and has potential to be used as a raw material for producing blended bio fertilizers [4]. This work evaluated the technical, environmental and economic potential to produce a blended bio fertilizer. The potential production of bio fertilizer from vermicompost and fly ash promotes the usage of organic fertilizers instead of chemical fertilizers at the same time promoting waste management [5].

2 EXPERIMENTAL PROCESS DESIGN FOR BIOFERTILIZER PRODUCTION

The vermicompost is discharged from the bins and is fed into the feeders where there is an opening that directs the vermicompost right into the chute of a screw conveyor [6]. The screw conveyor conveys the fly ash into a chute which then feeds into another conveyor. The conveyor feeds into a junction where the treated fly ash from conveyor belt is mixed with vermicompost, the mixture is fed into the second conveyor. The conveyor then feeds the mixture into a blending equipment at 10 tons/day. Water is added at a rate of 500 L/day to the blending equipment to prepare the bio fertilizer for wet granulation. The granulator forms granules of the bio fertilizer which are then fed by the conveyor to a rotary dryer where the dewatering process occurs up to 95% [7].

On the other side, fly ash is discharged from the storage vessel into a discharge bin. The discharge bin feeds into a screw conveyor which then feeds into a bio leaching tank. *Thyobacillus ferrooxidans* culture solution is also fed into the leaching tank from storage vessel into the leaching vessel. The leaching process takes place, with the conversion of FeS_2 in fly ash into H_2SO_4 through the action of a leaching bacteria *Thyobacillus ferrooxidans*. The drained H_2SO_4 is taped from the leaching vessel and pumped to a storage vessel for dilute H_2SO_4. The leached fly ash slurry is moved to a dryer and from the dryer, there is a conveyor that feeds right into a junction mixer. The vermicompost and leached fly ash are then blended in a ratio 1:2 ash as to vermicompost. The detailed process description is shown in Figure 1.

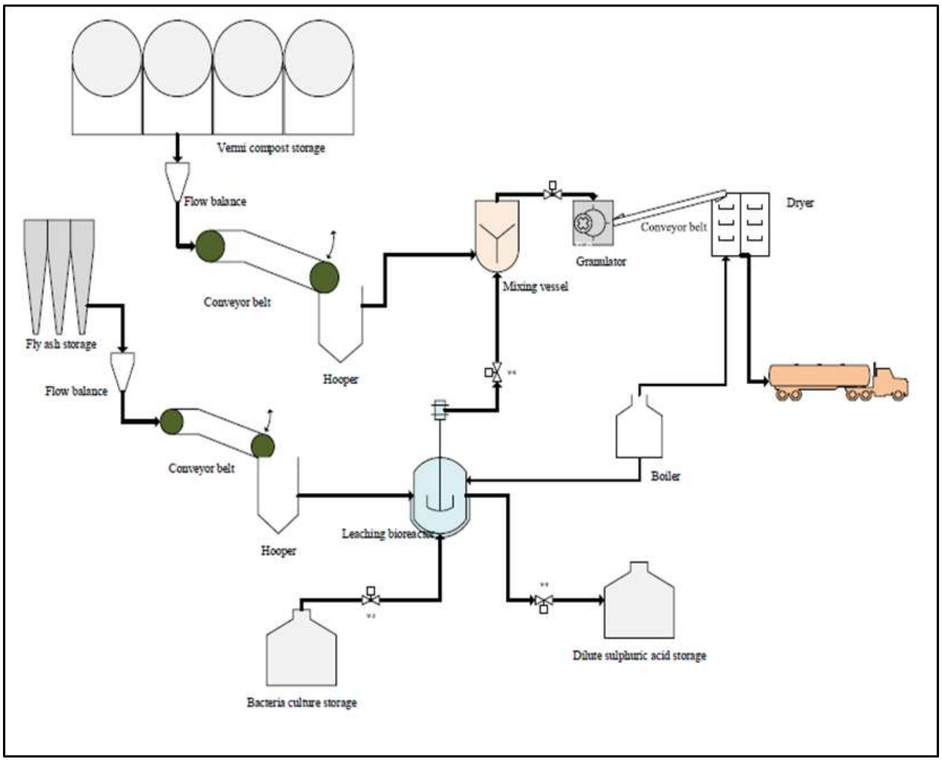

Figure 1. Process flow diagram for bio fertilizer from vermicompost and treated fly ash

2.1 Mass balances

The following assumptions were made: the culture solution is to be added to fly ash at a ratio of 1L/10kg, 95% of water in the bio fertilizer is removed by the second dryer. The operation time is 10 hrs./day and for a basis of 10 t/day of bio fertilizer production.

2.2 Evaluation of Monod parameters and bacterial growth (*Thyobacillus ferrooxidans*)

The *Thyobacillus ferrooxidans* inoculums will pass through a number of growth phases during the bio leaching process. During the log phase, cell numbers increase exponentially at a constant maximum rate as indicated mathematically in Equation 1.

$$\frac{dX}{dt} = \mu x \text{...} \quad \textbf{(1)}$$

Where X is the concentration of *Thyobacillus ferrooxidans*, t is the time in hours and μ is the specific growth rate in hours^{-1}. Upon integration between time t_0 and time t_1 when the concentrations of the cells are X_0 and X_1 an expression as indicated by Equation 2 is obtained.

$$\mu = slope = \frac{\ln(X_1 - X_2)}{t_1 - t_2} \text{..} \quad \textbf{(2)}$$

Table 1: Monod analysis for bacteria growth in the leaching reactor

Substrate; S (g/L)	t (Hours)	$1/\mu$
0	0.0	2.94
15	8.0	3.03
12	16.0	3.13
9	24.0	3.33
6	32.0	4.55

2.5	40.0	5.56
1.7	48.0	6.00

Where: Si =15g/L and S= 1.7g/L

Table 2: *Thyobacillus ferrooxidans* cell growth in bio leaching reactor

X (g/L)	t (Hours)	ln X
18.9	2.0	2.9
20.7	4.0	3.0
22.9	6.0	3.1
27.9	8.0	3.3
30.0	10.0	3.4

Thyobacillus ferrooxidans cell growth rate increases exponentially at maximum rate as represented by Equation 3.

$$\frac{dx}{dt} = \mu x \ldots\ldots\ldots\ldots \tag{3}$$

Where: x is the concentration of *Thyobacillus ferrooxidans*, t is the time in hour and μ is the specific growth rate in hours^{-1}. Upon integration, the following mathematical expressions are obtained as indicated in Equations 4 and 5.

$$\int_{x_0}^{x} \frac{dx}{x} = \int_0^t \mu dt,\ \ln(x) - \ln(x_0) = \mu t \ldots\ldots\ldots\ldots \tag{4}$$

$$\mu = slope = \frac{\ln(X_1 - X_2)}{t_1 - t_2},\ \mu_{max} = slope = \frac{2.9-0.0}{8-0} = 0.4h^{-1} \ldots\ldots \tag{5}$$

The maximum specific growth rate of *Thyobacillus ferrooxidans* is 0.4/hr. Therefore, μ is given by Equation 6.

$$\mu = \frac{\mu_{max} S}{K_s + S} \ldots\ldots\ldots\ldots \tag{6}$$

Where: μ_{max} is the *Thyobacillus ferrooxidans* maximum specific growth rate, S is the residual substrate concentration and K_s is the substrate utilization constant. Theoretically equal to substrate concentration when μ is half μ_{max} and is a measure of the affinity of the for its substrate as indicated by Equation 7.

$$0.125 = \frac{0.35 \times 6.66}{K_s + 7.1};\ K_s = 5.2\ \text{g/L} \ldots\ldots\ldots\ldots \tag{7}$$

According to the law of conversation of mass: Accumulation = mass in – mass out + generation. Therefore: Amount of oxidized FeS= 77.5/100×0.16= 0.124% of the feed, FeS is assumed to be 1.60% in fly ash found at Hwange Thermal Power Station in Zimbabwe. Therefore, the percentage of FeS remaining in the stream = 0.16 - 0.124 = 0.036%.

$FeSO_4 + H_2O \rightarrow$ bacteria $H_2SO_4 + 2Fe + \frac{1}{2}O_2$

2.3 Energy balances

The following assumptions were made: The system is an open system therefore heat change = Ĥ, Ĥ = mCPΔT is to be used to calculate energy associated with each stream and Cp = specific heat capacity. The specific heat capacity of vermicompost-fly ash blend was 4120 J/kg K and specific heat capacity of vapor was 4184 J/kg/K. The thermal properties of the drier are shown in Table 3.

Table 3: Thermal properties of dryer

Parameter	**Value**
Datum temperature	25 °C = 298K
Inlet stream temperature	35 °C = 308K
Temperature within the dryer	110 °C = 383K
Outlet temperature	110 °C = 383K
Specific heat capacity of blend fertilizer	4120 J/kgK
Inlet stream heat in blender	3218.4 J/s
Inlet stream enthalpy	Q + 3218 Watts
Outlet stream heat in blend fertilizer	3786.6 Watts
Outlet stream heat in vapor	3399.9 Watts
Outlet streams enthalpy	7186.6 Watts
Overall balance $(mC_p\Delta T)_{in} + Q = (mC_p\Delta T)_{out} + (mC_p\Delta T)_v$	10122 Watts
From steam tables, steam evaporation enthalpy	2056 kJ/kgK
Amount of drying steam required	4.9 kg/s

3 PROPOSED PROCESS EQUIPMENT DESIGN

The chosen equipment was the batch leaching vessel whose function is to oxidize sulphides from the fly ash using *Thyobacillus ferrooxidans* as a bio catalyst and the fluidized drum granulator whose function is to granulate the bio fertilizer.

3.1 Fly ash leaching tank design parameters

The assumption made was that operating conditions are at standard conditions. A summary of the leaching reactor is given in Table 4 and the leaching tank is schematically presented in Figure 2.

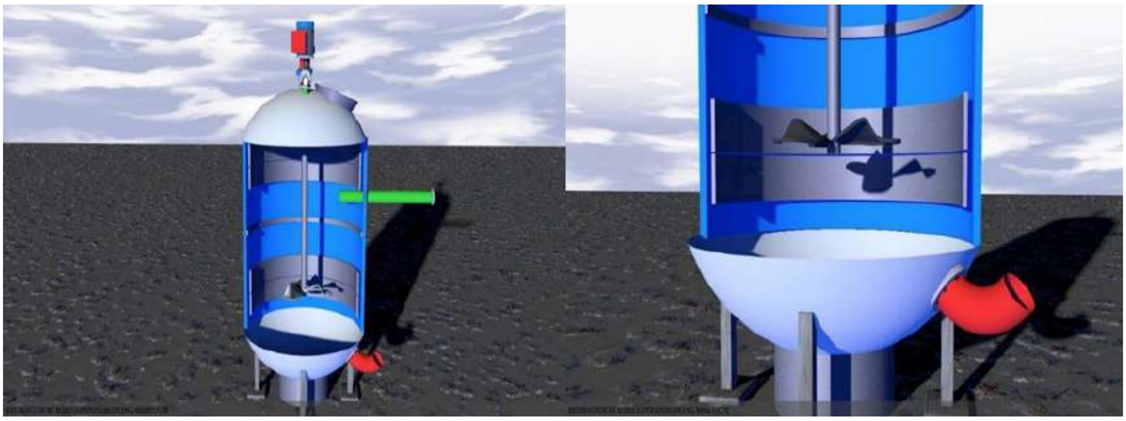

Figure 2: Fly ash leaching vessel cross-sectional view

Table 4: Fly ash leaching bioreactor design parameters

Item	Leaching bioreactor
No. required	1
Function	Leaching of the fly ash to oxidize sulphides
Operation	Batch
Type	Stirred tank bioreactor
Volume	4.4 m^3
Height	2.5 m
Diameter	1.5 m
Temperature	40 °C
Working pressure	1.8 atm
Batch time	10 hrs.
Height to diameter ratio	1.5
Type of head	Hemispherical
Depth of dished bottom	1 m
Wall thickness	0.019 m
Head thickness	0.021 m
No. of baffles	4.0
Width of baffle	0.7 m
Height of baffle	0.6 m
Material of construction	Carbon steel

3.2 Bio fertilizer granulator design

The fluidized drum granulator is the most recent technology and combines the use of a fluidized bed table and a drum. A summary of the granulator design is given in Table 5 and the schematic presentation of the design given in Figure 3.

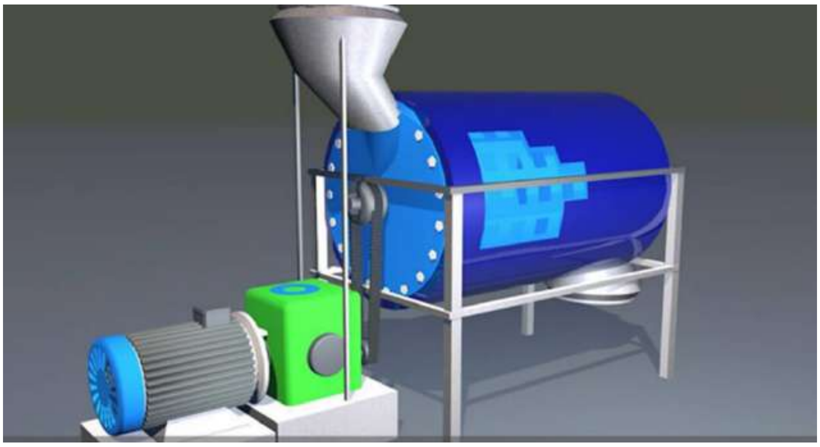

Figure 3: Granulator design for bio fertilizer granules production

Table 5: Bio fertilizer granulator design parameters

Item	**Fluidized drum granulator**
Particle size diameter	2.8mm
No. required	1
Function Cross sectional area	Granulating the bio fertilizer 6.28m^2
Operation	Continuous
Type	Fluidized drum
Volume	10.2 m^3
Length	3.8 m
Diameter Shear stress Voidage Mean residence time	2.0 m $26.4\ \mathrm{N/mm^2}$ 0.87 3.5 hrs
Temperature	55 °C
Working pressure	0.132 N/mm^2
Height to diameter ratio	1.5
Wall thickness	5.0 mm
Material of construction	Stainless steel

4 PROPOSED PROCESS CONTROL AND HAZOP ANALYSIS

The process parameters such as temperature, flow and pH are controlled to ensure safety operating conditions and to maintain maximum productivity. The process control loop for leaching reactor is shown in Figure 4. The main parameters under control were temperature and pressure. The same control mechanisms were applied on the granulator as represented in Figure 5.

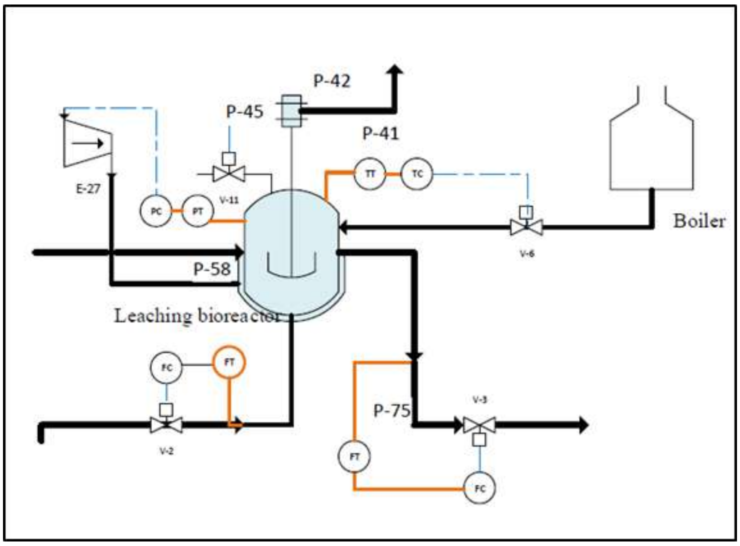

Figure 4: Fly ash leaching tank process control system

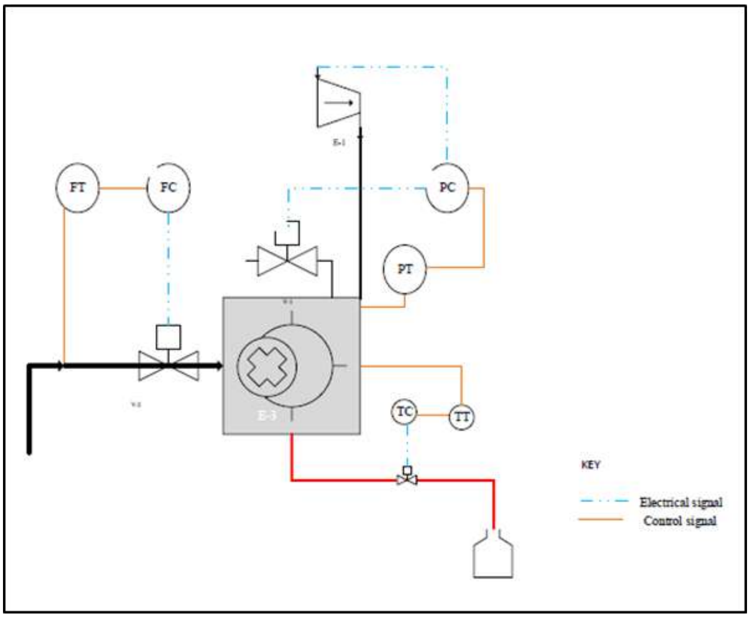

Figure 5: Bio fertilizer granulator process control system

5 SITE SELECTION

The model used for site selection is the decision matrix and for the plant layout. The plant site is located where the cost of production and distribution of the bio fertilizer are minimal.

5.1 Factors for site location

The factors considered included: land accessibility, plant capacity, taxation policies, environmental factors, geological factors, political factors, site characteristics, transportation, utilities access, labor accessibility, technological factors, climate, market availability and location of raw materials. There are two possible sites to erect the plant namely Willowvale Area in Harare (Site A) and Hwange Area in Matebeleland North (Site B). A decision matrix was used to determine which location would best suit the bio fertilizer plant as indicated in Table 6 and Table 7.

