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Preface

The 32nd SAIIE conference of the Southern African Institute for Industrial Engineering (SAIIE) continues to showcase industrial engineering research and practice in South Africa. The conference retains a focus on developing authors, reviewers, practitioners and researchers to create and sustain an active and reflective industrial engineering community of practice.

The submissions to this year's conference highlight the challenges in our country and the role that industrial engineers can play in making a difference. Of the 15 tracks in the final conference programme, 3 focus specifically on interventions and opportunities in the public sector. I remain proud to be associated with a community that actively seeks and takes steps to understand and solve the complex problems around us.

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 at the in-person conference event. Submissions were themed in tracks to explore ideas emerging from the papers and presentations.

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 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 8 of the 11 academic institutions with industrial engineering departments in South Africa. The maximum contribution to the proceedings by any one institution is 23%.

A total of 101 full paper submissions were received, and 79 of these were accepted after the peer-review process. The conference programme also includes six abstract-only submissions, three invited keynote presentations and six workshops. Twenty-one papers were selected for the special edition of the journal, and as a consequence these papers were withdrawn from the proceedings. A full list of these papers is included on pages 9 and 10 of this document.

This conference, therefore, has three outputs:

• The ***Conference Event*** includes a series of pre-recorded videos and the abstract of each paper shared with conference delegates using the online conference app and 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, honouring the best work submitted to this conference. The Special

Edition also contains submissions from other related conferences.

Thank you to Mia Mangaroo-Pillay and Anri Klopper, who assisted with administering the full paper review process. Thank you to Lynette Pieterse for your tireless administrative support and Thereza Botha for putting together the final conference proceedings. Thank you to the entire conference organising committee, whose enthusiasm and high standards push the conference to greater heights each year. These conference proceedings would not be possible without the time and wisdom of our reviewers. I know that every published paper is better due to your input. Furthermore, thank you to our authors for trusting us with your papers, for being brave, for your willingness to share and for pushing the boundaries of industrial engineering research and practice. And lastly, thank you to Prof Corne Schutte for your guidance and mentorship.

I trust that you will make the most out of the combined efforts of our authors and editorial and conference team and will find value in this publication and inspiration in the included ideas and work.

Dr Teresa Hattingh

Editor
September 2021

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THE DEVELOPMENT OF THE RAIL INDUSTRY IN SOUTH AFRICA WITH THE APPLICATION OF THE ELEMENTS OF FOURTH INDUSTRIAL REVOLUTION

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ABSTRACT

The rail industry has always been a frontier in mobility and technological advances. With the rapid and emerging technological advances in the industrial sector, some cutting-edge innovations in line with Industry 4.0 can be deployed for the development of the railway sector. This work enumerates the potentials of some elements of the Fourth Industrial Revolution (4IR) as well as their areas of application with the aim of transforming the rail sector in South Africa. Such innovations include: additive manufacturing, Automatic Train Control (ATC), Internet of Things (IoT), predictive maintenance, Artificial Intelligence (AI), smart sensors, big data, cloud computing, drones, and biometric ticketing. Selected literature survey was carried out on 4IR technologies as it applies to the rail sector. The synthesis of the existing works on the 4IR technologies demonstrate the feasibility of the technologies to transform the rail sector if implemented properly. These technologies can be deployed in the areas of design and manufacturing, procurement, logistics, assembly operations, supply chain activities, process planning, operations management and maintenance. This will create a smart and fully automated rail transportation system, thereby, leading to the digital transformation of the industry.

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1 INTRODUCTION

The Fourth Industrial Revolution (4IR) is an integration of various technologies driven by the cyber physical systems [1]. The interaction of the cyber-physical systems with other technologies such as the Additive Manufacturing (AM), Artificial Intelligence (AI), Machine Learning (ML), cloud computing, big data, and the Internet of Things (IoT), is geared towards increase in growth and productivity of the various organisations or sectors [1-2]. The 4IR is a fusion of various technologies across the cyber physical, digital and biological worlds which signalled a major shift across the industries as well as the advent of new business opportunities [3-4]. Hence, the application of the 4IR capabilities is rapidly transforming the industrial sector. The emerging technologies, which are innovative and disruptive, has brought about improved performance in the delivery of product and services, logistics and transportation, operation and maintenance amongst others [5]. Through access of information and data in real time, it has also enhanced globalisation and competitiveness as manufacturers and operators are now embracing digital solutions in order to gain a competitive edge. Olaniyi [6], stated that the implementation of the 4IR technologies in the transportation sector can enhance the standards of the modes of transportation to make them more reliable and efficient. Furthermore, the transfer of the 4IR technologies can also aid the local manufacturing sector. Zissis [7] stated that the implementation of the 4IR capabilities can cause systems to be smarter, organisations to be more efficient, processes less wasteful, production lines to be more flexible, and productivity to increase.

In South Africa, the capability of the 4IR technologies geared towards the revamping of the transportation sector has been highlighted. The need to deploy the technologies of the Fourth Industrial Revolution to the rail sector in South Africa stems from the fact that the rail sector are presently facing some challenges that need to be addressed. Some of these challenges include:

- development and use of modern fleets,
- quest for rail network expansion to foster interconnectivity between the towns and cities,
- interruptions of the supply chain activities,
- the need to improve on the real time monitoring and control, need for communication and intelligent coordination of the systems,
- the need for the deployment of biometric ticketing and drones,
- poor maintenance practises that often reduces the availability and reliability of the train systems,
- unreliable scheduling and unrealistic forecast,
- the need for improvement in ride comfort and safety as well as the overall performance of the system.

These challenges can be sufficiently addressed with the emerging technologies of 4IR. Such emerging technologies include artificial intelligence (AI), the Internet of Things (IoT), cloud computing, cybersecurity, robotics, automation, additive manufacturing, cyber-physical systems, genome editing, blockchain technologies, big data and analytics, virtual reality (VR), augmented reality (AR) and hybrid or mixed reality (MR) [8-10]. From the aforementioned, some of these emerging technologies that could find application in the rail sector include: additive manufacturing, Automatic Train Control (ATC), Internet of Things (IoT), predictive maintenance, Artificial Intelligence (AI), smart sensors, big data, cloud computing, drones, and biometric ticketing.

This study could contribute to the academia for future research purposes. It could also enhance the understanding of the stakeholders in the rail sector on the implementation of some recent innovative advances, capable of transforming the railway sector in South Africa. This study can also provide the right direction in which the South African railway should step towards for improved operation efficiency, asset management and increased profits.

The South African railway sector still lags behind in the implementation of the 4IR technologies. The developing nations can consider the implementation of the emerging 4IR technologies in line with the international best practices more specifically in the area of infrastructural development, operations and management. Hence, the aim of this study is to create awareness about the exploration of some recent innovative advances, which can be geared towards the development in the railway sector in South Africa.

There is a need to embrace digital technologies in order to improve the operations, service and maintenance activities in the railway sector. The digital technologies encompass the acquisition and analysis of digital data for component manufacturing, reliable forecast and good decision-making. The digital services are aimed at improving the nature of services rendered with improved customers' satisfaction. On the other hand, the automation of the railcar system will promote safe and operational efficiency with reduction in the operational error and cost while digital connectivity will synchronise the supply chain and rail network for effective delivery. The deployment these digital technologies in the railway sector will promote improved driver and passenger comfort, customer satisfaction and safety as well as significant reduction in catastrophic failure of system and energy losses through real time monitoring. It will also enhance the operation, maintenance, and performance of the railcar with significant reduction in the maintenance related cost through predictive maintenance. Furthermore, it will give room for proper scheduling and realistic forecast leading to increased availability and reliability of the system. Hence, these benefits will promote the overall efficiency and performance of the rail sector.

2 METHODOLOGY

This study reviews some selected articles relating to the application of the 4IR to the rail industry. The systematic review employed in this study involves the search for keywords, the identification of inclusion criteria, confrontation of the literature and derivation of lessons as well as future direction that can be helpful to the rail industry. Abdulrahaman *et al.* [11] stated that the systematic review can enhance a thorough synthesis of the existing literature in order to draw important lessons. Some of the keywords searched from the academic databases include: fourth industrial revolution, technologies of the fourth industrial revolution, and emerging technologies in the rail industry amongst others. The total number of the articles obtained from the academic database after the search was 76. Thereafter, the selection of the articles reviewed were based on the contents, similarities to the keywords and the title of the study. Duplicate articles were eliminated and this brought the total number of articles reviewed to 36. Hence, the inclusion criteria were based on the relevance of the articles to the study, similarity to the keywords, as well as year of publication. Following the review of the selected articles, a framework was developed which integrates the major elements of the Fourth Industrial Revolution (4IR) for implementation in the rail sector. First, selected literature survey was carried out on 4IR technologies as it applies to the rail sector. The synthesis of the existing works on the 4IR technologies demonstrate the feasibility of the technologies to transform the rail sector if implemented properly.

Some of the elements of the FIR find application in the rail sector namely, Additive Manufacturing (AM), Automatic Train Control (ATC), Internet of Things (IoT), Predictive Maintenance (PM), Artificial Intelligence (AI), smart sensors, big data, cloud computing, drones, and biometric ticketing. A framework which integrates some of the 4IR technologies for decision making in the rail industry is illustrated in Figure 1

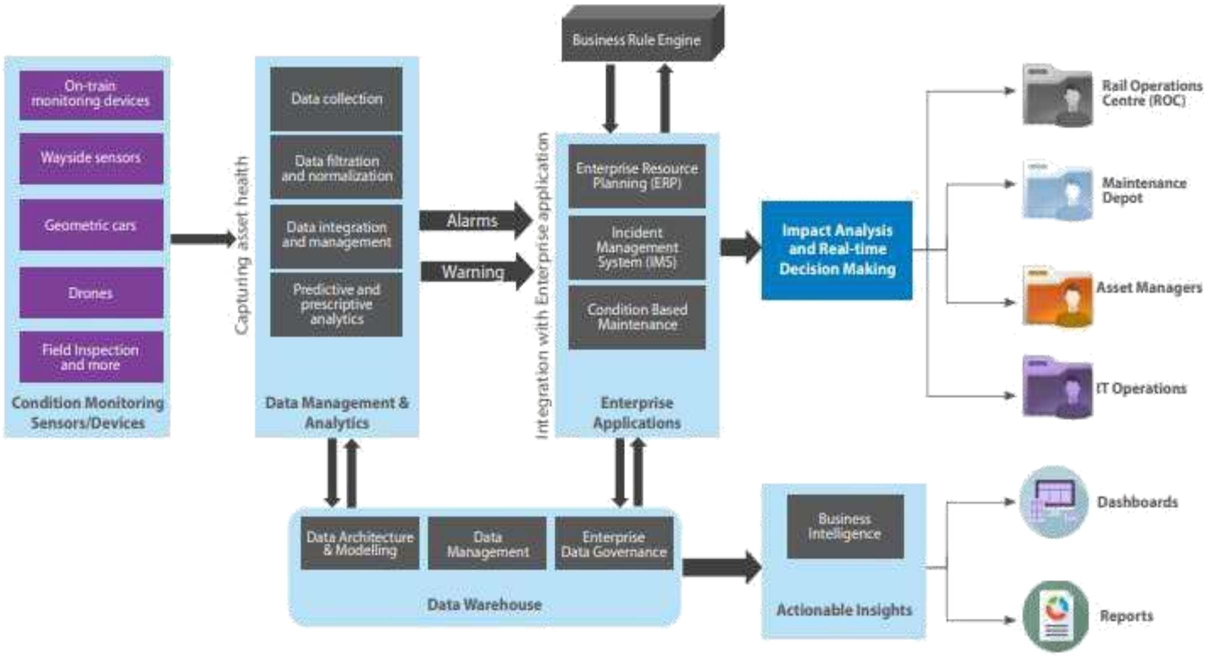

Figure 1: Framework for decision making in the rail industry [12]

2.1 Additive manufacturing (AM)

AM is the process of joining materials layers upon layers to make objects from a 3D model data [13]. The AM process has the potential to break creative barriers within the three major trends driving the industry namely product innovation, high-volume direct manufacturing and fuel efficiency with increased performance [14-15]. A major hurdle to maintenance and utility of trains is the lack of readily available spare parts. Phuluwa *et al*. [16] emphasises that lack of a well-defined and coordinated approach to move away from a linear to circular economy in rail industry can be seen as a potential challenge during the End of life recovery phases of the railcar components. The latest AM techniques can produce parts that meet the requirements of the railway agency in a cost and time efficient manner, which could substantially improve the train utility, as well as reduce down time.

Hence, the railcar manufacturers can explore the potential of the 3D multi-material technology to open up new design possibilities that would help meet the dynamic design and customers' requirements within the local contexts. The use of AM in the development of railcar will also eliminate the need for complex tooling and fixture, promote fast and efficient manufacturing process, enhance design modification for flexibility with reduction in material wastage and improved inventory etc. Krzyżanowski [17] stated that the implementation of AM technology reduce the manufacturing lead time, promote the availability of rail car in the market and also reduce the production times by up to 95%. Krzyżanowski [17] further indicated that innovative solutions have been introduced into the German railway sector through the use of AM technology. This has led to quick production spare parts that would otherwise be associated with longer manufacturing lead times as well as reduction in maintenance downtime. For proper implementation of AM in the transport sector, Muvunzi *et al.* [13] developed guidelines for the identification of situations where the application of the Additive Manufacturing (AM) technology would be more beneficial. The framework addresses the core functions of the products to be developed as well as the environment where it is suitable. The framework will also permit the screening of potential part candidates in order to promote the overall sustainability of the AM process in terms of material conservation, geometric complexity and functionality.

2.2 Automatic train control (ATC)

The development of cyber physical systems which integrates software with controls, communication network and the physical system is necessary for effective controls [18-20]. The rail car operators can deploy a Communications-Based Control (CBC) with signal systems to enhance effective communication between the railcar and the track equipment for tracking the movement and positions of the railcar. This will foster safety and effective management of traffic and rail infrastructure. The CBC system uses a high-resolution train location determinant, track circuit, high capacity multi directional data communication system and processor with automatic protective functions. The ATC of the railcar also has the automatic train supervision (ATS) functions, GPS-receiver, a camera array and a set of sensors, on-board Artificial Intelligence computing unit. This digital signalling with the aid of CBC and railcar control solutions are able to offer significant passenger and freight benefits at a lower cost, relative to wholly conventional based solutions [21-22]. ATC is usually required due to the increasing need for reliability and safety of the railcar. This system provides an alarm for any potential obstacle or interfering object, which appears to the driver as a visual image on the board monitor. The signals from the GPS satellites accompanied with the data collected from sensors and cameras will assist the train operators to process data in real-time, which will aid quick decisions making. In addition, the CBC and the ATC will also promote real time monitoring, as well as effective communication and proper planning of route accordingly to avoid traffic and interruptions. This will increase productivity and the overall systems' performance as the driver will be able to understand and avoid any possibility of collision with obstacles. The development of automated early warning system which provides an alarm for any suspicious interfering object has been reported [8]. The system has the potential to classify any nature of object and present it to the pilot as a visual image on the board monitor for quick obstacle avoidance [8].

2.3 Internet of things (IoT)

The Internet of Things (IoT) makes it possible to gather and transmit large amount of information for analysis and the development of predictive algorithm [23]. The rail systems communicate with other systems during operations. Information can be stored or shared seamlessly and in real time via the internet. The information obtained via the IoT can relate to the railcar condition, flow of passengers, weather conditions, asset location or condition, or other operational conditions. This can foster intelligent coordination of the rail system, optimisation of schedules, reliability and safety of the rail asset, interconnectivity, automation and maintenance of railcars [8].

The data gathered can also enable constant communication between the fleet and the main control centre while enhancing intelligent coordination to improve railcar operational efficiency and safety. This enhances smart ticketing, rail analytics, dynamic route scheduling and capacity planning. The communication between the fleet and the main control centre enhanced by IoT in real time is also necessary for traffic management, fleet and time management, coordination and optimisation of the train movement and in operations scheduling [9].

2.4 Predictive maintenance

The rail industry has been identified as one of the most asset-intensive industries, investing about 20% of its revenue in asset maintenance so as to ensure a reliable and safe operations [12]. Besides, the non-availability of rail assets due to maintenance, and breakdown which characterise the traditional scheduled or preventive maintenance can be reduced with preventive maintenance. The predictive maintenance involves the use of sensor for data acquisition from the asset and the development of predictive algorithm as well as diagnostic monitoring functions in real-time [12]. The preventive maintenance is a continuous inspection and diagnosis function, which involves the estimation of failure times of individual parts. The approach allows for continuous asset monitoring and management, proactive identification of defects, initiation of maintenance before failure thereby enhancing system's availability and reduction of maintenance costs. Sensors are usually fitted into railcar systems or along railway tracks to capture the condition of the rail asset in real time [12]. The data captured can be analysed and fed into predictive model to enable predictive maintenance operations. This could reduce wasteful planning and maintenance activities, while also reducing in service failure of parts. Hence, predictive maintenance, enhance better inventory management, eliminate unplanned downtime, while maximising equipment lifetime. It can also bring about the reduction in maintenance cost, increase in railcar availability while minimising costly delays or interruptions thereby improving ride comfort and safety [24]. This can also significantly improve the efficiency, safety, and quality of fleet management and services through wireless and condition monitoring. The data gathered in real-time through the smart sensors with other monitoring software or devices can be used to develop predictive algorithm or models, which will provide information relating to the technical conditions of some railcar components like the bearings, wheels, and bogies etc. The continuous inspection and diagnosis support systems will assist operators in the quick intervention as regards maintenance operations before a catastrophic failure. The development of a predictive software which can predict potential failure in the railcar systems has been reported [8]. The software employs sets of algorithms for the conversion of acquired data into useful information about the system's conditions and likelihood of failure. This information can be leveraged upon to forestall breakdown.

2.5 Artificial intelligence (AI)

Artificial intelligence refers to machine intelligence which relates to the learning and problem-solving capabilities of machines. It can act as a driver for many innovations and emerging technologies in the rail industry. For instance, Artificial Intelligence (AI) find applications in pattern recognition, image processing, diagnosis, remote sensing, process planning and optimisation, decision making and system control [25-27]. The capability of AI in system monitoring, fault diagnosis, identification of acoustic emissions, and predictive maintenance have been demonstrated [28-31]. The data captured via the use of sensor can be trained using specialised AI algorithms. Hence, the use of AI systems can help in diagnosing the technical conditions of the railcar and its tracking using the online mode (in real time) in order to obtain the system and measurement performance. Artificial intelligence can be explored in railcar manufacturing for nonlinear prediction relating to traffic, and the condition of rail infrastructure. Artificial Intelligence system can be used to detect malfunctioning railcar components through audio signals. The input data into the neural network are iteratively trained under supervised or unsupervised learning environment to recognize and identify important features relating to components health and failure with high level of confidence. The railcar operators now focus on the development of intelligence systems for the early detection of faults or mechanical malfunctions. This offers predictive maintenance, real-time detection and diagnosis of faults, and remote diagnosis of equipment. Artificial intelligence also acts as the building block of robotic solutions which can assist in the assembly operations, maintenance and repair works on railways.

Furthermore, the AI technology can also be deployed for the development of fully autonomous railcar with smart infrastructure components, which will permit the interconnectivity, and communication of the railcars with other systems. AI capabilities have been harnessed for the detection of faulty systems using audio signals [8]. The acquired data was pre-processing to allow the neural network to recognise and classify important features with high confidence level [8].

2.6 Smart sensors

Smart sensors are the basic building blocks of the Internet of Things. Unlike the basic sensors, smart sensors comprise is an integrated system comprising of a sensor, micro-processor and communication technology which enables it to take measurements as input data, process it and communicate in real time [32]. For instance, smart sensors such as load sensors, brake sensors temperature wheel sensors etc. can be integrated into the railcar system for measuring critical parameters or conditions of the railcar system in order to develop an effective monitoring system for robust communication and diagnostic functions. This will foster effective monitoring of the health of the rail car in real time. This will decrease the failure rate and enhance the reliability of the rail, tracks, and signals. The data collected through the smart sensors can be extracted and processed through the use of dedicated algorithms and relayed as signals via the monitoring systems for quick decision making.

The implementation of low-power wireless networks of sensors for the acquisition systems of accelerometric signals has been reported [8]. Specialised processing algorithm was employed for the extraction of required information for diagnostic purpose [8].

2.7 Big data

The challenges of globalisation and the dynamic nature of railway sector as well as the ever-increasing competitiveness and complexities in the rail manufacturing industries is causing the rail manufacturing industries to align with knowledge and data driven systems in their quest for improved productivity, cost effectiveness, proper scheduling, adequate monitoring and control. The big data analytics can help in the analysis and interpretation of information across the entire railcar systems or rail network. It can also enable the development of predictive algorithms, interpretation of information from different data sources, and real-time communications [12]. The right interpretation of the information relating to rail asset can help improve asset availability, service levels, and minimisation of service delays or unplanned maintenance. Also, through the concept of big data analytics, large amount of data relating to railcar operation and maintenance etc. can be gathered, processed and analysed to achieve a reliable forecast. Hence, big data plays a significant role as it assist the rail industries with the accurate analysis of necessary data to perform predictive function, thus, enhancing good decision-making. Proper data analysis will significantly improve the performance and safety of the railcar and railway systems while fostering proper design, planning, operation, improvement in fleet utilization, and management. It also enables the real-time condition monitoring tasks efficiently and securely executed [33]. The real-time railway condition monitoring for remote monitoring of rail assets in real-time has been reported [8]. Following the analysis of the data captured, abnormalities can be detected for immediate rectification by the operator.

2.7 Cloud computing

This secures and distribute repository for rapid access and analysis of big data. Through cloud computing, the servers and databases provide a secure undistributed repository for rapid access and sharing of information in real time. The cloud-computing infrastructure is designed to provide all the necessary accessories required to connect assets to smart sensor and other third-party devices through the right interfaces. Since the railcar has significant number of devices and applications that generate a vast amount of data, the data can be stored in real time while simultaneously providing absolute accessibility thereby, promoting easy convergence of network and data. Furthermore, the cloud-computing applications can easily provide interconnectivity and robust information sharing among trains, stations and service operators. It can also enhance easy connection to other software for the analysis of collected data and provide operators with all necessary information for quick decision making. It can also enable the rolling stocks manufacturers, signals and rail track stations and other operating stations to work cooperatively through the use of intelligent on-board devices. Monitors that can be connected to cloud-based applications to enable video surveillance across fleet fleets and operations in order capture and store important data in real-time [34-35]. The analysis of this data through big data infrastructure and a secure database for easy access to such data will assist in the optimization of designs, schedules, operations and also assist in keeping track of assets and operations.

The development of cloud solutions for smart rail assets have been reported [8]. The servers and databases provide a secure undistributed repository for rapid access and big data analytics of the data acquired from the smart sensors. Once the data acquired is effectively analysed and interpreted, it can be stored or shared in real time via other communication enabled devices [8].

2.8 Drones

The drones are automated inspection machines with embedded sensing technologies and AI capabilities suitable for inspections activities. The drone technology can be employed in the rail industry for the monitoring of rail infrastructure most especially in difficult to reach, dangerous or remote place such as high voltage electrical lines. Drones are capable of collecting detailed data in these areas for condition-based assessment. This will significantly reduce the risk, time, and cost of accessing these areas with the workforce. Besides, it allows for intelligent of rail asset and infrastructure management in order to improve its useful life, safety and reliability [36]. The inspection and monitoring of rail assets via advanced sensing technologies and Data-as-a-Service has been reported [8].

2.9 Biometric ticketing

his technology uses infrared lights flashing at a rapid pace to help a camera capture the shape, texture, and orientation of a body part in immense detail. The concept of biometric ticketing can be used to solve the queueing problem in train stations as the recognition technology can end railway ticket barriers and the associated rush-hour queues. With the biometric ticketing, payment, check-in, and seat distribution can be done faster and securely. The use of biometric ticketing will also promote safety as the technology can perform scans such as facial, fingerprint, retina or voice scans thereby providing a reliable means of customers' identification to promote safety and travel comfort [8]. The development of facial recognition technology with 3D scanning capabilities for human identification has been reported [8].

3 CONCLUSION

This study has proposed the application of the elements of the Fourth Industrial Revolution for the development of the rail industry. The identified technologies can provide satisfactory digital solutions to many challenges in the South African rail industry. If adequately deployed, it has the potential to revolutionise the design, manufacturing, operation and management of railcar systems, leading to rapid transformation of the sector.

4 RECOMMENDATIONS

It is recommended that the South African rail industry and the regulatory agencies act now by embracing these innovations and adjusting their business model to accommodate these disruptive technologies in order to gain a competitive advantage and emerge as frontiers in the rail sector line with the global best practices. The rail industry can also be transformed by the deployment of virtual reality (VR) and augmented reality (AR), with machine vision and light-based communication technologies.

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THE APPLICABILITY OF LEAN SIX SIGMA FOR SOLVING PROBLEMS IN A SOUTH AFRICAN MUNICIPALITY

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ABSTRACT

Lean Six Sigma has often been applied to solve problems in the manufacturing context. In this paper, we explore the feasibility of applying Lean Six Sigma (LSS) in the public services sector, specifically within a South African municipality environment. The motivation for the study was that the municipality observed managed to achieve only sixty-four percent of its annual targets and experienced several service delivery challenges. The research employed a qualitative research approach with the case study of a local municipality as the unit of analysis. Data was collected through semi-structured interviews and content analysis of documents. The findings of the research proved that Lean Six Sigma could be applied to some of the problems that are faced within the municipality and public sector at large.

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1 INTRODUCTION

According to the General Auditor's report, municipalities in South Africa have shown an adverse regression in their annual performance. In the 2017/2018 financial year, only 7% of all South African municipalities achieved a clean audit [1]. Given the impact that municipalities have on the quality of living of South African citizens, municipalities need to find ways to address this challenge, otherwise, the country will continue to face poor service delivery. The performance of municipalities is affected by varying internal and external factors, hence the need to understand the possible causes of the poor performance. Furthermore, there is a need to understand the feasibility of applying Lean Six Sigma in helping resolve these causes. This study aimed to understand the feasibility of applying Lean Six Sigma in public services, in a specific South African municipality. It focused on how Lean Six Sigma can be used to improve the current municipal performance through the minimisation of the problems faced.

Lean Six Sigma is defined by Antony et al, [2] and Maleyeff, [3] as a methodology that is aimed at improving process efficiency and achieving excellent customer service. The application of Lean Six Sigma originated from the manufacturing and production industries, hence has not been popularly applied in the services industry [3]. Over the years different public sectors such as healthcare, education, and banking have applied the Lean Six Sigma methodology and have proven it to be feasible and beneficial [2]to the public sector.

The study was focused on the District Municipality in the Limpopo Province of South Africa. The District Municipality in the Limpopo Province has been performing poorly for a few years, according to the Department of Cooperative Governance. In the year 2018, the municipality only achieved 64% of its annual targets. These problems indicate that there is a need for the municipality to improve its current operations and processes.

Taking all these factors into consideration, the critical research question for the study was: How is Lean Six Sigma applicable in solving problems in the public services sector, specifically within municipalities? Taxpayers in South Africa contribute the most to the municipal budget, hence it becomes a concerning matter when there is minimal improvement in the performance of the municipalities.

The main objectives of the study were:

1. To assess the application of Lean Six Sigma in solving problems within the public services sector.

2. To evaluate the feasibility of applying Lean Six Sigma in solving problems faced by municipalities.

The justification of the study is that there is minimal research and literature relating to Lean Six Sigma in the public sector, especially in the local context.

The paper is structured as follows: the literature review is outlined in section 2 and it will cover the theoretical view of the research topic and the related themes. Thereafter, the research methodology and data analysis strategy are detailed in section 3. Furthermore, the results are assessed relative to the research question in section 4. Section 5 concludes the paper and recommendations regarding Lean Six Sigma in the public services, specifically the municipality are given, based on the results and discussion that was conducted.

2 LITERATURE REVIEW

The literature review gives an in-depth analysis of the main themes in the study. The themes that were covered include the definition of Lean Six Sigma, the understanding of public services, and the applications of LSS in the public sector.

2.1 Lean six sigma

Lean is focused on continuous improvement through the reduction of variation (Muri), waste (Muda), and poor working conditions (Mura) [4]. It is a management tool that aims to improve an organisation's performance through the minimisation of waste and non-value-adding activities. The seven forms of waste include defects, overproduction, waiting, non-utilized talent, transportation, inventory, and motion [5]. Extra-processing is often referred to as the eighth waste. Additionally, Radnor et al [4] discuss five principles that govern lean which include defining the value from the customer's view, mapping out a value stream process, ensuring continuous flow and standardization, introducing the pull system which involves just-in-time, and lastly moving towards perfection as an organization. Six Sigma is a tool used for improvement because it helps reduce variation and errors in a process. It focuses on the identification of the root causes of a problem and correcting them [6]. Furthermore, it relies on statistical use through a framework known as DMAIC (Define, Measure, Analyse, Improve, and Control). Six Sigma in services is not commonly written on by academics. Most of the case studies that exist in literature are focused on North America and Europe [7]. Table 1 below highlights the differences between Lean and Six Sigma.

Table 1: Comparison between Lean and Six Sigma [8]

Lean	Six Sigma
Objectives • Eliminate waste, • Use fewer resources, • Simple problem solving **Tools** • Value stream mapping, 5S, • Just in Time, Kaizen, • Standardization • One-piece flow, visual control, • Inventory reduction, Waste reduction. **Results** Short term results	**Objectives** • Reduce variation, • Quality, • Complex problem solving **Tools** • Voice of Customer • Statistics, ANOVA, DOE • SPC, QFD • Process mapping, Affinity diagrams, and Pareto charts • DMAIC, Fishbone, SIPOC. **Results** Long term results

Lean was founded by the car manufacturing company Toyota in Japan, comparatively, Six Sigma was developed by Motorola in the 1980s [9]. Consequently, the initial use of Lean and Six Sigma was within the production industry. Even after Lean and Six Sigma became merged, the applications were still maintained within manufacturing organizations [10]. To understand Lean Six Sigma outside the manufacturing sector, an understanding of public services and the public sector is needed before investigating the possibility of applying LSS within that industry.

2.2 Public Services

Section 8 of the Public Service Act, explains that the public service of South Africa comprises individuals that occupy permanent positions in the national and provincial departments, municipalities, and any other organisations. These departments include public works and infrastructure, education, Cooperative Governance, Housing, Settlements and Traditional Affairs (CoGHSTA), defense, human settlements, and health. To identify public services, the following characteristics are used. Firstly, public services exist for reasons of policy and provide services to the public. Secondly, public services are redistributive in that those that cannot afford to pay for the service are often given the service at no cost. Thirdly, public services manage their priorities, capacity, and outputs differently from services that operate for a profit, and lastly, public service organisations operate in multiple hierarchies [11] [12]. Public services are beneficial to society in that they ensure the economic development of the country, improve living conditions whilst also addressing inequalities that exist within the given nation [13]. An efficient public service provider can achieve its objectives with the lowest tax incurrence on payers and without consuming the country's economic resources.