Table 6: Analysis for Willowvale Area (Site A)

Selection factor	Description
Plant location	Plant to be situated in Willowvale
Market study	This is a well-known area for selling farm input products hence very convenient access to farmers
Water accessibility	Water availability
Raw material accessibility	Raw materials have to be transported by road and rail to the plant
Labor accessibility	Labor is readily available due to the high population density
Transport network	Good road and railway network
Local community considerations	It creates jobs
Land accessibility	Land is available for constructing plant
Climate	Good climate

Table 7: Analysis for Hwange Area (Site B)

Selection factor	Description
Plant location	It may be located on power plant site, or near the power plant
Market study	The product would have to be transported to Harare where the market is large and central to end users of the product
Water accessibility	Boreholes would be sunk since council water is not readily available
Raw material accessibility	The site is considerably and economically nearby from raw material
Labor accessibility	Labor is readily available
Transport network	Presence of good road and railway network and the road transport is very reliable
Local community consideration	The plant will create employment to the local people
Land accessibility	Land is vast and there would be need to clear forests to occupy the plant
Climate	The area is very hot
Population density	High density suburb, mostly by workers at the power plant
Environmental considerations	Can be affected by the expansion

5.2 Decision matrix for site selection

The decision matrix favors Harare Willowvale Industrial Area for the plant site, with the higher score 81 out of 100 as represented in Table 8.

Table 8: Decision matrix for bio fertilizer plant site selection

Decision factor	Possible score	Hwange (Site B)	Harare (Site A)
Raw material accessibility	10	8	9
Marketing area	10	6	9
Transport network	10	6	7
Labor accessibility	10	8	9
Water accessibility	10	7	8
Land accessibility	10	10	9
Environmental impact	10	8	7
Disaster preparedness	10	7	9
Local community considerations	10	9	8
Climate	10	7	6
Total	100	76	81

5.3 Bio fertilizer Plant Site Layout

The site plan refers to the arrangement of physical facilities such as offices, road networks, plant areas and sources of utilities. The site layout is shown in Figure 6.

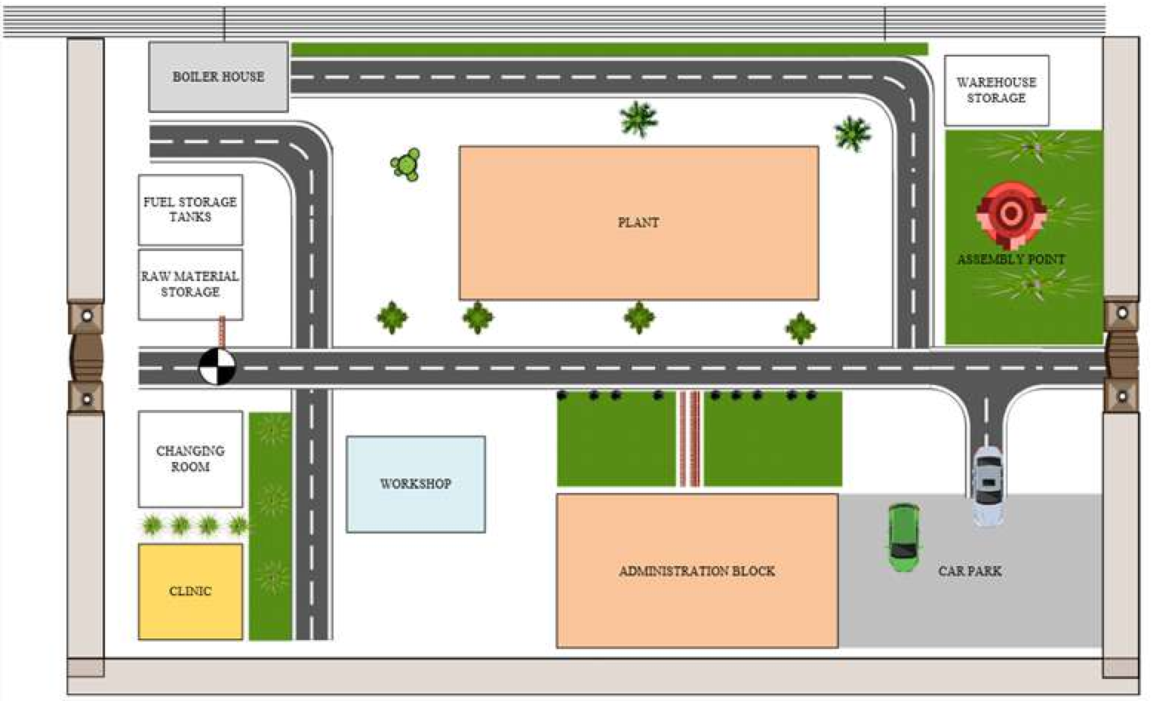

Figure 6: Layout of all buildings on bio fertilizer plant site

5.4 Bio fertilizer Plant Layout

Plant layout refers to the arrangement and geometry of all the plant equipment used in producing the bio fertilizer. The efficiency of production depends on how well the various machines and how production facilities located in a plant. The plant layout is shown in Figure 7.

6 ENVIRONMENTAL IMPACT ASSESSMENT

A preliminary environmental impact assessment as a result of the products and waste materials produced during construction and operation of the bio fertilizer plant is critical. The assessment covers the impact of liquids and solid pollutants on the environment. Recommendations are suggested on mitigation measures to control the potential environmental impacts so that there is compliance.

6.1 Governing Organizations and Acts

The Acts include the Mines and Minerals Act and the Environment Management Act (Chapter 20:27). The Environment Management Act provides for the sustainable management of natural resources and protection of the environment; the prevention of pollution and environmental degradation.

6.2 Environmental impacts and management from the bio fertilizer plant

The environmental impacts associated with the construction and operation of the proposed plant has been studied and the key findings and recommendations are given in Table 9 for the construction and operation phases.

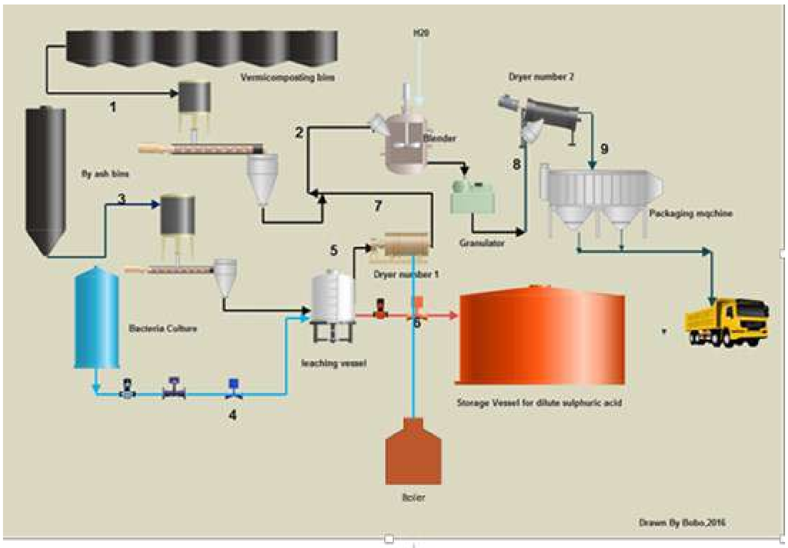

Figure 7: 2D plant layout for bio fertilizer plant

Table 9: Bio fertilizer plant Environmental Impact Assessment summary

Parameter	Project phase	Impact Management
Air quality	Construction	The proposed plant site is currently vacant hence there is no need of demolition hence are pollution due to dust will be less. However, some dust will be generated from excavation and concreting activities for the construction of buildings and equipment foundations.
	Operation	During plant operation, spent fly ash might escape as dust thus causing air pollution.

Noise	Construction	During the construction phase a lot of noise would be generated mainly because of the moving parts of the mechanical equipment on-site such as hammers, excavators and drilling machines which will be used for the construction of the plant. The expected construction noise levels will range from 40 – 80 decibels on-site and 40- 50 decibels for residential premises. These levels are well below the standard noise limit which is 80 decibels over a 25-hour period. Good site construction practices will be implemented by the contractor to further mitigate noise levels.
	Operation	During plant operation, noise will be generated from equipment such as motors and pumps. The noise levels are assumed to be lower and acceptable. No noise is anticipated after hours because the plant will be running on an 8-hour shift daily. The noise levels are well within the maximum range has noise monitoring will not be necessary.
Water quality	Construction	The construction of the plant will be mainly land based. The water quality impact will be very limited since no harmful substances will be used in the construction except for cement. As no quality impact is predicted, no water quality monitoring is considered necessary during the construction phase.
	Operation	During the operation phase, negligible oil spillages will occur which have the potential to contaminate water. The water required in the production process is the blending and leaching water which will be found from boreholes on-site hence will be within EMA limits and no waste water treatment plant will be required.

7 ECONOMIC ANALYSES

A detailed profitability study was done to investigate the economic viability of the bio fertilizer production using profitability estimators such as payback period, return on investment, breakeven point and the net present value. The assumptions on financing estimation of project costs, estimation of manufacturing unit cost and calculation of annual net cash flows were also covered.

7.1 Cost estimation and Estimation of total fixed capital investment

The capital cost estimation was for a 10 tons/day bio fertilizer production process. Fixed capital costs are broken down into direct costs and indirect costs. Direct cost consists of all major processing equipment, installation materials required and civil works, installation labor and supervision. The total purchased equipment costs are shown in Table 10.

Table 10: Purchased equipment costs list for the bio fertilizer plant

Equipment	**Quantity**	**Cost (USD)**
Fluidized bed granulator	1	80 000.00
Dryer	1	50 000.00
Pumps	2	13 700.00
Conveyor belts	1	12 000.00
Compressor	1	13 000.00
Tanks	1	60 000.00

Mixer	1	13 000.00
Storage vessel	1	15 200.00
Screen	1	2500.00
Valves	2	1 000.00
Grand total		260 400.00

Purchased equipment cost (PEC) = USD 260 400.00

According to tax guru in/income tax/cost inflation index.com, 2021 cost index was 525.4 and the cost index for 2020 is 569.5. Therefore, the cost will be as represented by Equations 8 and 9.

$$\text{Cost} = \text{Cost in 2020} \times \frac{\text{Cost index in 2021}}{\text{Cost index in 2020}} \ldots\ldots\ldots\ldots \quad \textit{(8)}$$

$$\text{Cost in 2022} = \text{USD 260 400.00} \times \frac{569.5}{525.4} = \text{USD 282 257.00} \ldots\ldots\ldots\ldots \quad \textit{(9)}$$

Therefore, the purchased equipment cost (PEC) is USD 282 257.00

7.2 Total Physical Plant Cost (PPC)

The plant is handling fluids and solids. The total estimated fixed capital cost is given in Table 11.

Table 11: Estimation of total physical plant costs

Factor	Use	Value
f 1	Equipment erection	0.45
f 2	Piping	0.45
f 3	Instrumentation	0.15
f 4	Electrical	0.10
f 5	Buildings	0.10
f 6	Utilities	0.45
f 7	Site development	0.05

Total PPC is PCE (1.0 $+f_1 + f_2 + f_3 + f_4 + f_5 + f_6 + f_7 + f_8 + f_9$) which is then PCE (1.0+0.45+0.45+0.15+0.10+0.10+0.45+0.05) and equal to USD 776 207.00

7.3 Total fixed capital cost

The total fixed costs are given in Table 12.

Table 12. Estimation of fixed capital costs

Factor	**Use**	**Value**
f 8	Design and engineering	0.25
f 9	Contingencies	0.10

Total fixed capital is PPC (1.0 + f_{10} + f_{11}) which is then PPC (1.0+0.25+0.10) and equal to USD 1 047 879.00

7.4 Direct costs

Material and labor involved in actual installation of complete facility (70-85%) of fixed capital investment. The total direct costs are shown in Table 13.

Table 13: Direct costs summary

Component	**Range (%)**	**Chosen (%)**	**Cost (USD)**
Purchased equipment cost (PCE)			282 257.00
Equipment installation	(20-50) of PEC	35	97 789.00
Instrumentation and controls	(15-30) of PEC	20	56 4510.00
Electricals	(10-50) of PEC	30	84 677.00
Buildings	(10-40) of PEC	15	42 339.00
Yard improvements	(10-15) of PEC	10	28 226.00
Piping	(10-80) of PEC	35	98 789.00
Land	(4-8) of PEC	5	14 113.00
Total direct costs			704 641.00

7.5 Indirect costs

These include rental of construction equipment, construction costs and machinery. The total indirect costs are shown in Table 14.

Table 14: Indirect costs summary

Component	Range (%)	Chosen (%)	Cost (USD)
Engineering and supervision	(5-30) DC	20	140 928.00
Construction expenses	(5-20) DC	15	105 696.00
Contingency	(5-20) DC	15	105 696.00
Contractors' fee	(2-15) DC	15	105 696.00
Total		458 016.00	

Fixed capital investment is the sum of Direct costs and Indirect costs and is USD1 162 657.00

7.6 Working capital

Working capital allows 10 % of Total fixed capital and is USD 104 787.79

7.7 Total capital investment (TCI)

Total investment required is the Total fixed capital and Working capital and is USD1 152 666.00

7.8 Total production costs

Total product costs consist of manufacturing costs and general expenses. Manufacturing cost includes direct production cost (variable production costs), indirect production cost and plant overheads.

7.9 Manufacturing costs

Manufacturing support costs refers to indirect factory-related costs incurred when a product is manufactured.

7.10 Variable costs

The variable production costs are given in Table 15.

Table 15: Variable production costs summary

Item	Cost (USD)
Raw materials	615 934.00 /yr.
Miscellaneous materials (10.0% of maintenance costs)	512.00
Utilities (5.0% of DC)	35 232.00
Total	651 678.00

7.11 Fixed costs

The fixed costs are given in Table 16.

Table 16: Fixed costs summary

Item	Cost (USD)
Maintenance costs (5.0% of Total fixed capital)	58 132.85
Operating labor (10.0% of Direct costs)	70 464.10
Supervision (5.0% of Direct costs)	35 232.05
Capital charges (5.0% of Total fixed capital)	58 132.85
Insurance (5.0% of Total fixed capital)	58 132.85
Total	280 094.55

7.12 Direct production costs

Direct production cost is the sum of fixed costs and variable costs and the total is USD 931 772.00

7.13 Plant overhead costs

Overhead expenses include rent, interest and insurance. The plant overhead costs are given in Table 17.

Table 17. Plant overhead costs summary

Plant overheads	Cost (USD)
Storage facilities (1.5% of FCI)	17 439.00
Medical services (1.0% of FCI)	11 627.00
Safety and protection (1.0% of FC1)	11 627.00
Total	40 692.00

7.14 Total manufacturing costs

Total manufacturing is the sum of variable costs, fixed costs and plant overheads and the sum is USD 972 464.00

7.15 General expenses

General expenses are the sum of administrative costs, distribution and selling costs, research and development. The total general expenses are shown in Table 18.

Table 18: General expenses summary

General expenses	Cost (USD)
Administrative costs	3 146.22
Distribution and selling costs	5 243.70
Research and development (5.0% of PC)	2 621.85
Total	11 011.77

Total production costs is the sum of total manufacturing costs and total general expenses which is USD 983 475.00.

7.16 Production price

Production of the bio fertilizer per hour is 10 000 kg. Assuming 330 working days in a year and 8 working hours per day. A summary of the production costs is given in Table 19.

Table 19: Summary of the production costs for the bio fertilizer

Item	Value
Annual production (kg)	3 300 000
Annual production (tons)	3 300
Total cost of production (USD)	983 475.00
Production price (USD/kg)	0.30
Assuming a profit margin (%)	80
Selling price	$\frac{180}{100} \times USD\ 0.30\ \text{kg} = USD\ 0.54/\text{kg}$
Total income	USD 0.54/kg ×3 300 000 kg = USD 1 782 000.00

7.17 Gross earnings/Income

Gross income is Total income less Total production cost which is USD 798 525.00.

7.18 Taxes

Tax rate is 15% of the gross income which USD 119 778.00.

7.19 Profitability analysis of the project

The lifespan of the bio fertilizer is estimated to be 10 years and annuity factor tables were used to find the discount factor, assuming that running cost remained constant and interest rate remained at 10%. A summary of the profitability analysis for bio fertilizer production is given in Table 20.

Table 20: Summary of the bio fertilizer production profitability analysis

Parameter	Formulae	Value
Net profit	Gross income - Taxes	USD 384 222.00
Net present value	Savings - [Initial investments + 5.6502 x Running cost]	USD 9 709 297.00
Payback period	$\frac{\text{Total capital investment}}{\text{Net profit}}$	3.0 years
Return on investment	$\frac{\text{Profit}}{\text{Total capital investment}} \times 100\%$	33.3%
Break-even point in units	$\frac{\text{Total fixed cost}}{\text{Unit Price} - \text{Unit variale cost}}$	4 610 664 units
Break even in dollars	$\frac{\text{Total fixed cost}}{(\text{Unit Price} - \text{Unit variale cost}) \div \text{unit price}}$	USD 2 489 758.00

8 CONCLUSION

From this study, it is technically, environmentally and economically feasible to produce a blended bio fertilizer from fly ash and vermicompost. A plant producing 10 tons/day of blended bio fertilizer from vermicompost and fly ash was proposed. The nutrients in the fly ash were leached out using a bio catalyst. The automated bio fertilizer plant will have the major environmental impacts to be controlled. A total capital equipment investment of USD 260 400.00 is required for a potential selling price of USD 0.54/kg for the bio fertilizer. The net present value of the project is 9 709 279, with a payback period of 3.0 years and rate on investment of 33.3%. Fly ash and vermicompost can be utilized to make a blended bio fertilizer.

9 ACKNOWLEDGEMENTS

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IMPROVING MANUFACTURING PERFORMANCE INA PRINTING PUBLIC INSTITUTION: A SOUTH AFRICAN PERSPECTIVE

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ABSTRACT

Lean manufacturing improved the performance of the Government Printing Works' (GPW) through the adoption of lean tools. An average of 50% overall equipment effectiveness (OEE), average of 4.5% down time due to printing machine breakdown and poor layout add to waste generated by the printing system. The objective of the study was to investigate the effect of lean systems in the printing industry. Taking the view that printing systems are production processes, this study designed a system for improving the productivity rate, and affords a preliminary validation. A qualitative research approach was adopted to collect and analyse data. Furthermore, literature was reviewed to ascertain the current knowledge and data available on lean manufacturing tools used in the printing industry. The study found that human factors, poor material management, equipment inefficiency and layout are causes of waste. Excessive motions that were found to be caused by poorly laid out factory reduce the printing system efficiency.

Keywords: lean manufacturing; value stream mapping; continuous improvement; competitiveness; defects

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1 INTRODUCTION

Lean manufacturing practices is important for organisational operational competitiveness [1]. The South African printing industry, including the Government Printing Works (GPW), employs approximately 45000 people with as many as 500 000 dependents and has an estimated turnover of R51 billion [2]. The GPW was established in 1888 as a security printer. The printing industry with the GPW included, is reported as having a high workload [3]. Long working hours are among the factors attributed to low labor productivity and to employee fatigue. The poor reward system has led to employee dissatisfaction and poor layout results in unnecessary motions that has negatively affected operational performance [3]. Late deliveries of printed materials; raw material wastages, waiting and current reject rate have also negatively influenced GPW's overall performance [4]. There are many factors which cause uncertainty and that have a possible impact on production and the business [5]. For example, customers demand that manufacturing industries should be more productive and compete in global markets in relation to delivery, cost, quality and use of technological factors [6]. Improved financial performance results from the utilisation of lean manufacturing tools in the printing process to reduce costs economically [7]. This research study sets out to investigate the effects of lean thinking on production processes at GPW. The paper also presents an approach to man power study in which a function is generated by the time study of the printing process.

2 LITERATURE REVIEW

The research studies documented quantitative and qualitative lean manufacturing operational benefits for manufacturing businesses which printing industry is part of [8]. Lean manufacturing as managing the shop floor through reducing manufacturing waste such as excessive inventory, motion, unnecessary waiting, over-production, over-processing and rework [9]. Reduction of waste in resources such as human capital, machinery and floor space by reducing idle time, set-up time and work-in-progress in the printing industry is referred to as lean manufacturing [10]. Lean manufacturing principles' implementation reduced waste and inventory [11]; [12]; [13]. There is a variety of lean manufacturing tools that are in use within the manufacturing sector. Good housekeeping, as postulated by [14], refers to implementing 5S to ensure continuous improvement as a lean manufacturing tool. Continuous improvement help reduce manufacturing costs and improves quality [15]. Waste reduction methodology as a lean manufacturing tool focuses on waste generated during print production which needs to be identified and eliminated. Ahuja [15] identified seven waste which include over-production, over-processing, transport, waiting, inventory, defects and motion. Quality improvement as a lean manufacturing tool involves continuously enhancing the business competitiveness through the use of total quality management, continuous improvement and value stream mapping in the print production of the business [9]. Total preventative maintenance (TPM) assist in overcoming delays and downtime from ineffectiveness of machines used in the printing system [11]. TPM reduce operating costs and waste by preventing breakdowns, set-up time, idling, stoppages and process defects [14]; [15]. In order to create an improved understanding of the flow of information and materials, value stream mapping (VSM) can be used [7]; [13]. VSM focuses on employee movement, material flow, visualizing work area and movement of machinery to reduce waste in print production [16]. VSM is applied in manufacturing in order to analyse and eliminate unnecessary inventories and waste along the value chain with an aim of reducing operating costs [13].

The term quality of conformance is used to describe that the manufactured product consistently upholds the specifications in product design [5]; [13]. Defect detection uses inspection, testing, and analysis to determine the existence of defects. This information is then used to draw conclusions on the quality of the overall process. Ghosh [17] postulated that, inspection is deemed necessary to control the quality of the product or service provided either online or offline. Defect inspection helps ensure that the faulty products do not reach the hands of the customer. The challenge with defect detection is that it does not improve the quality of the printed material or reduce the amount of paper waste associated with scrap. Lean thinking and its principles, as argued by Dora et al. [18] advance manufacturing efficiency by decreasing lead times through waste elimination and has been successfully applied to the manufacturing and operational environment. Fostered by a rapid spread into many other sectors beyond the automotive industry, there has been a significant development and localization of the lean concept in general. Lean is a philosophy that can be applied throughout the entire business process. Lean is a strategy that affects every aspect of the organisation. Although, Lean practices started in manufacturing, the methodology can be applied in every aspect in an organization [19]. Lean based methodology focuses on eliminating non-value-added activities and streamlining operations by coordinating all of the activities [20].

The primary objective of Lean manufacturing is to improve manufacturing operations, increase productivity, reduce lead time and improve the quality of products [11]. A Lean operation is a flexible system that uses considerably less resources, inventory, people, and floor space than a traditional operation. These improvements are accomplished by eliminating non-value-added activities, shortening manufacturing lead times, improving product flow, and establishing a process of continuous improvement [12]. As printing plays an important role in the national economy, there is a need to assist the printing sector to improve its profit margin. This can be accomplished through improved forecasting, planning systems, and cycle times to improve on delivery performance and decrease inventories to improve profit margins [5]; [21]; [22].

3 RESEARCH METHODOLOGY

The study adopted a qualitative research approach. A sample of eighteen (18) respondents, selected using purposive sampling, answered a semi-structured interview. According to Creswell [22], a qualitative research method is an exploratory research technique used to understand the underlying reasons, opinions and motivations of individuals in solving a problem. In-depth face to face, semi structured interviews and systems observations were used in this study owing to their usefulness in gathering data [23]. Open-ended questions were used in the interviews to collect empirical data from a selected panel of experts in the GPW. This approach allowed the researcher the flexibility to explore deep insight into respondents' knowledge and experiences, thus leading to relevant conclusions and recommendations. A systematic observation was conducted which considered the waste and inefficiencies of the printing process.

4 RESULTS AND DISCUSSION

Facility layout is an important element of a printing business to eliminate sources of waste. Hence, the basic purpose of layout is to ensure a smooth flow of work, material, and information through a system [24]. Looking at the information provided by 50% of the respondents, layout is a hindrance in achieving lean manufacturing. Human factor also was identified as the contributor to weakened productivity of the GPW as indicated by 67% of the respondents. 100% of the participants postulated that suppliers negatively impact the printing process due to late raw materials supply. Lean, as a philosophy that reduces delays through eliminating sources of waste, could be adopted to improve the situation. To understand and give support to the participants' responses, the system was also observed. Participants included senior management, middle management, lower management, planners, artisans and printer's assistants within the value chain. The current process is discussed below.

4.1 Current process

Technical planning undertakes the arranging part of the job and then moves onto 'Origination' for desktop publishing. Upon receiving approval from the customer, the signed proof is sent to ‘Origination’ to resume with the production of printing plates at the Visagie street factory. Printing plates are then sent to the printing divisions for production to resume. Unfinished printed material is sent to the finishing division. After finishing, depending on the customer’s specification, the finished items are delivered to the customer, or sent to the packaging section for specific packaging style before sending to the customer. Figure 1 represents the current process flow at the Bosman factory:

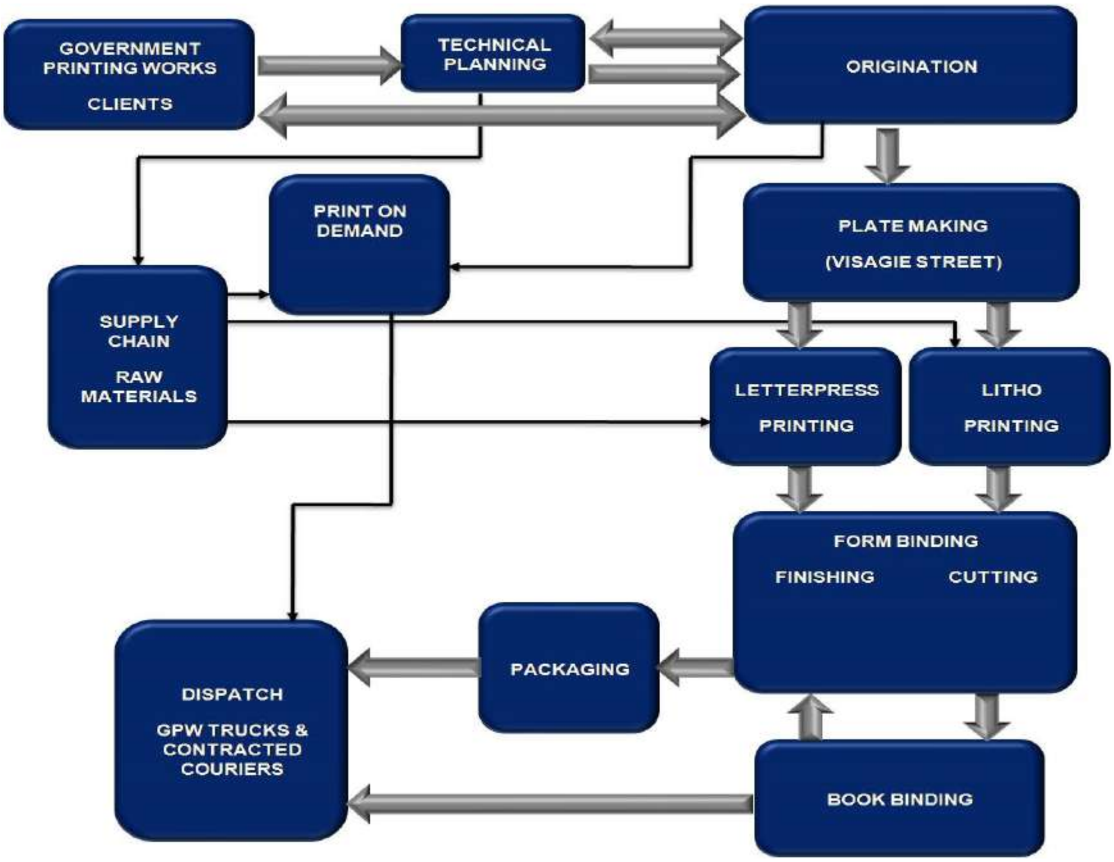

Figure 1: Current Bosman street factory process flow

The most significant causes of time delay identified in this research are; delay of material delivery to packaging section, quantity defects and incorrect quantity as well as lack technical skills. With late delivery of material and lack of technical skills currently affecting productivity. With the annual employee turnover of 5.8%, human capital as an input factor affects productivity negatively. Lack of operator training results in the inefficient use of the equipment acquired by the GPW. This is evident in the packaging section with a packaging line installed but with no trained operators, while for the machine to run flawlessly at least 3 operators must be on duty. Maintenance of the critical service lift is done by an external service provider which lengthens the response time in the case of a breakdown. The production is affected by the breakdown of the service lift, as the paper store is situated at ground floor level and the printing room at the first floor. The aging manually operated box-stapling machine delays the efficient packaging of the finished products for shipment to the customer. Every breakdown is fixed in no less than 2 hours, thus delaying packaging by at least 3 hours due to the increased inventory. The use of older printing machines affects productivity negatively. Older and outdated machines lack the most useful features compared to the modern machines including high production speeds and flexibility. The out of line finishing machines contribute to time wasted while moving unfinished material from the printing to finishing sections [23]; [24]. Factory design and layout prohibits efficient manufacturing of printed material, as different sections involved in the process are at different levels of the three-storey building. The 1600m distance between the printing plate-making machine (CTP) and the printing machine increases the time it takes to print after producing the printing plate. Completed items that do not meet the specifications become waste, as printed paper cannot be reused, likewise the used ink cannot be salvaged [25]. The machine proof produced using the poorly set and maintained machine tarnishes the quality of the entire production run. Different processes involved in the production of a printed material are discussed below.

4.2 Printing

Printed material is produced using a variety of processes including offset printing (Litho division), continuous printing (Letterpress division) and digital printing (POD). High volume products using the offset process are produced at 10000 units per hour by the Letterpress division. Artisans are not able to operate different types of printing machines, making it difficult to produce if the operator working on that specific machine is not at work in a shift. Such delays increase workload, creating a bottleneck in the printing process. The rest of the time was used for collecting job cards and proofs, collecting paper reels and for tea and lunch breaks.

4.3 Finishing

Finishing, form binding and book binding, are affected by the delays in Origination. More unfinished goods are received simultaneously from the POD and Letterpress printing divisions with very limited capacity to finish them that creates a vast unfinished goods inventory. Line balancing is a challenge whose effects are clearly visible at the finishing stage of the printed product. The increase of unfinished goods inventory is due to the finishing machines throughput of 7,000 booklets/hour which is slower than the printing speed of 10,000 booklets/hour from the web machine. The finishing process is similar to the other processes, considering that the printed products are security products. It is for this reason that, at each end of the production cycle, the finished and unfinished materials were moved to the storage area, as it would not be appropriate to leave material on the work area.

4.4 Packaging

The packaging machine has a throughput of 120 boxes per hour which delays the process even more. With one packaging line installed, the volumes of up to 5million units must be packaged into an average of 80,000 boxes in one season spanning over six consecutive weeks. Considering the machine capacity, the total boxes to be packaged requires at least 4 months, working an 8-hour shift for 5days a week. Due to the ever-demanding nature of the printed material, the GPW therefore incur additional costs for overtime remuneration for employees that worked extra hours to ensure delivery schedules are met. This becomes overwhelmingly too much to process and contributes to late delivery. Box material that is sourced from abroad is a source of additional costs due to the exchange rate. Delayed supply of box material result in loss of time and increase the underutilisation of equipment to understand the cause and sources of wastes in the printing process, value stream mapping was used.

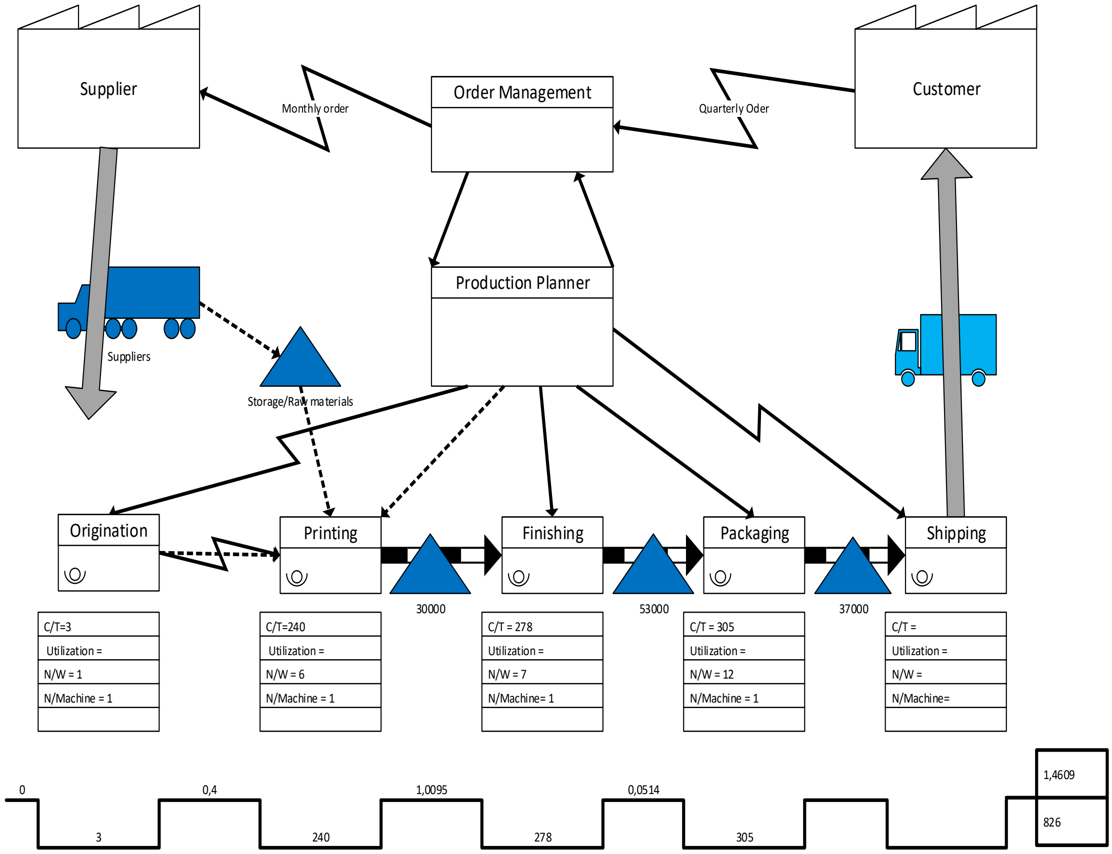

Figure 2: VSM current printing process

4.5 Distance between Machines

The distance between machines used has a negative impact on lean manufacturing, as longer distances take longer to be travelled when transporting materials between the machines. The distance from the Computer to the plate making machine (CTP) is 1600m. Relocating printing machines closer to the packaging and finishing machines would reduce distance travelled the OCE Digital Printing and CMC Packaging machines by 80.49%. This distance from all machines in the production line indicates a poorly laid out factory as presented by Table 1 below:

Table 1: Distance between machines

Machine Distance in Meters						
List of Machines:	**CTP (Printing plate making machine)**	**Solna Printing Machine**	**Dev Printing Machine**	**OCE Digital Printing Machine**	**Martini Stitching Machine**	**CMC Packaging Machine**
CTP (Printing plate making machine)	0	1600	1600	1600	1600	1600
Solna Printing Machine	1600	0	5	20	10	25
Dev Printing Machine	1600	5	0	25	10	20
OCE Digital Printing Machine	1600	20	25	0	35	41
Martini Stitching Machine	1600	10	10	35	0	6
CMC Packaging Machine	1600	25	20	41	6	0

4.6 Machine utilisation

Production time in hours is inefficiently utilised, as out of 6 work centres, only one work centre remained operational at 96% which is well above the industry's 85% [25]. A total of 5 other work centres operated below 60%, with CTP being the worst at 33%. The overall downtime of the 2 printing machines, i.e. Dev and Solna, was 68.2 hours over a 3months cycle reducing to an availability of the two printing machines. Machine utilisation over 3 months is presented by Table 2 below:

Table 2: Overall machine utilisation over 3months cycle

WORK CENTRE NUMBER	WORK CENTRE NAME	AVAILABLE HOURS	ACTUAL HOURS WORKED	UTILISATION PER WORK CENTRE	DOWN TIME IN HOURS
310900	CTP	451,44	149,8	33%	0
320622	DEV	451,44	249,1	55%	36
320822	Solna	451,44	204,7	45%	32,2
340702	OCE	451,44	432,15	96%	0
360744	Martini	451,44	261,15	58%	0
373010	CMC Packing	501,6	238,53	48%	0
TOTALS:		2758,8	1535,43	55%	68,2

4.7 PROPOSED APPLICATION OF LEAN SYSTEM

Interview participants identified shortage of skilled operators; poor quality raw materials and poor layout as sources of waste in the printing environment. Based on the identified sources of waste, the below strategies were suggested to improve the printing system.