2.3 Lean six sigma in public services

The services industry has seen enormous growth in the economy in recent years and has grown to be an important sector [14]. South Africa is shifting from a country that used to be heavily dependent on mining to a country that is dependent on services and the provision thereof, with the services industry contributing the most to the Gross Domestic Product (GDP) [14]. The service industry is faced with many challenges which decreases the level at which customer satisfaction is achieved. The reason for these hindrances lies in the fact that the services industry rarely uses data to make decisions, hence 30-50% of their costs are attributed to waste [9]. The difference in characteristics between the manufacturing industry and the services industry has been the main reason behind the slow deployment of LSS in the services industry according to researchers [9]. These differences include firstly intangibility which speaks to how services are not easily measured compared to products. Secondly, perishability whereby services wait to be executed and therefore experience a lot of work-in-progress. Thirdly, inseparability refers to the act where services are delivered and consumed at the same time, and lastly variability emphasizes that services are not easily reproduced in the same manner [9].

Additionally, public services have characteristics that are unique to them. These characteristics further influence the way Lean Six Sigma can be applied to public services. Firstly, each task has a different duration to the next task, for example, building infrastructure for electricity provision takes longer than license renewal. Secondly, the processes flow into various departments at the same time which often leads to mistakes or miscommunication. Thirdly, most of the work done requires multiple verifications from management which often delays the completion of the task. Lastly, workers are not motivated to apply a sense of urgency to their work [3]. According to Maleyeff [3], Critical Success Factors (CFS) are necessary for the successful application of LSS in the services industry. CFS are defined by Brotherton and Shaw (as cited by [15]) as the necessary things that need to be done correctly to assure success and gain a competitive advantage. The following is a list of some of the CFS for successful LSS applications in the services sector. Firstly, top management commitment means that the initiatives must be from company authorities (top-down rather than bottom-up) because of the influence that top management has over the entire organization. It was observed in recent literature that top-down management initiatives resulted in a quicker change of attitude amongst the workers ([9], [12]). Secondly, education and training which refers to training workers to better deploy Lean Six Sigma will result in the successful implementation of Lean Six Sigma within the organisation. This is because people will have a better understanding of the tools and techniques which is important for effective implementation. Thirdly, cultural change because Lean Six Sigma methodologies require the organisation to review its work culture and develop a plan to implement these new changes. This means that the workers need to adjust to this new culture as easily and quickly as possible. Fourthly, customer focus because Lean Six Sigma places great emphasis on customer satisfaction. Organizations need to ensure their objectives are customer focussed. Lastly, clear performance metrics because assessing which factors to measure is often difficult to determine in the services industry. Organizations need to know from the onset which performance metrics need to be measured ([16], [7], [3]).

2.4 Lean Six Sigma in the public sector

Different examples of Lean Six Sigma in the public sector are provided in this section to highlight successful possible applications. This section provides seven different such cases.

2.4.1 LSS at Linkoping Municipality

In a LSS study, the department that handled customer requests in the Linkoping Municipality [17] was investigated. To identify the problems within the department, the tools used were as follows: a process map, the voice of the customer, interviews, and critical to quality (CTQ). The problems that were identified included: a late response to customer requests, challenges with the IT systems that are being used, and the mix-up in the roles of each employee, poor sharing of information with customers, inconsistent standard operating procedures, and challenges in prioritizing customer requests. A root-cause analysis was performed for each identified problems. Some of the tools used in solving these problems were benchmarking and standardization. The process mapping was beneficial to the study in that it helped in identifying the roles of the workers and the activities to be performed and the problems that exist at each step of the process. The voice of the customer and interviews helped in clarifying the goals that the department needs to work towards, and which goals to prioritize. The CTQ tool helped in quantifying the customer requirements which made it easy to set targets. The cause-and-effect analysis aided in understanding the root cause of the varying problems. Benchmarking contributed to the improvement of the process whereas the standardization tool was used to indicate which parts of the process need to be standardized [17]. In this case study, the Lean Six Sigma tools were used to identify the root cause of the problems in the municipality and to give improvement suggestions.

2.4.2 LSS in a German Municipality

This case study investigated three different departments within a German municipality. These were the customer office department that handled land acquisitions and building constructions, the department responsible for subsidy applications and administration processes, and the department that handled the business administration process. Although there was resistance to change by the organization, there was a level of improvement that was achieved for each department. The department responsible for subsidy application and administration processes did exceedingly well after the implementation of Lean Six Sigma that it was awarded five million Euros [18].

2.4.3 Hospital X in India

A speciality hospital in India is responsible for providing healthcare services to 700-800 patients per day. Due to the high number of visitations in the hospital, the hospital experiences long queues and high waiting time, with the Outpatient Department having a waiting time of up to two hours. This high waiting time resulted in other hospital processes being affected. The hospital decided to use LSS to investigate the root cause behind the long queues. The DMAIC methodology was used to reduce the average waiting time and the variation in the process. Initially, the average waiting time in the department was 60 minutes with a 30-minute standard deviation. Any patient that was in the queue for over 60 minutes was considered a defect. After implementing LSS tools the average waiting time was reduced to 24.5 minutes with a standard deviation of 10 minutes [2].

2.4.4 Local government

A UK local council [2] was facing the challenge of filling teaching vacancies in the local schools. Initially, there was a lack of sufficient data to understand the problem clearly. This required the collection of data for 6 months, after which LSS was applied to try to solve the problem. The local council intended to improve the filling rate of vacancies in schools. After using LSS tools and creating a process map that highlighted the exchange of resources and information, several improvements were made which included the development of a new process. Furthermore, a data collection system was implemented which resulted in a cost savings of £60 000 per annum and a fill rate improvement of 35% [2].

2.4.5 Improving vehicle maintenance.

The Oregon lane county [3] received a non-compliance warning for its safety regulations after the occurrence of a fatal accident. An audit was performed to identify the root cause and the variation that exists between the safety procedures applied by the county and the actual regulatory requirements. It was discovered that the accident was due to a lack of standards in their pre-trip inspections of heavy equipment. The application of LSS resulted in the improvement of safety as opposed to achieving narrow compliance [3]. The application of LSS entailed the mapping out of current processes, identifying areas of improvement, and creating a standard procedure for pre-trip inspections [3].

2.4.6 Standard bank

Standard Bank [8] managed to save R438 million within four years of implementing a Lean Six Sigma project. This was achieved by improving one department in the bank, the Personal and Business Banking division. The department was chosen due to its high levels of inefficiency, frequent reworks, high rate of error, and multiple forms of waste. Furthermore, the division lacked a system that measured its performance hence making it difficult to track the root cause of the problem. After the implementation of Lean Six Sigma, the division has a system to measure and track performance which is moving it closer to continuous improvement and a highly efficient system [8].

2.4.7 Improving a classified information review process.

An organisation [3] that had great customer feedback noticed after a while that their process was not on time when it came to delivering service. The DMAIC methodology was used alongside process mapping. It was discovered that there was a poor tracking database, inconsistent documentation, the lack of prioritization criteria that hindered the efficiency of the process. Process modifications were made such as the implementation of a standard operating procedure which resulted in an improved cycle time [3]. According to a report by Poggenpoel [19], there is a less than 50% chance of South African public sector organisations to address any of the challenges they face. Hence the need for methods and tools that facilitate process improvement, which LSS can aid in doing. The next section will articulate the method used to collect and analyse data in this study. The tools used are described in detail including the research design, the instruments, and the sample size.

3 RESEARCH METHODOLOGY

The study followed the qualitative research design, and this was done using the case study approach, archival sources, and interviews as the research methodology. A qualitative approach was selected because the study aimed to understand the use of Lean Six Sigma in solving problems in the municipality. Qualitative studies make it easy to interpret phenomena and what those interpretations mean in each context. One of the advantages of qualitative research is that it gives access to detailed information about the research topic which is useful in answering how and why questions [20]. Case studies are useful for areas of study where the theory is not adequately written on. In this study, the case study approach aided in understanding how Lean Six Sigma can be applied in the public sector and helped in clarifying the debate behind the difficulties of Lean Six Sigma in the public sector. Case studies give a real-life context of the situation that is being researched [21] which gives the researcher a better understanding of the topic. This eliminates the need to conduct experiments or simulations to get information. Case studies are criticised for not being a robust method of research [22]. Another common criticism for the case study method amongst various authors is the use of one case study for analysis. This is because scientific generalisation cannot be made from a single case study [23]. To overcome the challenge of robustness, thorough theoretical reviews were made at the beginning of the research. This will limit bias and make it easy for scientific generalisation to be made. The challenge of using one case study can be justified by the argument made by Yin [21] that a single case study should suffice if it meets the established objective. The unit of analysis for the case study is the processes and systems within the South African municipality. Figure 1 below summarizes the steps followed in collecting and analysing data for the study. Firstly, a systematic literature review was conducted to understand the topic in detail and to aid in developing interview questions that were relevant for the study. Secondly, semi-structured interviews were conducted with the CoGHSTA senior manager, a municipal worker, and the supply chain manager. One of the disadvantages of semi-structured interviews are that they are time-consuming [24]. To overcome this challenge, the interviews were timed to be no longer than an hour. Another disadvantage is that the information gathered during the interview may be difficult to analyse and generalise [24]. This was followed by the transcription of vital points that were deducted from the interviews. Lastly, the responses were grouped according to categories in the data analysis section of this report. This made it easier to analyse the information.

Figure 1: Steps followed in conducting the research study

Furthermore, the case study considered documents that were made available by the CoGHSTA and that were published on the District Municipality in Limpopo Province website. All the documents that were not on public domains were accessed with the given permission. For data analysis, transcribing and content analysis were used. The sample size of the case study was limited to one firm/company. According to Tellis [23], single case studies are useful in studies that want to confirm or challenge the application of a theory. The chosen municipality is a district municipality that covers a variety of processes and offers services in both urban and rural areas.

4 ANALYSIS AND RESULTS

This section presents the results obtained from the data collection process. The semi-structured interviews with the three personnel from the municipality were approximately an hour long for each interviewee.

4.1 Case Description

Every municipality in South Africa consists of political and administrative institutional structures which are responsible for ensuring service delivery and the fulfilment of municipal Key Performance Areas (KPAs). The structure of the municipality is complex with multiple departments and offices. This case study seeks to investigate some of the challenges which inhibit the municipality from achieving its KPAs on financial viability and management. The Chief Financial Officer (CFO) is the senior manager who is responsible for this KPA. Under the office of the CFO, there is the Supply Chain Management department that is responsible for the municipality’s supply chain, logistics, acquisition, and asset management. Upon identifying the problems that exist within the municipality (during the semi-structured interviews), the researcher classified the problems that can be resolved by LSS and those that cannot, based on the literature that has been covered. The aim was to achieve the second research objective which seeks to investigate the applicability of LSS within a South African municipality.

4.2 Content analysis

The municipal documents and literature analysed are described in Table 2. The selected category of analysis is dependent on areas that have a significant impact on the municipal’s performance. Literature was then used to substantiate the findings, perform a comparative analysis and correlate the findings of the study to previous work. The table below details information on the departments that are being assessed and explains the documents that were used in performing a detailed analysis.

Table 2: Detail on how the collected data will be assessed

Category	Explanation
Technical services	Content analysis was performed across the different annual municipal reports and performance plans. This aided in identifying problems that are consistently occurring in the municipality throughout the financial years.
Supply Chain Management	The inventory management policies, the supply chain policies, and municipal balance sheets were reviewed alongside the input collected from the interview.
Financial Viability	The municipality's annual financial reports and the auditor general's reports were reviewed for analysis.
Literature	Recent related work was used to identify the problems in the municipality operations which can be potentially solved by LSS tools.

Both the interviews and content analysis aided in evaluating the feasibility of applying LSS within this municipality to solve some identified problems.

4.2.1 Technical services

This department has several key objectives that are related to the development and maintenance of infrastructure, the maintenance of roads and the management of transport, and the maintenance of water and sanitation structures. There were some difficulties that the municipality experienced in achieving some of its targets and goals during the 2017/2018 and the 2018/2019 years. The municipality recorded an average of 2.04 out of 5 in the annual performance of KPAs, which indicates a poor performance towards service delivery. Furthermore, infrastructural issues were mentioned to occur frequently such as ageing water infrastructures, unmetered reservoirs, illegal water connections, lack of water maintenance plans, high water, and sanitation backlog, and incomplete infrastructural projects associated with the poor planning of projects. Additionally, other challenges communicated included the appointment of contractors that are capable of fulfilling duties, the late appointment of contractors, and the lack of resources. The lack of review on work performed by contractors exacerbated the problems. Lastly, overtime working was higher than 30% of the time which depletes the budget resulting in additional expenditure.

4.2.2 Supply Chain Management

The municipality's ability to reach targets, and deliver services relies heavily on the supply chain management department. The problems highlighted in the reviewed documents were as follows. An average of 2.5 was achieved out of 5 in the annual performance of the KPAs, and this was attributed to the lack of educational workshops for stakeholders within the department, wrong statements in inventory record keeping, and a lack of monthly inventory counts and reconciliation. Furthermore, problems such as the lack of compliance to detailed processes, poor contract management of service providers or third-party distributors, and poor constitution of committees responsible for the selection of service providers. Additionally, frequent deviations from the procurement process, poor streamlining of the process, the lack of reconciliation on distribution losses, and the inadequate detailing of the scope of work for contractors has led to more challenges in this department. Other problems that were communicated included the inadequate asset verification process, completed work-in-progress (WIP) wrongly classified as on-going WIP and poor records management. The cost of inventory has been on average 18% higher than the value of the inventory in the previous financial year.

4.2.3 Financial viability

Finances affect the municipality's ability to carry out daily functions. Problems that occur in this department have an adverse impact on all the other departments. The problems that were found are as follows. This department had a 2.5 average annual performance on its KPAs, and this could be due to several causes such as the lack of communication between the department and the infrastructure department which often translates to incorrect reporting of the current state. Furthermore, the late appointment of service providers, the inability to stick to the budget, and the failure to monitor the invoice tracking system. Additionally, problems included the lack of standard procedures on receiving, recording, and payment of invoices, inconsistency in financial statements, the inability to collect revenue, and the understatement of resources and inventory in financial statements. Lastly, the failure in filling high skills vacancies and the overpayment of workers that claim to work overtime without detailing the stipulated hours that were worked. The outcome of the content analysis highlights the need for the municipality to better improve the organisation's performance. The responses reflect the existing need for a new way to tackle bottlenecks, variation, and the failure to achieve goals. Although the interviewees regard the municipality's performance measures as adequate, it is evident that the implementation of those performance measures continues to fail. The interview results also illustrate that the municipality's challenges exist across all levels within the organisation from top management to the bottom. Given that there are multiple problems and that the current tools of solving the problems are not serving their purpose well, it is worth investigating whether LSS can be a useful tool for the municipality.

4.3 Results of data analysis

The tables below contains a summary of the problems that have been identified. The problems are grouped according to categories for ease of assessment. These categories are Equipment, Man, Maintenance, Method, and Management.

4.3.1 Equipment

This category focuses on the challenges that the municipality faces in handling its resources and equipment. Table 3 highlights the problems faced within this category and explains whether LSS tools and techniques can be helpful in addressing the problems.

Table 3: Equipment-related problems

Problem	Can be resolved by LSS (yes/no)	Justification
Lack of resources and internal capacity	No	No literature covers the building of capacity for organizations
Lack of water-borne sewerage systems	No	No literature covers the building of capacity for organizations
Inadequate water infrastructure network	No	No literature covers the building of capacity for organizations

None of the identified equipment-related challenges can be solved by LSS tools.

4.3.2 Man

This category focuses on human-related challenges. Table 4 below, highlights the problems faced within this category and explains whether LSS tools and techniques are helpful in addressing the problems.

Table 4: Municipal problems caused by man-related activities

Problem	Can be resolved by LSS (Yes/ No)	Justification
Political interference	No	Although, LSS deals with management it does not consider management within the political field.
Demotivated workforce	Yes	Section 2.3 emphasises the importance of employee attitude and behaviour in the implementation of LSS in public services
Misstatements in inventory record keeping	Yes	Inventory management is one of the toolkits that are mentioned in section 2.1
Unequipped workers/ poor understanding of duties	Yes	Education and training are one of the Critical Success Factors in the application of LSS.
Poor constitution of committees responsible for awarding contractors' jobs	No	Although LSS advocates for the training and educational empowerment of workers, it does not however, have guidelines that influence the appointment of workers within organisations.
Not completing projects	Yes	Identification of root-causes, bottlenecks and process variations is necessary to solve this problem.
Poor compliance to process steps	Yes	The performance of the process must be evaluated in the Measure part of the DMAIC tool. This aids in understanding the part of the process which workers fail to adhere to and to understand why they struggle to comply with the steps in the process.
Not monitoring invoice tracking system	Yes	Use of 5S can reduce this problem and section 2.4.7 also addresses poor monitoring.

4.3.3 Maintenance

This category focuses on the challenges that the municipality faces in maintaining it resources, assets, and infrastructure. Table 5 below, highlights the problems faced within this category and explains whether LSS tools and techniques can be helpful in addressing the problems.

Table 5: Problems encountered in the maintenance category

Problem	Can be resolved by LSS (yes/no)	Justification
Unaccountable water losses	Yes	Waste management of resources is required.
No routine maintenance of infrastructure	Yes	Process standardization is required to ensure frequent routine maintenance.
High cost of inventory compared to value of inventory	Yes	Inventory management and the elimination of inventory waste from the 7 wastes.
Lack of reconciliation on losses during distribution	Yes	This due to process variations, whereby the process requires that reconciliation be done however, the workers do not follow the process
Frequent inventory shortage	Yes	Inventory management

4.3.4 Method

This category focuses on the challenges that the municipality faces within its processes and the techniques used. Table 6 indicates the problems faced within this category and explains whether LSS tools and techniques can be helpful in addressing the problems.

Table 6: Problems that occur due to errors in the method used

Problem	Can be resolved by LSS (yes/no)	Justification
Poor selection of service providers	Yes	This problem is due to inconsistencies in the process and benchmarking is required to solve this problem
Delayed delivery of resources	Yes	Inventory management, transport waste and waste of waiting can be applied
Delays in fulfilment of inventory orders and no re-order point	Yes	Inventory management is an LSS tool and is detailed in section 2.7
Poor record keeping and inventory tracking	Yes	Inventory management and LSS applications detailed in section 2.4.7
High backlogs in water and sanitation provisions	Yes	Backlogs are one of the challenges that Lean Six Sigma seeks to improve
Poor streamlining of SCM process	Yes	Value stream maps will be useful in resolving this challenge
High bureaucracy in the process	No	Municipalities exist as part of government and must adhere to Legislature. As indicated in section 2.2, public services exist for reasons of policy.

4.3.5 Management

This category focuses on the challenges faced by municipal management. Table 7 below, highlights the problems faced within this category and explains whether LSS tools and techniques can be helpful in addressing the problems.

Table 7: Problems identified to have been caused by management

Problem	Can be resolved by LSS (yes/no)	Justification
Appointing incapable workers	No	This decision is influenced by the political administration of the municipality and they often engage in fraudulent appointments which cannot be resolved by LSS.
Lack of consequences for underperforming workers	No	The municipality has an existing consequence management team which should be ensuring the implementation of consequences for underperforming workers.
Poor organisational planning	Yes	Critical Success Factors include proper planning and commitment from top-down management.

Inability to ensure projects do not run over budget	No	There are no LSS tools that deal directly with budget management.
Poor communication across departments	Yes	Top-down management commitment and a value stream map detailing information flow would resolve this problem.
Mismanagement of funds	No	Budget management is not directly addressed in the LSS toolkit
Poor filling of vacant positions	Yes	Section 2.4.4 illustrates the use of LSS to fill vacant positions
Inconsistency in finances	Yes	Process mapping, section 2.4.6 covers the application of LSS in a financial department and the removal of errors within the department.
Lack of educational workshops	Yes	Educational training in LSS is important
Poor contract management	Yes	This is a s result of unmotivated workers and poor employee attitudes and thus LSS can be applied

Of the 34 problems summarized above, 24 of the problems are solvable by LSS (70.5%) whereas 11 of the problems are not solvable by LSS. The reasons for these conclusions are indicated in Table 3 to Table 7 above. It can be concluded using literature and comparative analysis that LSS can be used within the municipality. This highlights the achievement of the second research objective. Table 8 below indicates the frequency of the number of problems under each category that are solvable by LSS.

Table 8: The number of problems faced by the municipality that are solvable by LSS

Category of problems	Equipment	Man	Maintenance	Method	Management
Frequency of problems solvable by LSS tools	0%	75%	100%	86%	60%

From the findings above, all the problems within the equipment category cannot be solved using LSS tools and techniques. These findings correlate with the available literature in that very few examples covered the solving of equipment challenges by using Lean Six Sigma.

5 DISCUSSION

The project aimed at determining the feasibility of applying Lean Six Sigma to solve problems within public services. The research question was, how feasible is the application of Lean Six Sigma in solving problems faced by the public service sector, specifically a municipality? A conceptual framework of the specific areas where LSS can be successfully applied in the public sector was established. The developed framework was used to refine the interview questions. The questions were posed to the senior manager at CoGHSTA, a worker at the municipality, and the SCM manager through semi-structured interviews. Furthermore, an in-depth analysis of a South African municipality's challenges was conducted. This was useful in creating guiding criteria for assessing the applicability of LSS in the municipality.

5.1 The applicability of LSS in solving problems in the public services sector

From the literature covered in section 2, it was proven that LSS can be applied within public services. Multiple organisations in the public sector have utilised LSS in different parts of their organisation. The Linkoping municipality employed LSS within their customer service department to improve customer and worker interactions, reduce process variation, and improve customer satisfaction. Standardization, process mapping, and root-cause analysis were used to resolve the challenges mentioned. A municipality in Germany applied LSS in three different departments, one department handled land acquisitions, the other department was responsible for subsidy applications and the last department was the one that handled the business administration process. The local government in the UK applied LSS to improve the rate of filling vacant positions within local schools whereas a hospital in India used DMAIC charts to remove variation in their process and to reduce the customer waiting time. Root-cause analysis was performed in an Oregon County to identify the variations that existed in their safety procedures which resulted in the development of a standard operating procedure (SOP) and the identification of areas that need to be improved within the process. Additionally, the literature assessed the application of LSS within Standard Bank in South Africa, the challenges that were solved included: high inefficiency, frequent reworks, high error rate, and multiple forms of waste, and the lack of a performance measurement system. Continuous improvement is being practiced in the banking division currently. Lastly, an example of an organization struggling to provide a service within the required time and had a poor tracking database applied the DMAIC methodology and used an SOP to alleviate their problems. Although applying LSS within the above-mentioned organisations was a success, multiple challenges were encountered due to the organisations belonging to the public sector. Some of the difficulties in applying LSS in these organisations included the cultural practices of a hierarchically structured organization, resistance by management to change, and a lack of knowledge on TQM. These challenges relate to the difficulties that were described in the literature within section 2.3. The literature explains that some public services sectors have characteristics such as a lack of motivation by the workers and the lack of urgency by management due to the lack of competition within the industry. Secondly, public sectors are governed by bureaucracy and a strict hierarchy which influences the flow of information across departments negatively. The results obtained from these examples are significant in indicating the areas within public services where Lean Six Sigma has been successfully applied. Additionally, it was important for the researcher to investigate the successful application of LSS within the public sector so that the attributes of the processes where LSS was successfully applied can be determined. This can be used as criteria for determining the processes within a municipality that could benefit from the use of LSS. It is important to note that the examples which have been used in the literature are from different backgrounds and they utilise LSS in vastly different scenarios. Secondly, the identified cases fall into different industries within the public sector such as the hospital sector, education sector, and municipality operations. This increases the scope of the criteria which will be used to determine feasibility. Furthermore, this removes bias and allows for generalization.

It is important to note that the listed examples above, followed guidelines like those that were highlighted in section 2.3 The organisations had clear performance metrics to measure success at the end of the implementation of LSS, they investigated the work processes thoroughly through process mapping, and they understood the financial benefits of implementing process improvement. Although LSS is a significant tool, it cannot be applied to all parts of a public sector organization. The various real-life applications mentioned above, have specific attributes that one can draw from to assess the applicability of LSS in other organisations.

5.2 The applicability of LSS in solving problems within the municipality

The District Municipality in Limpopo Province is one of the municipalities in South Africa that is underperforming. The municipality has had difficulties in meeting its KPAs and passing the Auditor General's assessments in the 2017/2018 and 2018/2019 financial years. From the data collection, it was evident that various departments within the municipality are faced with multiple challenges. These challenges include but are not limited to poor record tracking systems, poor process mapping and poor adherence to the process by workers, miscommunication between departments, inadequate routine checks, poor inventory management, and a demotivated workforce. Most of these challenges have hindered the municipality from achieving its quarterly and annual targets.

Given that the problems identified during the interviews and from the documents varied greatly and were high in number, it was important for the researcher to group the data into manageable categories so that it is easier to analyse. The categories which were used were man, methodology, maintenance, management, and equipment. The man category was a reference to problems that were due to human activities, the methodology category was for all the process-related problems, the management category investigated all the problems which resulted from the organisation's management, the maintenance category refers to all activities relating to the maintenance of the process resources (or equipment), whereas the equipment category refers to all the machinery utilised within the municipality. From the findings, it was deduced that all equipment-related problems could not be resolved by Lean Six Sigma whereas all the maintenance problems in the municipality could be addressed by using LSS. The reason behind the problems within the equipment category not being solvable by LSS could be because of the limited number of real-life examples (or cases) illustrating that from the literature. There is a possibility that different outcomes could have been achieved if far more examples of the real-life application of LSS were given. The reason behind the limited number of examples is due to the limited number of reliable, peer-reviewed research papers that investigate LSS applications within the public sector. The problems in the man and method category could be resolved by LSS tools 75% and 86% of the time, respectively. This affirms the second objective in that, it indicates a high frequency of municipal problems that can be solved by applying LSS. The findings from this research are important in that, the adoption of LSS within municipalities could be of great value in improving municipal process and ensuring better service delivery. This is especially important for a public sector organization that influences the quality of life for the people. It would also be beneficial to the stakeholders to find techniques that would guarantee them a positive outcome from the Auditor General's ratings. Given that the municipality is a public sector organisation, some of the challenges experienced by the researcher while trying to understand the problems within the municipality are common to those mentioned in the literature. Maleyeff [3], highlights characteristics that make it difficult to implement LSS, these characteristics which were true for the municipality are as follows. Multiple verifications from management are required when workers perform their duties. This is problematic in that it limits the efficiency part of LSS to be implemented. Secondly, most processes flow into other departments which makes it difficult to maintain constant communication and to reduce errors. Lastly, the lack of urgency by workers and management results in the risk of futility in the implementation of LSS. Another challenge that was experienced within this research, is that although the municipality has a lot of data that can be used for statistical analysis, the discrepancies within the "as is" processes in the municipality have created some gaps in the data. For example, the infrequent checking of shelves in the warehouse and the poor record-keeping system have led to missing information hence creating gaps in the data. This is a common challenge that is found within the public sector as is mentioned in section 2. However, these challenges can be overcome with the continuous practice of LSS.

6 CONCLUSION

This section indicates the researcher's reflection on the entire study. The study set out to evaluate the feasibility of applying LSS to solve problems within the public services sector, specifically within the municipality. Following the literature review, the research scope was developed, and the research method was selected to address the objectives. The research study started by investigating the applicability of solving problems using Lean Six Sigma within public services, and further went on to investigate the use of Lean Six Sigma within a municipality to solve problems that are being faced. The theoretical frameworks that were developed were related to the District Municipality in Limpopo Province. This was useful in answering the research question. The conclusion from this research is that Lean Six Sigma is applicable in solving problems within the public sector and it is applicable within a municipality in South Africa. Although not all the techniques and tools within LSS can be applied, it is important to note that some tools can be introduced to the municipality. This includes tools such as value stream mapping that can be used to redesign and redefine municipal processes. Another technique can be the standardization of processes to improve resource use, improving the flow of communication across departments, and reducing errors and inefficiencies. Furthermore, waste reduction techniques will aid in eliminating redundant, non-value-adding activities. Additionally, root-cause analysis tools such as SIPOC and Fishbone diagrams would be useful in identifying unknown causes that result in challenges in the municipality. Difficulties that exist in implementing LSS in the public sector have been identified. The difficulties are mainly due to management, the workers, and the work culture in organizations that have a hierarchical structure. The lack of knowledge of LSS is another problem that arises in this sector. It is important to note so that any application of LSS that is to be implemented can be employed to overcome these challenges. The literature and real-life application of LSS in other public sector organizations were key in developing guiding criteria that can be used to determine the areas within the municipality where LSS can be applied. Once the criterion was highlighted, it was used in justifying the researcher's position on the problems in the municipality that could be solved by applying LSS techniques. This resulted in most of the problems being solvable hence achieving the second research objective. The results from this study can be used as the foundation for future studies on the implementation of LSS in the public sector. Given that public sectors vary in operational policies, there might be some variations in using the findings of this research in other organizations. Other research studies could investigate the feasibility of applying LSS in other public sector processes. Additionally, other researchers could investigate the formulation of guiding criteria that can be used to identify problems that are solvable by LSS. Their findings could be compared to the findings of this research to verify whether the criterion is similar or if variations would arise.

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SYSTEMS THINKING AND STRATEGY IN THE CONTEXT OF FAST ADAPTABILITY: AN INITIAL CONCEPTUAL MODEL

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ABSTRACT

Over the past 10 to15 years, disruptive technologies and rapidly changing regulatory requirements have led to a massive increase in business risk for new product development, resulting in ever-shorter development times and product life cycles. The implication is that, to create sustainable growth and to be successful in markets, will require the capability to continually create new sources of competitive advantage. This forces companies to rethink their strategy development and implementation processes from scratch, which means they must adjust and implement their strategies even faster. A review of extant literature identified the need of a holistic framework, based on a Systems Thinking approach, to enable companies to cope with increasing complexity in uncertain and complex times. This paper proposes a Conceptual Systems Thinking model that may be used to define and implement strategies to safeguard and enhance competitiveness.

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1 INTRODUCTION

Over the last 10 to 15 years, the business environment for companies and organisations changed dramatically. Disruptive technologies and products are increasingly attacking existing business models and threatening the existence of entire corporations.

As a case in point, the automotive industry is currently facing extensive disruptive threats. With the rapid progress of the electrification of the powertrain, businesses in this industry need to change their existing business models radically. Following a study of McKinsey, up to 15% of all new sold cars, may already drive in full autonomous mode by 2030 [1].

In addition, driven by the diesel scandal of VW, many countries and cities decided to ban new fossil-fueled vehicles within the next 7 to15 years. Norway as an example made the decision to permit only emission-free vehicles by 2025. Paris also plans to ban all petrol and diesel vehicles by 2030 [2, 3, 4].

As a consequence, these internal and external market conditions lead to shorter and shorter product and business model life cycles. [5] The rapid progress of digitalization, such as in the case of 3D Printing, intensifies this process even further. For the future, this means, creating sustainable growth and being successful in markets require the capability to create new sources of competitive advantage continuously.