TPM

TPM as a productivity improvement tool assisted in improving GPW's productivity through improving equipment efficiency [26]. The procedure below presents how TPM could be used to assist in improving the utilisation of resources:

Action plan:

a) Remove all equipment used for the printing process from Bosman street factory.
b) Install equipment at Visagie street factory closer to each other.
c) Production management and maintenance management discuss new maintenance schedule.
d) Educate machine operators about new plans.

4.7.1 Sustain developed maintenance plans

Resources required:

a) Rigging company.
b) New factory space.
c) Equipment maintenance manuals to identify maintenance needs per machine.

Targeted outcome:

a) Improved overall equipment efficiency.
b) Effective machine operators that are knowledgeable.
c) Supportive management to improve machine efficiency.

4.7.2 Operator training

Training employees with an aim of improving efficiency during production assisted in improving performance by reducing time wasted during machine set up and minor equipment maintenance [27]; [28]. The procedure is discussed below explaining the action plan, resources needed and targeted outcomes.

Action plan:

a) Identify problem areas.
b) Select operators to be trained.
c) Appoint apprentices to increase operator base.
d) Set out clear and achievable operator training targets.
e) Recognise and reward successful operators.

Resources needed:

a) Operator training manuals.
b) Knowledgeable facilitator to train operators.
c) Reward system.

Targeted outcomes:

a) Effective and efficient operators.
b) Motivated operators.
c) Supportive management to continuously encourage operators.

4.7.3 Material management

Raw material wastage and its quality affects operational performance of the GPW [29]. Since lack of material availability increase delays while waiting for supply, it is vital to ensure that correct inventory level is maintained. Furthermore, the quality of materials affects the production process and ultimately the quality of the printed material. To reduce challenges associated with material, the procedure presented below was followed in developing a material resource plan:

Action plan:

a) Establish demand management team.
b) Adopt the use of a material resource planning system.
c) Ascertain material demand volumes.
d) Source reliable supplier.
e) Compare previous demand with future demand to develop new order points.
f) Regularly check physical stock to test the effectiveness of the material resource planning system.

Resources needed:

a) Demand management personnel.
b) Material resource planning system.
c) Physical stock item forms to record stock.

Targeted outcomes:

a) Reduced risk of material shortage.
b) Identification of reliable suppliers.
c) Effective material resource planning system.

4.7.4 Layout

The use of layout design to eliminate time and skill waste enabled GPW to improve on its performance. The initial layout between printing and packaging made the process flow inefficient. Improving layout reduced the non-value adding movement in the printing, finishing and packaging section. The current system process chart indicated that there were less inspection activities on the proposed system, with 21 compared to 270 activities in the current system. Furthermore, there was a significant decrease in delay activities from 355minutes to 98minutes as well as in the transport activities, from 755minutes to 532minutes. The decline of these activities had a positive impact on productivity, as 986 minutes of production time was saved, equaling 35.4%. The improved layout is represented below by Figure 3:

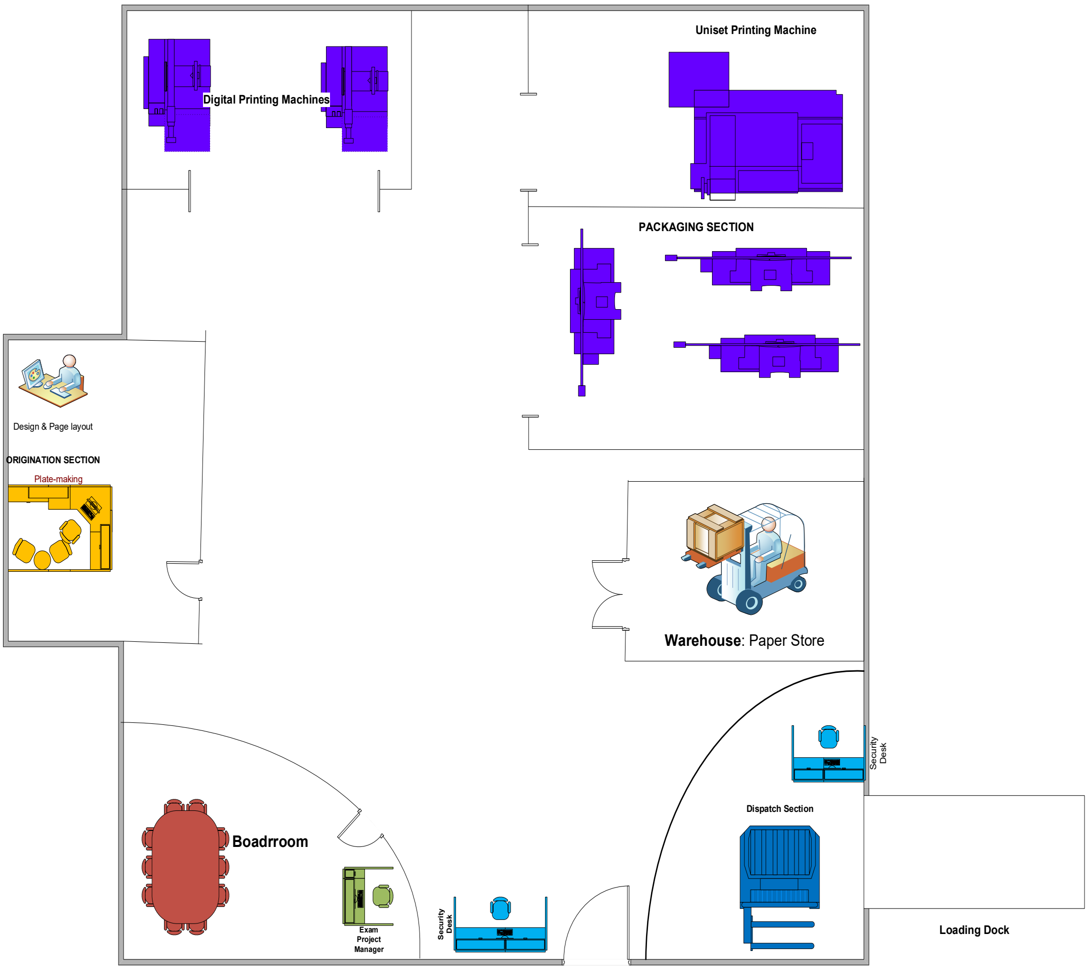

Figure 3: Improved layout

4.8 Roster plan

Implementation of a Roster Plan reduced time wasted for breaks, i.e., tea and lunch. Before the implementation of a roster plan, employees had to stop production earlier than their official breaks to allow clearing the floor of the security material and ensuring proper storage of these materials. Furthermore, upon returning from the respective breaks, more time was wasted collecting material from the storage area. The roster plans allowed employees to take staggered breaks ensuring production never stops due to employee breaks. A total of eighteen (18) participants contributed to the research study, eleven (11) are males and seven (7) were females. The current system loses 250minutes per tea break and 322minutes per lunch break equaling 572minutes lost per shift amongst printing, finishing and packaging sections.

Table 3: Time wasted during official breaks in minutes

ITEM	PRINTING SECTION	FINISHING SECTION	PACKAGING SECTION
Tea Break	45	65	140
Lunch Break	100	92	130
Total Time Wasted	**145**	**157**	**270**

The saved time after adopting lean manufacturing tools assisted the printing system to print an additional average of 15000 exam papers over 145minutes saved, based on the 10000 Exam papers/hour production rate. Furthermore, the additional 15000 printed item could be processed at the finishing section during the saved time of 157minutes. Further down the production line, this additional 15000 exam papers could be packaged using this saving of 270minutes for the packaging section. The total saved time could see the increase of 15000 exam papers, from 30000 up to 45000 completed exam papers, packaged and ready for delivery.

4.9 LIMITATIONS OF THE STUDY

Like any other study, the paper comes with some limitations that must be pointed out. First, the results of the study were limited to a sample composed of 18 participants using semi-structured interviews who were based in one public printing works in Gauteng province of South Africa. This placed a restriction on the extent to which the findings could be generalised to other public printing works in other provinces.

4.10 RECOMMENDATIONS FOR FURTHER RESEARCH

The study identified sources of waste and the effect it has on performance. Further research should be undertaken to develop a framework that can be used to promote lean manufacturing in the printing industry. The study has contributed hugely to understanding the impact of lean manufacturing for the Public Printing Works in South Africa. The main findings of the study showed that layout and human factors affect efficiency of the printing industry. To effectively eliminate sources of waste, printing companies should design processes properly. Excessive motions and distance between machines that were found to be caused by poorly laid out factory were reduced due to improved layout. Further studies can conduct on how to implement lean manufacturing processes and establishing a lean manufacturing system in a public printing institution.

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EXPLORING REGULATION AND LEGISLATION - APPLICATION OF SELECTED NANOTECHNOLOGY INITIATIVES IN THE FOOD INDUSTRY: HUMAN HEALTH

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ABSTRACT

Nanotechnology is congruent to various industries such as medical, food and agricultural sector. However, its potential unintended effects to human health have raised concerns from the public. Currently, there is insufficient conclusive knowledge of the potential risks that may result from either direct consumption of Nano-enabled food products or exposure from Nanomaterial. This is due to its dynamic phytochemical properties, functions, interactions, dosage and toxicity. To prevent future undesirable effects, robust regulations and legislations are required. This paper presents information on food regulation and legislation. It provided awareness and theoretical information worth considering when establishing legislation or regulations. Data was collected via a systematic review. This study used content validity and inter-rator reliability. No ethical clearance was required. The results showed that there is an ambiguity among scholars regarding the responsibilities and role played by the Regulator to control the application of Nanotechnology in the food industry.

Keywords: Nanotechnology, Nanomaterial, Disruptive Technology, Regulation, Toxicity mechanism

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1 INTRODUCTION

The food industry has enjoyed the application, innovation, research and development of Nanotechnology since 2003 [1, 2 and 3]. In the recent years, the application of Nanotechnology regarded as disruptive technology, is situated firmly as part of the Fourth Industrial Revolution (4IR) to achieve tremendous benefits to mankind [4]. Publications from Allan et al., [5]; Gottardo et al., [6]; Akakuru et al., [7]; Zhang, Rui and Simpson [8]; Mishra et al., [2]; Adeyeye and Fayani [9], Jain et al., [10] and Lyons and Smith [11] support that the application of Nanotechnology is cost effective and plays an essential role in the food industry, by improving food texture, colour, taste, nutrients, quality, active packaging, and up-grading food safety measures. Ashraf et al., [12] and Zorraquin-Pena et al., [13] report that Nanotechnology has been used in various food sectors such as fresh produce, meat and meat products, dairy products and in baking industry to improve product quality and shelf life.

According to Leidy and Ximena [14] Nanomaterials can be used to improve and maintain the quality of food products. A study by Gottardo et al., [6] corroborates with Adeyeye and Fayani [9] and Jain et al.,[10] who are of view that Nano-encapsulation of bioactive compounds such as carbohydrates, lipids, vitamins and proteins are nutritionally beneficial. It allows bioactive compounds to resist hostile conditions such as acidity, high pressure and high temperature in order to reach a suitable target [15]. In addition, Nano-silver is used for coating vitamins to prevent denaturation until it reaches its target site [9]. This is in agreement amongst Adeyeye and Fayani [9], Garcia, Shin and Kim [16], He, Deng and Hwang [3] and Lyons and Smith [11] that the use of inorganic Nano-particles such as silicon, silver, copper and metal oxides, which possess gaseous and moisture barriers, thermal resistance and anti-microbial properties can be used to prevent growth of microbes. Valdiglesias and Laffon [17] describe other significant uses of Nanotechnology for example the use of analytical methods to detect and inactivate chemical contaminants and microorganisms present in food products.

Nanomaterials, such as silicon nanoparticles (SiNPs), due to its affordability and minimal toxicity can be functionalised as a coating agent in the pharmaceutical and food industry [4 and 18]. SiNPs are highly reactive with lipids and can change its functional properties. SiNPs can also be synthesised with electrons to make it faster, non-reactive and flexible while increasing its stability.

Despite the innovation that Nanotechnology can bring, there is some trepidation concerning potential risks to human health [6, 7, 10, 11 and 19]. There is limited knowledge in the application of Nanotechnology, concerning its unique phytochemical properties, functions, interactions, dosage, toxicity and non-scale. This limited knowledge has raised concerns to the public, scientists, government agents and researchers [3 and 6]. According to Leidy and Ximena [14] there is limited evidence regarding the potential hazards and risks that may affect human health after being exposed to Nanotechnology products or after consuming nano-enabled food products. Studies by He, Deng and Hwang [3] and Jain et al., [10] describe the potential chronic diseases that may result from the excessive consumption or exposure to Nanomaterials. Of concern, there is a potential to increase the production of reactive oxidative species (ROS) which is known to trigger the generation of new blood cells and result in cell mutation [20]. In the long term, this may cause damage to organs or have potential carcinogenic effects.

1.1 Scope

Many uncertainties remain concerning Nanotechnology because of a lack of exclusive legislation to regulate Nanotechnology globally [5, 10 and 21]. Yet, the product development and innovation of Nano-products are exponentially growing in comparison to regulatory frameworks [5]. This paper aims to present current regulations and legislation in the application of Nanotechnology focusing on the food industry. It will provide awareness to the public and offer theoretical information that can be considered when establishing legislation or regulations. Furthermore, this paper will outline the possible concerns and review the current theoretical knowledge related to risks of Nanotechnology. Moreover, it will endeavour to present crucial challenges that are delaying legislators in developing regulations and legislation in Nanotechnology.

2 LITERATURE REVIEW

The application of Nanotechnology in the food industry can be regarded as a novel solution to challenges currently experienced worldwide and is outlined in the Millennium Development Goals, particularly those relating to food insecurity, the rapidly growing population, climate change and pandemic diseases [6, 12, 10, 22 and 23]. There is still a debate around the definition of Nano-materials and Nanotechnology [16]. However, Cushen et al., [19], Chellaram et al., [24], Allan [5] and Gottardo et al., [6] define Nano-materials as a material with one or more internal or external dimensions at a nanoscale ranging from 1 nm to 100 nm. However, according to Ashraf et al., [12] this definition is not appropriate as it is only applicable to materials in a solid particle form and does not distinguish the difference between toxic and non-toxic materials. Nanotechnology is a phenomenon that is derived from chemical manipulation of atomic molecules at various nanoscales to achieve desirable functional properties [12 and 15]. Therefore, it can be inferred that there is no standardised definition.

Adeyeye and Fayani [9] and Ashraf et al., [12] report that scientists are concerned with the lack of specific legislation controlling the application of Nanotechnology and the consumption of the nano-enabled products for a prolonged period of time because of potential negative human health effects. In addition, a study by Lyons and Smith [11] criticises the use of nanoparticles such as Hydroxyapatite, Silica-dioxide, Iron-oxide and Titanium- dioxide (TiO2) in American and Australian products such as baby formulas. Akakuru et al., [7] agrees with He, Deng and Hwang [3] that there are nanomaterials used directly in contact with food but that have not been approved yet, such as silver nanapacticles. However, there is an exceptions, for example, Iron-oxide and TiO2, which are currently used as a food pigment agents, food flavouring enhancers and disinfectant agents [26]. Based on preliminary research it can be concluded that there are no approved risk assessments, validation procedures and toxicological mechanisms for nanomaterials.

2.1 Titanium-dioxide

The use of TiO2 in various food products is a topic of interest and argument globally. TiO2 is mostly used as a food additive to offer whitening properties in various products such as fresh produce, chocolates, doughnuts, ice cream, chewing gums, cheese, ready prepared mashed potato, coffee creamer, yoghurts, pop-tarts, and confectionary [11 and 25]. Interestingly, Akakuru et al., [7] agrees with He, Deng and Hwang [3] that the prolonged consumption and exposure of TiO2 may cause adverse damages in humans by causing possible geno-toxicity and a possibly impaired immune system response. France questioned the safety of TiO2 as a food additive and led a re-evaluation of TiO2 in 2017 [11]. In addition, France Farms™ and Food Bill Revisions™ support a ban of TiO2 in the food market which was then passed in 2018. Some U.S. organisations have discontinued the use of TiO2 in their products [3]. The Food and Drug Administration (FDA) and European Union (EU) ([5] and [11]) have approved the use of TiO2 in trace amounts (between 1 um to 100 um). According to Allan et al., [5] the EU regulation number 1169/2011 stated that the use of TiO2 should be legibly declared under the ingredients list with the word "Nano" in brackets next to TiO2 or E171. In 2014, the clause on labelling of Nano-materials was eliminated from the legislation because it was suspected to cause confusion among customers [5]. It is argued that the amendment of the regulation to exclude mandatory labelling of Nanomaterials, denied the consumer of their four basic rights; to be informed, to choose, to be heard and to be safe [25]. However, given that the FDA and EU have approved the use of TiO2 it can be deduced that this Nano-material is generally regarded as safe (GRAS) for use.

According to He, Deng and Hwang [3] regulations and legislation are an official source and a mutual point of reference between the public and organisations. They could play a critical role for the inference of Nanotechnology applications in food products. Nanotechnology and its applications have economically contributed approximately $3 trillion from 2003 until 2020 to the global economy. Jain et al., [10] conceptualise the importance of understanding the toxicity effect of nanomaterials in order to design and engineer safe and predictable products. Therefore, more effort is still required from regulators and legislators in order to prevent future catastrophes and improve public perception of Nanomaterials in food.

2.2 EU regulation

The EU has enacted the most comprehensive and stringent regulation compared to other governing bodies across the world [16, 27 and 28]. According to Allan et al., [5] the EU uses a safe-by-design approach. This encourages Nano-products must be safely produced from farm to fork. Great emphasis is evident in agriculture and in the research and development stages. Allan et al., [5] corroborates a study by Valeria et al., [25] which states that the EU has provided a legally binding definition on terminology of Nanomaterials. However, Allan et al., [5] and Adeyeye and Fayemi [9] criticise this definition on the grounds that there are no acceptable definitions for Nanomaterial. Valeria et al., [25] mentioned that the EU regulators has published five regulations regarding Nanotechnology that includes Reg: 1332/2008, Reg: 1333/2008, Reg: 450:2009, Reg: 10/2011 and Reg: 2015/2283. The latest Regulation of novel foods, states that nanomaterial registered under the EU must be authorised (if it does not pose potential risk) before it is used in food products and that the preparation procedures must be known [6 and 25]. Despite this, He, Deng and Hwang [3] argue that there is still more effort required to establish legislation that is more robust. Leidy and Ximena [14] and Mech et al., [29] posit that the European Food Safety Authority (EFSA) admits that there is a poor understanding and insufficient scientific evidence on the potential risk posed by Nanomaterials. Another school of thought suggests that there is vigorous scientific evidence (risk assessment test, testing procedure, physiochemical characterisation methods) shared by scientists and scholars to EU policy makers. However, they state that the EU regulations and legislation are still too lenient and key areas are not covered in the recent regulation [5, 6 and 16]. Although there are gaps in EU legislations regarding Nanotechnology, the existing legislations can be used as the foundation to develop further legislation.

2.3 The Food And Drug Administration (FDA)

The Food and Drug Administration is a United States Federal Agency that is responsible for regulating food additives including Nanotechnology products in food colorants and flavours. Leidy and Ximena [14] and Garcia et al., [16] describe the process of regulating new flavouring and colouring agent and it includes the following steps: risk assessment analysis (to ensure its intended functions and safety), approval, registration on the GRAS list database, and establishing or maintaining regulation of food additive in packaging labelling. However, the FDA does not intend to establish a specific, detailed and legally binding regulation on Nanotechnology applications except the guidelines for industries to voluntarily adopt regulations. According to Lyons and Smith [11] and Garcia et al., [16] the FDA emphasised that although nanomaterials may have a GRAS status it does not imply that they are safe at its nanoscale. In contrast, Allan et al., [5] reported that FDA has built a research facility that has a laboratory for conducting analysis and safety assessments of products containing Nano materials. In addition, the FDA has initiated a program to train its staff on data analysis, assessment tests and gap analysis to establish a possible standard on food Nanotechnology. The FDA has collaborated with the EU and other departments operating under National Health, to focus on the following: human health, human exposure assessment, nanomaterial measurement infrastructure, risk assessment and risk management and environmental informatics and modelling [5]. The FDA uses a horizontal scanning approach that is referred to as the data collection technique to conduct hazard analysis or risk assessment of potential threats that may develop in a medium to long-term time period. In addition, the contribution of FDA in controlling the use of Nano edible products in the food industry is at an early stage but continuously improving to meet the changing research and development sector.

2.4 Other countries

Canada has implemented a policy for regulating Nanomaterials and its objectives include: defining the term Nanotechnology, establishing a list of Nanomaterials, creating a register all products and devices associated with Nanotechnology and maintaining the policy under the jurisdiction of Health Canadian Government [5 and 14]. Garcia et al., [16] reports that Canada has also created a website for sharing and the exchange of relevant information regarding Nanotechnology. Other countries are still at an early stage with developing a regulation and requiring resources for future projects [5]. However, some private organisations are adopting the EU and FDA regulations to meet customer expectations.

2.5 The gap of knowledge

From the analysis of the preceding sections, it can be inferred that there is no specific legislation focusing on the applications of Nanotechnology therefore guidelines, standardised test methods, controlling methods, monitoring procedures and traceability programs for Nanotechnology used in food products are limited.

The existing legislation does not cover every aspect of Nanotechnology yet, product development and innovation of Nano-products is growing at an exponential rate. This is due to insufficient scientific evidence on risk assessments, toxicity mechanisms and interaction ability. According to He, Deng and Hwang [3] a lack of scientific data and tangible evidence is the main challenge preventing regulators from making stringent regulations.

According to Jain [10] in order to establish regulations and legislation in the application of Nanotechnology, the toxicity mechanism of nanomaterials must be studied and known to predict the interdisciplinary interactions and possible adverse effects. Another factor that needs to be considered when evaluating the interaction characteristics is the surface area and size of dimensions. Risk assessment frameworks should involve a systematic thinking, probability analysis lifecycle and event trees [6 and 30]. Another school of thought states that microbial system, silico and vitro approaches can be used to assess nontoxicity of nanomaterial. Moreover, invitro, invivo and silico have been used to assess toxins and these methods are highly recommended [12]. Scanning electronic microscope and dynamic light scattering are techniques used to determine the size of Nano-particles. Scientists suggest that the nature of Nanomaterials should be identified and if there are intentionally or unintentionally present in food products in order to conduct its risk assessment. Nanomaterials tend to undergo physicochemical changes upon processing and depend on the method (during emulsion, gridding and spray drying) packaging and preparation [5 and 16]. Therefore, it can be inferred that there are test methods that can be used for risk assessment purposes. In conclusion, more informative studies are required for the relevant stakeholders and government agencies to establish stringent regulation and legislation.

3 RESEARCH METHOD

Theoretical research is conceptualised as a framework that consists of a logical exploration and understanding of the existing theories. It can also include addressing the gap of knowledge and applying the known information to develop discussions while determining the missing information [31]. This paper will follow a theoretical strategy and was stimulated by a critical thinking.

According to Naylor [32] there are several research methods available. These includes; action, case-study, content analysis, correlation, development, ethnography, experimental, ex-post facto, grounded theory, history, observation, survey, quasi experimental and systematic review. A systematic review is an ideal technique to adopt in order to achieve a solid and informed literature review. A systematic review method will be utilised for convenient data collecting and for accurate representation of qualitative data on Nanotechnology in food products.

This study adapted a qualitative approach to provide an informative, rigorous, holistic and complex picture of the problem statement and used non-probability and purposive sampling. Purposive sampling allowed the selection of an appropriate and representative sample of data in a heterogeneous population [31].

An electronic comprehensive search was performed using different databases such as Web of science, Scopus and ProQuest. The search was limited to English articles and peer reviews published from the years 2016 to 2021. The search included the phrases “Nanotechnology effects”, “Nanotechnology health risk” and “Food Nanotechnology legislation”. The preliminary articles were exported to EndNote. The 3-phase selections outlined by Xiao and Watson [33] were used, Phase 1: removing duplication, Phase 2: screening the article for meeting the desired criteria based on title and abstract and Phase 3: selection based on full text availability. Only 31 peer-reviewed articles were shortlisted and used for the main paper. To avoid risk of bias, descriptive statistics was used and will be presented in bar graph in the results and discussion.

Content validity was achieved by consulting with an expert [33]. Inter-rator reliability was used to confirm the reliability of the results by reading and analysing shortlisted data twice at different time intervals after a period of 7 days. No ethical clearance certificate was required for this study.

4 RESULTS AND DISCUSSION

This chapter will summarise findings and provide discussion of the results noted in this study. 11 peer reviewed publications were categorised into subtopics to achieve an explicit discussion. The selected studies cover the theme of the study profoundly and more than 65% of the subtopic of the study are discussed robustly in the 11 studies.

A. Benefits of Nanotechnology

B. Knowledge of toxicity mechanism of Nanotechnology

C. Nanoparticles interaction

D. Definition of Nanomaterial

E. Monitoring, control and traceability of Nanomaterial

F. Scientific evidence on Nanotechnology risk

G. Challenges on regulation of Nanotechnology

H. Regulations and Legislations on Nanotechnology

I. Guidelines on Nanotechnology

J. EU regulation

K. FDA regulation

L. Private agents (ISO)

Table 1: Authors and their views on regulation of Nanotechnology per subtopic or theme.

References	A	B	C	D	E	F	G	H	I	J	K	L
Valeria *et al.*, (2016)	+	+	+	+		+	-	-	+	-	-	-
Jain (2017)	+	+ -	-	+		-	-			+		
Abbott, Merchant and Sylvester (2017)	+	-				-	-	-		+	+	+
Garcia *et al.*, (2018)	+	+		-	-	+	-		+	+	+	
Smith and Lyons (2018)	+	+	-	-	-	-	-	-	+			
Adeyeye and Fayemi (2018)	+	-	-	+		-	-	-		+	+	
He, Deng and Hwang (2018)	+	+	-	+	-	+	-	+ -	+	+	+	
Leidy and Ximena (2019)	+	-		-		-	-	+		+	+	
Akakuru *et al.*, (2020)	+	+	-	+		-	-			-	+	-
Allan *et al.*, (2021)	+	+	-	-	-	-	-	-	+	+	-	+
Gottardo *et al.*, (2021)	+	-	-	+			-	+		+		+
Total for positive point of view %	100	64	9	54	0	27	0	27	45	72	55	27
Negative point of view %	0	45	91	36	36	64	100	54	0	18	18	18

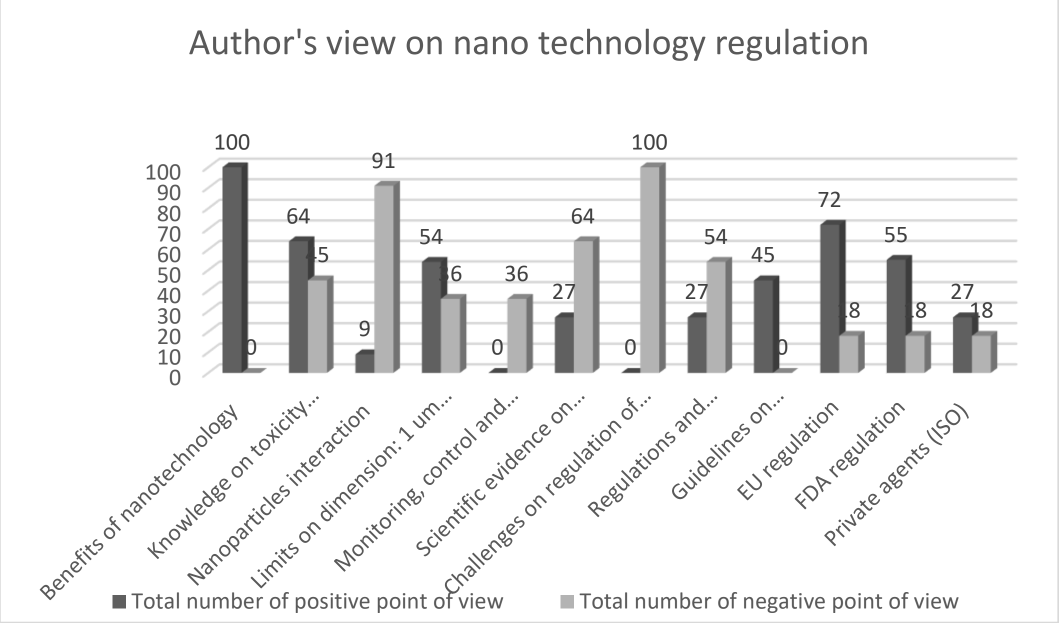

Figure 1: Illustrate author's view on Nanotechnology

There is correlation among authors Mishra et al., [2]; Allan et al., [5]; Gottardo et al., [6]; Akakuru, et al., [7]; Adeyeye and Fayemi [8]; Jain et al., [10] and Lyons and Smith [11] that Nanotechnology throughout the globe is a novel and beneficial solution to a host of different problems. However, there is a debate on the unknown toxicity mechanisms and the increasing production of food product with Nanomaterials and has prompted researchers to lay a foundation that could lead to possible regulations and legislation on Nanotechnology. In order for regulators to establish robust legislation, first a definition of Nanomaterials must be recognised and accepted globally. Nevertheless, the graph in figure 1 shows that 54% of the researchers agree with the definition provided by the EU. According to the findings, 36% of researchers find that the definition of Nanomaterials are non-operational, too generic and only applicable to solid Nanomaterials. According to Wulff et al., [34] the size of silver (Ag) at Nano scale (from 20 nm to 113 nm) has similar toxic affect compared to its smaller size. The debate among scientist, policy makers and governmental agencies on this terminology is on-going; hence, the definition is not legally binding. However, many legislators are defining Nanomaterials based on threshold of size and dimensions.

There is ambiguity and inconsistency regarding toxicity mechanisms of Nanotechnology as 64% of the researchers report that Nanomaterials can result in chronic cancerous diseases whereas 45% of the researchers state that there is limited scientific and clinical testing confirming that Nanomaterials can cause health risk. Existing clinical trials were based on animals not humans, therefore it can be inferred that more tests are required and must be conducted on preserved human blood cells. Jain [10] advises that to achieve accurate results the tests must be conducted before, during and after exposure to different Nanomaterials. Khotimchenko [35] and Kvashnina [36] support the notion that more Nanotoxicology assessments are required to understand potential hazards and their severity to human health. In addition, the existing testing methods (invitro, invivo and silico) require modification in order to keep up with Nanomaterials complicated with phytochemical properties and their interaction abilities [37]. This calls for a test paradigm to assess potential hazards and risks resulted from accidental or intended use of Nanomaterials by using proper testing strategies such as high-test screening assays (HTSS) and modus operandi in food metrics. It can be concluded that there are prescribed testing methods that have been used to test for chemical toxicology but the results will be declared as invalid since there are no verification and validation methods.

91% of the researchers agree that there is a gap of knowledge on the interaction of Nanoparticles with human cells and other Nanoparticles. However, 9% of the researchers indicated that Nanoparticles tend to increase oxygen reproduction and react with free oxygen ions in blood cells resulting in gene mutation, death cells and organ damage[37 and 38].The dynamic properties of Nanomaterials have led researchers into a dead-end about Nanomaterial's interaction, but future work can emerge from the 9% peer review publications. Therefore, it can be inferred that there is progress in terms of theoretical knowledge, but they are still limited information in terms of risk analysis. Hence, more studies that are practical are required.

Only 36% of the researchers attribute the gap of knowledge around the standardised monitoring, control and traceability procedure of the Nanomaterials. This is due to a lack of information on the above topic. It can be argued that it is necessary for regulators to be successful in establishing the monitoring procedures, validation tests and traceability procedures to control the application on Nanotechnology. Nonetheless, 45% of peer review publications have confirmed that there are guidelines published by EFSA and FDA, which cover these procedures. Hence, the existing guidelines can be used for best practice and reviewed annually. If the guidelines are effective and show progress, they can be improved and then act as a key indicator and foundation for stringent regulations and legislation to be implemented. EFSA [37] has published guidelines on the application of Nanotechnology and includes risk assessment testing and physiochemical characterisation methods [2, 3 and 11]. The EFSA [37] confirms to have published guidelines on the food chain regarding risk assessment, testing strategy of Nanotechnology and recommendations for future work in this area. However, EFSA reported that there is still more research required in this field.

Figure 1 also illustrates that 75% of the researchers acknowledge the responsibility of the EU in legislating and regulating the application of Nanotechnology in food chain. The current EU legislation covers more areas in this field compared to other legislators and it is adopted globally. This is because EU is a well-developed country and all the necessary resources are available. Besides that, the EU population comprised of more informed and health conscious citizens, therefore this legislation needs to prioritise the public's interest and demands. The EU regulation covers Nanotechnology in the food industry and the aim of this legislation is to ensure safety of the Nano-products and authorisation for explicit use, labelling requirements and address risk assessment of food products. This legislation provides the framework that includes defining the term Nanomaterials and promote guidelines published by other governmental agencies such as ECHA, OECD and EFSA [5 and 6]. However, there are 18% of researchers who believe that the current EU regulation can be more robust and detailed [38]. Therefore, it can be inferred that there are still areas that EU regulation does not cover such as quantitative testing procedures in integrated food, validated risk assessment procedure and toxic mechanisms.

Researchers [3, 5, 6 and 16] presented in the Figure 1 have agreed that there are challenges preventing the governmental agencies from developing cohesive legislation. Major uncertainties and a wide gap in knowledge are the main cause of deficiencies in the regulation.

There are some key challenges faced by regulators that include the following, the first being that Nanomaterials have unique, dynamic and complicated physicochemical properties that are difficult to categorise into a certain criterion in order to establish its definition [6 and 35]. The second is that there is a lack of knowledge on how to monitor and trace various sources of Nanomaterials in order to predict the risk and severity. Moreover, there are no validation methods to use for measuring exposure of Nanomaterials in trace content on environmental metrices. Lastly, once the Nanomaterials migrate into the environment, it is very difficult to evaluate its bioavailability and there is limited understanding of its toxicology.

5 CONCLUSION

A systematic review provided robust data to add value in overcoming the challenges that prevent policy makers from strengthening the legislation concerning Nanotechnology. It was noted that there is a lot of debate among researchers that has resulted in confusion in the public. This study was able to provide a summary of the testing methods and strategies that can be used to measure the concentration content, surface area, size and geno-toxicity. Invitro testing is highly recommended and reliable but it still requires more modifications in order to improve its functions.

Governmental agencies rely on the information and research provided by researchers and scholars. When there is ambiguity among researched peer review publications, it affects potential regulatory frameworks. It is critical that scholars, academia, research industries and government agencies collaborate and share resources and knowledge to contribute towards a regulatory framework to keep up with increasing production of Nano-products. It is recommended that a platform that will allow all the relevant stakeholders to share their work, criticisms and agreements be established to harmonise resolutions and standardise legislation at an international level. This will allow International and private organisations to be on a same level and improve global compliance. The harmonised regulations and legislation will prevent exploitation of consumers in poor countries and provide opportunities in international trading. Private and public standard-setting bodies such as ISO and British Standard Institution (BSI) can add value by adopting harmonised standards. Regulators must also be informed at an early stage of Nanomaterials before its commercialisation to determine if the existing legislation addresses it aspects, concerning of health risk and environment.

For future work, it is suggested that more informative and empirical studies are conducted on Nanotechnology to improve public awareness because there is limited evidence on human clinical trials on Nanomaterials toxicology.