This forces companies to rethink their strategy development and implementation processes from scratch. This means, the businesses must adjust and implement their strategies in even shorter periods. Therefore, following the success of Google, many companies implement agile processes, such as scrum and OKR, to increase their speed and flexibility, lately [6] [7]. On the one hand, the use of agile methods can enable them to adapt to the constantly changing market requirements, and on the other hand, it may foster building up resilience against disruptive technologies and disruptive threats. Thus, in addition to digital transformation, there is also a consideration to drive the agile transformation actively. As a result, companies' strategies are becoming more dynamic and complex compared to the past. Therefore, the primary challenge for organizations will be to develop and adapt their strategies faster than their potential competitors. The slower this process progresses, the greater the risk of losing market share or being forced out of the market by a disruptive technology. In addition, to remain successful in the market in the future, companies must ensure that their strategies do not have a negative impact on each other where appropriate.

Once having defined a strategy companies need to implement it as fast as possible. Nevertheless, there may be temporary overlap, where the employees will still work towards the old strategy. Naturally, companies try to minimize this overlap period as much as possible to avoid a waste of resources. Obviously, it is not possible to switch on and off strategies without any delay for practical reasons. Furthermore, companies must establish a culture of change. Without the commitment of the employees, it may be difficult to implement any changes. Therefore, it is essential to accompany people during change processes and deal with their concerns seriously. However, to ensure a quick adaption of the strategy, as well as a fast and successful implementation afterwards, companies need appropriate processes and tools. Usually companies use standard tool sets, such as the Boston-Consulting-Group-Matrix BCG Matrix BCG Matrix [8] or the McKinsey-Matrix [9] or a Balanced Score Card [10].

In general, none of those standard approaches usually reflects on the complexity and the dynamics, which actual and future strategies will increasingly require. In addition, the implementation using a more traditional approach such as Balanced Score Card may not offer enough flexibility within these short time frames required in the context of disruptive technologies.

To fulfil these requirements, companies need an agile causal chain of performance measures, as well as a fast strategy development process to adapt with fast changing environments. Using a process, based on a Systems Thinking Model, may enable companies to act faster than potential competitors, which can lead to a strategic advantage. This points to the aim of this paper focused on developing a conceptual model for defining and implementing strategies in this fast-changing environment.

The next section of the paper discusses some relevant literature to base the conceptual model on. The rest of the paper will then focus on the research method followed as well as the introduction and discussion of the conceptual systems thinking model.

2 LITERATURE REVIEW

Following Zahn, companies can create competitive advantages either from attractive positions in an industry or from unique resources. However, competitive advantages will not last forever and may erode over time. Therefore, strategizing becomes a key part for strategic management and sustainable business. He characterizes advanced strategic thinking as follows [11]:

- It includes different kinds of knowledge.
- It needs to connect past, present and future.
- It must create space for smart opportunism.
- As a strategic instrument, it needs to foster creativity and energy on all business levels.
- It should build the base for creatively developing and comprehensively testing new strategies and strategy approaches.

2.1 Strategy Development

To select the most effective or appropriate strategy it is important to take the correct decisions. As a powerful instrument, the OODA (Observe, Orientate, Decide, and Act) loop can support the individual strategy development. Crucial for its success is the processing times of the single steps. The faster the business can act, the more ahead it can be from its competitors. [12] In a next step, Brehmer added dynamics to the OODA loop [13]. Following Oosthuizen the Dynamic OODA loop (DOODA) illustrated in Figure 1 is a major improvement, as it points out the areas of sense-making in relation to the mission objectives.[14]

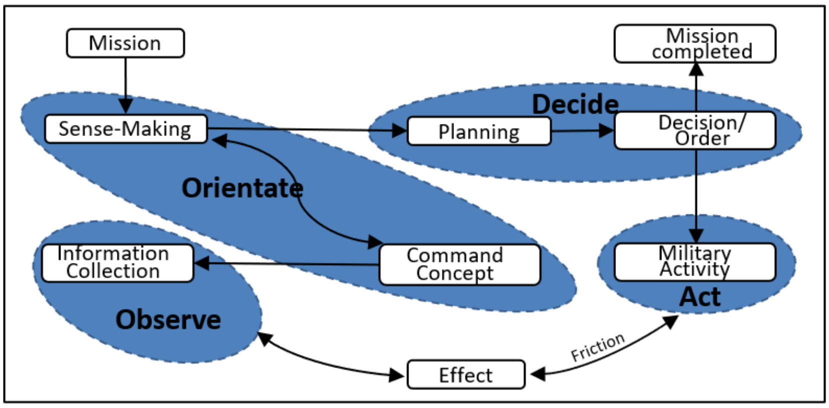

Figure 1: DOODA Loop adapted from Brehmer 2005 [14]

2.2 Strategy Implementation

According to Egelhoff and Bonoma, implementing a strategy is as critical and important as strategy formulation [15] [16]. Srivastava and Sushil used a framework with the four key dimensions, align, automate, act, and adapt to optimize the strategy execution process. Following them, factor alignment is the basis for strategy execution. [17, 18, 19] Conducting a literature review, they identified seven key factors for the alignment process illustrated in Figure 2: [20]

- AL1 **Business Units**
- AL2 **Resource commitment**
- AL3 **Policies**
- AL4 **Operations**

- AL5 **Structure**
- AL6 **Best practices**
- AL7 **Community orientation**

To develop their model Srivastava and Sushil conducted three surveys with active companies in the infrastructure sector within India. As a result of their research, they discovered that “structure” has the highest influence on all the other factors among the considered ones. This means, the starting point for an effective strategy execution must be a structure-strategy fit. Srivastava and Sushil remark, that increasing the structure-strategy fit activity, does not lead to more effective strategy execution. Further the highest dependency with strategy shows the factor “operations”, which means it is affected most by the other factors: “Community orientation - best practices” and “Community orientation - operations”. “Structure” and “resource commitment” showed a high criticality in relation to the influence on the other aligned factors. However, “structure” influenced all alignment factors significantly. [20]

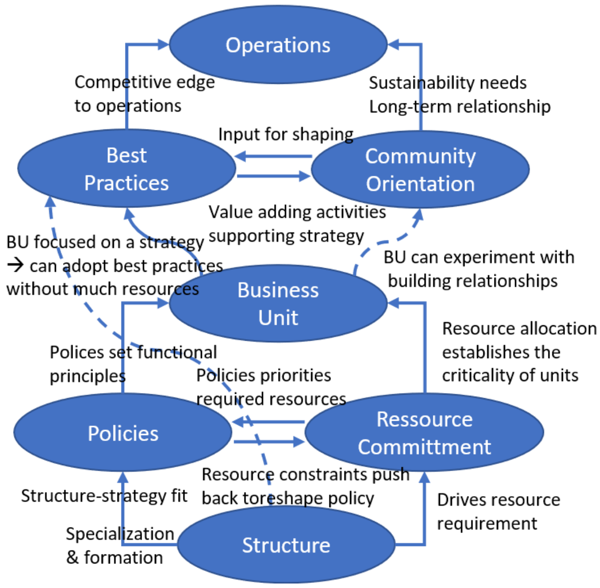

Figure 2: Total Interpretive Structural Modelling model of alignment [20]

As the findings of Srivastava and Sushil showed, “structure” plays a significant role with regard to strategy execution. This is where organizational alignment comes in. As a modern approach, alignment theory, addresses organizational efficiency. The basic idea behind it is, that high efficiency requires a relationship between culture, structure and strategy. [21]

Generally, in literature two forms of organizational alignment - vertical and horizontal are found. Vertical alignment deals with the definition of strategies, objectives and action plans on all organizational levels. Horizontal alignment addresses the cross-functional and intra-functional integration on the lower levels in terms of strategy. [22] Quiros developed her model on the basis of the competing values model (CVM). She identified the dominating cultural and structural alternatives within the CVM model. For this purpose, she took those cultural alternatives into account, which play an active role in the model, and removed those, which are dependent of the behaviour of other alternatives. In a next step, she integrated strategic patterns into the model. [21] Therefore, Quiros focused on the extreme strategic points as defined by Miles et al: the defender, the prospector, the analyser, the reactor [23]. Excluding the reactor strategy and mixing up the different alignment options led to the final model shown in Figure 3.

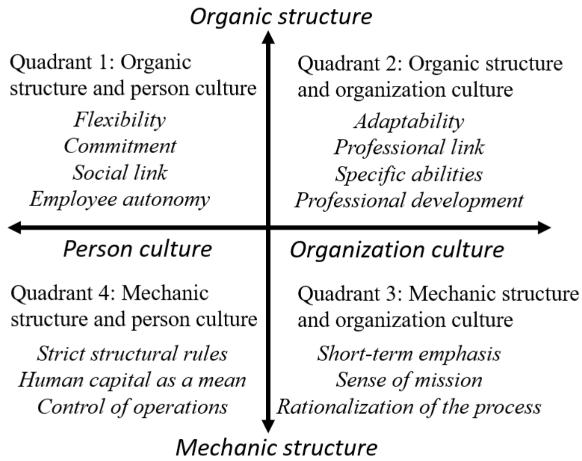

Figure 3: Model of Organizational Alignment [21]

Following Nicholas and Steyn, it is also possible to implement strategies using product portfolio management (PPM). Therefore, they differentiate the different functions in an organization as follows: [24]

- *Strategic Management:* Defines vision, mission statements and the strategy.
- *Portfolio Management:* Selects the right projects.
- *Gating methodology:* Steers the projects based on performance and gating criteria.
- *Project Management:* Executes the projects right.

During the project selection process it is of great importance to choose those projects which offer the best strategic fit. [24] To get PPM into an agile context focussed on previously as well, Vähäniitty sees the following key elements for agile PPM: [25]

- Define responsibility for portfolio-level decision-making
- Public accessible ongoing activities list
- Portfolio synchronization
- Regular steering group meetings at synch-points
- Ensure that incentive systems do not foster local optimization

To ensure that agile PPM meets the strategic targets best, Stettina and Hörz furthermore emphasize the need of strategic product backlogs containing the most important strategic objectives. [26]

2.3 Strategy and System Approaches

Torres et al researched feedback systems for the strategy development process using a system dynamics (SD) approach. For their research, they defined five use cases within the food industry. First, they started with the description of the strategy process, followed by the identification of the drivers of this process. To define the relevant equations, they interpreted every strategic key component as an asset stock developing over time. Subsequent to that, they defined different strategy scenarios and designed feedback loop diagrams, which they observed over the period of one year to discuss the results and the effectiveness of the strategic initiatives. Although, it was difficult for participants to understand and interpret the effects of the feedback loops, interactive modelling was useful for choosing the best strategic initiative, as it avoided linear and static perspectives. [27]

Papageorgiou and Hadjis focused on how to support decision makers in highly turbulent dynamic environments. They argued that SD modelling has the potential to understand and simulate the effect of decisions in such environments due to its two-way feedback loops. On the one hand, individual or socio-cultural decisions are initiated by the surrounding environment. On the other hand, the decisions support the decision makers to achieve the desired state of the system. New information drives this process continuously. [28]

Reiner et al researched how to minimize the supply risk caused by non-stationary product demands in environments with shorter and shorter product life cycles. This relates well to the current research on shorter development cycles in the automotive industry. They showed the potential of SD models on how to achieve the optimal pricing point and therefore the optimal profit. [29]

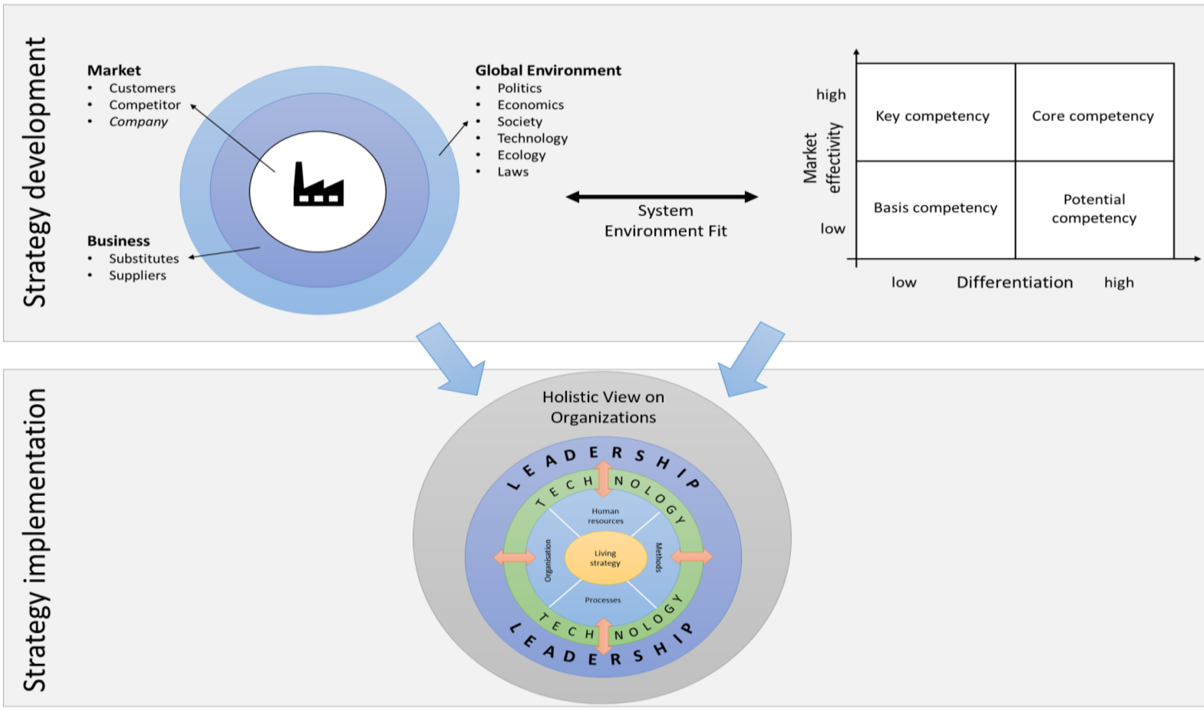

Figure 4: Systemic approach for strategy development and implementation in a holistic framework [30]

Driven by the fact, that companies have to deal with increasing dynamic and complex environments and market situations, Weissenberger-Eibl et al. introduced their own system thinking framework for strategy development. The framework itself consists of the following three sub models as shown in figure 4:

1. A model for Strategic foresight, which deals with fostering knowledge about the market and the dynamic environment and decision making in uncertain and complex environments. [30]
2. A model for competency differentiation, which deals with core competencies across an organisation to defend or to increase market share in complex and dynamic environments. To identify and classify the companies core competencies they used the core competency model from Wildemann [31].
3. A model for leadership and culture, which deals with strategy implementation. Therefore, they have identified four fields of action: Organization, Processes, Methods and Human Resources. Usually, the management has an intrinsic motivation to drive these fields, that in turn drive the strategy. To support the further development of these areas, technology serves as a lever. [32]

In another approach, Nieminen and Hyytinen focused on strategic decisions and systems in complex socio-technical environments. [33] Therefore, they referred to the theory of Kemp et al, which defines the three levels: [34]

- Regime level, which stands for the as-is situation, such as technologies, scientific paradigms, politics, culture and markets.
- Landscape level, which covers the environment including political changes or changes in economy.
- Niche innovations, are innovations coming from outside with the potential to replace the existing regime level.

To test their approach they initiated various piloted case studies based on Foresight, Impact assessment, SD modelling and Societal embedding. [34] Auvinen et al came in one of this pilots to the conclusion, that SD modelling is useful for creating different scenarios, as well as analysing impacts and interactions over time. [35]

There are several approaches, which used SD modelling for choosing the best strategic scenario or for taking the right strategic decision. Moreover, Weissenberger-Eibl et al created a high-level holistic framework with respect to strategy definition and implementation in dynamic and uncertain environments. As mentioned in Section 1, this article focuses on similar challenges as Weissenberger-Eibl et al. but aims at deriving a concrete conceptual model to support strategy formulation and execution processes in highly dynamic and complex environments.

The next section refers to the research methodology pursued in this paper.

3 RESEARCH METHODOLOGY

As showed in Section 1, this research study aims on formulating dynamic hypotheses and developing a Systems Thinking based conceptual model for strategy definition and strategy implementation in dynamic and highly complex environments. Therefore, this research study will follow a modified version of Forrester's six-stages approach suggested by Martinez-Moyano and Richardson [36]. In particular this means, that the initial step discussed in this paper aimed at the conceptual model covers the first two stages of the six-step approach (problem identification and definition, and system conceptualization). The next step aims at formulating the model, which includes the structure, the variables and the independencies. The chosen design for this and future research is an exploratory multiple-case study, which follows the proposed research design of Cooper and Schindler. Furthermore, it will be a explorative qualitative approach, as this research eventually aims at capturing in-depth information about current processes and practices with respect to strategy formulation and strategy execution to be able to simulate and test the SD model. [37]

Generally, quantitative research to be addressed in a future paper includes nonprobability sampling, such as Snowball sampling, Convenience sampling or Purposive sampling, to receive a more representative data set. Thus, the data set will be gathered from sources with insightful experience and unique characteristics [37], which are purposefully chosen [38]. Therefore, in a first step secondary data sources, such as case studies, will be analyzed. Subsequentially, individual face-to-face semi-structured interviews with selected employees and managers of different levels of one of the big German automotive suppliers, which is currently facing the same challenges as described in the first section, as well as a document analysis will be conducted. The results of these interviews then form the basis for further substantiation and validation of the hypotheses of the conceptual model formulated in step 2. This approach will be in accordance to the recommendation of Yin, as different multiple data sources (triangulation) strengthen the validity of the multiple case study. [39]

The next section formulates a System Dynamics conceptual model for the strategy definition and strategy execution as the initial step in the research approach discussed in this section.

4 INITIAL CONCEPTUAL MODEL

Processing times of the single steps in the DOODA Loop [13] are as crucial for strategy formulation as for the OODA Loop [12]. Generally, one of the core elements of a successful strategy definition process is decision making [30], which is reflected explicitly in the DOODA loop. Thus, shorter cycle times will lead to faster decisions, which will result in shorter completion times of the overall mission result and a higher competitiveness. Additionally, the level of differentiation plays a significant role in achieving a higher competitiveness. Basically, the higher the level differentiation is, the higher the competitiveness will be [30]. Therefore the underlying hypothesis of this paper is, that the faster organizations can adapt to changing market conditions in a structured manner, the more sustainable their success will be. These dynamic hypotheses are not handled as classical hypotheses in the statistical testing manner. This and typical system dynamic testing and validation approaches are normally handled as suggested by Sterman [40]. According to him, feedback loops are a useful systems thinking tool to simulate dynamic complex systems [40]. Using the above dynamic hypothesis form a reinforcing feedback loop around "Observations", "Orientation", "Differentiation", "Opportunities", "Decisions" and "Actions". Further, it's a well-known fact, that continuous increasing competitiveness results in market domination and in its most extreme form in a monopoly market position. Thus, continuous increasing competitiveness will reduce the observations in the long run and builds a ripple effect. The resulting feedback loop by integrating the findings is shown in figure 5.

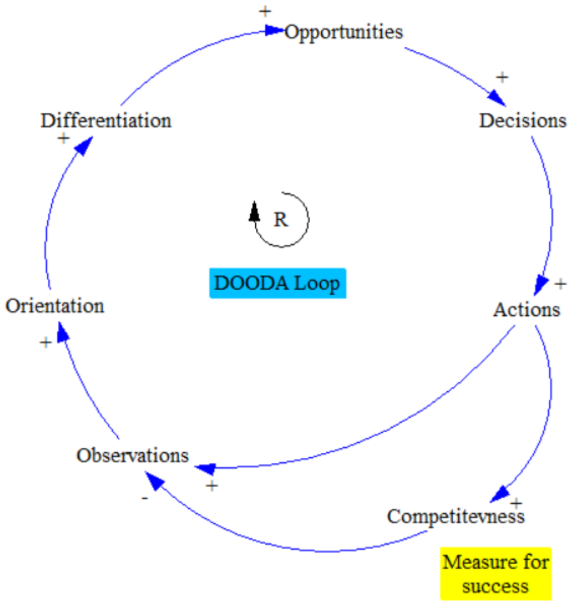

Figure 5: Basic DOODA Feedback Loop adapted from Bremer [14] and Weissenberger-Eibl et al. [30]

As highlighted by Sterman [40], arrows and their polarity (+/-) represent positive and negative causal relationships in System Dynamics causal loop diagrams (e.g. figure 5). The short arrow in the middle shows the direction (clockwise / counter-clockwise) and if the feedback loop is reinforcing or balancing. Each pair of variables linked by an arrow and a positive or negative sign at the arrowhead represent in a Dynamic Model a dynamic hypothesis. Generally, dynamic hypotheses are read in the direction of the arrows. For example, in figure 3, more "Observations" lead to more "Orientation".

In a next step, exogenous variables with a significant impact on the decisions and actions, such as market or business influences [30], are added into the model shown in figure 5. Obviously, your own behaviour and actions can affect the business and market decisions in the mid-term or long-term in a delayed feedback loop. However, firstly as it is not possible to influence the behaviour of these variables directly, and secondly, influences such as disruption or legal regulations, are variables outside of the system, we will define these in the following conceptual model as exogenous. Furthermore, according to Sterman, a good system should contain only a few exogenous variables and a broad model boundary without compromising the specifications of the model [40] This exogenous extension of the current model can be seen in figure 6.

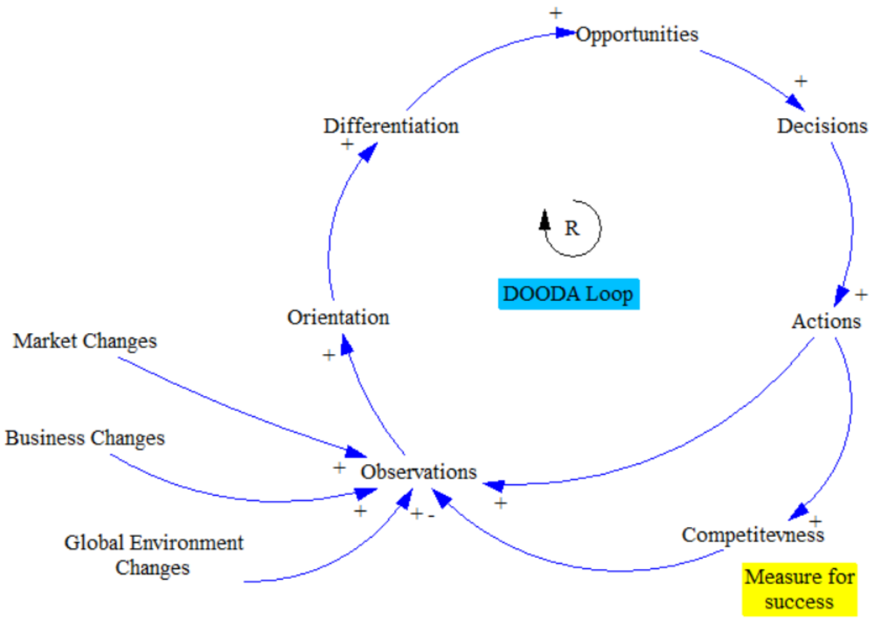

Figure 6: Enhanced DOODA Feedback Loop adapted from Bremer [14] and Weissenberger-Eibl et al. [30]

As literature showed, as important as the strategy formulation, is a successful strategy implementation [15] [16]. In this study it was found, that structural and organizational alignment ensures a proper strategy execution [20] [21]. According to Srivastava and Sushil [20], the biggest influence on strategy execution in their model was indicated as the factor “Operations”. Moreover, “Structure” and “Resource Commitment” had a high criticality on influencing the other aligned factors. Further it was found in this study, that it is crucial to select the right projects within this process [24], using an agile project portfolio approach. Combining these findings form an initial balancing feedback loop around strategy implementation and vertical and horizontal factor alignment, which is illustrated in figure 7.

Enhancing figure 7 with the detailed steps from the models shown in figure 2 and figure 3 define 3 balancing feedback loops around strategy implementation (B1), agile factor alignment (B2) and financial capabilities (B3) as shown in figure 8.

Combining the strategy feedback loops from strategy definition from figure 6 and strategy execution from figure 8 with model of Weissenberger-Eibl [30] in figure 4 defines the overall initial model, indicated as figure 9. Essentially this conceptual causal feedback loop model is derived from a systems thinking point of view, initially integrating different literature views as argued in this and preceding sections.

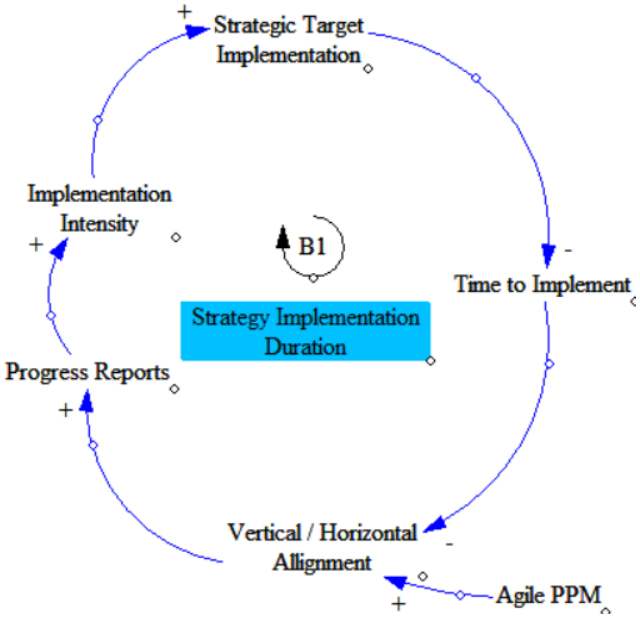

Figure 7: Strategy Implementation feedback adapted from Srivastava and Sushil [20], Quiros [21] and Steyn [24]

5 CONCLUSION

This paper aimed at investigating the processes of strategy definition and implementation to increase the competitiveness and defend or extend the market shares in dynamic and highly complex environments. Therefore, an appropriately detailed literature review was conducted, which was split into 2 categories: Strategy definition and strategy execution. The results of this literature research led to the formulation of dynamic hypotheses for each of the categories resulting in 2 separate System Dynamic causal loop diagrams with the use of System Dynamic Tools. One of the findings in this analysis is that shorter completion times in combination with a high level of differentiation are key elements for a sustainable strategy definition process. It was also found in this study, that agile PPM can enhance the vertical and horizontal alignment process significantly, as it selects and synchronizes the right projects most effectively. Subsequently, the two causal loop diagrams were combined into the final initial conceptual model. As one of the main conlcusions of this article, this leads to the formulation of the following hypothesis for additional future research: In dynamic and highly complex environments an efficient strategy decision process combined with an agile PPM approach, that steers the horizontal and vertical alignment most effectively, leads to a higher competitiveness and thus to more financial capabilities. Although, the intention of this paper was to address all of its objectives, its outcomes are not free of limitations. For example, it covers only the first two stages of the modified of the six-stages System Dynamics modelling process suggested by Martinez-Moyano and Richardson [36] (problem identification and definition; system conceptualization; model formulation; model testing and evaluation; model use, implementation and dissemination; design of learning strategy/infrastructure), which resulted in a initial causal loop diagram. Therefore, further researches need to be conducted, where this paper left off, to develop a full capable System Dynamics simulation model, adjust and validate it, using quantitative data and test the dynamic hypotheses, as proposed by Luna-Reyes and Andersen [41]. The authors of this paper are currently part of such further studies focused on System Dynamics modelling of strategy formulation and definition processes in complex and highly dynamic environments. Further studies may also focus on ripple effects, that may affect the strategy process in a negative way, such as a rapidly changing agile backlogs, as well as the synchronisation of the definition and execution process in general.