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NANOTECHNOLOGY IN FOOD SAFETY AND THE FOOD PROCESSING INDUSTRY

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ABSTRACT

Nanotechnology particularly in the food processing industry has generated significant interest among manufacturers. There are many benefits of using Nanotechnology, which can aid in the improvement of food safety and food quality. However, there are numerous controversial concerns surrounding its use in food, regarding the underlying safety concerns due to the gaps of knowledge that exists when evaluating the toxicity of Nanomaterials. This study was theoretical and qualitative, and used a systematic review to collect data. The sample size was 50 journal articles, books and/or papers. Suitable keywords were input then searched on various sites. Data bases included databases Science Direct, Google Scholar, Emerald, and Springer. No ethical clearance was required. It discussed food safety standards in relation to the safe use of Nanomaterials in food processing applications. The study found that currently there are more pros than cons when using Nanotechnology in the food processing industry.

Keywords: Nanotechnology, food safety, Nano-encapsulation, Nanosensors, Nanoparticles

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1 INTRODUCTION

Palit [1], Ashraf *et al.* [2], and Shafi *et al.* [3] agree that the United Nations, Sustainable Development Goals (UNSDG's) on food security has created a pathway for Nanotechnology to be used in the development of food security programs.

Nanotechnology has influenced the food processing industry in different aspects, from farm to industry and to fork. Colica *et al.* [4] suggests that the food processing industry has been researching and investigating technologies that would be able to assist in the improvement of the nutritional value, shelf life, and traceability of food products. Initially industries used and developed Nanomaterials to improve the quality of products but now industries have shifted their thinking to use Nanotechnology to improve food safety as well [5].

The distinctive qualities and properties which is provided by nanomaterials, create countless possibilities for addressing food safety and quality related issues in a completely different and new perspective [6].

Chung *et al.* [7] defines Nanotechnology as the convergence of science, engineering and technology to design and produce systems that can manipulate atoms and molecules at a nanoscale. Askew [8] asserts that the material properties at nanoscale compared to macroscale are noticeably different, therefore Nanomaterials have many new benefits to offer in different applications in the food processing industry. The advantage of the small size of Nanomaterials is that it can have higher levels of strength and stability along with the ability to have increased chemical and biological activities. Drawing from Enescu *et al.* [9] Nanotechnology appears to be the latest scientific advancement that can offer key improvements for current challenges in food security and food sustainability.

Bose [10] states that complaints concerning food quality and sources, from consumers has driven researchers to develop different technologies which would ensure food safety without having adverse effects on the nutrition of products. However, the main problem with arising from using nanoenabled materials, according to, Nutfatihah and Siddiquee [11] is that there is hesitance among consumers concerning the use of Nanotechnology in products due to possible adverse health effects. The increased use of Nanotechnology overtime along with the concomitant exposure of Nanomaterials to humans has created the impression that Nanotechnology could have possible negative health implications. Moreover, other problems advise, Sonawane, Patuk and Arya [12] is that due to the concerns arising from Nanotechnology in the food-processing sector there is an urgent need to investigate the effects of Nanotechnology from a safety level for human consumption.

Consequently, a uniform international regulatory framework for Nanotechnology in food is necessary [13]. This is reiterated by Villena de Francisco and García-Estepa [14] and Kaur [15] who report that a safety standard concerning Nanotechnology in food processing industry is necessary and urgently required. It can be argued that there is inadequate knowledge surrounding the safe use of Nanotechnology in the food industry. Considering this there is a need to evaluate the impact of Nanotechnology in the food safety sector. Arising from the lack of available literature surrounding the food safety standards relating to Nanotechnology in the food industry, this paper will investigate and review pertinent literature to identify and reveal possible gaps relating to those safety standards.

The Codex Alimentarius was updated to include the use of Nanotechnology in food and agriculture [16]. Therefore, this could also be used to identify current methods which organisations' have adopted to ensure the compliance of the foods within the food safety standards that are manufactured using Nanotechnology.

2 LITERATURE REVIEW

This section will address current knowledge and developments of Nanotechnology in the food processing industry.

Some useful insights expressed by Hayes and Sahu [13] are that Nanotechnology has the ability to transform the agriculture sector and food processing systems. At the nanoscale level of food products, Nanotechnology can be used to affect the efficiency, bioavailability, safety, and nutritional value properties of products and ingredients [17]. The rapid development in Nanotechnology controls the development of the food system from cultivation to production along the entire value-chain. Askew [8] established that the utilisation of microscopy in food structure analysis and quality assessments has made tremendous progress. This finding indicates that there is a scope available to possibly increase the use of Nanotechnology in food products.

Chung *et al*. [7] states that currently Nanotechnology has been widely used and researched in the food sector to help improve food safety, for example pathogen detection in food packaging. Another interesting development by Chung *et al*. [7] was progression detection and packaging strategies to supply quick, non-destructive nourishment quality and safety evaluation and investigation for the industry. This highlights that there are significant developments in the field of Nanotechnology that can be used in the food industry to assist in the manufacturing of food and the maintenance of the food safety standards.

Aigbogun *et al*. [18] and Dholariya, Borkar and Borah [19] suggests that Nanotechnology can be used to improve food packaging, for example, antimicrobial packaging in which Nanoparticles coat packaging materials to reduce the growth of bacteria and improve food storage by reducing the presence of oxygen present in packaged food items. Other benefits proposed by Shukla *et al*. [20] include improved mechanical barriers, detection of microbial contamination and potentially enhanced bioavailability of nutrients. However, these food contact substances contain Nanomaterials, which have the potential of migrating from the food packaging onto the food items. Therefore, before widespread use in the industry it would require regulatory compliance.

There has been no consensus by the International Food Safety authorities regarding the safety of food incorporated with Nanomaterials, in conjunction there has been little evidence that states that the ingestion of the Nanomaterials could have harmful effects on humans [21]. The toxicity of engineered nanoparticles is a new and evolving field, which requires extensive research with concerns of the effect's nanoparticles can have on the environmental [22].

Due to the rapid increase of consumer awareness around the source and health advantages of food products, researchers are being prompted to push in further in the area of Nanotechnology [23]. Gao [24] states that it difficult to bridge the gap between industry and fundamental research concerning Nanotechnology because in many sectors of fundamental research it is seen as a long-term and costly investment [22]. The current food safety standards could also be cross referenced for the level of compliance required and currently been used by food industries producing nano-enabled products [25].

Another area is nanoscale ingredients which is already been developed by the food industry to enhance colour, texture, and flavour of food products [26]. Nanoparticles such as Titanium dioxide (TiO_2), Silicon dioxide (SiO_2) and amorphous silica are being used as food additives. Food safety, and concerns around improper hygiene, poor food handling practices and contaminated food supplies, according to Bueno *et al*. [27] are important aspects which can lead to food borne diseases. These must be controlled to ensure that the processed and packaged food products are free from pathogenic microorganisms. Nanotechnology is mooted to provide advanced platforms that exploit properties of materials at nano-metric sizes [25]. Of interest, Nanotechnology has the ability to re-innovate agriculture, food, biomedicine, environment safety, energy conservation sectors. Nanosensors are devices at a nanoscale that are used to measure physical quantities and form a fundamental part in the development of Nanotechnology [27].

The gap of knowledge in the study can be reported as the minimal amount of data and legislation that is applicable in the food sector concerning Nanotechnology. The lack of knowledge around the interactions at molecular, physiological levels of the nano-sized materials, as well as the potential effects and the possible impact it could have on the consumer's health and the environment is of significant concern [28].

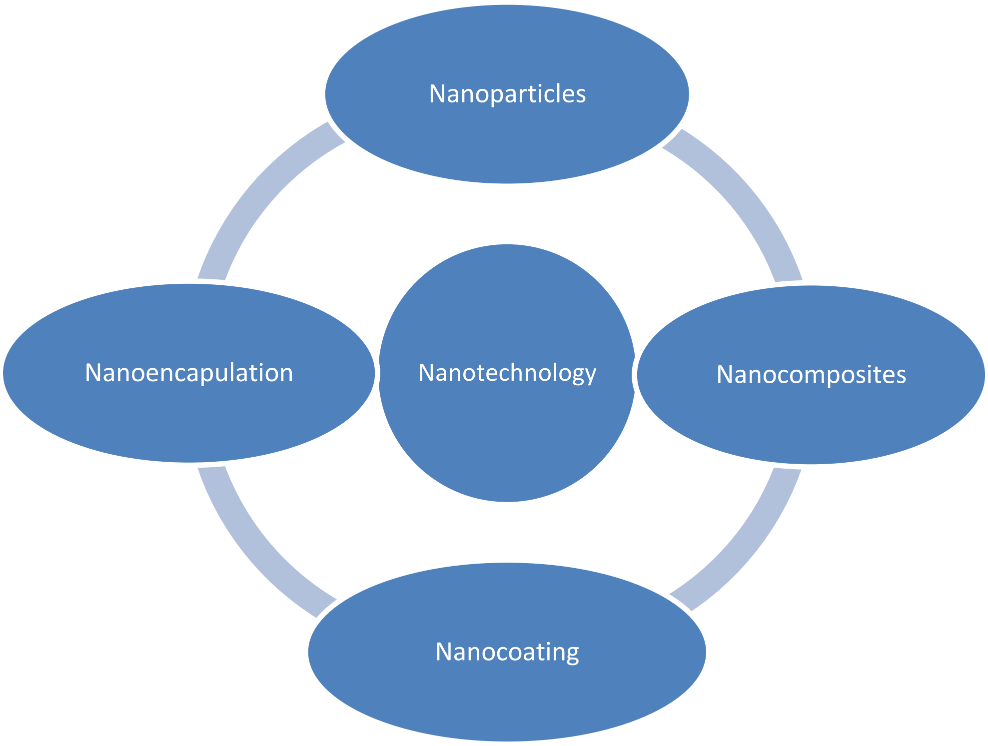

Figure 1: Diagram depicting possible avenues to pursue in the results and discussion as adapted by authors.

The following authors [8], [10], [29], [30] - [36] report that there are the possible areas that need to be further investigated with the field of Nanotechnology in food processing. The key areas that were highlighted were: Nanoparticles, Nanoencapsulation, Nanocoating and Nanocomposites. Figure 1 shows the possible key methods of Nano processing in the food industry. These will be further discussed in this research paper.

3 METHODOLOGY

This study followed a theoretical and qualitative strategy. A systematic review was undertaken to collect data. The theoretical study used secondary sources of information obtained from peer-reviewed articles. Qualitative data analysis was verified by evaluating various explanations and searching for common ideas or lack thereof amongst the available literature data [37] and [38].

3.1 Search strategy used

The literature search spanned from 02 April 2021 to 14 August 2022. Published peer viewed journal articles and websites formed the primary sources of data collection. Some of the data referencing sources used included databases available from library sites such as Science Direct, Google Scholar, Emerald and Springer. Keywords were noted, recorded and they were then searched on various sites to find articles relating to the topic. The keywords used included the following:

“Food safety and Nanotechnology” OR “Nanoparticles and Food Safety” OR “Codex” OR “Nanotechnology in the Food Industry” OR “Nanoparticles and Nanomaterials” OR “Benefits and Effects of Nanotechnology in Food Sector”

Figure 2: Keywords used for research

3.2 Study selection process

A sample size of 50 articles, books and journal articles were used in this study. Articles that were generated from the electronic search were then downloaded and references were imported into the Endnote referencing management software. References were filtered and the duplicated references were removed. Titles and abstracts from all articles were reviewed for suitability to the study, and all articles which were ineligible were removed from the list. Three different criteria were used:

a) The benefits of Nanotechnology in the food industry

b) The risks of Nanotechnology in the food industry

c) Availability of standards pertaining to Nanotechnology use in food industry.

3.2.1 Data Extraction and Reporting

After the complete analysis, the following information was extracted from articles that were used:

- Title, author information, year of publication, Journal published, Website (referencing use)
- Benefits, risks, study methods used.

4 FINDINGS AND ARGUMENTS

The rapid development around Nanotechnology have been primarily introduced in the literature review. It was found that Nanotechnology could help produce formulations and products that could promote health and safety. This section will delve further into Nanomaterials and Nanotechnology processing methods.

Sahoo *et al.* [39] and Ashfaq *et al.* [40] suggest that nanomaterials can be classified as nonorganic based, organic based and a combination of both. Organic nanomaterials in nature are more biodegradable than the inorganic one. Regardless, the inorganic nanomaterials are more used in food packaging systems as an antimicrobial agent.

4.1 Nanoparticles

Krishnan *et al.* [31] finds that nanoparticles are used in the food manufacturing industry to enhance food stability and maintain food colour. For instance, silicate nanoparticles can be used to restrain the flow of oxygen in packaging and restrict moisture leakage. This allows the food to remain fresher for a longer time. It aids in biofilm formation, which can be described as tightly packed bacterial cells that are attached to numerous substrates, which can form a barrier that can inhibit any kind of penetration. Eleftheriadou, Pyrgiotakis and Demokritou [29] show that biofilm formations could be inhibited by nanoparticles. Some of the problems that biofilms cause in the food manufacturing industry include biofouling, biocorrosion and accumulation [10].

A subsequent example is glycerol monolaurate that is used to act as an antimicrobial agent against numerous gram-positive bacteria. It can be used in the prevention of biofilm formation of three different strains of *Staphylococcus aureus* and Methicillin-resistant *Staphylococcus aureus* (MRSA). Organic compounds such as essential oils have antimicrobial properties and can be highly sensitive to extreme physical conditions. Whereas inorganic nanoparticles have shown strong antibacterial activity in low concentrations and are found to be more stable in extreme conditions. Consequently, manufacturers have recently expressed significant interest in the use of these nanoparticles in antimicrobial food packaging [10].

4.2 Nanocomposites

Ates *et al*. [33] highlight that nanocomposites are a combination of nanoparticles and polymers. It is used to assist in the maintenance of the quality of food products. An example of this is, the minimising of carbon dioxide by nanocomposites, which act as a gas barrier in carbonated drinks. These types of nanocomposites are used in the food manufacturing industry in cans and glass bottles to layer bottles to lower costs. An additional advantage is that they also increase the shelf life of the product.

From the point of view of science and technique, there are still some challenges in the use of nanocomposites. Science shows there are a few conflicts or balances in nanocomposites that require detailed investigations and techniques and reveals that regardless of the large quantity of graphene nanocomposites produced, majority of them are limited to laboratory-scale [41].

4.3 Nanoencapsulation

Bioactive compounds found in food generally become degraded and eventually inactivated due to the extreme environmental conditions. Therefore, He, Deng and Hwang [32] offer nano-encapsulation as an alternative method where bioactive compounds are crucial. Such bioactive constituents can be used to enhance the shelf life of the food products by decreasing the degradation process until the product has reached the targeted site. An example of this is curcumin. This sensitive bioactive compound, *Curcuma longa* (turmeric) is found to be stable at different ionic strengths upon encapsulation [10].

In the agricultural sector, Nanotechnology could assist in the development of nano-encapsulated pesticides that increases its absorption and allows a lower dosage to be used [8]. In the food sector, nano-encapsulation is a prominent feature of Nanotechnology applications. Nanoparticles are used to encapsulate food ingredients and additives in order to conceal their unpleasant tastes and flavours as well as to protect the encapsulated ingredients from degradation. Additionally, it can be used to improve the dispersion of water insoluble food ingredients [21].

Currently many methods of nano-encapsulation each with their own merits & demerits have been progressively increasing. Methods such as coacervation, solvent evaporation, emulsification and many others are been considered for nano-encapsulation for food substances [42].

4.4 Nanocoating

Ali *et al*. [22] report that the composition of nanoparticles consists of uniform layers between a 10nm and 100nm thickness. The use of edible nanocoating's on numerous food materials could provide a barrier to moisture and gaseous exchange, and resultantly maintain flavours, colours, enzymes, antioxidants, and anti-browning agents of food products. Another advantage is a possible extended shelf life because a reduction of oxygen present in the packaging that promotes microbial growth.

Bose [10] purports that nanocoating could also enhance the shelf nanosensorslife of manufactured food products, even after the packaging is opened. An example of this is, a nano-sized titanium dioxide (TiO_2) based photo-indicator which can be used as detector, which would gradually change the colour in response to any minor changes in the quantity of oxygen.

4.5 Nanobiosensors

Nanobiosensors can be highly sensitive to food spoilage and can indicate small changes in the colour and gases produced by the food items. An example of this is the gold-based nanoparticle, which is used in milk products for the detection of aflatoxin B1 [10]. In agriculture, nnanosensorscan be used on fruits and vegetables to indicate if there is any pesticide residue on their surface. There are some nanosensors that can be used to identify carcinogens in food materials [34]. In food microbiology, nanosensors can be used effectively to warn distributors and consumers on the safety status of the food products because it can indicate the presence of pathogens in food materials.

The use of nanobiosensors could show small changes in the storage environment of the product (for example: humidity, temperature, and microbial contamination) that could lead to degradation [34]. Numerous nanostructures such as nanorods, nanoparticles and nanofiber are used as biosensors.

4.6 Smart and active packaging

Mustafa and Andreescu [43] state that annually approximately a third of the food produced globally is wasted due to spoilage or contamination. Nanotechnology could also be used to support the development of both smart and active packaging to increase food safety and help reduce food wastage. An example of active packaging is the addition of nano clay or silica particles to plastic beer bottles to slow- down oxygen diffusion and increases shelf life [44]. Specific molecules found in active packaging have the ability to absorb or release certain components into or from encompassing environments of the packaged food product [45]. The use of Nanotechnology in smart packaging includes the incorporation of sensors in the packaging material that would indicate when the products are deteriorating. An example of this would be the use of intelligent inks that turns red to make the consumer or retailer aware that the product should not be consumed [8]. The use of nanocomposites as an active material in packaging and coating of material could be used to improve food packaging [30].

4.7 The challenges of existing nanotechnology

Overtime there has been a significant amount of research done on Nanotechnology but the progress in concerns regarding the toxic side effects of Nanomaterials in the food manufacturing industry has not been covered sufficiently [10]. Accordingly, there is concern that those nanoparticles can cross biological membranes, tissues, cells, and organs more easily than compared to larger sized particles. If the nanoparticle enters the blood stream, the Nanomaterials would then be able to circulate throughout the body and could interfere with the cellular functionality and could possibly cause oxidative damage and eventually lead to cell death (Risks of Nanotechnology) [36]. Nanoparticles could become an indirect source of food contaminants. There is a lack of effective analytical methods and predictive models to evaluate the safety of nanoparticles [21].