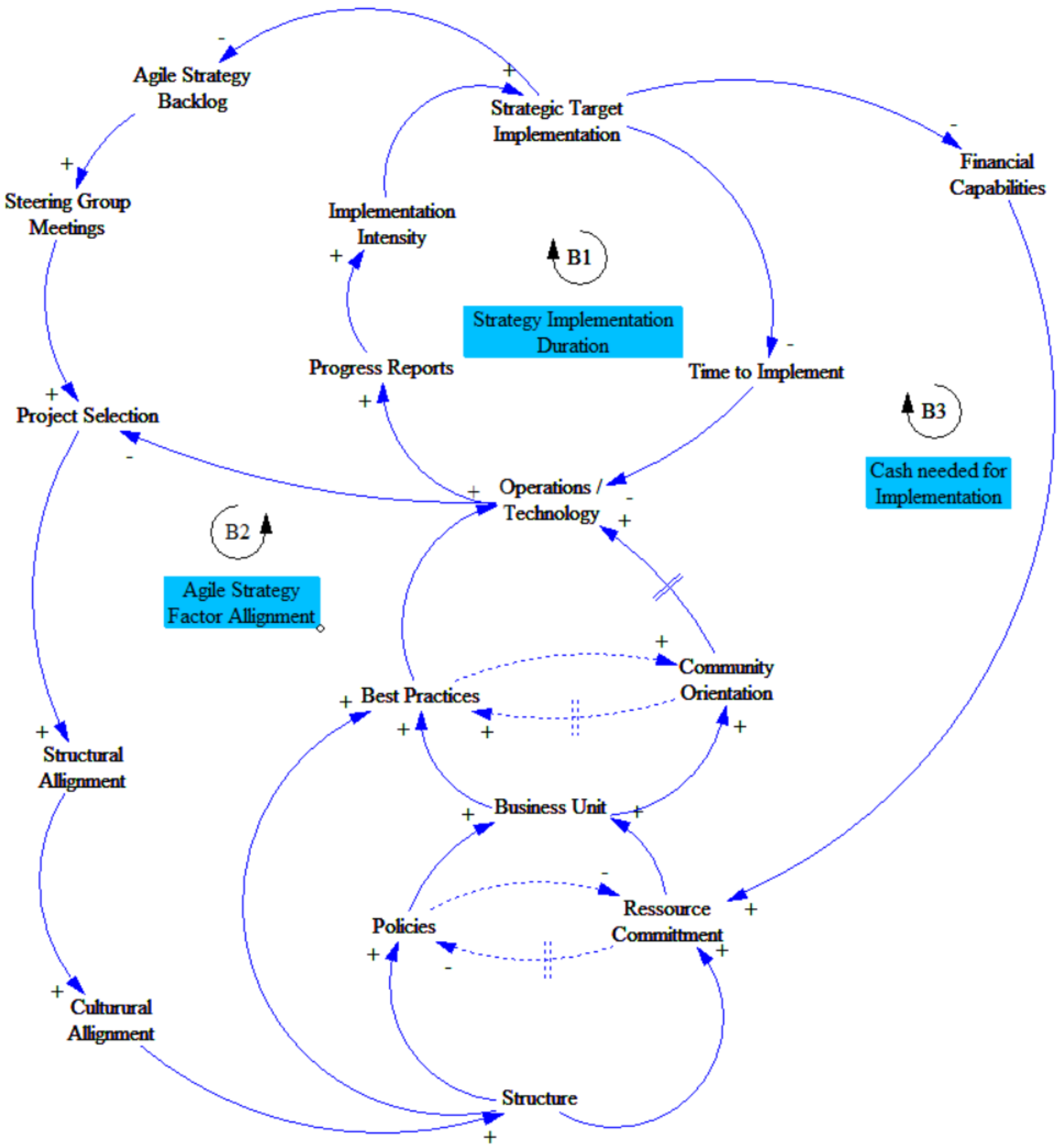

Figure 8: Enhanced Strategy Implementation feedbacks adapted from Srivastava and Sushil [20], Quiros [21] and Steyn [24]

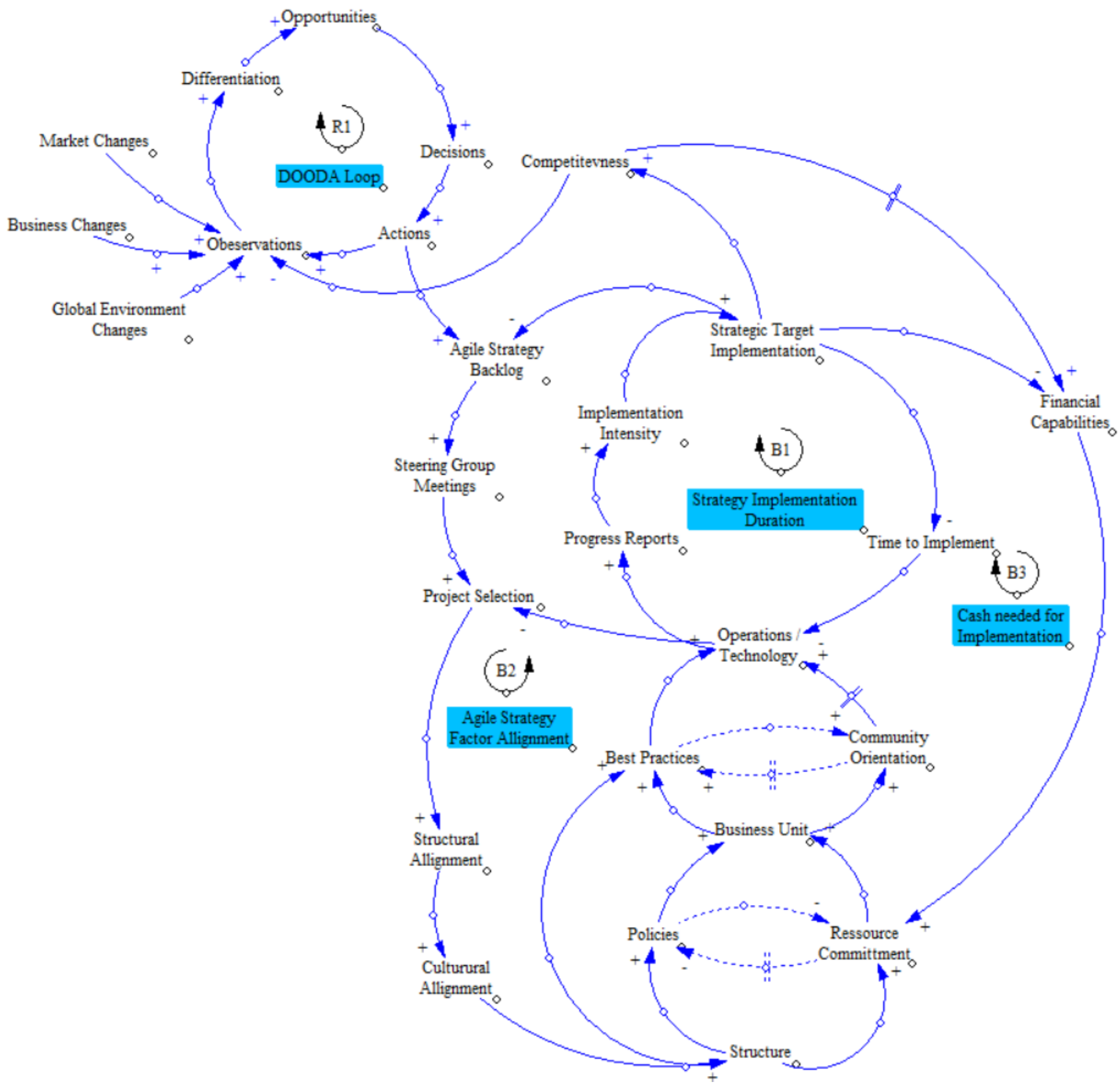

Figure 9: Initial Conceptual Model for strategy definition and implementation adapted from Bremer [14], Srivastava and Sushil [20], Quiros [21] and Steyn [24]

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A CASE STUDY ON A HYBRID EVALUATION AND SELECTION FRAMEWORK FOR DISCRETE EVENT SIMULATION SOFTWARE

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ABSTRACT

An increasing number of companies are turning to discrete-event simulation (DES) software to improve their business strategies in this — the 4th Industrial Revolution. The first step to implementing new simulation software in a company is the proper evaluation and selection of a viable software option. This paper presents a case study of a hybrid, two-phased evaluation and selection framework. The framework describes the first phase in which simulation packages were screened and evaluated based on important features and in line with the case scope of requirements of a company. In the second phase, detailed analysis was done of those packages that satisfied the requirements of the first phase. The framework applied in this case study is an approach that can assist potential DES software users within various fields with the evaluation and selection process.

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1 INTRODUCTION

Growing competition in many industries has emphasised the development and use of automated manufacturing systems to improve productivity and reduce costs [1]. Because of the complexity and dynamic behaviour of such systems, simulation modelling has become one of the most popular methods to facilitate the design and assessment of operating strategies. The growing popularity of simulation techniques has increased the number and variety of discrete-event simulation (DES) software packages available in the market. Selecting the optimal DES software is hard. Even for large international companies with their own simulation resource capacity, evaluating DES software each on their own merits or in comparison with other packages presents a major challenge. According to Gupta [1], the selection of an inappropriate package can cause significant financial loss and the disruption of simulation projects. However, appropriate guidance in simulation software selection could reduce the scale of such problems.

Many studies explore the selection of simulation software, and we will discuss these in more detail in the literature review to this study.

This study presents a hybrid framework that was derived from an internal company case scope of requirements and procedures, as well as a two-phased evaluation and selection methodology for DES software developed by Tewoldeberhan, et al. [2]. The term 'hybrid' meaning that the framework is composed of different methods.

The case study company, hereafter referred to as Company A, specialises in the development, design and manufacture of large- and medium-calibre ammunition families and is a world leader in artillery, mortar and infantry systems and plant engineering. Company A has no formal DES simulation team or infrastructure in place, but has identified the potential of this type of software for in-house simulation capabilities. The outcome of this study will form the basis for the selection of a suitable DES package for Company A to use in the foreseeable future.

The structure of this paper is as follows: First, we describe the background literature of the project, introducing the state of the field, and presenting selection methods available from the scientific community. Second, we describe the theoretical framework that was used here. Third, we cover the results obtained by applying the framework. Finally, a summary and conclusion of the results and issues for further research are presented.

2 LITERATURE REVIEW

Evaluation of DES software is not new. Many researchers have carried out surveys on available packages for different purposes. Hlupic [3] developed a software tool (SimSelect) that selects simulation software, given the required features. Nikoukaran, Hlupic, and Paul [4] created a framework of criteria to be considered when evaluating DES software. Other researchers, such as Banks [5] and Pidd [6] showed a similar framework in earlier literature. The primary 'shortcoming' of their research and frameworks is that it is technologically outdated, having been done in the late 1990s and early 2000s. Another problem is that only knowledgeable individuals in DES software can effectively utilise these frameworks.

Companies and institutions that use simulation packages, adopting different methodologies and approaches, frequently conduct research and analysis for their own use. Published results on projects of how to conduct the evaluation and selection process of DES software are, however, very limited.

Tewoldeberhan et al. described one of the most elaborate methodologies on the subject [2]. The first phase of this methodology starts with selecting simulation packages that meet the most important features and criteria. In the second phase, a detailed evaluation and analysis of the selected packages are done. One restriction with this methodology is that some of the research and references are outdated relative to the exponential growth of simulation software in the last two decades. Tewoldeberhan et al. [2] also designed a case study for the research according to an existing simulation team and infrastructure, for an ideal collaborative structured methodology - which for many companies is not the case.

This research paper will follow an approach similar to that of Tewolderberhan, in that the theoretical framework is designed around a case study, to be implemented at Company A.

3 THEORETICAL FRAMEWORK

To evaluate simulation packages, and to select the best one for a large company, is a time-consuming task unless an efficient methodology is used. Usually, choosing from a list of alternatives requires detailed knowledge of the selection criteria and the ability to score alternatives using these selection criteria. If there are many alternatives and the criteria list is long, the evaluation becomes a challenging task. Therefore, a hybrid evaluation and selection framework, based on Tewoldeberhan, et al. [2]'s two-phase methodology is proposed. This hybrid framework is adapted to provide any company that does not have a simulation team or an associated infrastructure in place, with the means to efficiently evaluate and select appropriate DES software based on a relative scope of requirements.

The developed framework also employs a two-phase methodology, as illustrated in Figure 1. In the first phase, simulation packages are screened and evaluated based on their ability to meet the most important requirements and criteria. In the second phase, a detailed analysis is conducted for packages that satisfy the requirements of the first phase, from which the most suitable package can be selected.

During these two phases, numerous interactions take place between the potential software user(s), the company's management team, the information technology (IT) department, and simulation package vendors. The potential software users are the identified simulation engineer(s), who are in charge of defining the scope of requirements, as well as evaluating and motivating the software for selection. The IT department forms part of the selection team, that together with the management team approves the selection based on the evaluation and selection strategy followed by the users and vendor inputs. Interactions between the stakeholders are indicated in Figure 2.

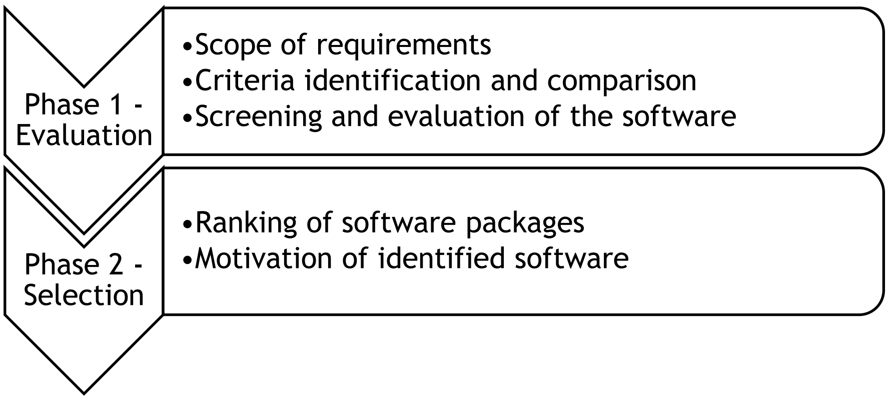

Figure 1: Overview of the Hybrid Evaluation & Selection Methodology

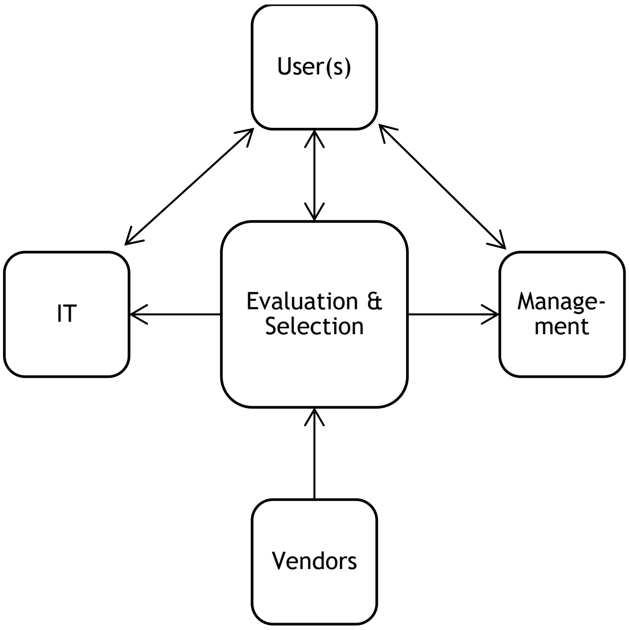

Figure 2: Stakeholder interactions during the Evaluation & Selection Process

3.1 Phase One: Evaluation

In phase one, a scope of software requirements is created, and a wide range of DES software packages are checked for the availability of these required features [2]. To accomplish the evaluation phase, the following steps are taken: scope of requirements compilation, criteria identification and comparison of discrete-event simulation software, and screening and evaluating the simulation software. The detailed methodology of phase one follows.

3.1.1 Scope of Requirements

The purpose of the scope of requirements for the simulation software is to define the purpose of the software for the company and to summarise the problem or opportunity and clearly state the main criteria of the software requirements. The following sections, derived from Company A's scope of requirements [7], will provide the criteria required to proceed with identifying the potential software options:

1. Purpose of the Software

Defines the purpose of the required software, summarise the problem or opportunity, and state the main objectives and results of the software.

2. Product Functional Requirements

Details the functional requirements and outcomes of the software to be purchased.

3. IT Digitalisation Requirements

Define the IT requirements that the software must offer. Indicate if the software must integrate with the company's existing IT infrastructure. And, define the IT infrastructure that will be required to support the software.

4. Technical Data Sheets

Request comprehensive technical data sheets/proposals for the software that is being supplied. This will potentially form part of the future agreement.

5. Installation & Commissioning

Define if installation and commissioning are required from the supplier, or if this will be done by the company. If done by the company, confirm if the supplier will issue certification of conformance or will provide supervision.

6. Training

Specify any relevant training requirements for operators, maintenance, refresher courses, etc.

7. Software Requirements KPI's

List the key and critical factors for the vendor to conform to, such as the delivery date and main capability requirements.

8. Product Acceptance Criteria

Define the test method to be used for purchase acceptance. Consider the inclusion of an acceptance certificate, signed by the company and the vendor.

9. Product Life Span

Indicate the expected life span of the software.

10. Maintenance & Support

Indicate whether maintenance and/or support should cover the life span of the software. Define the potential software maintenance and support that will be required, and indicate who will be responsible. If the company will be responsible for maintenance, the vendor to certify the company to conduct maintenance. If the vendor will be responsible, a standard license agreement (SLA) and turnaround times to be agreed upon and contracted. Define the requirements, i.e. response types based on types of failures. The maintenance/service schedule must be requested, as well as after-hours and weekend support. Define the IT infrastructure maintenance and support requirements.

11. Applicable Documentation & Packaging

Indicate any manuals/documents that are required. Define any specific method of packaging that may be required.

The initial scope of requirements is discussed between the potential user(s), IT department and management team for additional feedback and consistency.

3.1.2 Criteria Identification and Comparison

This section provides a comparison of simulation software, as well as a general gauge of the products' capabilities, special features, and usage. It is based on the biannual survey, from the October 2017 issue of the OR/MS Today magazine. The most popular tools and most relevant parameters were selected and then compiled in a white paper by Anylogic [8]. It should be noted that Anylogic is also a vendor in this field. This white paper is used only as a reference baseline to analyse and contrast simulation software, and identify potential packages that will comply with the scope of requirements. The capabilities and specifications, as well as additional packages, are cross-evaluated from direct vendor feedback and/or their websites.

The simulation software comparison is compiled in the following sections:

1. Vendor and Markets

The potential vendors, together with typical applications, primary markets, and other software by the vendor are defined.

2. Technical Compatibility

Here the vendor's software supported operating systems, compatible software to perform specialised functions, being controlled or run by an external program, and multiprocessor CPU support are defined.

3. Model Building

The vendor's software functionalities are defined, including input distribution fitting, graphical model construction, output analysis support, code reuse, optimisation, run time debug, support of model packaging, cost allocation/costing, model building using programming/access to programmed modules, batch run/experimental design, free features, and mixed discrete/continuous modelling (levels, flows, etc.).

4. Animation

The vendor's software animation, animation export, real-time viewing, 3D animation, and CAD drawing import capabilities are defined.

5. Support/Training

The potential consulting available, user support/hotline, user group or discussion area, training courses, and on-site training by vendors are identified.

6. Other Information

Other information, including student version availability, major new features (since 2015), and vendor comments.

3.1.3 Screening and Evaluation of the Software

Once the characteristics of the packages are identified, screening and evaluation are performed. Screening is done by using the criteria obtained in the previous steps. The packages that that satisfy all the criteria are kept for further ranking, while those who do not conform to one or more of the criteria are removed from the potential list.

After filtering the packages (by using the criteria), a comparison table is constructed on the remaining packages, including the following criteria:

- The simulation software package (as supplied by the vendor)
- Compatibility with other software
- Key features associated with the software
- Limitations associated with the software
- Approximate prices.

3.2 Phase Two: Selection

In phase two, discrete-event simulation packages are ranked according to the most important criteria specifications and selection thereon motivated for IT and management approval.

3.2.1 Ranking of Software

By using the compared software package analysis and filtered evaluation from phase one, a ranking table featuring the main requirements is compiled. The main simulation requirements are defined as [7]:

- Supported operating system
- Compatible software
- Input distribution fitting
- Graphical model construction
- Output analysis support
- Optimisation
- Run-time debug and code reuse
- Cost allocation
- Batch run/experimental design
- Mixed discrete/continuous modelling

- 3D animation capability
- CAD drawings import
- Approximate price range
- Future integration capabilities with other company systems.

It is important to note that the main simulation requirements are subject to each company's scope of requirements and will potentially differ for each company.

3.2.2 Motivation

After ranking is done and the best package identified, a software motivation needs to be compiled to aid in the sensitivity analysis and procurement approval. Some of the aspects that could be included in the simulation motivation are [9]:

- The department/division to use the software
- Identified potential user(s)
- Selected software
- Vendor
- Training and support providers
- Contact persons
- Supported operating systems
- Compatible software to perform specialised functions
- References
- Background
- Potential projects
- Initial ROI guidelines
- Licensing strategy.

3.3 Framework Summary

The value of this framework lies in its uncomplicated approach to efficiently evaluate and provide relevant DES software selection criteria to individuals who are not even experts in the field. In particular, to companies that have identified a scope of requirements for DES type software, dedicated to production process simulations.

4 PRACTICAL APPLICATION OF THE FRAMEWORK

The framework has been applied in practice to select a new discrete-event simulation package for Company A. Following the methodology explained above, a detailed scope of requirements for the software was compiled.

The main functional requirements for the simulation software were:

- Discrete-event simulation capability
- Data input functionality in the form of SQL/Excel/Access
- 3D Object-oriented modelling capability, with CAD/Solidworks/SolidEdge drawing import capabilities
- Batch run/experimental design capabilities
- Output analysis support in the form of comprehensive reports, charts and diagrams
- Detail specifications to consider as part of the functional requirements for the plant simulation software is listed below.

Supported Operating Systems:

- Windows

Compatible Software to Perform Specialised Functions:

- Excel; Autocad; SolidEdge; Solidworks

CPU Support:

- Multiprocessor CPU support

Data Input:

- Input distribution fitting capabilities; CAD drawings import

Modelling:

- Graphical model construction

Output Analysis Support:

- Charts; Sankey; Bottleneck analysis; Energy/power analysis; Neural networks

Optimisation Capabilities:

- Generic algorithms, optimisation engine, etc.

Coding:

- Reusable; run-time debugging; access to programmed modules

Simulation:

- Batch Run/Experimental Design capabilities; mixed discrete/continuous modelling; animation export; 3D animation

Costing:

- Cost allocation capability

License:

- License change-over capability to other systems (e.g. PC upgrades).

Utilising the defined scope of requirements, the simulation software comparison from the referenced Anylogic [8] white paper was used as baseline criteria evaluation for more than ten software packages. These packages were screened and evaluated to identify appropriate package solutions, with the main summarised comparative characteristics compiled in Table 1.

.

Table 1: Evaluation table for filtered software packages

Simulation Software	Compatibility	Key Features	Limitations	*Approximate Pricing
Package A	Excel, Access; OptQuest; Stat::Fit; Any Java/DLL library e.g. for Bayesian or neural networks	Allows three types of modelling: Agent-based, discrete-event, and system dynamics Well known Extend default models with Java	Difficult to use and requires a large study of documentation and tutorials	R280,000 & (R1400 for 3-day training course) *~ (20,000 USD)*

Simulation Software	Compatibility	Key Features	Limitations	*Approximate Pricing
Package B	Excel Stat::Fit OptQuest SQL databases	Excellent customer support Most cheap commercial tool Creation of a class of models that can easily be tailored to different systems	Few modelling components Poor documentation/ web-tutorials No 3D object-oriented modelling	R110,000 (including training and annual maintenance) *~ (7500 USD)*
Package C	Excel and other database software C++ applications	Perform database queries for data import Send messages between objects Support Dynamic Data Exchange 3D simulation and very clean GUI Support any connectivity that C++ offers Use sockets to send and receive data	Second most expensive tool Lack of objects to use in the simulation (can create some)	R350,000 (R280,000 additional seats) *~ (25,000 USD)*
Package D	Matlab; Excel; SAP; Simatic IT; Teamcenter; Autocad; Microstation; SolidEdge	Greatest compatibility with other company fit software (SAP & Teamcenter) Already established relation with vendor	Most expensive tool	R350,000 (standard) R700,000 (professional) *~ (25,000 USD | 50,000 USD)*

**Note that pricing approximates are subject to change based on annual evaluation, and license and subscription developments.*

By using the compared software package analysis and filtered evaluation from phase one, a ranking table featuring the main requirements is compiled. Capabilities are ranked with the following symbols and highlighted colours: (A/green) – best in class; (B/orange) – average in class; (C/red) – worst in class.

Table 2: Ranking table for filtered software packages

Capabilities	Package A	Package B	Package C	Package D (Standard/ *Professional*)
Supported Operating System	Windows, Mac, Linux (A)	Windows (A)	Windows (A)	Windows (A)
Compatible Software	Excel, Access, SQL, OptQuest, Stat::Fit, Java (B)	Excel, SQL, Stat::Fit, OptQuest (B)	Excel, C++ (B)	Matlab, Excel, Simatic IT, Autocad, MicroSt, *SAP*, *Teamcenter* (A)
Input Distribution Fitting	31 predefined dist, Stat::Fit, ExpertFit (A)	Stat::Fit (B)	ExpertFit (B)	22 predefined distributions (B)

Capabilities	Package A	Package B	Package C	Package D (Standard/ *Professional*)
Graphical Model Construction	Yes (A)	Yes (A)	Yes (A)	Yes (A)
Output Analysis Support	Reports, logs, charts, db output (B)	N/A (C)	Charts, graphs, dashboards, Excel (B)	DataFi, charts, Sankey, Analyser tools, reports (A)
Optimization	OptQuest (B)	OptQuest (B)	OptQuest (B)	Neural networks, Dynamic prog. (A)
Run Time Debug & Code Reuse	Yes (A)	Yes (A)	Yes (A)	Yes (A)
Cost Allocation	Yes (A)	Yes (A)	Yes (A)	Yes (A)
Batch Run/Experimental Design	Parameter variation, run compares, Monte Carlo, Sensitivity analysis, calibration (B)	Multiple replications and scenario management (B)	Built-in experimentation engine (A)	Experiment Manager supporting distributed simulation (A)
Mixed Discrete/ Continuous Modelling	Yes (A)	No (C)	Yes (A)	Yes (A)
3D Animation Capability	Yes (A)	No (C)	Yes (A)	Yes (A)
CAD Drawings Import	Yes (A)	No (C)	Yes (A)	Yes (A)
Price Range	R280 000 (B)	R110 000 (A)	R350 000 (C)	R350 000 / *R700 000* (C)
Future Integration Capabilities	No (C)	No (C)	No (C)	Yes (A)

The primary sources of the information compiled in Table 1 and 2 are the referred to Anylogic [8] white paper, as well as direct communications with the screened packages and/or technical information provided on the vendor websites.

Based on the ranking and comparison evaluation between the identified software packages, the most suitable software was selected, in this case study it was Package D. The motivation for the selected package was derived from three main sections: software capability motivation, initial return-on-investment targets, and license motivation.

i. Software capability motivation:

Package D will provide the company with the ability to model and simulate stand-alone, as well as integrated facilities, processes and operations in a 3D object-oriented environment with detailed mathematical distributions and accurate real-state data incorporation. Current state analysis and optimisation and future state design effects can be simulated at a fraction of the cost and time, in relation to other methods. It will also aid as a steppingstone in setting up Company A's in-house plant simulation structures. From here, they will then be able to grow into more in-depth solutions that the professional system will provide with future integration capabilities and with other developing structures such as existing Enterprise Resource Product (ERP) software.

ii. Initial Return-on-Investment (ROI):

The main ROI points consolidated by the software supplier [10] on various company surveys using Package D include:

- Overall average value/cost ratio was 12:1 (This means for every R1 invested in simulation, R12 returns as value)
- 5-20% reduction in new system costs
- 20-60% reduction in inventories and throughput time
- 15-20% increase in productivity of existing systems

Company A's initial expected outcomes from the implementation of the software included:

- 2-3 Large modelling projects in the first 12 months with cost planning savings from direct/indirect simulated decision support of 10%, which will be determined on the balance of total project cost and/or 20-30% reduction in planned throughput times and material handling and transport.
- 5 small/medium projects in the next 12 months with a focus on immediate material/product flow optimisation with aim of 10-20% increase in productivity and utilisation and/or cost reduction planning from reduced waste streams and inventories of 10-20%.
- Other goals include model support for sales/marketing purposes of plant layouts and production simulation; decision support based on simulated analysis with as-is/what-if scenarios; concept and detail design support to analyse the integration of process and systems.
- The confidence on return of initial capital investment will be set on 12 to 24 months. With ROI on simulation projects done directly after each project, with quarterly and bi-annual measurement to capture indirect impact results.

**Note that with simulation software, determining ROI is not always directly quantifiable, with indirect factors being of major value within a whole of a product/process start-to-end phase.*

iii. License Motivation:

An important factor identified for motivation is that Package D has integration capabilities with other existing company software with the eye towards future development. Although upgrading to a professional license will be required for full integration, initially a standard license is recommended to set up baseline structures within the company's IT structure and complete initial projects for Phase 1 (2 to 3-year lead time). This is the initial simulation modelling and project development phase. When the structure and operations are set up, Phase 2 will be the direct integration and development of database link-up with other systems. This will be a separate project when systems are fully setup and operations have experience with the software, together with consulting support, trade-in value options and subscription services to upgrade to the professional license in the future.

The motivation to phase out license capabilities is to ensure that Company A can get the most out of the Phase 1 solutions and setting up structures, and then in Phase 2 develop in an integrated project with professional license adoption. This is because Company A will not be able to fully utilise the extra integration functions of the professional license without setting up the product life-cycle management (PLM) and simulation modelling structures in parallel, which can be done with a standard license.

5 SUMMARY AND CONCLUSIONS

The hybrid evaluation and selection framework applied in this case study can assist potential new simulation software users in the evaluation and selection process. Although the methodology may seem limited in terms of the number of packages evaluated, it still represents an efficient strategy for evaluating and selecting DES software dedicated to production process simulations.

The hybrid framework was applied practically in Company A with both the evaluation (Phase 1) and selection (Phase 2) of the most suitable DES software. Phase 1 represented a detailed scope of requirements constructed by the potential software user(s), in collaboration with and the approval of the IT department and management team. The characteristics and comparison of more than 10 different simulation packages were then filtered through as a baseline for evaluating appropriate software packages currently available in the market. The four filtered software packages, based on the scope of requirements, were then screened and evaluated for selection. Phase 2 consisted of the ranking of the software, based on the main software requirements identified, and completed following the motivation for selection of the most appropriate and highest-ranked package – in this case, Package D.

On the whole, the hybrid evaluation and selection framework used was found to be efficient and acceptable. Since the main concept behind the framework is to comply with the internal case scope of requirements and be an effective strategy, the results found are acceptable. In addition, the framework used is so simple that it can be applied in different application domains.

The study concludes with a derived framework from Tewolderberhan's approach that provides a more efficient and less complicated methodology with a case study reference. The limitations of the Tewolderberhan approach is that the evaluation phase only represents a holistic approach to collaborative evaluation and selection between various departments. This is because of the varying structures and procurement strategies at different companies. Further research could lead from this study that would also benefit within a reference capacity.

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SORTING USING VISION SYSTEM

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ABSTRACT

Sorting is a process of arranging things in order, shape, size, colour etc. Sorting is a very important aspect and it plays a key role in a production line. The main purpose is to design and implement a system that will be able to sort material using a vision system. This technology can be used in material handling in logistics, recycling station, post office, and packing industry. In this paper, the operation of a text detection algorithm operated using MATLAB C languge. The text detection algorithm is executed to identify the name bullet shell and send the appropriate commands to the microcontroller using to control the actuators to perform the sorting operation. In this paper sorting Operation will only be tested in bullet shells.

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1 INTRODUCTION

Industrial sorting automation is in high demand in the industry as it directly affects the growth of the engineering industry. The quality and accuracy of products play a big role in the industry. Most of the industries are using manual sorting systems to do the project [1]. Manual sorting takes time and is associated with human error and it prevents the industry from performing best [2]. If the human error costing very high bad production to the companies, it is very important that shareholder look at that and see what is it that can help to replace this type of error.Cliff Holste [3], have been working with many small and big companies to improve the distribution performance, and reported that shoes sorting is improved by 20% which is better that than how it was operating since 1980.

To clean the recycled material means more money for the company China has been reported as one of the largest importers of recycled raw materials. In 2004, it recycled more than $3.1 billion worth of the United States scrap [4]. This is all because the chain has it have a high population. Designing the sorting system will increase the rate of production, last year the residents of Cheshire West and Chester, recycled about 57% of household waste [5], this can be improved by implementing the system. Sorting is very important because it increases production, it is associated with less price cost and quality of production. This system can be used in the manufacturing industry to do a task like counting, sorting, matching, locating, recognizing, reading, classification, measuring and monitoring of material. There are different places where sorting can be applied, in an area like recycling facilities, food technology industry, packaging, Post Office for the letter sorting, filling, manufacturing processes, and transport system but this one they do not use vision system [6].

Different past sorting systems have been analysed to determine the success of the project. This includes the M&M's and Skittler sorting machine and Fruits tracking system. The M&M's and Skitter sorting machine is a system which uses colour sensor to sort candy of six different colours. This system is designed to use RGB colour sensors. M&M's and Skittles sorting machine uses Arduino controller, stepper motors, an RGB colour sensor, exit tube, button, and hopper [7]. This system can still be developed and integrated more to sort any type of colour object, but the condition holds about a dimension of the object that it must stratify the machine dimensions.

Fruit trucking system is used to find fruits and position them according to colour and size [8]. The fruits move in a conveyor belt combined with actuators to place them in the correct position. The system has great ability applying in practice especially in the production line.it helps improve quality of the product. It requires high hygiene safe condition and limits exposure to workers. This system is suitable for packing and sorting application with automated actuators as industrial robots. This system uses a vision system based on a computer to find the position and properties of the fruit. This sorting system used a high-resolution camera mounted on a stand to capture fruits moving on a mechanical conveyor belt. Using the captured images, the system software will perform algorithms to find the characteristic of fruits to sort. The location of the object to sort is sent to the database [8]. The data will then be used by the pick and place process that synchronizes with the controller of the actuators to sort fruits. The computer send the control signal to the controller, then the output signals at the actuators control actuators to pick the fruits.