Saqqua [46] and Jagtiani [47] and Primožič, Knez and Leitgeb [48] purport that although nanotechnology offers incredible improvements to the food industry, public concern is large. They also explain that direct exposure of nanoparticles to consumers could pose as a serious health problem. However, they advise that if food industries continue to keep nanoparticles bound to the packaging materials of food, the exposure limit is very low. Although, nanoparticles migration to human is high risk.

4.8 Consensus standards

A study by Bell and Tomsen [35] states that consensus standards have become a necessity in both domestic and international trade. The standards could play a role in the development of public and legal policies pertaining to Nanotechnology. Attaining consensus on appropriate procedures would assist in the identification and management of any risks pertaining to Nanotechnology that could reassure and address consumer concerns. They had also stated that the International Organisation of Standardisation (ISO) was currently working on the development of standards pertaining to Nanotechnology, primarily through the work of Technical Committee 229. The Standard would include terminology, nomenclature, measurement, characterisation, health, safety, environment and material specifications.

Saqqua [46] and Primožič, Knez and Leitgeb [48] elucidate the urgent need for specific legislation pertaining to nanotechnology in food industries, and states that protocols for toxicity testing of nanomaterials in food are in development stages by organizations such as the International Alliance for Nano Environment, Human Health and Safety Harmonization.

4.9 Discussion

In the Findings and Arguments sections, the benefits and risks of using nanotechnology in the food industry were identified. The benefits included the following:

- Nanoparticles: The use of nanoparticles can be used to enhance food stability and maintain food colour. An example used in food industry currently is silicate nanoparticles helped to restrain the flow of oxygen in packaging and restrict moisture leakage which allowed food products to stay fresher for longer periods of time.
- Nanoencapsulation: This process can be explained as using encapsulating materials using a range of different coating materials at a nanoscale. The development of this technology has primarily been used in agriculture.
- Nanocomposites: Nanocomposites is the combination of nanoparticles and polymers. It was used in the food industry to maintain the quality of food products and increase shelf life. The challenges involved with nanocomposites from science and technique point of view showed that few conflicts, especially with scale-up initiatives, which require more in-depth investigation.
- Nanocoating: The use of nanocoating provided a barrier over the food product to moisture and gaseous exchange which in turn maintained the foods flavours, colours, enzymes, antioxidants, and anti-browning, as an addition helped to increase shelf life.
- Nanobiosensors: The development of nanobiosensors helped to identify the smallest changes that occurred in food items, which indicated food spoilage [49] and [50]. Examples of biosensors used in food industry included nanorods, nanoparticles and nanofiber.
- Smart and Active Packaging: As discussed, a third of the global food wastage was due to spoilage or contamination. The development of active and smart packaging with the use of nanotechnology helped reduce food wastage by improving food safety.

In contradiction, nanotechnology faces numerous challenges. There have been numerous concerns over the toxic side effects that could occur with its use and the use of nanomaterials in the food industry. Public concern is large especially due to the lack of regulations and standards pertaining to nanotechnology and its use in the food industry. It is worth noting that currently, there are developments in the creation of standards in Nanotechnology. Proposed risks are mainly assumptions and there is insufficient research and information to support this claim.

5 CONCLUSION

Evolution in Nanotechnology could enable the control of ingredient functionality, heightened hygienic manufacturing with less use of detergents, smarter packaging, and larger interaction of consumers with their food. Currently there is no corroborated evidence that food derived from Nanotechnology could be any safer or could be considered more dangerous than their conventional counterparts. Despite the controversy and concerns of the public there is no solid evidence to prove Nanotechnology and the ingestion of Nanomaterials could harm human health. Therefore, due to the lack of evidence it can be concluded that Nanotechnology can aid in the improvement of food safety.

Concerning the standards pertaining to Nanotechnology, there has been no finalised standard that addresses Nanotechnology directly. However, it was identified that ISO through consensus standards have been working on developing standards that would have the ability to influence public policies and laws on a national and international basis. When all these major factors come together with the Standards which are been developed for Nanotechnology would support the responsible and commercially viable development and public acceptance of Nanotechnology.

From the discourse above, it can be gleaned that future work should include conclusive toxicity testing to ensure that nanoenabled food materials are safe for use irrespective of them being used as food components or food packaging. Moreover, this information should be shared with peers so that the knowledge shared could be developed to further the maturity of nanotechnology in the food industry. There is a need for standardization and uniformity of practice so that the food industry can exploit the full potential of nanotechnology, this can be derived from the development of appropriate standards.

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APPLICATION OF LEAN PRINCIPLES IN RAILWAY MAINTENANCE

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ABSTRACT

A properly built and managed transport network forms part of the country's economic backbone. Most countries have expanded their economy by investing in the transport sector. Of note is that the railway sector, to remain competitive, has engaged in lean maintenance to reduce maintenance costs, improve reliability and customer will. This paper highlights lean tools applied in different maintenance environments in comparison to their application in railway maintenance. This study follows a deductive philosophy and uses secondary data sources to create new concepts. The literature was collected through a systematic literature review to remove bias in the data set. Identified lean tools were then analysed and a lean maintenance framework was formulated through meta-synthesis. The paper provides a flexible framework for implementing lean maintenance in the rail environment. Its flexibility allows organisations to cater to their different dynamics. It further highlights supporting activities to implement different steps within the proposed framework.

Keywords: Lean maintenance, maintenance framework, lean principles, lean tools

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1 INTRODUCTION

Lean is performing value-adding activities to the product/service with fewer costs [1]. It can also be defined as a way to eliminate waste and maximise value in processing [2][3]. Lean thinking focuses on waste elimination, value addition and continuous improvement, therefore, it is a quality-enhancing mechanism [4], [5]. In an organisation, there is a need to eliminate non-value-adding activities, examples of these activities are inventory, overproduction, inspections and transport [1], [6].

In lean thinking, there are lean principles and lean tools. Lean tools are used to implement lean principles. According to Shakir and Iqbal [7], the concept of lean can be explained by five fundamental principles: specify the value, identify the value stream, flow, pull and perfection. Lean tools are used in implementing lean principles. According to Stephenson [8], lean tools include 5 S (sort, set in order, shine, standardise, sustain), value stream mapping, eight waste elimination, continuous improvement (Kaizen), total productive maintenance, process mapping exercises and supplier development. In addition, Huang, Bian, and Cai [6] suggested other tools, such as comprehensive production maintenance and production line constraint theory.

Over the years, lean has primarily been applied to manufacturing with little emphasis on maintenance, especially railway maintenance [9]. However, faced with massive competition from other transport sectors, the railway sector has to improve the quality of maintenance service and reduce maintenance costs and cycle time to have a competitive advantage. This can be done by implementing lean tools [10], [7]. The application of lean helps to increase reliability, eliminate waste, improve resource utilisation, increase customer satisfaction, improve the operation process's value and reduce the repair time [11] - [12].

As such, the purpose of this research is to;

- Reduce the gap in the current research on transforming rail maintenance from a state full of waste to a free waste state
- Provide a framework for implementing lean principles in railway maintenance

2 LEAN MAINTENANCE

A Toyota manufacturing company first introduced the concept of lean to reduce manufacturing costs by eliminating waste[12]. However, if lean is to be implemented in other sectors, there is a need for some adjustments to lean principles and tools as they were initially meant for improvement in production [7].

Lean maintenance is a methodology to reduce/eliminate waste and improve maintenance efficiency [7], [12]. It is introduced to remove waste and inefficient methods to reduce downtime and increase mission availability and resource utilisation [13]. Through lean maintenance, competitive advantage can be increased, resulting in direct and indirect savings [10], [14]. Furthermore, lean tools are implemented to improve the maintenance process, thereby increasing the system's reliability and availability [15].

The concept of lean maintenance eliminates/reduces waste and improves the efficiency of some of the activities. However, identifying waste is usually more complex than eliminating it [7]. Removing waste saves time and improves resource utilisation and equipment availability through maintenance time reduction. According to Shou et al. [18], Huang, Bian and Cai [6], waste includes outdated procedures, overstocked, underused inventory of equipment, material, parts, wasted labour and transportation and maintenance projects may also include unproductive work, delays in motion, unnecessary motion, poor management of inventory, rework, underutilisation of people, fault happening repeatedly, maintenance personnel action delay and ineffective data management and misuse of machinery. In a maintenance environment, to quickly identify waste, activities are put into three groups which are Non-

Value-Adding Activities (NVAA), Value-Adding Activities (VAA) and Necessary but Non-Value-Adding Activities [7], [12], [17].

It is important to note that the customer depends on the context, for example, in aircraft maintenance, the customer can be the aircraft operator who wants the aircraft to be maintained on time and within budget also the pilot can be the customer who requires all the equipment to operate within specification all the time and the passenger can be the customer as well as they will also require the aircraft to depart and arrive on time.

Overall, lean has been applied differently in different sectors, thereby creating different lean maintenance implementations. Some of the sectors in which lean has been applied include but are not limited to aviation, health and rail.

2.1 Lean maintenance in the aviation industry

Implementing lean in the aviation industry aims to eliminate waste and inefficient procedures to reduce downtime and increase the availability of aircraft [13]. Karunakaran [13] identified waste within the aircraft life cycle. Implementing lean maintenance After 30 years of operation, the aircraft fleet is affected by many problems associated with aging. When the aircraft is new, it could fly 100-120 hours per month, whereas, after some time (30 years), it can only run 35-40 hours per month due to several factors, such as frequent technical problems. Therefore, with age, aircraft availability is decreasing, signalling the need for a maintenance approach to reduce downtime, the number of technical failures, and the time spent maintaining. During maintenance, if the aircraft fleet spends much time within the maintenance facility, it is a sign of waste within the maintenance system [13].

For any implemented lean tool to be effective, the system should be inclined towards achieving continuous improvement [13]. The aircraft undergoes two types of schedules: 300 and 900-hour servicing, then after 4000hrs, it goes to a maintenance depot for overhaul and cleared for another 4000hrs. Maintenance processes are also optimised. Three ways of optimisation at the intermediate level are proposed: work content at an individual level, servicing cycle level and facility level.

The lean maintenance framework used had the seven steps: pre-preparatory stage, preparatory stage, the establishment of value, identification of current value stream, development of future value stream, standardising of flow and striving for perfection.

As specified by Ayeni, Ball and Baines [19], lean maintenance in aviation has adopted some of the lean tools such as the 5S and JIT.

2.2 Lean maintenance in the health industry

In today's world, biomedical equipment is now sophisticated and with the emphasis on providing quality health care systems by the state, it is crucial to keep this biomedical equipment running. According to Thapa, Saldanha and Prakash [20], 80% of medical equipment failures are due to preventable factors and poor maintenance contributes to 60%. Due to the criticality of the industry, equipment needs to be reliable and available all the time. To reduce unavailability, failures and time to repair should be reduced, whereas the mean time between failures should be high [19]. One of the successful implementations was done by Thapa, Saldanha and Prakash [20] in maintaining biomedical equipment at Yenepoya Medical College, focusing on the Intensive Care Unit (ICU). Following DMAIC (Define, Measure, Analyse, Improve, Control), a methodology was proposed for implementing lean maintenance. DMAIC was integrated with tools at each step to ensure proper implementation.

2.3 Lean maintenance in rail

In applying lean maintenance in rail, organisations can optimise their maintenance procedure, thereby increasing the quality of maintenance. As a result, downtime due to maintenance will be significantly reduced and the availability of rolling stock will increase. However, breakdowns in machinery and equipment in the rail industry result in train delays, ultimately leading to revenue loss [15].

In implementing lean maintenance on 3kVDC traction substations, Croucamp and Telukdarie [21] focused on the supply chain. In doing so, the aim was to reduce/eliminate waste within the maintenance supply chain of rail, thereby increasing maintenance time and availability of trains. In addition, the methodology was used to reduce the time spent in the tender process. The methodology to apply lean maintenance in the supply chain of rail included 5 phases: cost classification, process presentation, value stream mapping, problem definition tree and recommendations and evaluation.

Tendayi and Fourie [5] focused on the supply chain in looking at lean implementation in the rail environment. Several tools were identified that can be used in the rail environment in the context of the supply chain: value addition, waste elimination and continuous improvement.

In another research done by Schlake, Barkan and Edwards [14], lean production principles were applied to railcar inspection and maintenance practices. Waste was divided into two groups, direct waste and variability, where direct waste included accidents, In-service failures (ISF), car damage, unnecessary motion and information collection. In contrast, variability is a waste since it necessitates buffering in the form of extra inventory, capacity or time. For example, variability in train arrivals and unexpected failures may result in the need for extra yard tracks, rail car inspectors, repair personnel and variability in run times, including inspection and repair times or labour availability.

The lean maintenance literature in the rail environment analysed shows that most focused on eliminating waste in the supply chain. The principles applied include waste elimination, value addition and continuous improvement. Therefore, this shows the need to develop a framework that will incorporate other lean principles.

2.4 Gap analysis

From the literature review on lean maintenance, there is a limited number of frameworks that are used to implement lean in the rail maintenance environment. Hence this study aims to develop a lean maintenance implementation framework that can be used to implement lean principles in the rail environment.

3 METHODOLOGY

The research followed a systematic literature review. A systematic literature review is defined as a scientific research approach. It is used to appraise, summarise and communicate the findings and implications of many research publications on a particular subject. It is an evidence-based process that evaluates all published and unpublished literature on the topic. On maintenance, several researchers also adopted a systematic literature review for their studies [20], [21]. A systematic literature review is used to gather and study several research studies and publications in line with the topic at hand. This helps to answer predefined questions by incorporating practical evidence from all the relevant studies. The study was conducted in five phases as shown in Figure 1.

The Systematic Literature Review (SLR) method is an evidence-based process. Systematic Literature Review is intended to evaluate all published literature on the topic. The method makes it easy to follow what the researcher did. It is a transparent process. A systematic literature review minimises bias from the researcher [22][22]–[25].

A systematic literature review is a systematic way to collect, integrate, evaluate critically and present findings from multiple research studies on a research topic. The Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) is used to ensure the proper review method is followed. The PRISMA methodology addresses quality issues, such as bias, replicability and credibility, and offers a broader and more accurate understanding than a traditional literature review.

For validating the developed framework, purposeful sampling was done to identify SMEs. The needed participants were individuals with an experience in rail maintenance. These included personnel working at the Passenger Rail Agency of South Africa (PRASA), both at maintenance depots and head office. Personnel in academia who focused on rail maintenance were also included in the validation stage.

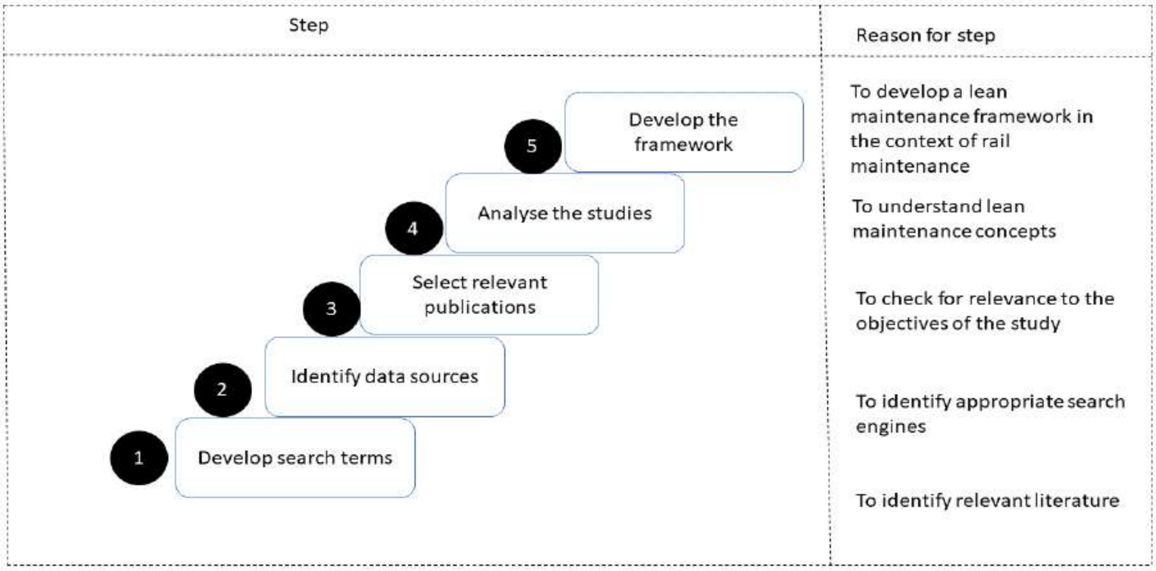

Figure 1 Flowchart of research methodology

4 LITERATURE REVIEW

This section of the literature review covers data sources, collection, and selection criteria. The search terms used in data sources and collection are highlighted and the search engines. Under selection criteria, the explanation will be given as to how the author arrived at the articles that were reviewed and an explanation as to those which were discarded will be given.

4.1 Data sources and collection

In identifying studies on lean maintenance, two search terms were used:

- application of lean in maintenance
- lean maintenance in railway

The search fields used were article title, abstract, and keywords. The search engines used were Web of Science and Scopus. The initial search yield is displayed in Table 1.

Table 1 Initial Search Results

Search terms	Search field	Scopus	Web of Science
Application of lean in maintenance	Article title, abstract and keywords	352	161
Lean maintenance in railway	Article title, abstract and keywords	9	5

4.2 Selection criteria

Out of 527 publications found in the primary search, an extensive review was done to establish whether each publication fit the systematic literature review. The first screening criterion was to check whether or not the publication was related to the topic of lean maintenance implementation. The second vetting process was to check whether the publication was relevant to the scope of the study. A total of 436 publications were found to be unrelated to the topic of study. Of the 91 publications related to the topic, only 25 papers were relevant to the current study.

Figure 2 shows the PRISMA flow diagram. It highlights the inclusion/exclusion criteria which was used to identify the relevant studies to the research at hand.

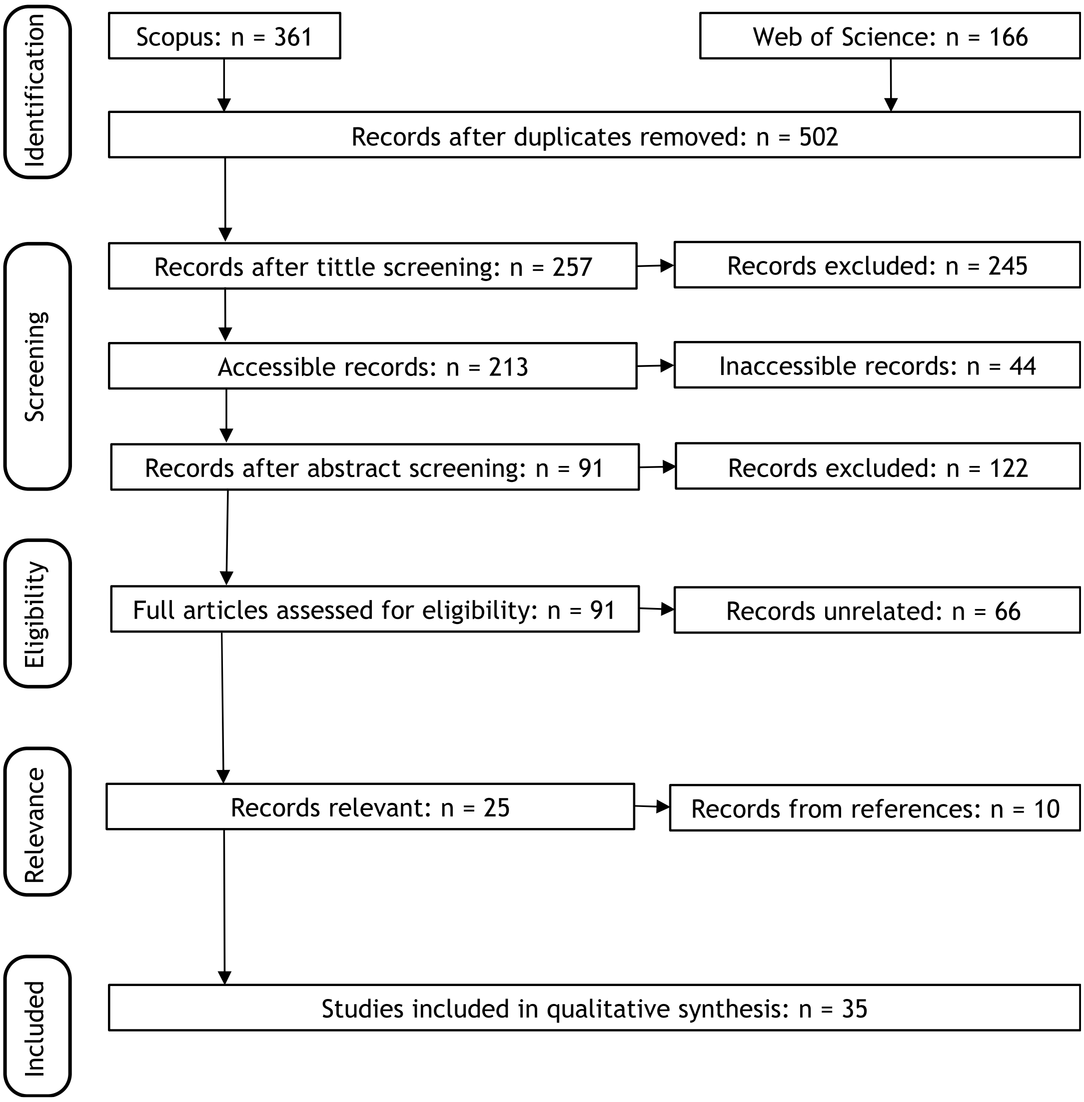

Figure 2 PRISMA flow diagram

5 RESULTS OF SYSTEMATIC LITERATURE REVIEW

The following section is divided into two sub-sections: i) descriptive statistics and ii) conceptual aspects.

5.1 Descriptive statistics

In analysing the literature, documents related to lean maintenance were in the form of journals, conference papers, industry research reports and book chapters. In the review, the author focused on lean maintenance implementation by selecting material with rich lean maintenance implementation empirical data. A total of 25 publications were relevant to the current study of lean maintenance implementation. From these papers, the next step was to read the whole paper to understand the study objective, the research approach used, key concepts, and the lean tools used in each paper.

Publications ranged from 2009 to 2019. The most publications that were considered were done in 2018 which had eight (8) publications whilst the least number of publications were in 2010, 2012 and 2015 with two (2) publications. Number of publications per year is shown in Figure 3.

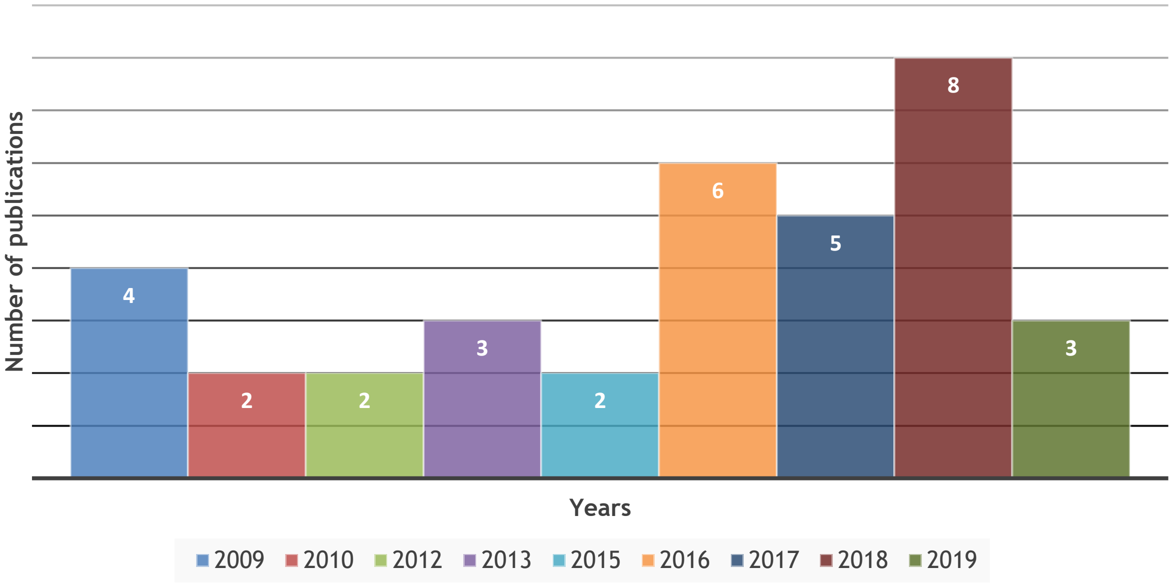

Figure 3 Number of publications per year

The articles that were analysed, 71% were journal articles, 23% conference papers whilst 6% were book sections. Type of publications for the articles is shown in Figure 4.

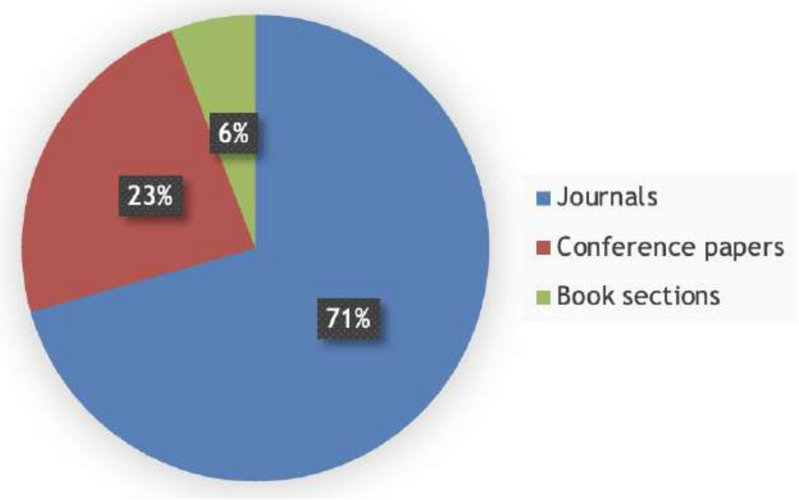

Figure 4 Type of publications

5.2 Conceptual aspects

Different concepts were identified from the systematic literature review. The identified concepts that are used in lean maintenance are as follows:

Table 2 Identified concepts

No	Concept	Reference
1	Understand the needs of the customer	[8], [13], [21], [26]-[31]
2	Value stream identification	[13][32][15][12][26] [13], [15], [27], [33]-[37]
3	Identification of non-value-adding activities, value-adding activities and necessary but non-value-adding activities.	[8], [13], [15], [26], [28], [33]
4	Analysing the current state of lean maintenance	[8], [13], [26], [33]
5	Impediments of lean maintenance implementation	[21]
6	Application of lean maintenance principles and tools	[13], [15], [26]
7	Support from the government	[21], [38]
8	Training programs should be made available to workforces at different levels to spread the required skills and techniques for minimising waste, such as cost and time control, scheduling, and risk analysis	[13], [39]
9	Continuous improvement	[8], [13], [15], [27], [28], [40], [41]

The key performance indicators in the rail environment include rolling stock availability, reliability, health and safety, maintenance cost, speed, quality, value, environmental impact, client satisfaction and waste.

6 LEAN MAINTENANCE IMPLEMENTATION FRAMEWORK

6.1 Developing the framework

After analysing data through a systematic literature review, a framework that can be used in the railway sector to implement lean maintenance was developed. The framework consists of nine steps. The first step is to educate everyone involved in lean maintenance and its benefits. The second step is to identify customers. The third step is identifying impediments to implementing lean maintenance in the railway sector. The fourth step is to specify the value. The fifth step is value stream identification. The value stream is made out of all the activities that create customer value and satisfy the demands and expectations of the customer. In this step, value-adding activities should be distinguished from non-value-adding activities and necessary but non-value-adding activities. Distinguishing these activities helps to identify the sources of waste. The sixth step is establishing flow by minimising waste and focusing on value-adding activities. The seventh step will be to set activity standard times. The eighth step is to pull maintenance execution. Finally, the ninth step is to seek perfection; this is achieved by repeating steps one to eight. Repeating these steps means Kaizen (continuous improvement) is achieved.

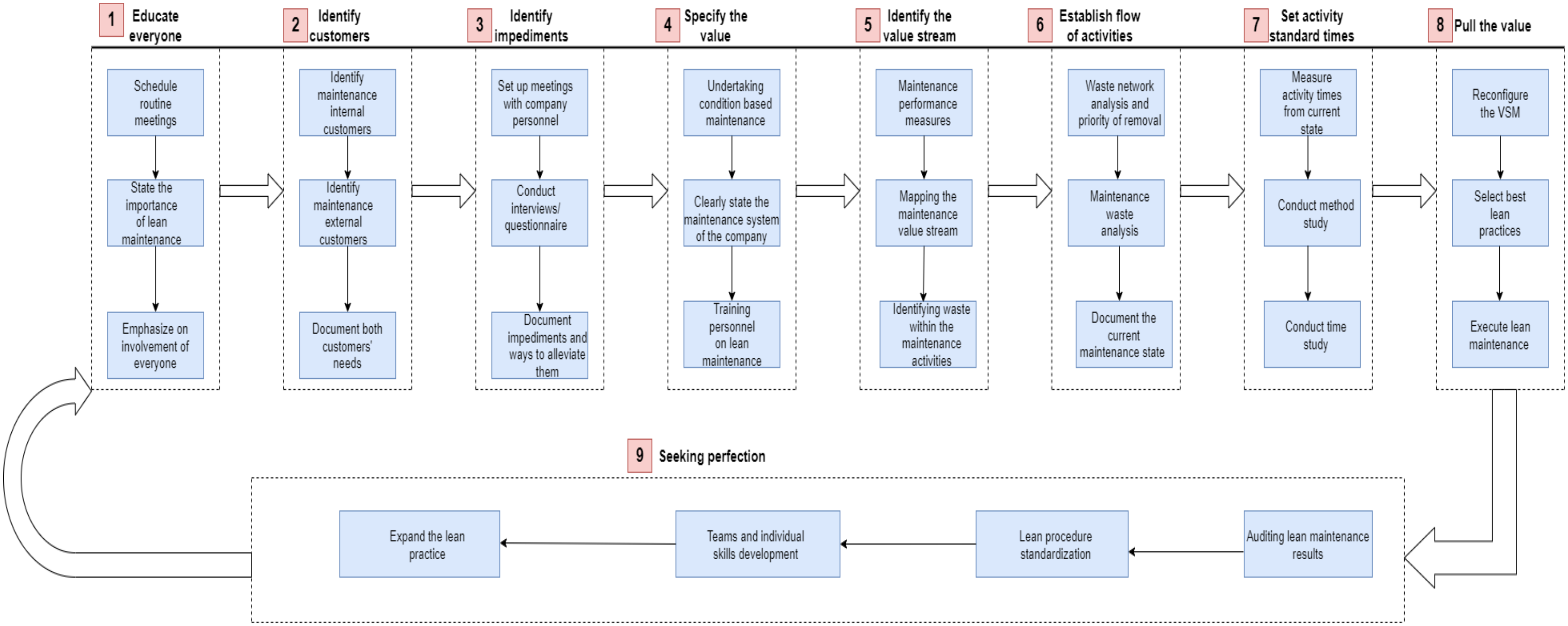

Figure 5 Developed lean maintenance implementation framework

Table 3 explains the step, the reason for the step, and the tools used for the developed lean maintenance implementation framework. Table 3 will be used with Figure 2, a developed lean maintenance implementation framework. This is to help in implementing easier the developed framework.

Table 3 Developed lean maintenance implementation framework

No	Step	Reason for Step	Tools to be used
1	Educate everyone within the railway industry about lean maintenance	To ensure everyone involved understands the rationale behind implementing lean maintenance	Scheduling routine meetings perhaps twice or more per week
2	Identify customers	This helps to caution everyone involved in who is affected by maintenance services as some customers might be overlooked	Value stream mapping, Process mapping
3	Identify impediments to the implementation of lean maintenance in the rail environment	To ensure that all stumbling blocks to the implementation are planned and catered for beforehand	Interviews, Questionnaires
4	Specify value	This helps to outline value from a maintenance point of view as well as from the customer	Value analysis mapping
5	Identify the value stream	To identify waste within the system. To identify NVAA, VAA, NNVAA	5 Whys, Process mapping, Value stream mapping
6	Establish flow of activities	To standardise the way of performing activities as well as the sequence of events	5 S process, 5 Whys
7	Set activity standard times	To standardise the duration of activities	Method study, Time study
8	Pull maintenance execution	To produce what the customer needs	Just-In-Time
9	Seek perfection	To involve the customer in the process	Kaizen

6.2 Framework validation

The framework was validated by interviewing Subject Matter Experts (SMEs). Purposeful sampling was done to select the participants. SMEs were personnel with experience in a rail maintenance environment. A pre-read document was made available to them through email so they could familiarise themselves with the proposed framework and how it was developed before the interview. The interviews were conducted telephonically or through Microsoft teams, depending on the comfortability of the participant. Structured questions were used to gain insight from the SMEs. The interview questions covered the identified concepts and the developed framework. The developed framework focused on the need, use, redundancy, usefulness, and applicability of the developed framework for the rail maintenance environment.

During the interviews, the interviewer was taking notes of the contribution being made by participants. The interview sessions were recorded. Consent to recording the interview session was sought before the interview. Recording helped the interview to go through the interview session later to identify some of the points raised by participants.

Five (5) SMEs participated in the validation process. All the five (5) participants agreed that the identified concepts are relevant to lean maintenance in rail environment, they were properly identified and that if they are properly used can help organisations to effectively implement lean maintenance in rail environment. Four (4) were satisfied with the identified concepts, however, one suggested that the second concept (value stream identification) should be linked with ISO9001. However, the author believed this was beyond the scope of the current research.

On the developed framework, the SMEs agreed on the need and usefulness of the developed framework. They further highlighted that the rail maintenance environment lags behind the lean implementation. However, one SME proposed the inclusion of Mission Directed Work Teams (MDWT). This would have increased the scope of the research hence it was not incorporated.

Stating the specific maintenance strategy to be used was suggested by one SME, however, the developed framework is supposed to be generic to allow different organisations to alter it to suit their needs, hence the idea has not cooperated. Due to the input given, the proposed framework became the final developed framework since there were no significant alterations that SMEs suggested.

7 CONCLUSION

Based on an extensive review of the lean maintenance literature from different environments and the worldwide railway sector, a framework for applying lean in rail maintenance has been developed. It has been developed to make maintenance reduce/eliminate waste maintenance in the rail environment. In the literature review, lean principles and tools were identified for formulating a maintenance implementation framework.

The lean maintenance framework consists of nine steps. These include educating everyone about lean maintenance, identifying customers, identifying impediments to lean maintenance implementation, specifying the value, identifying the value stream, establishing a flow of activities, setting activity standard times, pulling maintenance execution, and seeking perfection.

The nine (9) steps are supported by different activities which enable practitioners to implement the proposed framework. These activities help the maintenance practitioners to know how they can implement each of the proposed step. This then makes the current study unique in the sense that it goes beyond highlighting the steps to be used in implementing lean maintenance in rail environment but also in providing supporting activities to implementing the highlighted nine steps.

8 FUTURE WORK

The lean maintenance implementation framework can be further developed to suit the rail maintenance environment better. Further work can be on the inclusion of ISO9001 on value stream identification. This ensures that practitioners practicing lean maintenance in the rail environment remain in line with the ISO9001 standards.

Further research can be done on the developed framework by incorporating Mission Directed Work Teams (MDWT). These will help form effective work teams hence improving productivity and efficiency.

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SAIIE 10 APPENDIX A

Table 4 SME input analysis questions

Aspect	**No**	**Question**
Identification of concepts	1	Do you think the identified concepts are relevant for lean maintenance in the rail environment?
	2	Do you think the concepts were properly identified?
	3	Do you think all concepts needed to perform lean maintenance in railway were identified?
Framework developed	4	Do you think the framework can be used for effectively implementing lean maintenance of rail environment?
	5	Do you think that necessary changes that can be made?
	6	Are there any comments/additions/subtractionsto the construct of the framework that you would like to make?