The design, production, storage and delivery of cartridge cases to factories, user units and individuals place an enormous logistic demand on all military systems. In addition, the humble cartridge case ties up and immense amount of money, quite large portions of which are not recovered being lost in the chaos of battle, training and shooting ranges. The cartridge case in most instances is made from expensive materials that are usually in short supply because of competing demands from other industries [9]. The recovery process creates a logistic demand of its own. All the spent cases need to be gathered, sorted, packed and transported back to the factories where they originated. When cartridge cases in shortage or not sorted, it reduces time for reloading and result in the downfall of business due to less cartridge at shooting ranges.In recycling station, cartridge cases are sorted according to material type and manufacturing name.

Sorting cartridge case by hand can be time-consuming and it can burn finger if it hot. Manual sorting is associated with lot human error [10], which lead to product failure and product wastage. Product failure leads to land pollution and manufacturing cost increases high. Labour worker is costly and a company called Tecknovio report that by the year 2020, US will save up to 20% labour savings achieved by replacing labour workers with robots [11].

2 METHODS

Three methods have been suggested and tested for this project and all these methods used more the same operation. The methods are Optical Character Recognition (OCR), Templet matching, and Blob Analysis. All this method will be tested and the best one will be selected.

2.1 Optical Character Recognition (OCR)

Optical character recognition is the mechanical or electronic conversion of the image with text into machine-encoded text [12]. It is also known as the common method of digitizing texts and the OCR selected here is software-based. The advantage of OCR is its easy storage, easy editability and ease of searching text. It form part of research pattern recognition, artificial intelligence, and computer vision. The following figure 1 shows how the OCR takes places:

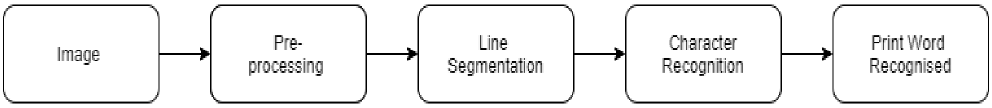


Figure 1: Optical Character Recognition(OCR) Operation [13]

From figure 1, the image is accepted as input, and it's pre-processed noise like salt and paper other noise. Noise can be removed using a medial filter. The other pre-processing can be if the image is blurred, the image is can become blurred due to object is moving. A Wiener filter is used to restore a blurred image. The next step is contrast enhancement this can be done using histogram equalization and then contrast stretching using image adjustment operator. The next step is performing line segmentation, the line segmentation is done by using morphological operation. Then character recognition/identification using the given template. Each character is segmented separately, then scaled down to a standard size. Each character is compared with a set of predefined character templates. Using correlation function from MATLAB to find co-relation factor of segmented character with a pre-defined template. The character that gives the maximum score is set to print. The last step is to print the characters that have been recognized.

2.2 Template Matching

Template matching is the process or technique that is used in digital image processing for finding small parts of an image that match the template [14]. This method can be used in companies for quality control and the selection of images. The following figure 2 is the operation of template matching.

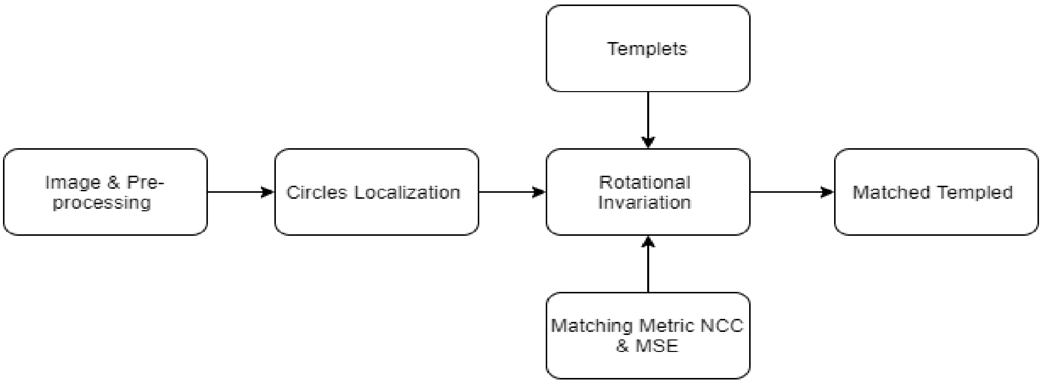


Figure 2: Template Matching Operation [14]

From figure 2, the image is accepted and pre-processed, this is done by changing an image to grayscale and then used Sobel operation for edge detection. The Hough Transformation is then used for circle detection. Then the image cropped, and then the cropped image was then scaled to predefined template size. Then the predefined template was compared with the new cropped image to normalize cross-correlation and mean square error. The comparison was done using the using rotation invariant, the cropped image was being rotated from 0 to 350 degrees, with a step of 10 degrees. Two methods were tested in this section Normalized Cross-correlation (NCC) and Mean Square Error (MSE). The matching template was measured by high value in NCC and by lower value in MSE.

2.3 Blod Analysis

The blob analysis is the technique that is used in image processing based on the analysis of consistent image regions [15]. It is a choice for an application whereby images are analysed and clearly discernible from the background. The advantage of the blob detector is filter has versions at multiple scales. The biggest response is when the filter has the same location and scale as a blob. The following figure 4 is the operation for the blob analysis.

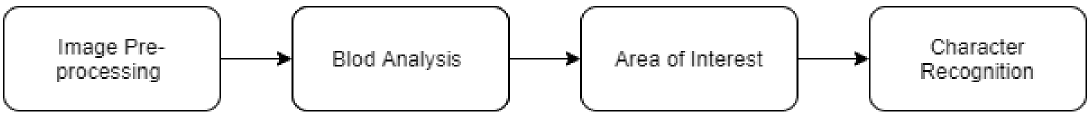


Figure 3: Blod Analysis Operation [15]

For blob analysis, the image is accepted as input, the pre-processing for the image is done, first by converting RGB image to grey image, then the grey image is complemented. The next step was to calculate the threshold of a grey image. Lastly for pre-processing, the grey image is converted to a binary image. The first step was to initialize the blob analysis system to a maximum count of 500. Then the blob analysis was run to find the connected components and the statistics. The constraints were then set and only the area that meets the area of constraint were kept. The remaining region was passed into the OCR function; the OCR function was set to accept rectangular region of interest as input. Then the size is slightly increased to include the additional background pixels around the image's text character. The polarity was to determine the polarity of text on the background. The last step is to recognized text and displayed them on the original image.

3 DESIGN

The following figure will be used to explain the sorting system. The Logitech camera will be connected to the computer using the USB cable. The computer will be connected to the Arduino using the USB cable. Arduino shall be connected to the two servomotors, using japer wires for transmission of the pulse.

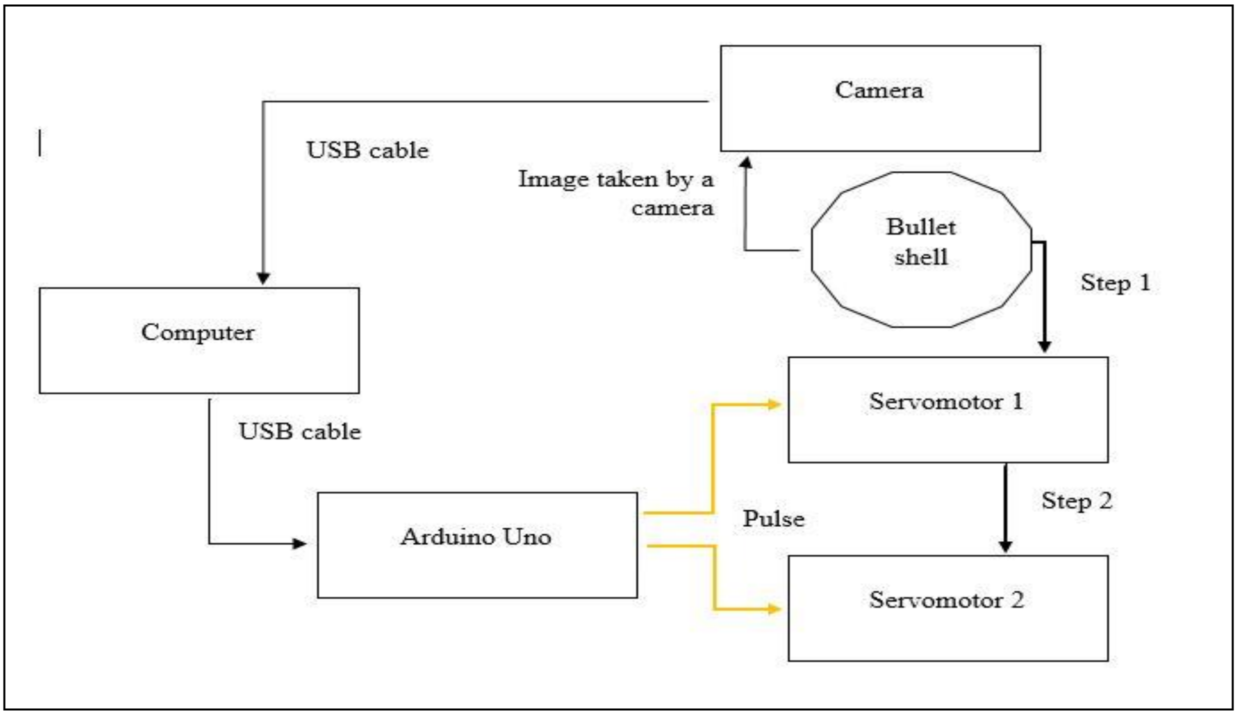


Figure 4: Sorting Design System

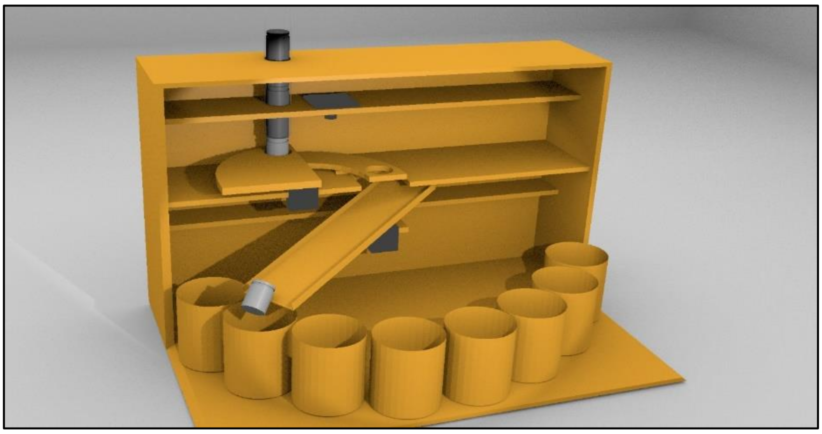


Figure 5: Sorting system prototype

From figure 4 and 5, images a captured by a camera from the back of the bullet shell, then the image is sent to the computer using a USB cable. In a computer, a text detection algorithm shall be executed. When the algorithms have detected the text, then servomotor 2 will be controlled to set the actuator to be in a position of the reorganized text slots. Then the servomotor 1, will control the bullet shell so that it can be a dropped in to an actuator in servomotor 2.

The sorting using a vision system will be tested in seven different bullet shells of different manufactures. The table below shows the bullet shell that will be used different manufacture name and their slots:

Table 1: Manufacturer names

Bin Number	Manufacturers Name
1	FEDERAL
2	GECO
3	NGA
4	PMP
5	PPU
6	S&B
7	SPEER
8	WINCHESTER

4 RESULTS AND DISCUSSION

The three method that were introduced it was Optical Character Recognition (OCR), template matching and lastly the blob analysis.

4.1 Optical Charactter Recognition (OCR)

When the OCR method was being analysed it was found that the output results were not according to the specification. The following figure 6 and table 2 show the software-based OCR results that were obtained.

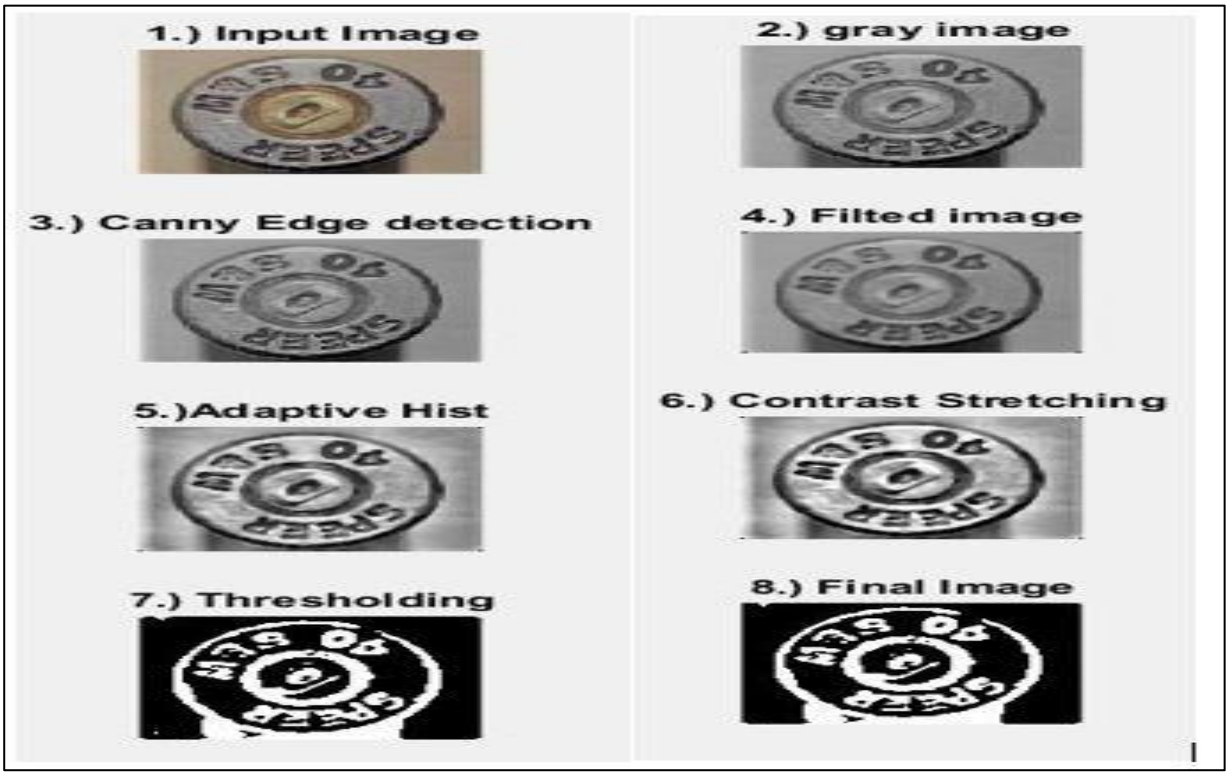


Figure 6: OCR Results For Speers

Table 2: OCR Results Test

No.	Input image	Word from image	Test Passed/Failed
1		415QVWO0V4VX11464979P4J14	Failed
2		BK4V4OYWJ44HA4144VO4FFAV	Failed
No:	**Input image**	**Word from image**	**Test Passed/Failed**
3		K491KL1LXAA41Z1T0Q4K1XJY4P4FL44PNA	Failed

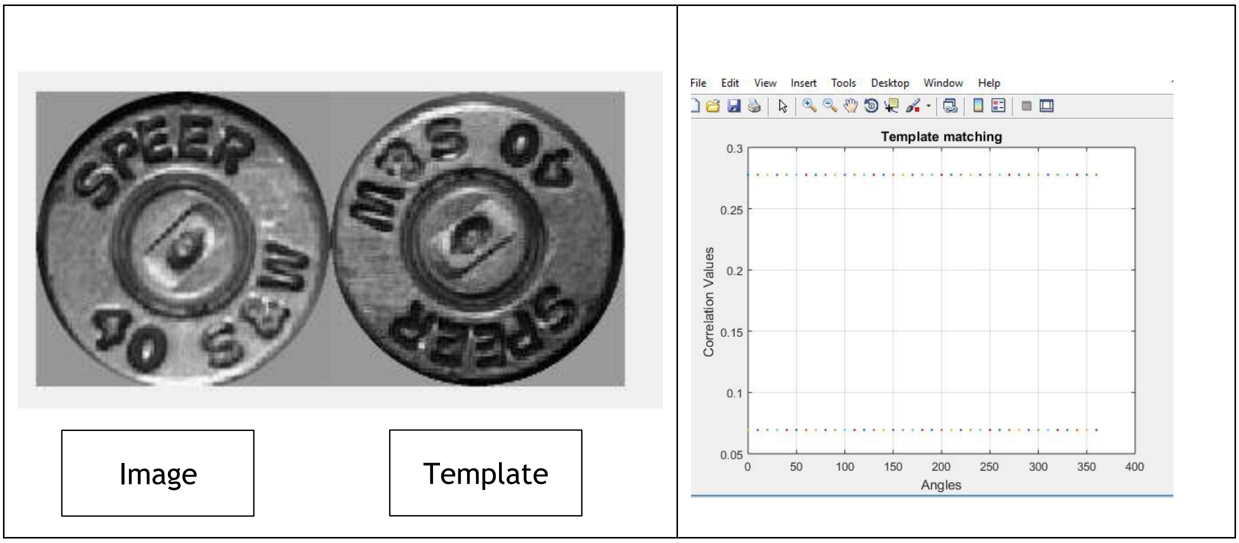
Three cartridge cases where tested using OCR methods, table 2 show the results that were found OCR. It can be observed that the results do not correlate with the name of manufacture.

4.2 Tempale Matching

Template matching test was performed using different bullet shell and templates. One bullet shell was tested in time to compare it with different templates. The tables below show results for template matching, using MSE and NCC test graph.

Table 3: Tempalate Matching

Image of left and Temple on the right	NCC (high value) and MSE (Lower values)



It can be observed that the value for NCC is the same for all the angles when rotation process performed. The values for the MSE was also found to be the same for all the angles. This method was voted to be unsuccessful for this project since NCC and MSE must change with every rotation.

4.3 Blob Analysis

The Blob Analysis test is performed using for different cartridge case, following figure 7, shows results that were obtained.

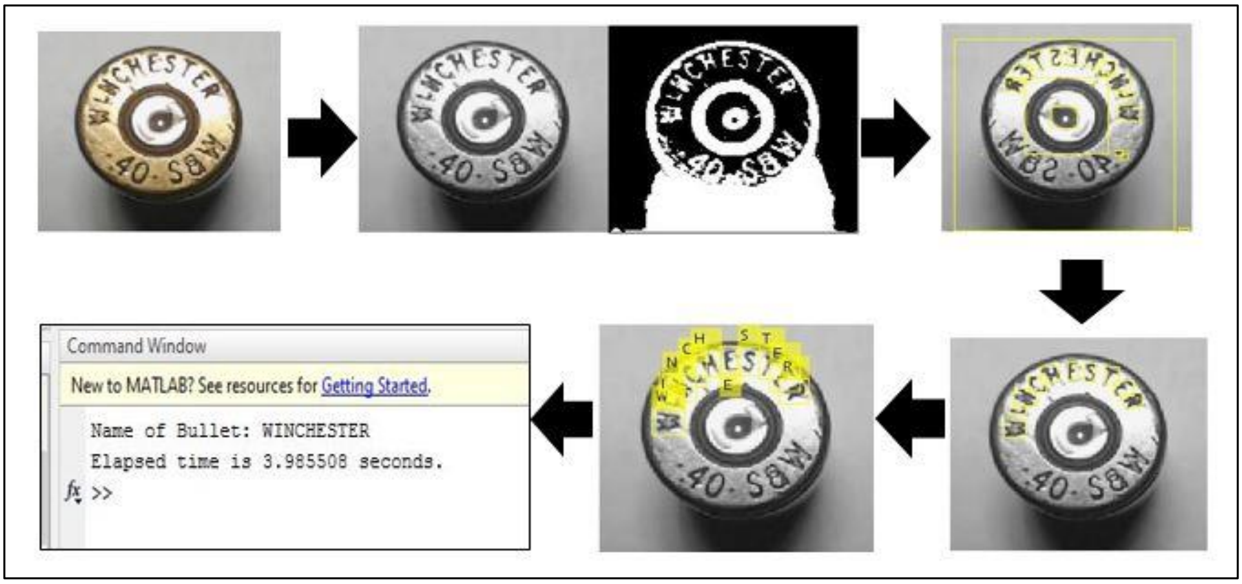


Figure 7: Manufacturer Name

Then flowing figure 7 shows results that were found for the name of the bullet shell (Winchester) and the total time it took the system to recognize the name of the manufacture. The manufacture name was found and it is Winchester and the time to recognize the name was found to be T=3.985508 seconds.

It can be observed from figure 7, that when using the blob analysis, when the image is inserted in blob analysis, the algorithm was able to detect manufacture name of the cartridge case as

'WINCHESETER'. The Method was voted to be successful. The following table 4 shows the results obtain when the blob analysis method has been used.

Table 4: Different Name Recognition

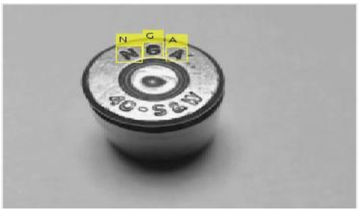
No:	Input Image	Output Image	Shell Name
1			FEDERAL
2			Geco
3			NGA

Table 4 shows the results that were found when 3 bullet shells were tested. It can be observed from the figure that all the results that found, all three results are according to manufacture sluts. If this test can be done to also other results it can show that the results shall be correct.

There was an error when recognising some of the bullet shells. S&B shell in figure 8.

Figure 8: S&B Shell

The cartridge case which was not reorganized very well was 6 (S&B), it shows the results as "S&B D" which is not the manufacturer name of the cartridge case "S&B", the letter D is not correct, and it is not part of the manufacturer name. The mark in the cartridge case that was found as letter D, shows that there was damage in the cartridge case. This system is affected if the text is not visible or the shell has been damaged.

5 CONCLUSIONS

The future work includes fully implementing the autonomous system that can be sort 20 bullet shells in less than 10 seconds, the second one is adding the error slot in the system to accommodate any error if the shell manufacture name not recognized. It is not advisable to design a heavy system or that will cover a lot of area since cost and can affect the buying price. Form all three methods proposed only blod analysis The vision system can be able to do repetitive tasks, with high speed, high accuracy, and high consistency. The system has been designed to minimise errors in a factory and to increase production.

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MONOLITHIC DESIGN OF AUTOMOBILE SHEET METAL COMPONENTS FOR THE DEEP DRAWING PROCESS: A REVIEW

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ABSTRACT

The automotive industry is one of the leading users of aluminium sheet metal. Single parts comprising of sheet metal plates, brackets and hinges are joined together via the TIG welding, bolting and riveting processes. The parts move through many workstations. This increases the machinery investments, energy and labour costs. Lead time is high and so are the material handling costs. A huge storage facility for both the component parts and joining material (bolts, nuts, rivets) is required. The joining material itself increases the weight of the final product, while at the same time, the joined sections can be points of weakness. The stress concentration at the joining points reduces the fatigue strength. In an effort to eliminate the aforementioned disadvantages, this paper reviews the monolithic (one piece) design of the aluminium sheet metal components for the deep drawing process. The paper also looks at the use of the deep drawing process in manufacturing monolithic parts in one shot regardless of complexity while at the same time producing a mechanically stronger product through strain hardening. The paper also discusses the benefits which come as a result of monolithic design, which are: lightweight products, reduction of process routes, high raw material utilization and high energy efficiency.

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1 INTRODUCTION

The recent developments in car production show an increase in the adoption of lightweight materials and technologies. This is done in order to meet the customer demand for low fuel consumption and the environmental restrictions on the amount of carbon dioxide emissions [1]. One of the most important car body manufacturing process is sheet metal forming [2]. The deep drawing process is by far the most widely used sheet metal forming technology. The automotive industry is one of the leading users of aluminium sheet metal. The aluminium sheet metal offers multiple lightweight design possibilities and has high strength properties [3]. It is malleable and this allows it to be shaped into aerodynamic designs. The mass production of complex shaped functional components is possible and the properties can be tailor made [4]. A typical car has more than 300 sheet metal components [5]. Sheet metal is used in the construction of the body panels of the car such as the doors, bonnet/hood, roof, fuel tank and the fender. Figure 1 below shows some of the deep drawn sheet metal parts.

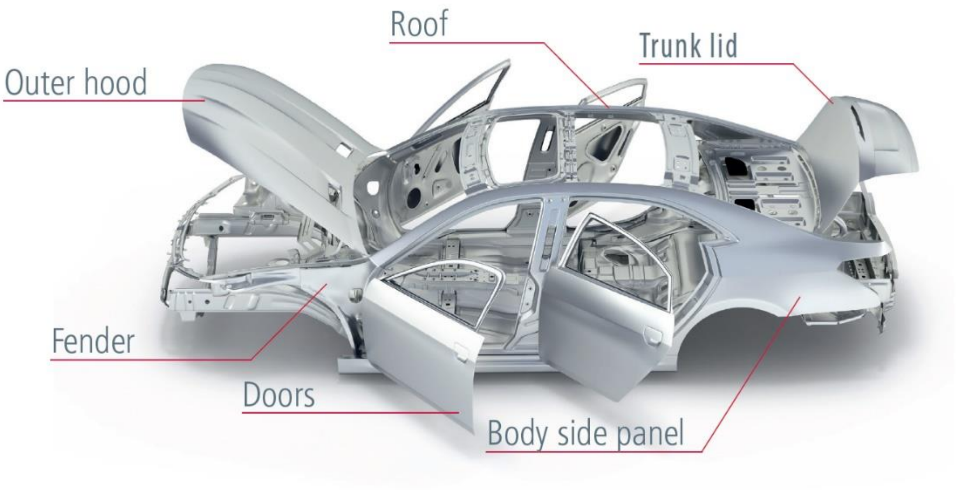

Figure 1: Car deep drawn sheet metal parts [6]

Cars do not serve as a mode of transportation only, but also as camping vessels on many adventures. The need for shelter during camping in remote locations motivated the development of the aluminium roof for truck campers, which are mounted on top of the SUVs. Most of the aluminium roofs for truck campers consist of up to 42 or more single parts comprising of sheet metal plates, brackets and hinges. The individual components are joined together via the TIG welding, bolting and riveting processes. The method of single parts with subsequent joining has some shortcomings, which can be grouped into 3 categories: pre-production, production and post production limitations.

The pre-production limitations are associated with the manufacturing of single parts, where a large proportion of manufacturing costs are incurred. Firstly, a company may have to acquire pre-cut individual components from vendors. Secondly, these subassemblies require bots, nuts and the joining material for welding. The joining material is, in many cases, outsourced. Thirdly, having many parts per product results in a requirement for a huge storage facility for the component parts and joining material [7].

On the production line, the parts move through many workstations, which leads to longer lead times and higher material handling costs. Additionally, a lot of manufacturing time is consumed as setup time, loading time and unloading time. This increases the time to market, thereby limiting the company’s ability to meet the customer requirements faster than competitors. The machinery investments are also high and so are the energy and labour costs. Moreover, dimensional accuracy is negatively affected because each part has its own tolerance zone which is difficult to manage when they eventually get joined together.

At the post production stage, there are post processing costs associated with the joining processes. High heat generated during the welding results in a build up of residual stresses. The product has to undergo heat treatment before released to the market. The total number of individual parts is a key measure of quality [8]. The joined sections act as points of weakness. Stress concentration at the joining point results in reduced fatigue strength when compared to the rest of the members. The joining material, especially in bolting, adds weight to product [9]. Part scraps are also significant with an increased number of parts.

Driven by the need to eliminate the disadvantages stated above, this paper therefore reviews the monolithic (one piece) design of vehicle aluminium sheet metal components for the deep drawing process. The key contributions of this paper are listed below:

- To provide a systematic literature review on the disadvantages of the TIG welding processes.
- To discuss the applicability of the deep drawing process in the manufacture of monolithic aluminium sheet metal components.
- To compare and contrast the deep drawing process against the TIG welding process for the aluminium sheet metal components.
- To highlight and discuss the benefits of monolithic aluminium sheet metal for the deep drawing process.

The rest of the paper is organized as follows. The next section systematically reviews the TIG welding process its disadvantages. This is followed by the monolithic design for the deep drawing processes. The applicability of the deep drawing process and its advantages are discussed. The major advantage discussed is its ability to manufacture monolithic sheet metal parts in one shot regardless of complexity, while at the same time producing a mechanically stronger component through strain hardening. Next is the deep drawing process for the elimination of the TIG welding process and lastly, the paper discusses the benefits of monolithic aluminium sheet metal design for the deep drawing process.

2 MONOLITHIC DESIGN FOR THE ELIMINATION OF THE TIG WELDING PROCESS

The Tungsten Inert Gas (TIG) welding process is also known as Gas Tungsten Arc Welding (GTAW), Wolfram Inert Gas (WIG) (in Europe), or Heliarc welding [10]. It is the most preferred joining process for aluminium alloys. Before going into its demerits, it is important to note that the process has a lot of advantages, some of which are:

1. It produces high quality welds, which makes it one of the most popular welding technologies today [11].
2. It does not produce slag. Argon and helium are used as shielding gases to protect the base metal from reacting with oxygen and water vapour in the atmosphere [12].
3. Its weld is cleaner and neater when compared to other welding processes [13].
4. Its weld is strong and non-porous due to absence of trapped gases [14].
5. It produces a precise weld and it is used in products which require fine tolerance margins [15].

The advantages stated above and many not stated make the TIG the most common welding process for aluminium sheet metal parts [16]. However, it has some demerits and these are discussed below:

2.1 High energy costs

The TIG welding process uses a lot of electricity on a single pass. This electricity is converted into heat for melting the base metals at the joining point, but not all the electricity is converted into usable heat. There is massive heat loss in aluminium welding [17]. Experiments done by Donegá et al [18] show that the thermal efficiency (TE), that is, the ratio of the heat transferred (HT) to the base metal to the heat supplied ranges between 61% and 79%. Some studies show that it can be as low as 50% [19]. This is very low when compared to consumable arc wielding processes such as MIG, where the heat transfer efficiency is between 80 and 90%. The melting efficiency (ME) too, which is the heat that actually melts the base metal does not exceed 50% [19]. The ME is measured in this way: out of the heat transferred (HT) to the base metal how much of it is used to melt that metal. The heat losses are due to conduction, radiation, convection (which is driven by the Marangoni effect) and spatter (which is less when doing TIG welding) [20]. This is diagrammatically represented on Figure 2 below:

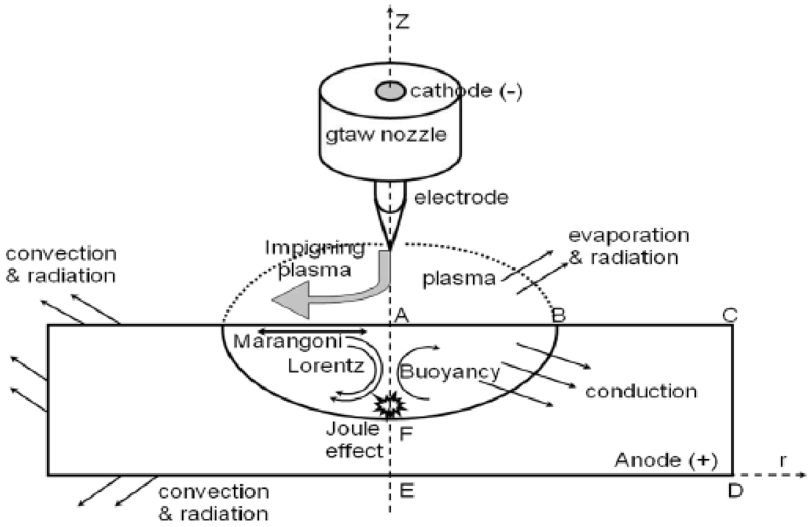

Figure 2: Heat transfer in TIG welding [21]

The power requirement is also high. The minimum power density i.e., the transferred power per unit area required to cause some localized melting on the base metals is 10 W/mm^2 [22]. If the power density is too low, the heat is quickly conducted onto the surface but melting does not occur.

2.2 Limited sheet metal thickness that can be welded in a single pass

Even though the TIG welding process doesn't require a filler metal [23], it has a maximum penetration of only 3 mm thickness. The process becomes more expensive when welding parts which have thicker cross sections [24]. The thicker sheets need multi-pass welding, making it a time consuming process. This also increases the power requirements.

2.3 High post processing costs

TIG welding causes localized melting on the base metal. A lot of heat is introduced to the base metal [25] and this causes a huge temperature difference within the metals, after which there is uneven cooling. As a result, there is a build-up of residual stresses at the weld zone [26]. As aforementioned, the lack of penetration results in the need for multiple passes. This increases the heat affected zones (HAZ) [25-26]. This disrupts the material microstructure and changes the metallurgical properties. Hence, the welded part has to undergo heat treatment. Other authors like Shrivas et al [29] researched on TIG minimizing the heat affected zones, but this is only beneficial for thin sheets.

2.4 High manpower demand

TIG welding is associated with high labour costs. Labour can take up to 86% of the total welding costs [30]. Even though the use of robots in substitution for human labour brings higher welding speed, greater consistency and better accuracy, there are high investment costs involved.

2.5 Welding defects

The welded point can act as a point of weakness. Porosity is significant and is the most common defect [31]. According to the American Welding Society (AWS), the sum of the diameters of visible porosity must not be greater than 9.5 mm per linear inch (25.4 mm) of the weld. Studies by Luan et al [32] show that porosity can go up to 50%. Aluminium complicates the welding process by forming a porous layer of oxide which can be up to 0.3 mm thick [33]. Cracking at the joining point can also be significant. This compromises the integrity of the joint and can lead to premature failure.

3 MONOLITHIC DESIGN FOR THE DEEP DRAWING PROCESS

Among the different types of sheet metal forming technologies is the deep drawing process and stretch forming. In the deep drawing process, the sheet metal is placed over a die cavity, held down flat against the die by a blank holder and then pushed by a punch into a die opening in order to produce a cup-shaped, box-shaped or concave-shaped part [22]. It is widely used for rapid mass production in the automotive industries [34], where it produces hollow parts, whose base thickness is equal to that of the wall thickness [35]. The parts are axisymmetric [36], lightweight, strong due to strain hardening and corrosion resistant [37]. It is diagrammatically represented together with the stretch forming process in Figure 3 below:

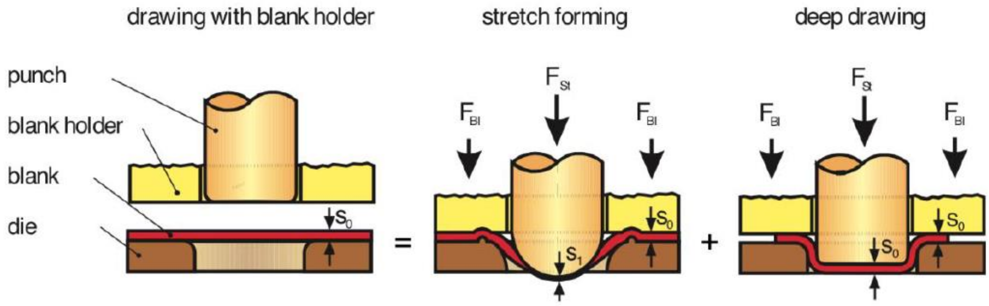

Figure 3: The stretch forming and deep drawing processes [38]

In the deep drawing process the sheet metal is formed under a combination of tangential compressive stress and radial tensile stress without altering its thickness. In stretch forming, a locking bead and beading rods prevent the blank from sliding into the die under the blank holder. This subjects the blank to tensile stress during penetration of the punch and the sheet metal thickness is reduced. Despite these differences, practical deep drawing is, in general, a combination of both deep drawing and stretch forming processes. As the process begins, the punch moves down and causes a stretching on the sheet metal. Deep drawing only starts when the bottom part has been formed [39]. This is shown on Figure 4 below:

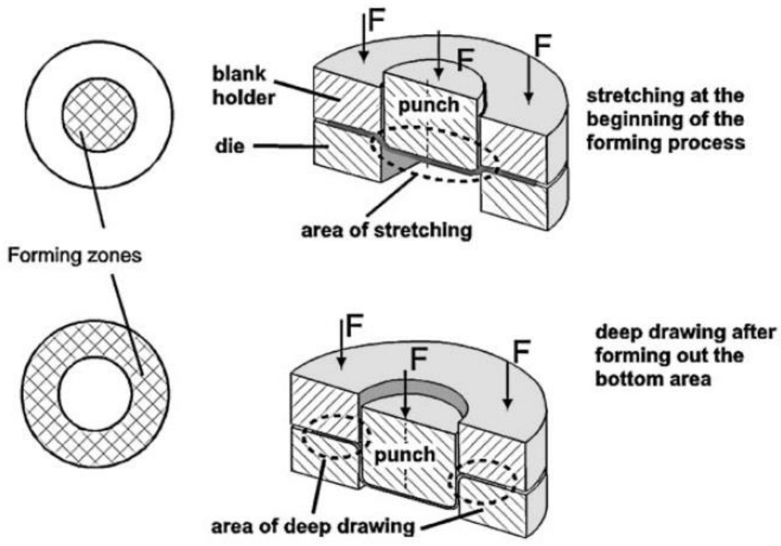

Figure 4: Stretch forming and deep drawing on a sheet metal [39]

The sheet metal benefits from strain hardening. The atoms within the sheet metal become closely packed through the reduction of its thickness under mechanical loading and this results in a mechanically stronger part. This can further be explained in terms of the stress zones that occur in the deep drawing process. These are illustrated in Figure 5 below:

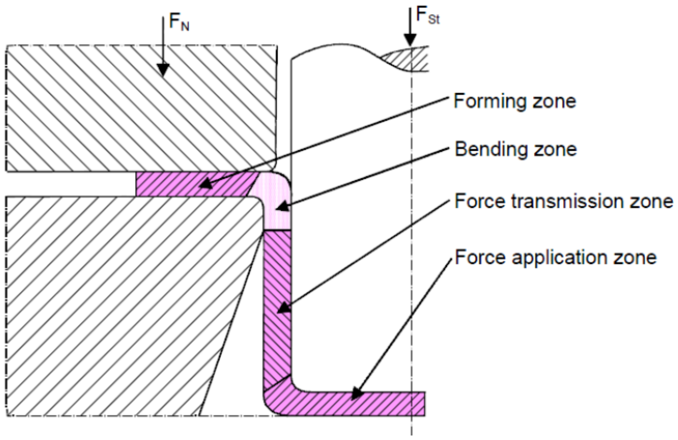

Figure 5: Deep drawing zones [40]

The punch applies compressive force at the base of the sheet metal where stretch forming begins. This makes the base to be mechanically stronger. As the punch moves down, these are the main areas:

- *The force application zone:* this is where the punch force is applied.
- *The force transmission zone:* the applied force is transmitted through this zone. The material gets thinner as it experiences tensile forces, which are as a result of it being stretched.
- *The bending zone:* the sheet metal bends over the die edge radius. Here the sheet metal experiences tensile forces outwardly where there is contact with the punch and compressive forces inwardly at the point in contact with the die.
- *The forming zone:* it is referred to as the area of deep drawing in Figure 4. This area also experiences both compressive and tensile forces.

4 DEEP DRAWING PROCESS FOR THE ELIMINATION OF THE TIG WELDING PROCESS

In comparison with the TIG welded components, the deep drawn products use less raw material, have lower product mass and have a potential of saving up to 80% of the production time [41]. This is represented in Table 1 below, where the production of an aluminium AA6061 monolithic cylindrical cup was virtually demonstrated using both the TIG welding and deep drawing process:

Table 1: Comparison between a TIG welded and a deep drawn cylindrical cup [41]

	TIG Welded Component	Deep Drawn Monolithic Component
Mass	139 grams (neglecting weld bead mass)	131.78 grams
Cycle time	150 – 222 seconds	20 seconds
Total weld length	370.15 mm	0 mm
Total weld mass	370.15 grams (variable)	0 grams

The drawing process for the sheet metal components has advantages such as high suitability for mass production and the ability to form very thin walls. The sheet metal conditions for a successful deep drawing process are that it must have constant thickness and it must not have undercuts in the direction of the punch. The aluminium material experiences strain hardening which increases the strength and durability of the final product.

5 BENEFITS AND DISCUSSION

The benefits of monolithic design of the aluminium sheet metal components for the deep drawing process are diagrammatically represented on Figure 6 below:

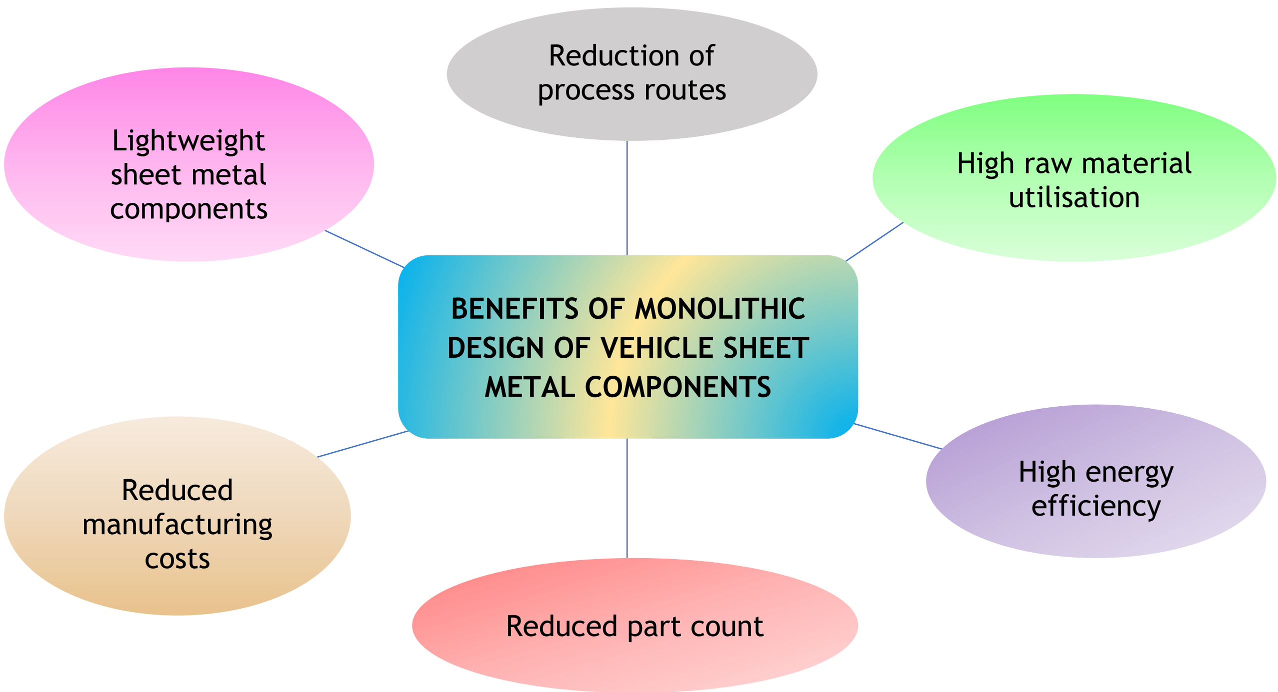

Figure 6: Benefits of monolithic design of aluminium sheet metal components for the deep drawing process

These benefits are explained below:

5.1 Lightweight components

Lightweighting results in raw material savings, reduction of fuel consumption and reduction of carbon dioxide emissions. Weight reduction through monolithic design eliminates bolts, nuts, screws, rivets and other joining material which increase body weight. This makes the resulting component to have excellent strength to weight ratio and high product efficiency.

5.2 Reduction of process routes

The following is achieved:

- Less transportation of parts between one workstation and another during processing.
- Less material handling of parts.
- Less loading/unloading costs between workstations.

5.3 High raw material utilisation

The consumption of raw materials is reduced through the creation of lightweight products. This reduces the raw material costs for the company and extends the period of availability of mineral reserves.

5.4 High energy efficiency

The manufacturing industry consumes 42% of the total electricity produced globally, 75% of the annual global consumption of coal, 44% of the world's natural gas and 20% of oil [42]. An average passenger car releases approximately 4.6 million tons of carbon dioxide annually [43]. Hence, energy efficiency through lightweighting has a lot of benefits. At the production stage, the machines use lesser energy as they have to process lesser raw materials. After production, the lighter product uses less energy and releases fewer emissions.

5.5 Reduced part count

Monolithic designs simplify the assembly line [44]. This eliminates the TIG welding process, the assembly of individual parts and the different process routes that the product goes through. Also eliminated is the machinery and tooling for the assembly line; the buying of spare parts for replacements; and the need for a storage facility for individual parts such as a warehouse. This results in better performance of the product [45].

5.6 Reduced manufacturing costs

This can be achieved through the following:

- Reduced raw material usage, that is, resource efficient production.
- Elimination of costs associated with the joining processes such as TIG welding. These include high power consumption, demand for man power and post-processing costs.
- Elimination of machinery, tooling and man power required for the assembly line of single parts.
- Reduction of manufacturing time.

6 CONCLUSION

The main objectives of the paper were to review the monolithic design of vehicle aluminium sheet metal components for the deep drawing process. The monolithic design eliminates the disadvantages associated with the TIG welding process, which include high energy and post processing costs and high manpower demand. It also reduces the part count, number of workstations, lead time, labour, material handling costs and storage requirements. Through the deep drawing process, the sheet metal components can be produced from an aluminium sheet metal in one shot. The process is well adapted for the production of geometrically complex sheet metal components and for improving the strength of that material through strain hardening. The benefits are lightweight components, high raw material utilization, high energy efficiency, reduction of product parts and reduced manufacturing costs.

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SYSTEM DYNAMIC MODELLING OF PROJECT EXECUTION: INTRODUCTION OF PRO-ACTIVE DESIGN IMPROVEMENT

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ABSTRACT

The aim of this paper is to explore the modelling of project execution with respect to the introduction of pro-active design improvements. Although several models of project execution exist a need for an explicit description of the effect of pro-active design improvement such as Model Based System Engineering and Front-End Engineering Design has been identified from literature. This paper uses System Dynamic modelling methods and expands on existing models to propose possible modelling approaches to describe the impact of pro-active design improvement methods. Useful system dynamics simulation results to shift design change patterns earlier in the project life cycle are also presented.

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1 INTRODUCTION

1.1 Problem statement

In most modern and free market economies projects and project execution are increasingly important drivers for product delivery. For companies to maintain competitiveness in increasingly marginal market conditions it is vital to foster effective project execution capabilities. Despite the requirement for effective project execution, projects continue to suffer cost and schedule overrun. The reason for this could be twofold. On the one hand the demands on project execution are ever increasing. On the other hand project execution continues to fall short despite the major efforts to improve.

In fact, the probability for cost and schedule overrun is high, given the increasing complexity of projects and the project execution environment. One of the significant areas of research in project execution is project execution modelling [1]. The main objective of project execution modelling is to predict cost and schedule performance. This is important in managing the risk associated with projects and allows the project manager to test various scenarios in project execution and develop strategies to improve the predicted cost and schedule performance in the modelling environment. Several models exist of project execution [2] [3] but they tend to lack an explicit description of the effect of pro-active design improvement such as Model Based System Engineering (MBSE) and Front-End Engineering Design (FEED). Front end characteristics of projects are specifically addressed in more detail by Williams and others [4].

1.2 Why model design improvement?

Design improvement is a key outcome of the Systems Engineering process utilised in design of complex systems. However it remains one of the most overlooked and unaccounted variables in project execution. Design improvement is achieved through the iterative cycle of design, integration and validation. The focus of proactive methods such MBSE and FEED is to increasingly shift design improvement iterations to earlier stages of the project life cycle. Therefore modelling of these design improvement methods allows the project manager to understand the important attributes that must be achieved by the design improvement methods in order to be effective.

1.3 Background and research context

This paper is part of a larger research project by the authors into the role of MBSE in project execution. The broader aim of this research is to establish and evaluate the relationship between structured design methods such as MBSE and effective project execution in a complex design and construction environment.

The authors of this paper produced a series of papers on the role of MBSE in project execution [1] to [4].[5] explored aspects of Systems Thinking and Model Based Systems Engineering (MBSE) in Project Management. A conceptual model for MBSE deployment is proposed. [6] builds on the conceptual model and presents a framework for deployment of structured design methods proactively within a development project. This framework reflects a Model based systems engineering methodology incorporating a systems thinking approach.

[7] presented a case study of the design change iteration pattern observed during a power utility development project as a case study. A proactive approach, based on MBSE, was put forward as possible means to improve on project performance. The basic theory explaining the observed design change patterns was introduced. The theory supporting the application of proactive methods, such as MBSE, was also discussed. This entails that the pattern of design change iterations can be shifted by reducing the Undetected Period.

[8] further evaluated early life cycle design management though a case study on MBSE deployment in project execution. The case study emphasised the importance of engineering effort early in project life cycle. There is evidence that the design process was or could have been influenced proactively thought the deployment of a holistic engineering strategy such as FEED.

1.4 Objective and research approach

This paper examines the modelling of project execution with respect to the introduction of pro-active design improvements. Building on the observations made in prior research, the objective is to demonstrate that a shift in design change pattern can be simulated through modelling according to System Dynamic methods. The research method used in this paper is then focused on system dynamics and simulation. As the research approach in this paper is exploratory only the focus will not be on full validation of the system dynamics model presented as expounded on for example by Barlas [9] [10].

1.5 Structure of this paper

Section 2 provides a background and relevant literature review of System Dynamic modelling and design improvement concepts such as MBSE and FEED. Section 3 explores current models for project execution from an appropriate literature review context and discusses the importance of the rework cycle. Section 4 addresses modelling of design improvement using a system dynamics approach to the research. Sections 5 to 7 contain a discussion, conclusion and view on future research.

2 BACKGROUND: LITERATURE ASPECTS FOR SYSTEMS AND DESIGN IMPROVEMENT

2.1 Systems thinking

According to Kim [11] systems thinking is a way of talking about and seeing reality that help us better understand systems in order to improve quality of life. It also encompasses the vocabulary and tools to communicate system behaviour.

Kim [11] defines a system as “any group of interacting, interrelated, or interdependent parts that form a complex and unified whole that has a specific purpose” to clarify this reality view.

The defining characteristics of a system are [11]:

- Systems have purpose
- All parts must be present to achieve the purpose
- The order of the parts affects the performance of the system
- Systems attempt to achieve stability through feedback

Flood [12] notes emergence and interrelatedness are the fundamental concepts of systems thinking. Forrester [13] points out that systems thinking alone “usually lacks the discipline of explicit model creation and simulation and so relies on subjective use of unreliable intuition for evaluating the complex structures that emerge from the initial description of the real system”. Therefore, according to Forrester [14], system dynamics is the necessary foundation underlying effective thinking about systems. Kim [15] suggests that systems thinking has an important role to play in developing a learning organisation “because the tools and methods of system dynamics enable you to not only be a user and interpreter of theory but also an active theory builder”.

2.2 Systems in context

It is useful to view systems within their context. Kim [11] proposes the following levels of perspective that influence system performance as seen in Figure 1.

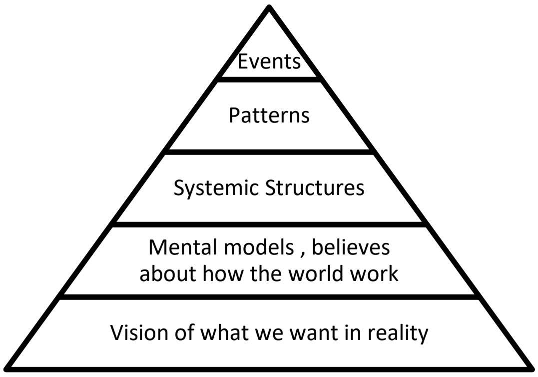

Figure 1: Layers of System influence adapted from Kim [11]

Kim [11] goes on to note that our ability to influence the future increases as we move from the level of events to that of vision. Our focus shifts from the present to the future. Consequently the actions we take at the higher levels have more impact on future outcomes than on present events. Kim [15], when discussing the importance of theory building, concludes that theory plays a critical role in how we create the conceptual patterns through which we see our world. Systems thinking provides some of the necessary theories and tools for developing an organisation's theory building capacity. Our ability to develop new theories will allow us to get out of existing grooves in thinking, to envision an entirely different future and then take the necessary steps toward creating that future.

2.3 System dynamics modelling

2.3.1 Causal loops

Causal loops highlight interrelatedness of parts thereby describing the forces that are producing the behaviour we are experiencing. Many if not all systemic behaviours can be described through two basic processes namely reinforcing and balancing processes [16] [17]. The combination of these processes gives rise to a variety of dynamic behaviours in systems. Figure 2, adapted to reflect somehow on e.g. a desired design maturity, depicts a balancing loop and response while Figure 3 depicts a reinforcing loop and response that may be the result of e.g. design savings achieved not balanced by a targeted limit.

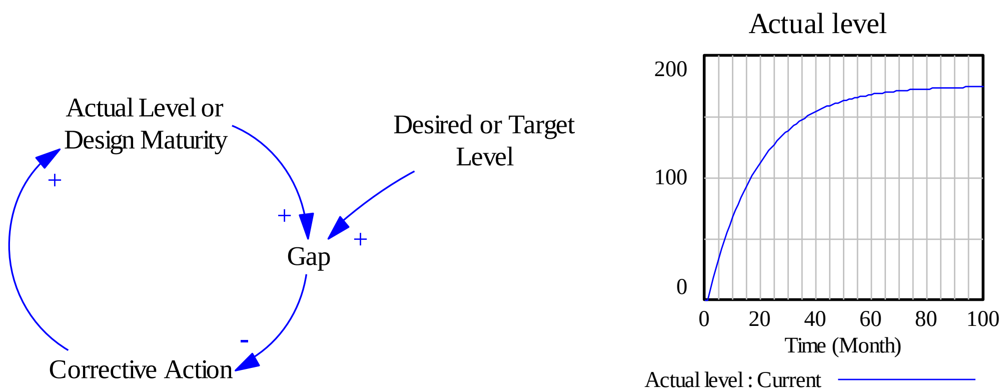

Figure 2: Balancing Loop and Response

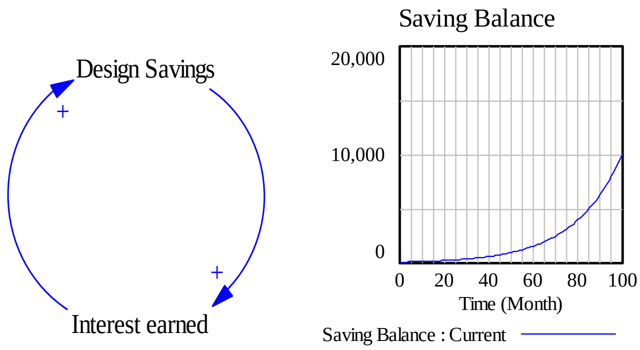

Figure 3: Reinforcing loop and response

2.3.2 Stocks & Flows

A stock and flow diagram is another tool that can be used to describe our understanding of the system structure. Stocks represent things that can accumulate over time. Flows represent rate of change over time. An example of a Stock and Flow diagram, adapted to reflect design changes as a stock, is provided in Figure 4.

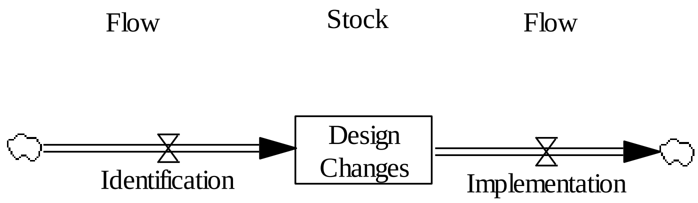

Figure 4: Basic stock and flow diagram

Ford [18] gives a detailed description on the modelling process. Through this process the modeller will start with stocks, add the flows and check the units. Ultimately the modeller will fill out the picture with the convertors. On the process of modelling Maria [19] offers some sound advice: “On the one hand, a model should be a close approximation to the real system and incorporate most of its salient features. On the other hand, it should not be so complex that it is impossible to understand and experiment with it. A good model is a judicious trade-off between realism and simplicity”. In this vein the design references in figures 2 to 4 explain to some extent how design, design changes, design savings etc. may be thought of in a systems context. These causal loop as well as stock and flow concepts will be further explored in sections 3 and 4 to assist in developing an adapted design improvement system dynamics model.

2.4 Design improvement concepts

2.4.1 MBSE

To explain Model Based Systems Engineering (MBSE) it is foremost important to first define Systems Engineering. INCOSE [20] defines Systems Engineering as:

> *“Systems engineering is an interdisciplinary approach and means to enable the realization of successful systems.”*

INCOSE [20] goes on to say:

> *“Systems engineering integrates all the disciplines and speciality groups into a team effort forming a structured development process that proceeds from concept to production to operation.”*

Holt [21] defines MBSE as follows:

> *'Model-based systems engineering is an approach to realising successful systems that is driven by a model that comprises a coherent and consistent set of views that reflect multiple viewpoints of the system.'*

While the model centric nature of MBSE is important one should also take note of the need to accommodate multiple viewpoints. This aspect resonates with to the traditional definition of SE which focuses on the interdisciplinary approach and integration of all disciplines into a team effort.

In this paper the approach to MBSE is that of defining a system first through modelling, including design, integration, testing and validation, before establishing the system in the physical environment. Steimer, et al. [22] describes MBSE as an approach for the development of complex systems by iteratively connecting the development activities of all involved disciplines (e.g. mechanics, electronics, IT) with a formalized central system model, beginning in the conceptual design phase and continuing throughout development and later life cycle phases.

In the context of design improvement and value improvement practices MBSE is also an important consideration. The objective here is to introduce design changes early in project live cycle thereby eliminating late design changes resulting in cost escalation and schedule overrun. The theory behind shifting in design change pattern is that the design change iteration pattern resulting from a reactive approach to design management can be influenced if a proactive approach is followed. The theory presented is that the application of proactive measures, such as MBSE, will lead to a general shift of the design change iteration pattern [7].

2.4.2 FEED

There are various terms referring to the period or phase from when a project is conceived until it is planned and executed. Shlopak, et al. [23] define Front End Loading (FEL)as "a process by which a company develops a detailed definition of a project that was initiated to meet business objectives" [24, 25]. Likewise Merrow [25] sees FEL as "the definition of a project, from formation of the core team until full-funds authorisation is achieved". Other terms used are front end planning, pre project planning, feasibility analysis, conceptual planning and early project planning. In this context front end engineering design (FEED) is defined as the part of FEL that is focused on defining the basic specification for the system to be developed. This ultimately takes the form of the Scope of Work for projects implemented through various forms of execution contracts and is the basis for cost estimation and fund approval.

Figure **5** depicts an influence curve for projects which suggest that the ability to influence project cost diminishes as project definition increases[26].

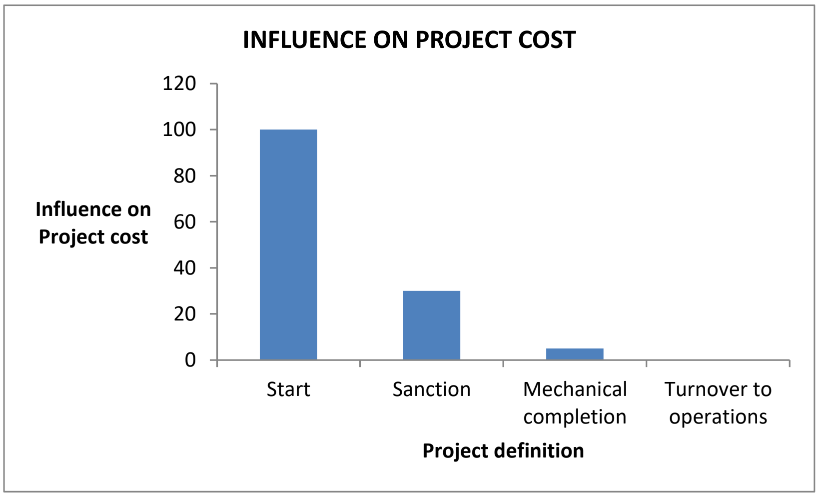

Figure 5: Influence Curve for Projects Adapted and inferred from [26]

Shlopak, et al. [23] cite a number of references, e.g. Merrow [25], that indicate a correlation between the quality of FEL activities and the overall project success. CII (Construction Industry Institute) developed a project definition rating index (PDRI) that measures the front end scope definition level. Statistical evidence supports the view that a project will not perform better than the quality of its front end planning process [23, 24].

However it is necessary to adapt the front end activities depending on the specific context to achieve an optimum cost benefit ratio [27] [4]. Shlopak, et al. [23] also observed that FEL differs between project types and cannot be transferred directly. For instance construction and NPD (New Product Development) FEL are not readily transferable to shipbuilding. Shlopak, et al. [23] pay particular attention to the problem of late design changes. FEL can benefit the project by early identification and elimination of design changes through the focus on four essential conditions:

- Integrated project team
- Good project control measures
- Well defined scope
- Timely application of value improvement practices (VIPs).

VIPs include Constructability Analysis, Design to Capacity, Value Engineering, Process Simplification, Customising standards and Specifications, Technology selection, 3D CAD and Waste minimisation.

3 PROJECT EXECUTION MODELLING: BRIEF LITERATURE OVERVIEW

3.1 Current models for project execution

Traditional project management models include Critical Path Method(CPM) and Project Evaluation Review Techniques (PERT)[28]. These models describe processes, resources, targets and scope in a static fashion with activity duration estimates and precedence relationships used to describe a network of development activities. Ford and Sterman [28] note that “these models are limited by the use of an indirect project measure (time) to bundle the characteristics of relationships among scope, resources and processes in each activity into a single duration estimate”. More importantly iteration also tends to be ignored in these models by implicitly incorporating it into precedence relationships and duration estimates.

System dynamic models are used by several researchers to describe the phased network structure of projects.[28] Ford and Sterman [28] identify the need to model iteration in project execution. Methods such as design structure matrix begin to describe iteration by mapping and predicting information flows among development phases. [29]

3.2 Reference model selected

Ford and Sterman [28] present a model for development dynamics that includes iterative flows of work, distinct development activities and available work constraints both within and among development phases.

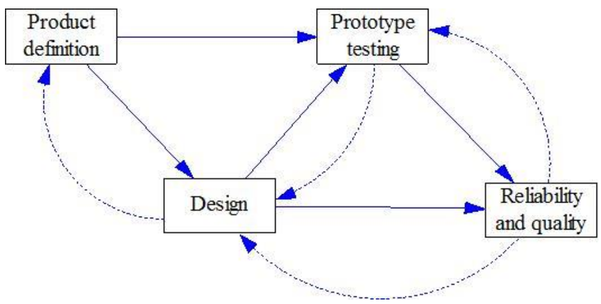

Figure 6: A Project network for a development project adapted from Ford and Sterman [28]

The three main features incorporated in the model in Figure 6 are:

- Circular iteration
- Multiple development activities
- Concurrence

Figure 7 represents the basic stock and flow structure employed by Ford and Sterman [28] to model circular iteration.

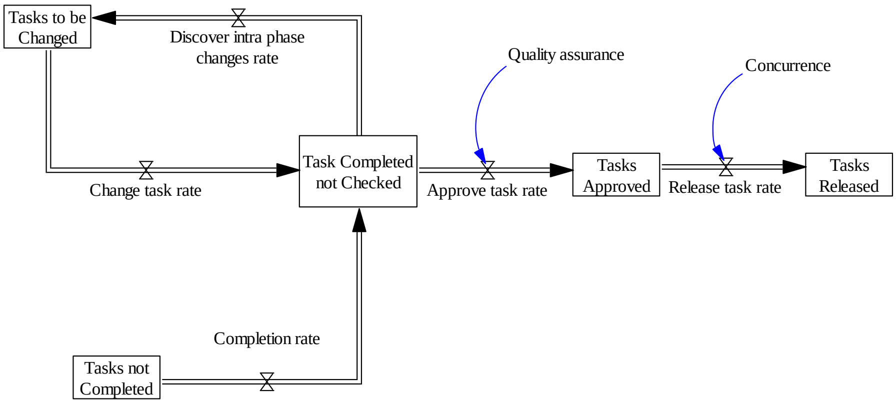

Figure 7: Stock and Flow structure for circular iteration adapted from Ford and Sterman [28]

The three development activities incorporated into this model are completion, quality assurance and change. The internal process concurrence relationship answers the question how much work can be released for downstream phases based upon the how the work has progressed thus far.

3.3 The rework cycle

According to Lyneis and Ford [30] the rework cycle is the most important single feature of system dynamics project models. They point out that the rework cycle's recursive nature, by which "rework generates more rework", creates problematic behaviour that stretch out over the entire project duration. This behaviour results in many project management challenges. A key characteristic of the rework cycle is undiscovered rework. Typically this results from errors that are not discovered immediately but are only detected as a result of downstream work such as integration or testing. This rework discovery may occur months or even years after the rework was created [30].

Several authors have developed models for the rework cycle such as Abdel-Hamid [31], Minami, et al. [32], Ogano [33], Ford and Sterman [28]. The essence of the rework cycle is retained throughout all current models of project execution.

Figure 8 depicts a typical rework cycle.

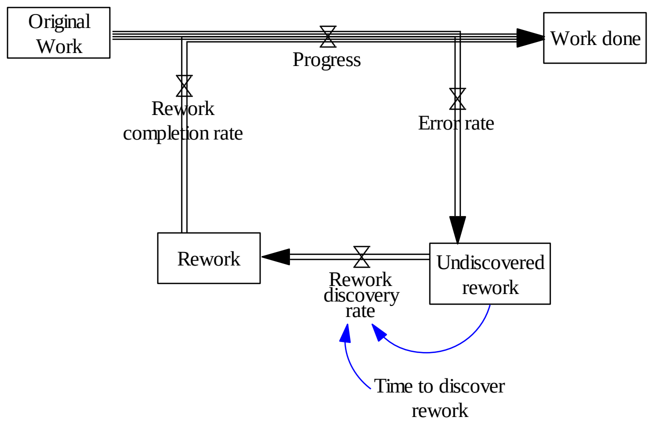

Figure 8: Rework Cycle

Design changes are similar to rework as it causes the repetition of tasks already completed. This view is also supported by authors such as Love [34]. While the stock and flow discussed in Figure 7 may seem different than the typical rework cycle in Figure 8, it retains the recursive nature of the rework cycle and will be used as the reference model for the rest of this discussion.

4 MODELLING PROACTIVE DESIGN IMPROVEMENT: SIMULATION AND SOME RESULTS

Despite significant effort in developing models for project execution it remains largely focused on the reactive nature of project management and has not yet fully explored modelling of proactive approaches. MBSE and FEED are among these proactive approaches that should also be brought into consideration for modelling. Steyn and Pretorius [8] point- out a key objective of proactive measures is to shift the reactive design change pattern typically observed in projects to a more proactive pattern through the early application of structured design methods such as MBSE.

The objective of this paper, to expand on what has been stated previously, is therefore to illustrate that such a shift in design change pattern can also be induced in a modelling environment. When reflecting on the design change and systems engineering processes it is noted that integration is a key driver to change discovery. This is typically accomplished by integration of designs and integrated reviews representing a broad range of stakeholders , interrogating the design from various perspectives in order to identify changes and rework not known to the designer[22].

In order to model proactive measures the focus should be on the introduction of design integration and how it results in design changes. In Figure 9 the basic stock and flow of Figure 7 adapted from Ford and Sterman [28] is augmented in this current research to accommodate design integration through modelling.

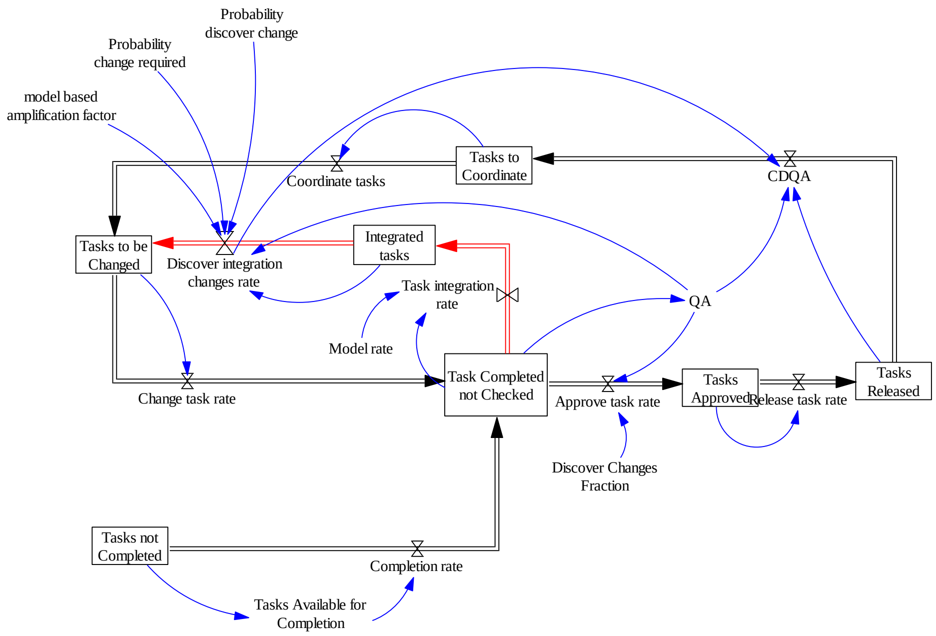

Figure 9: Stock and flow updated for proactive measures

The new flow considered in this research, highlighted in red in Figure 9, is defined using the following equations:

(d/dt)Integrated Tasks = Task Integration Rate-Discover Integration Changes Rate (1)

*Task Integration Rate = MIN(Task Completed not Checked/Project Scope, Model rate)*Task Completed not Checked*model based amplification factor* (2)

*Discover integration Changes Rate= Probability change required*Probability discover change*QA*model based amplification factor*Integrated tasks* (3)

The stock and flow diagram depicted in Figure 9: also includes more aspects of the base model adapted from Ford and Sterman [28] to illustrate the impact of the new flow on existing flows.

In particular the equation for CDQA, Coordination due to Downstream Quality Assurance, is updated to:

*(d/dt)CDQA = Probability change required*Tasks Released*Probability discover change*QA-Discover integration changes rate* (4)

The rationale for this change is that early discovery of design changes should reduce the load of tasks to coordinate between project phases. This reasoning is to some extent supported by the work of Riley [35] on design changes coordination and project uncertainty.

4.1 Model Variables

4.1.1 Task integration rate

This parameter reflected in the adapted model figure 9, defines the rate at which design tasks are integrated into a model of the system. It is derived from the minimum of the Model rate and the fraction of tasks completed not checked over Project Scope multiplied by Tasks available for integration (Tasks completed not checked) and model based amplification factor.

4.1.2 Model rate

In the current model, presented in this paper as figure 9, this variable is a constant fraction (%) of available tasks that will be integrated in a model during each iteration.

4.1.3 Model Based Amplification Factor

Model amplification factor represents that factor by which modelling increases the number of design changes that will be discovered from reviewing the available integrated tasks. This is based on the number of different modelling perspectives employed. This could also be based on the number of modelling methods employed. The argument is that each distinct modelling approach increases the probability of discovering design changes.

4.2 Model output

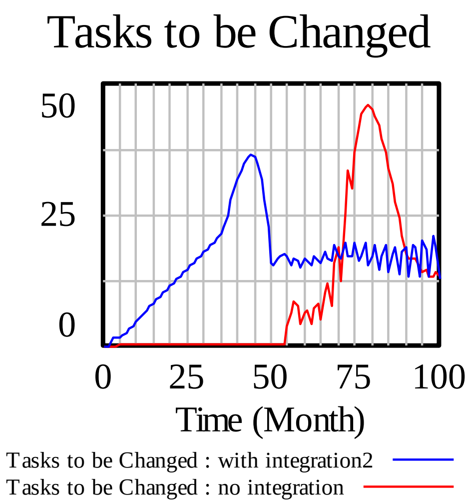

Figure 10: model output incorporating the effect of model based integration

Figure 10: reflects the simulated shift in design change pattern achieved through the application of model based integration. This is only shown as an initial result to illustrate the possible effects that may be achieved by implementing this new system dynamics model in a SD modelling environment such as Vensim.

5 DISCUSSION

The SD modelling done with initial results illustrated in Figure 10 suggests that a shift in design change pattern can be induced in the modelling environment. The modelling also helped to identify possible parameters to consider in the modelling strategy namely model rate and model based amplification factor (related to the number of distinct modelling methods used.)

The modelling also suggests that there is a limit to the benefit that can be derived from a proactive approach. It suggests that too great an emphasis on modelling will be counterproductive and will result in many changes. This will certainly be the case if cost is factored in. This could be further offset by the cost of secondary changes not factored into this system dynamics model. This may be a topic to consider in future research.

MBSE as a design improvement method is supported in the system dynamics model approach presented with emphasis on a critical number of design tasks (e.g. high volume parts or highly integrated tasks) and the amplification factor related to the number of different design modelling methods (e.g. 3D modelling, P&ID, DSM). In essence more design modelling methods employed should increase the likelihood of picking up needed design changes earlier and is reflected in an increased amplification factor in the model. FEED is likewise supported in the application of design improvement from very early in the project life cycle by adding the new design integration flow relationships in the system dynamics model.

6 CONCLUSION

The paper explored the application of system dynamic modelling as an approach to describe the importance of proactive design improvement methods on project execution. Proactive design improvement employing approaches such as MBSE and FEED and the modelling of projects execution through traditional methods as well as the use of system dynamic modelling were discussed. The importance of the rework cycle in system dynamic modelling of project execution was pointed out also in the context of design improvement.

A new extension of the reference model used by Ford and Sterman [28] to cater for proactive approaches was proposed. This revision of the original system dynamics model incorporated new parameters such as model rate and model based amplification factor. The resulting model was used to simulate and demonstrate a shift in design change pattern as predicted in earlier research work [8]. The practical project and design management value of the new system dynamics model to cater for design changes can also be found in enhanced decision making possibilities available to management earlier in the design and project life cycle.

7 FUTURE RESEARCH

Future work considered may include calibrating the new system dynamics model and model updates to real world experiences and data in order to validate the proposed changes. The effect of the cost of secondary changes not factored into this system dynamics model may also be investigated in future.

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I want to as friend recognize the important continuous research efforts and contributions of Philip Steyn, the first author of this paper. Philip sadly passed away recently. He was an excellent and committed engineer and will be missed sorely. Thanks my friend Philip.

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THE DISASTER RELIEF SUPPLY NETWORK

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ABSTRACT

Millions of people are affected by disasters every year. In these situations, many entities such as governments, military, NGOs, and volunteers enter the disaster situation to assist victims. Relief can be in the form of rescue operations, medical assistance, or the provision of relief supplies. The primary challenge in relief is the inherent instability in the aftermath of a large-scale disaster - compounded by a lack of coordination of stakeholders, lack of communication, inexperienced volunteers, and superfluous goods being brought into an already clogged and badly managed system. The result is a situation where the entities aiming to aid victims, end up worsening the situation and causing more problems than they solve. The disaster relief effort can thus be envisaged as a complex and time-critical supply network. This paper develops a conceptual framework that provides a basis for exploring disaster relief efforts through a supply network lens.

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1 INTRODUCTION

Every year hundreds of natural disasters occur across the globe: thousands of people lose their lives, millions are affected, and billions of dollars of damage is incurred [1]. With the occurrence of such an event, the global community – from countries and large organisations to individual benefactors – assists the afflicted country. This assistance is either in the form of monetary donations, relief provisions such as food, water, and shelter, or physical teams of relief workers that aim to assist with rescue operations, medical assistance, or distribution of relief provisions [2]

For example, the Gorkha earthquake in Nepal took place on 25 April 2015 [3], and by 28 April 2015, 20 countries as well as the EU, The World Food Program, UNICEF, and UN had committed and mobilised at least the following aid (based on published numbers only, more resources were reported to be sent but not explicitly stated): 39.9 Million USD; 344 tonnes of relief provisions (blankets, shelter, water, food, and medical supplies); 1572 relief and medical personnel; 4 field hospitals; 17 aircraft, and 17 helicopters. Relief aid continued to pour into Nepal from all over the world. The challenge with this situation, as well as most other disaster situations, is coordinating the sheer number of governments, organisations, people, aircraft, and volume of goods flooding into a situation that is already, by its very nature, unstable [4].

This situation is not unique as millions of people are affected by natural disasters every year. In these circumstances, many entities such as local government, international governments, military, NGOs, humanitarian organisations, and volunteers enter the disaster situation to assist victims and offer relief. Relief can be in the form of rescue operations, medical assistance, or provision of food and shelter – to name a few.

The primary challenge is the inherent instability in the aftermath of a large-scale natural disaster. This is then compounded by a lack of coordination of stakeholders, a lack of communication due to damage to infrastructure, inexperienced volunteers and organisations, and tons of superfluous goods being brought into an already clogged and badly managed system. The result is a condition where the entities aiming to aid victims end up worsening the situation and causing more complexity and problems than they solve [5], [6].

The disaster relief effort - getting provisions and services to those who are most in need – may, thus, be envisaged as a complex and time-critical supply chain or supply network. This paper seeks to identify the key factors, variables, and concepts relevant to disaster relief supply networks through the development of a conceptual framework.

2 RESEARCH METHODOLOGY

This research adopted a qualitative approach to the identification of the key factors, variables, and concepts relevant to disaster relief supply networks. The most appropriate point of departure was deemed to be a survey of the relevant and nascent literature. A systematic literature review was selected as "Systematic reviews are more rigorous than a traditional literature review because they use a systematic approach to search, select, and appraise the produced evidence" [7, p. 123].

The steps followed in the systematic literature review [8], [9] were as follows:

1) Formulation and definition of the topic to be studied.
2) Development and validation of the search protocol (search criteria) to identify relevant literature.
3) Application of search criteria identified in step 2 to search the literature and identify applicable sources.
4) Screening identified literature for relevance (inclusion or exclusion) in the study.
5) Assessment of the quality of included sources.
6) Data extraction from included literature.
7) Analysis of extracted data.
8) Synthesis of extracted data.

9) Reporting of research findings.

Through a preliminary review of the body of knowledge, several overarching themes were identified, namely, “Anatomy of disaster”, “Disaster management” and “Supply chain evaluation criteria”. Search parameters and criteria for these primary themes were then developed as shown in Table 1.

Table 1: Search parameters and criteria

Anatomy of a disaster	Disaster management	Supply chain evaluation criteria
“natural disaster” AND “timeline”	“disaster management”	“supply chain evaluation framework”
“natural disaster” AND “timeline” AND "sudden onset"	“disaster management” AND"sudden onset"	“supply chain evaluation framework” AND humanitarian
“natural disaster” AND “timeline” AND "sudden onset" plus medical journalsexcluded	“disaster management” AND "sudden onset natural	“supply chain evaluation framework” AND “humanitarian”AND “disaster”
	“humanitarian system" - refugee	"supply chain evaluation framework” AND “humanitarian” AND “disaster” and "sudden onset"

Using the search criteria, relevant literature was identified in the ProQuest database. ProQuest was the database of choice as it contained the largest number of relevant sources. Various rounds of searches were conducted with increasing levels of specificity to obtain a manageable volume of sources. The process detailed in Figure 1 was followed to evaluate sources – screening for inclusion and assessing the quality of the work.

Once formal academic sources and published articles had been exhausted, it appeared that there were gaps in the information. As a result, grey literature was included in the study consisting of non-traditional documents such as newspaper articles, disaster situational reports, and policy documents [10]. Grey literature sources were identified by searching phrases such as “disaster types” in the Google search engine and selecting trusted sources e.g. The International Federation of the Red Cross and Red Crescent societies (IFRC), World Health Organization (WHO), Centre of Research on the Epidemiology of Disaster (CRED) and United Nations Office for the Coordination of Humanitarian Affairs (OCHA). At this point, a comprehensive and robust body of literature had been collected from which relevant data were extracted and analyzed.

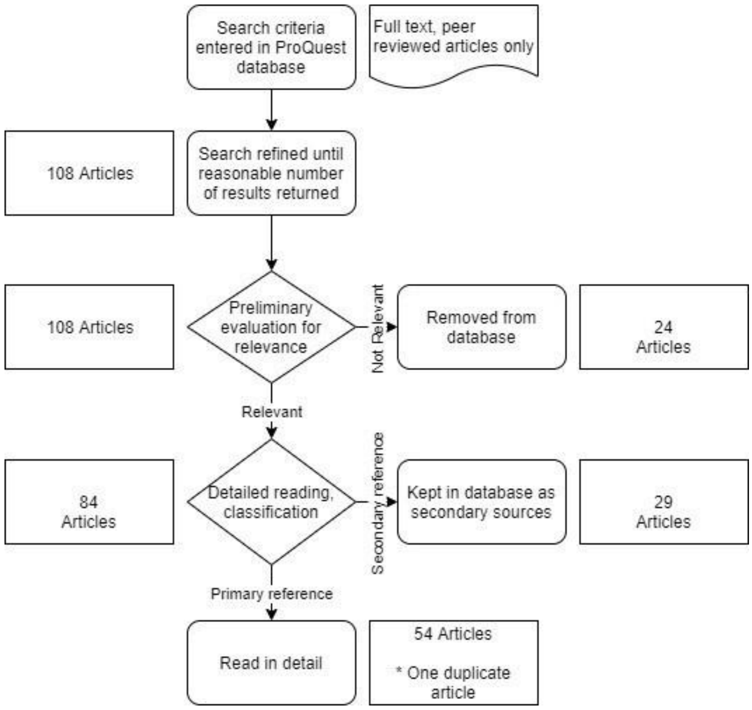


Figure 1: Literature review process (based on [11])

A qualitative thematic analysis was conducted using NVIVO, a software program designed for qualitative and mixed-method studies, specifically the analysis of unstructured text, audio, video, and image data [12]. Relevant literature was captured in Zotero (an open-source reference management software package [13]) and transferred to NVIVO. All sources were reviewed through first considering the abstract of each paper and if found to be relevant evaluating the full paper. All applicable sources (53 articles) were reviewed. From the review, relevant themes were identified, and this data was added to the literature through the coding functionality in NVIVO. Once the literature was completed, emergent themes were identified and structured into the conceptual framework which is discussed in section 3.4.

3 DISCUSSION OF RESULTS

In this section, the insights from the thematic literature review are discussed. This discussion follows the structure presented in Table 1, by evaluating each of the overarching themes. First, the anatomy of a disaster is explored to introduce how a disaster typically unfolds and the expected phases of such an event. This then provides the context and processes for comparison to a supply network. Secondly, the humanitarian system will be discussed, investigating the typical participants of disaster relief. This identifies the possible participants in the supply network. Finally, the characteristic disaster response event will be considered from the perspective of a supply chain evaluation framework to compare it to the characteristics of a supply network.

3.1 The Anatomy of a Disaster

The Centre of Research on the Epidemiology of Disaster (CRED) defines a disaster as “a situation or event that overwhelms local capacity, necessitating a request at the national or international level for external assistance; an unforeseen and often sudden event that causes great damage, destruction and human suffering” [14]. Disasters are classified as natural

(geophysical e.g. earthquakes, meteorological e.g. storms, hydrological e.g. floods, climatological e.g. drought, biological e.g. epidemics, extra-terrestrial e.g. space debris impact), technological (industrial accidents e.g. chemical spill, explosion, oil spill), and complex disaster groups.

Disasters are further classified into sudden-onset and slow-onset disasters. The United Nations Office for the Coordination of Human Affairs (OCHA) defines a slow-onset disaster as “one that does not emerge from a single, distinct event but one that emerges gradually over time, often based on a confluence of different events” for example drought or displacement of people due to civil unrest. In contrast, a sudden-onset disaster is caused by a catastrophic, sudden- onset event such as a tropical storm, earthquake, or tsunami [15]. Typically, sudden-onset disasters lead to powerful images being published by international media spurring a flurry of donations globally. This spike in attention also puts pressure on national and international agencies to respond and lend aid to the affected country, which in turn leads to pressure on the country’s organizational and logistics systems creating a unique set of circumstances [16]. This highlights the criticality and complexity of the supply network of aid into the affected region.

3.1.1 Phases of disaster

Disaster management is typically divided into four phases [17] i.e. mitigation, preparedness, response, and recovery. The proactive phases are mitigation and preparedness that take place before an event occurs. The mitigation phase consists of activities aimed at preventing a disaster from happening entirely or lessening the impact of a potential disaster. The preparedness phase aims to prepare for a potential disaster and to make sure that the country or region has sufficient capacity to cope with the eventuality of such an event [18], [19]).

The reactive phases are response and recovery. These take place after the disaster event has occurred. During the response phase critical personnel, equipment and supplies need to reach the hardest-hit areas as timeously and effectively as possible. Response efforts are typically 1-3 months [19]. This again emphasizes the criticality of the response supply network. The key to this supply network is the humanitarian system (HS), discussed.

3.1.2 Disaster response

To understand the response to a disaster, one must first understand how a disaster typically unfolds. Literature detailing the sequence of events in the very early stages of a disaster is primarily available from a medical perspective. It is apparent from the literature that many challenges exist in the early hours and days after a disaster has occurred. The most significant challenge is the availability of data and information and how the aforementioned is communicated to relevant stakeholders. This information is critical for decision-making as disaster events develop. First responders, engaged in mission-critical activities such as search and rescue, treating patients, and stabilizing the environment, have the added responsibility of assessing and evaluating conditions on an ongoing basis, communicating to other role players, and amending response efforts accordingly [20]. Figure 2 presents an outline of events typically following a largescale natural disaster.

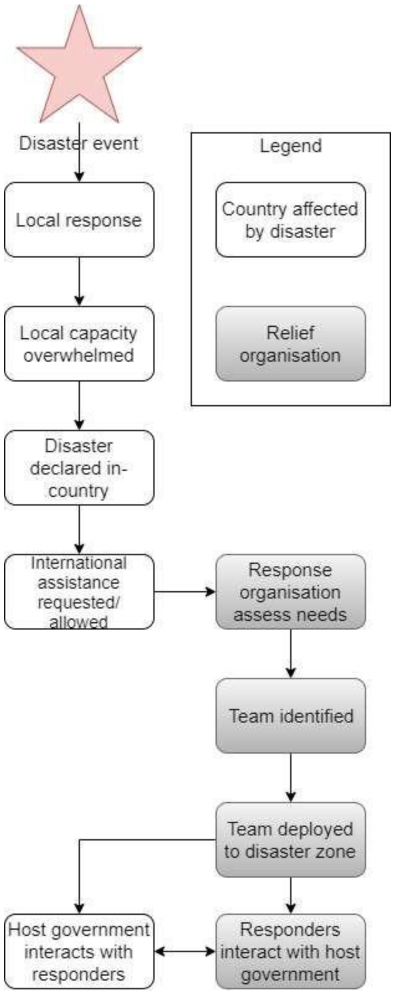


Figure 2: Basic disaster response based on Anaya-arenas et al.[21]

This diagram is an oversimplified view of what disaster response should look like. Once the complexities of the humanitarian system are added, however, the picture changes drastically.

3.2 The Humanitarian System

Active Learning Network for Accountability and Performance in Humanitarian Action (ALNAP) defines the humanitarian system as: "The network of interconnected institutional and operational entities that receive funds, directly or indirectly from public donors and private sources, to enhance, support or substitute for in-country responses in the provision of humanitarian assistance and protection to a population in crisis" [2].

1) Humanitarian needs over the preceding period
2) Supply of funding and how funding was spent
3) Size and structure of the HS
4) Assessment of the performance of the HS

Although global humanitarian needs and funding thereof are important elements of the HS this study focuses primarily on the latter elements of the report, namely, the structure and assessment of the HS or supply network. Upon closer inspection of the various stakeholders involved in humanitarian relief, a complex system begins to emerge. Figure 3 depicts these entities in relation to each other.

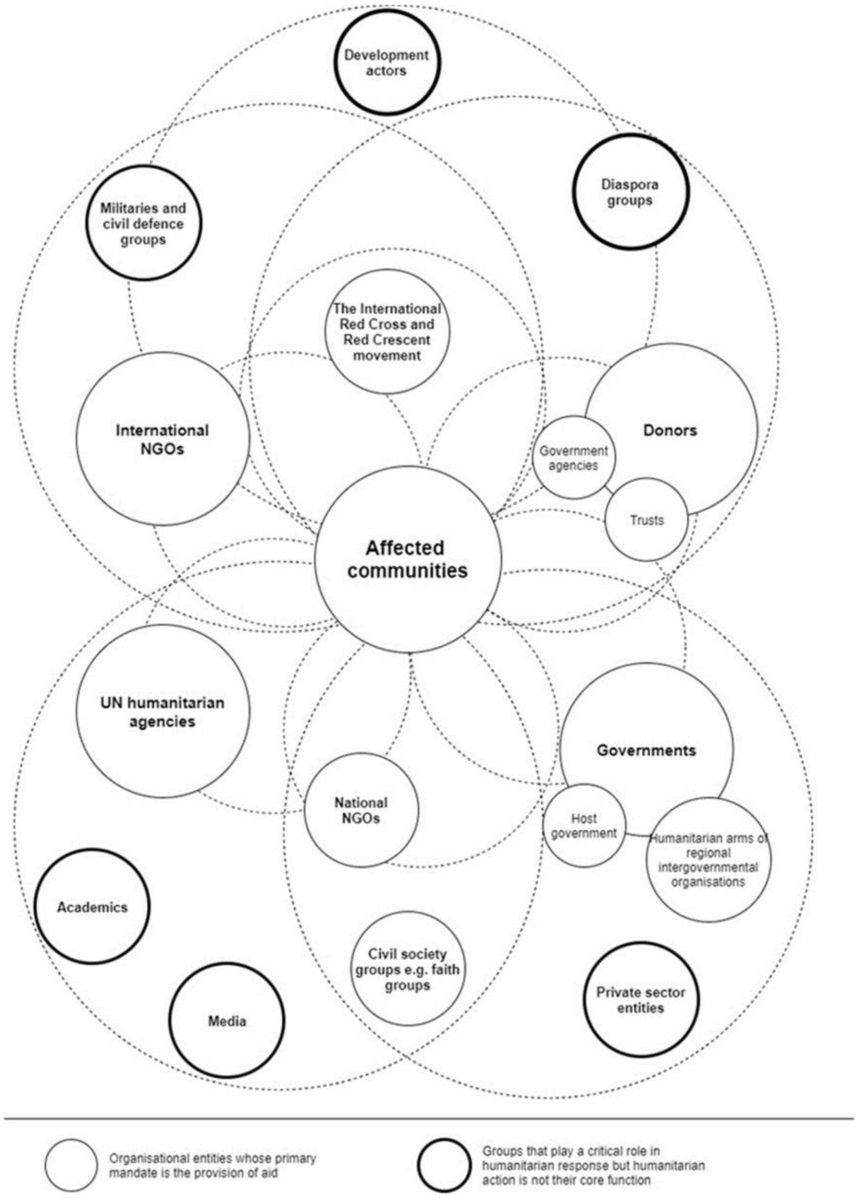


Figure 3: Organizational entities in the humanitarian system (ALNAP, 2018)

Figure 2 is now considered through the lens of the complex humanitarian system (Figure 3), the situation depicted in Figure 4 portrays what becomes the expected occurrence in the event of a disaster response situation. Figure 4 describes a system with 3 role players and considering the example of the Nepal earthquake in 2015, where 450 relief organizations responded to the crisis, the complexity of the system and the coordination thereof becomes apparent [23].

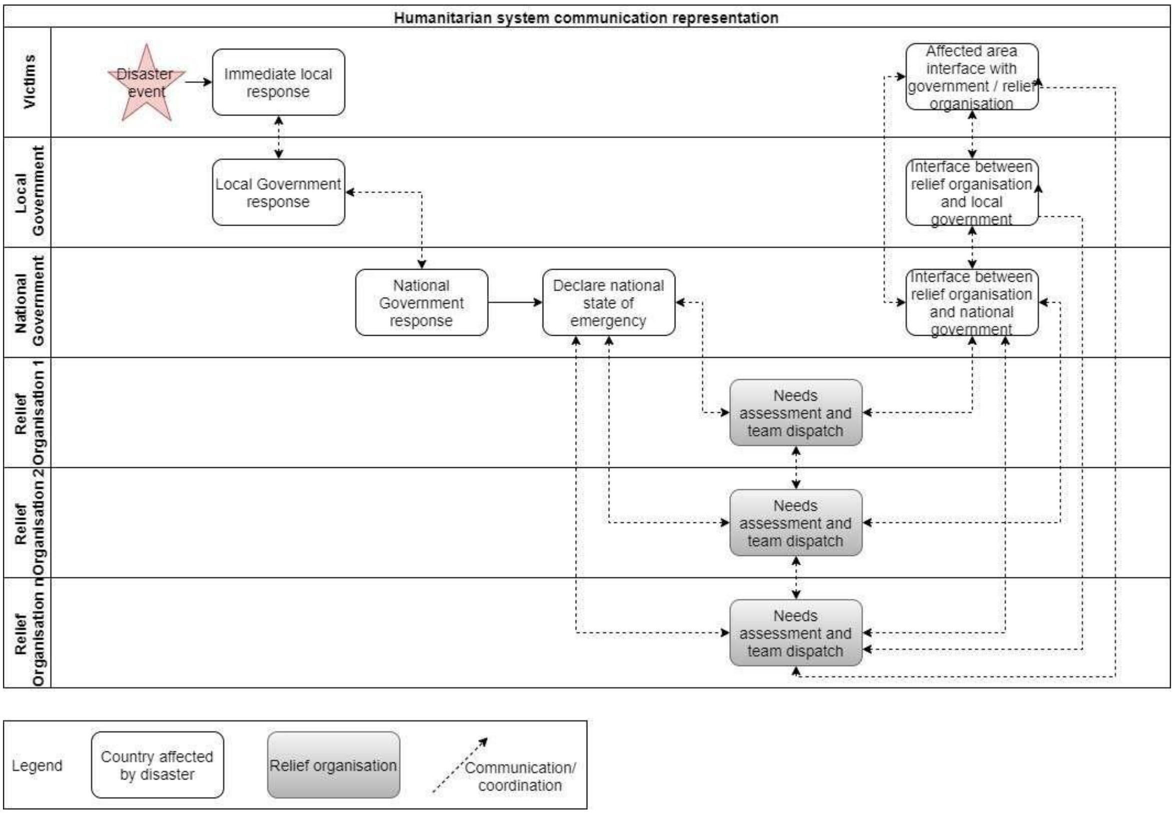


Figure 4: Disaster response with multiple stakeholders, based on Anaya-arenas et al.[21]

A search of the OCHA ReliefWeb website reveals 2 925 affiliate organizations operating in the humanitarian aid sector alone. It is important to note that this is a list of affiliate organizations and is thus, by no means exhaustive. The involvement of such a large number of stakeholders points to a complex system of agencies with varying levels of experience, expertise, and ability to offer effective assistance in a situation where all stakeholders should work together and share information to achieve the required goal of assisting those in need. To this end, many studies have been conducted and frameworks developed to guide and regulate the humanitarian system. The most notable frameworks identified in the literature are: The Sphere project [18], [24], [25], Hyogo framework [18], [26], [27], Sendai framework [26]–[28] and the WHO Cluster Approach [25], [29], [30].

Such structures govern how stakeholders interact when disaster response efforts are required. The expected engagement model between governments and relief organizations is as follows: first response is conducted by local government, once the local capacity is overwhelmed an appeal will be made to the national government for assistance. If national capacity is overwhelmed, the government can choose to declare a national state of disaster and appeal for international assistance which can be offered by non-governmental relief organizations or other governments [21]. Although the affected government has the authority to grant or deny access within its borders, Adivar and Mert [31], note that the typical lack of a central authority causes challenges with disaster relief as government rules and regulations have to be adhered to, yet relief organizations are not accountable to the affected government but rather their own governing bodies and ultimately their donors.

3.3 Supply chain evaluation frameworks

3.3.1 Supply chain

The Association for Supply Chain Management (ASCM) defines supply chain management as "the design, planning, execution, control, and monitoring of supply chain activities with the objective of creating net value, building a competitive infrastructure, leveraging worldwide logistics, synchronizing supply with demand, and measuring performance globally" [32]. The diagrams juxtapose the concepts of logistics and supply chain:

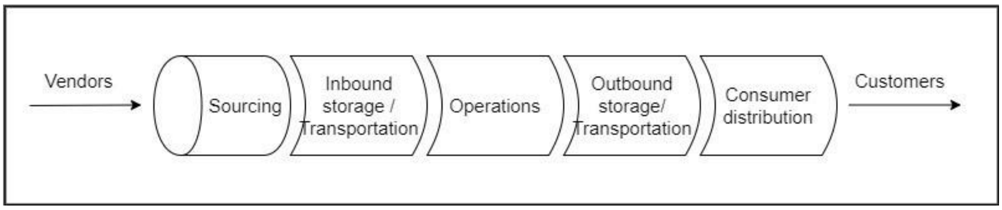


Figure 5: Logistics Supply Chain [33]

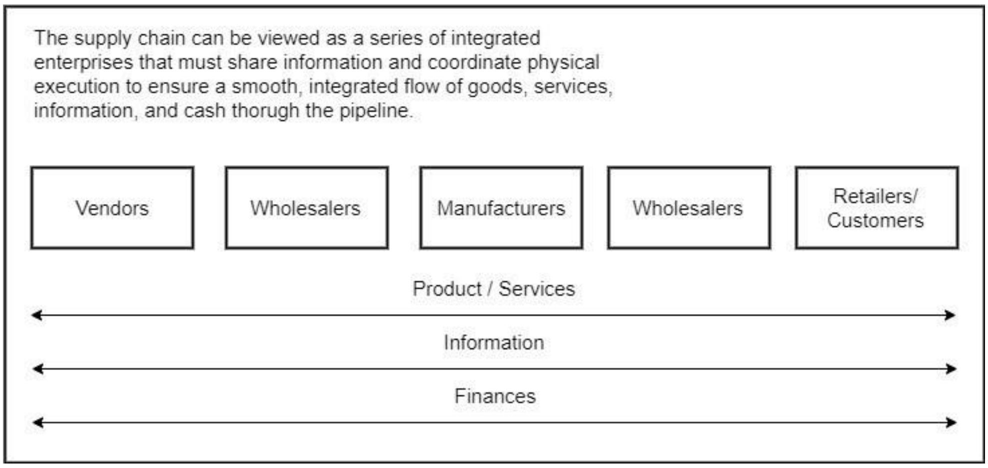


Figure 6: Integrated Supply Chain [33]

Considering Figure 5 and Figure 6, *logistics* is defined as the process surrounding physical goods and physical goods only. Elements considered from the logistics point of view are:

3.3.1.1 Source of goods (Vendors, suppliers)
3.3.1.2 Type of goods and related transport requirements
3.3.1.2.1 Transport of goods (inbound and outbound) including all elements of transport e.g. vehicles and personnel
3.3.1.3 Warehousing
3.3.1.4 Inventory

The definition of the *supply chain* includes:

3.3.1.5 Logistics
3.3.1.6 Information
3.3.1.7 Coordination
3.3.1.8 Communication
3.3.1.9 Finances

3.3.2 Supply network

In this section, the concept of the "supply network" will be contrasted to the concept of the "supply chain" as described in section 3.3.1. Braziotis et al. [34, p. 648] define a supply chain as "a set of primarily collaborative activities and relationships that link companies in the value-creation process, to provide the final customer with the appropriate value mix of products and/or services" and a supply network is defined as "a set of active members within an organisation's SCs, as well as inactive members to which an organisation relates, that can be called upon to actively contribute to an SC if a need arises." The study by Braziotis et al. [34] identified 7 key dimensions by which to evaluate the differences between supply chains and supply networks, this comparison is included in Table 2.

Table 2: Differences between supply chains and supply networks [34, p. 649]

Dimensions	Supply chain	Supply network
Focal concept	Products (and services)	Relationships
Design and configuration	Linear and ongoing, relatively stable structures (due to established power attributes)	Non-linear and dynamic structures (non-established power attributes)
Complexity	Low	High
Operations	Predictable and stable	Unpredictable/un-solidified
Coordination	Management focuses on the coordination of flow (information, products and finance) and on integration	Management focused on the coordination of the web of inter-firm relationships
Integration	Structured	*Ad hoc*/unplanned
Means to enhance competitiveness	Cooperation, collaboration, and coordination among SC members involving competition between these members in some occasions	Cooperation, collaboration, and coordination among members of a web of SCs. At the same time, it involves conflict and competition too

From this comparison, it becomes clear that a supply network is a more dynamic, complex system that focuses on relationships rather than the delivery of products and services. The complexity of the system is depicted in Figure 7.

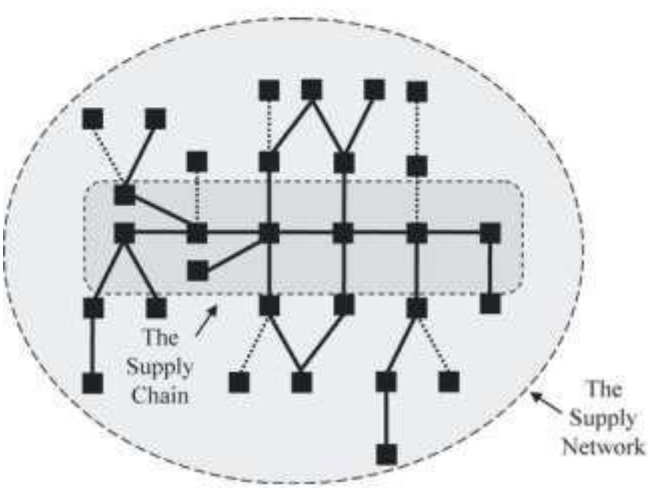


Figure 7: Supply chain and supply network: a diagrammatical representation [34, p.649]

It can, thus, be concluded that a supply network represents a complex system of supply chains with active and inactive members. This very closely aligns with the humanitarian system as described in section 3.2.

3.3.3 Development of the Conceptual Framework: The humanitarian system as a supply network

Limited literature is available that explores the dynamics of disaster response from a supply chain perspective. Through the systematic review of the literature, it became apparent that the nature of humanitarian relief work, of which Disaster Supply Chain Management (DSM) is a subset, is multi-disciplinary. Available literature stems from varying academic disciplines, such as operations research (location and network design-, transport- and combined problems), healthcare/medicine, disaster management, and business logistics. It was interesting to note that while literature had been written from multiple fields and points of view, emergent themes were notably similar. Figure 8 is a schematic view of emergent themes in the literature, which form the framework of the study.

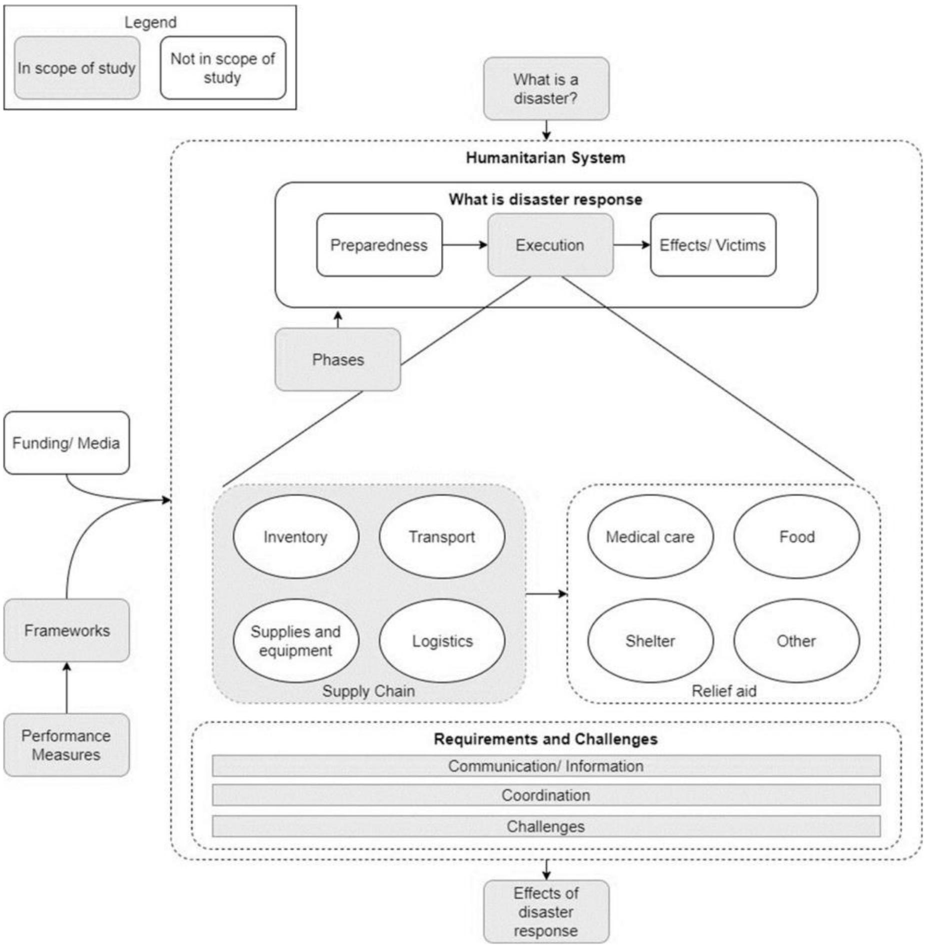


Figure 8: Conceptual Framework of Emergent Themes

Van Wassenhove [35], argues that disaster relief is 80% logistics and that the only way to comply with increased requirements for accountability and transparency is through improved supply chain management.

The Association for Supply Chain Management (ASCM) defines supply chain management as "the design, planning, execution, control, and monitoring of supply chain activities with the objective of creating net value, building a competitive infrastructure, leveraging worldwide logistics, synchronizing supply with demand, and measuring performance globally" [32]. Logistics in the context of this paper is defined as the process surrounding physical goods only. Elements considered from the logistics point of view are, thus, source of goods (vendors, suppliers), type of goods and related transport requirements, transport of goods (inbound and outbound) including all elements of transport e.g. vehicles and personnel, warehousing, and inventory. The supply chain similarly then incorporates, logistics, information, coordination, communication, and finances [33].

Supply chain management in the disaster response context borrows heavily from the commercial discipline of supply chain management [19], [31], [36]. There are, however, stark differences between the commercial and disaster response supply chains, as outlined in Table 3.

Table 3: Similarities and differences between the commercial and disaster response supply chain [35], [37]

Differences	Similarities
Lack of control over the timing of disasters and unpredictability of disasterevents.	The vendor-managed inventory modelcould potentially be applied.
Short lead times and urgency of delivery.	Distribution planning is critical to DRO operations [21].
Lack of data availability.	Requirement for transportation planning and shipping.
Lack of resources for example ERP systems and funding [38].	Requirement for resource planning [39].
“Once off” nature of disaster events.	
Disaster response organisation (DRO) isnot the owner of the supply chain relationship for example the supplier relationship.	
Challenging environment for inventory planning due to unpredictability.	
Varying levels of implementation anduse of inventory control systems.	
Supplier management is not applicable.	
No formal transport management system (TMS).	
No requirement for production planningand manufacturing although resource planning is applicable.	
Ordering and order confirmation are often done by donor agencies and not the DRO itself.	

From this comparison, it is clear that there are significant differences between commercial and disaster response supply chains. Commercial supply chains tend to be linear, predictable and controlled whereas disaster supply chains are organic in nature and unpredictable – reinforcing the conclusion that the disaster supply chain may be better classified as a supply network.

A supply network may be defined as “a set of active members within an organisation’s SCs, as well as inactive members to which an organisation relates, that can be called upon to actively contribute to an SC if a need arises” [34, p. 648]. As mentioned, Braziotis et al. [34] identify 7 key dimensions by which to evaluate the differences between supply chains and supply networks. While supply chains focus on products and services, have linear, continuous, and stable structures, are predictable, stable, and structured with relatively low complexity, supply networks concentrate on relationships, are non-linear with dynamic structures, are Ad hoc or unplanned, unpredictable, and highly complex. In supply networks management tend to focus on the coordination of the web of interim relationships [34]. Competitiveness is enhanced by cooperation, collaboration, and coordination among the members of the web of supply chains while also involving conflict and competition [34]. This description of a supply network closely aligns with the humanitarian system described.

Contrasting the concepts and requirements of the humanitarian system and disaster response, as well as the definitions of logistics, supply chain, and supply network the following comparison is developed:

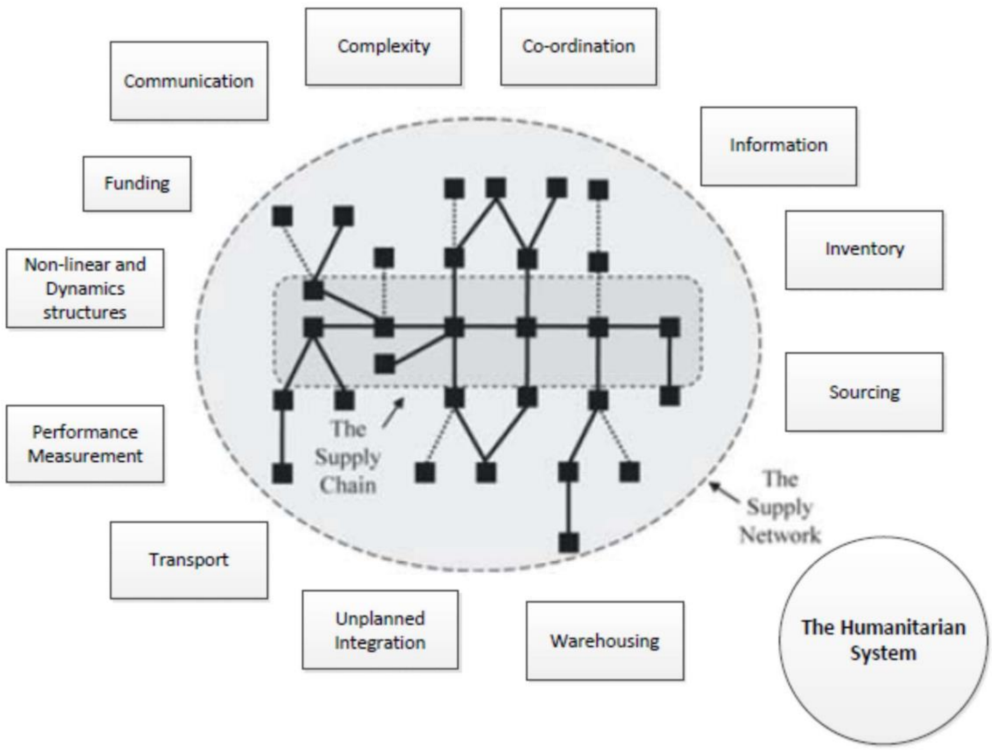
Characteristic (Alphabetical)	**Logistics element**	**Supply chain element**	**Supply network dimension**	**Disaster response requirement**
Communication		✓	✓	✓
Compexity			✓	✓
Coordination		✓	✓	✓
Funding		✓	✓	✓
Information		✓	✓	✓
Inventory	✓	✓	✓	✓
Non-linear and dynamic structures			✓	✓

Performance measurements		✓	✓	✓
Sourcing	✓	✓	✓	✓
Transport	✓	✓	✓	✓
Unplanned integration			✓	✓
Warehousing	✓	✓	✓	✓

Figure 9: Characteristics comparison [33], [34]

Although Figure 9 is an oversimplified representation, it indicates that the requirements of disaster response appear to align closely with what supply networks require. This leads to the conceptual framework for the humanitarian system as a supply network shown in Figure 10.

Figure 10:



Conceptual framework for the humanitarian supply network

This provides a view of what needs to be considered by each entrant into the entities such as local government, international governments, military, NGOs, humanitarian organisations, and volunteers when they enter the disaster situation. This can also assist in the various stakeholders finding synergies in their efforts and in their requirements to assist the victims and the impacted area. This conceptualisation then aligns with the definition of a supply network mentioned where the set of "active members" of the supply chain are the local entities that operate in the affected area and the "inactive members" are those entities that are external to the affected area "that can be called upon to actively contribute to an SC if a need arises".

4 CONCLUSION

This study has, thus, developed an initial conceptual framework for the humanitarian supply network in the case of a sudden onset disaster where the humanitarian system is activated. This was achieved by examining the context and processes for comparison to a supply network i.e. the way in which a sudden onset disaster unfolds, the four (4) phases of disaster relief were identified, namely, mitigation, preparedness, response, and recovery. These phases are facilitated and supported through the humanitarian system, which in turn consists of numerous role players. The possible participants in the supply network were then identified by exploring the role players and stakeholders in a humanitarian system. Supply chain evaluation frameworks were considered to compare the characteristics of a disaster response system to a typical supply network.

The complexity and dynamics of a disaster relief response effort cannot be underestimated, and simply superimposing supply network principles on such a fluid system could be considered trite. The conceptual framework has, however, provided a point of departure for further research on leveraging supply network principles in disaster response situations, and could be used to further inform large organisations that participate in disaster relief efforts, in the evaluation of these efforts, and in establishing systems for disaster relief efforts.

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LESSONS LEARNED DURING RISK MANAGEMENT IN THE FEASIBILITY PHASE OF ARESTARTED PETROCHEMICAL TANK FARM PROJECT: A CASE STUDY

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ABSTRACT

This paper contains the process followed and lessons learned while conducting project risk management during the feasibility phase of a restarted tank farm project. The initial projectwas halted during the construction phase in 2016 due to technical soil condition problems. Afeasibility study was conducted in 2020 to produce updated construction tenderdocumentation, a cost estimate and construction schedule. This paper answers the questions "What was the risk management process followed during the feasibility phase?", "What lessons were learned during this risk management process?" and"What risks were identified during the feasibility phase?". The list of 187 identified risks wasused to produce a Risk Breakdown Structure, and to derive a list of 11 project specific risks related to restarted tank farm projects. The answers to these questions can be used to informrisk identification and decision making in similar projects.

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1 INTRODUCTION AND BACKGROUND TO THE CASE STUDY

When conducting a literature review on risks associated with restarted projects, very little peer reviewed research was found. One can argue however, that feasibility phase risks for a construction project would also be applicable to the risks associated with the feasibility phase of a restarted tank farm project as these are both construction projects. It can, however, be expected that some additional project-specific risks will be identified during a well-structured risk identification process. This paper attempts to fill a research gap by presenting a list of systemic project risks and project-specific risks, which may be used during the risk identification process of the feasibility phase of a restarted project. This paper uses the Association for the Advancement of Cost Engineering International (AACEI) definitions of systemic risks (uncertainties that are an artifact of an industry, company or project system, culture, strategy, complexity, technology, or similar over-arching characteristics) and project- specific risks (uncertainties related to events, actions, and other conditions that are specific to the scope of a project) [1].

Since this article's focus is on the risk identification process, it excludes other parts (risk analysis, risk evaluation, risk treatment, monitoring and review, communication and consultation) as described in the ISO31000:2018 risk management process [2]. Risk sources, detailed risk event descriptions, consequences, and treatment plans are not discussed in any detail as these may be context specific.

1.1 Organisation context and problem statement

In 2010 the project owner appointed a contractor to construct a tank farm with 10 tanks, for storing various types of fuels. The scope of the project included the design and construction of the tanks, associated utilities, facilities, and systems for full operation. The purpose of the project was to allow for extended planned refinery shutdowns in the area, increase the number of products which can be stored, and to reduce the risk of supply interruptions to customers. During the execution phase of the project, some of the tanks failed due to

construction and soil stability issues and it was concluded that the tanks needed to be dismantled and replaced. The project was therefore stopped and already procured equipment and other components were mothballed for 5 years. In 2020, the project owner appointed a new consultant to conduct a bankable feasibility study, which had the following high-level objectives:

- Confirm the tank operations philosophy and design basis for the new tank scope.
- Conduct condition site assessments on the status of existing equipment, infrastructure, utilities, facilities, systems and associated designs to determine what can be re-used should the project go into execution again.
- Design some new fuel tanks and associated infrastructure. The consultant had to complete these designs and integrate them into the existing design.
- Update design documentation for old and new designs for civil / structural / geotechnical, firefighting & protection, instrumentation / control / electrical, mechanical, piping, tanks, and security & ICT works.
- Provide sufficient documentation to pass the feasibility stage gate review.
- Create an updated bill of quantities (BOQ), cost estimate construction schedule, as well as tender documentation for use during the construction phase of the project.

The table below contains a list of the original and revised project scope.

Table 1: Original and revised scope

Type of tank	Original Design Scope	Revised Scope
Fuel Type - 1	3 new 20 000 m^3 tanks 2 new booster pumps	1 new 20 000 m^3 tank1 new booster pump
Fuel Type - 2	1 new 20 000 m^3 tank 1 booster pump	3 new 20 000 m^3 tanks 2 new booster pumps
Fuel Type - 3	3 new 20 000 m^3 tanks 2 new booster pumps	1 new 20 000 m^3 tank1 new booster pump
Fuel Type - 4	1 new 20 000 m^3 tank 1 booster pump	3 new 20 000 m^3 tanks 2 new booster pumps
Fuel Type - 5	2 refurbished 18 000 m^3 tanks1 new booster pump	1 new 20 000 m^3 tank1 new booster pump
Total	10 tanks, 7 booster pumps	9 tanks, 7 booster pumps

The feasibility study started in March 2020 and was concluded in February 2021.

1.2 Paper structure

This article is structured as follows:

1. The research process followed for this research's consisted of a literature review, data gathering as part of the risk management process, data analysis and results.
2. The results are then presented in terms of the following:
   - The outcome of the risk identification process, which includes 91 feasibility phase risks, 86 construction phase risks, and 10 commissioning and handover risks as well as a risk breakdown structure (RBS).
   - The lessons learned during risk managing the feasibility phase of the project. These lessons include the most important risks to focus on, the importance ofidentifying and managing feasibility phase risks and the importance of identifying interface risks.
3. A discussion follows and elaborates on the validity of the checklist, unique risks associated with restarted projects which were identified during this research, a proposed risk breakdown structure for similar feasibility phase projects as well as the benefits and shortcomings of the research results.
4. The paper ends with a conclusion, acknowledgements and reference list.

2 RESEARCH PROCESS

This section discusses the literature review, how the data was gathered and results were prepared.

2.1 Literature review

This article follows a research method which is exploratory in nature [3]. The outcome of this literature review is presented in terms of published research on petrochemical projects and risk management and restarted projects. The first part is important as it would provideassurance regarding the validity of the risks identified for petrochemical projects and the second part would provide some input on the risks which might be encountered when managingrestarted projects.

2.1.1 Published research on risk management and restarted projects.

Project risk management is a well described project management discipline. The business case, processes and procedures and intended outcomes are widely described in standards such as IS031000 [6], guidelines like the Project Management Body of Knowledge (PMBoK™) [5], Association for Project Management (APM) [7] and Association for the Advancement of Cost Engineering

International (AACEI) [8], books by authors such as Dale Cooper [9], David Hillson [10] as well as Chris Chapman and Stephen Ward [11, 12] and a plethora of peer reviewed research. The risks management frameworks and processes described in the literature are generic and intended to be applied during any of the phases in the project lifecycle [11, 13] and it is left to the project risk practitioner to align the project phase objectives with the guidelines set by these standards and guidelines.

It was difficult to find peer reviewed research and other publications on restarted projects, with the exception of research related to the restarting of projects after the COVID-19 pandemic [14-16]. The latter included work by the South African Construction Development Board [14] and Adhikari and Poudyal [15]. When searching for “stopped project”, some references related to projects being stopped as part of gateway processes were found [5, 17,18]. These were not applicable to the case study project, as this project was halted during construction.

No peer reviewed research could be found related to restarted projects and risks for the feasibility phases of those projects. When searching for terms like “abandoned project”, “mothballed project”, “restarted project”, “suspended projects” and combinations of these terms, some short, non-peer reviewed work was found. A possible reason for the lack of peerreviewed research on restarted projects is that the project owners would be reluctant to disclose information related to previously failed projects, as it may include reputational risk.Publications by Hunsberger [19], the IPA [20] and Tsongas [21], were all of the “lessons learned” variety, which can easily be used as objectives with related risks as part of a risk identification process. Their recommendations / objectives are documented in Table 2 below.

Table 2: Project restarting objectives

Objective	Hunsberger [19]	IPA [20]	Tsongas [21]
Determine the reasons for shelving / stopping the project	x	x	x
Locate all information relating to the previous and current status of the project	x	x	x
Speak to the previous project manager (if possible)			x
Treat the project as if it was brand new			x
Consider lessons learned from stopped project	x		
Re-resourcing the project	x		
Develop a restart plan		x	
Develop a risk analysis and risk mitigation plan forrestart		x	
Recognise that stopping/restarting in construction can be a major challenge for site logistics and resources		x	
Reconfirm business and project objectives, priorities,targets, and success criteria		x	
Strong team development and application of good project controls		x	

Reconfirm the design basis and update the risk mitigation plan		x	

2.1.2 Published research on petrochemical projects.

Should one need to do some research to create a list of risks for the feasibility and construction phases of petrochemical projects, several useful peer reviewed articles were found. The majority of these articles do not make a distinction between feasibility and execution phase risks [22-26] while some others include specific lists for the feasibility phase of these type ofprojects [27]. This however, does not prevent the project risk specialist to use these lists andcategorise the risks according to the various phases of the project lifecycle in which these risks may realise.

It should also be noted that the majority of these risks appear to be systemic project implementation risks, such as “Lack of experienced owner and contractor resources” and “Lack of discipline and ineffective control of project scope” [25]. Research conducted in South-Africa related to the risks associated with petrochemical projects indicated that petrochemical project risks are similar to that of normal construction risks and that petrochemical projects are “riskier” than normal projects [23]. Some of the research also included project specific risks such as “Working adjacent to existing live plant leading to exposure to high H_2S gas” [24] and “Civil & Structural Works: Civil & Structural Works in Utilities and Offsite for Pipe rack, SWS area, Air Compressor, Euro IV Tank Farm and other Miscellaneous Civil Works for Cable trench, Road crossing and Sleepers” [27]. None of these projects indicated specific risks related to restarted projects which were in the feasibility phase.

2.2 Data gathering

The data was gathered during the risk management process which took place from April 2020to January 2021. This process was aligned to the risk management steps as described in ISO31000 [2] PMBoK™ [5] which included setting the project context, doing risk analysis and evaluation, assigning treatment plans and treatment plan owners, as well as regular reviews on the identified risks. The project risk management plan required that a baseline risk registerbe created using existing risk registers, as well as appropriate research. This register containing 179 items was created from the existing project owner’s project risk register, risksregisters where the consultant was contracted on similar projects, the root cause analysis report from the failed project, as well as a safety risk assessment which had been conductedby the project owner.

Due to the COVID-19 pandemic, not all the planned project risk identification and review workshops could take place using a “face-to-face” format. After the baseline risk register was created, the risks were distributed to the project owner and consultant discipline leads. Virtual risk reviews were conducted by the risk consultant with the discipline leads and projectowner representatives to ensure that the risk register risks were applicable to the project, had appropriate risk treatment plans and were assigned to the most appropriate task owners.Of these 179 risks, 64 were reviewed and closed because they were either not applicable to the project or were in some way duplicated. A total of 24 new risks were added during this initial risk identification process.

This risk register was reviewed and evaluated in a face-to-face meeting which took place in June 2020. The outcome of this meeting was a list of 107 ranked risks. Extensive interface risk identification took place during August and October 2020. This is a structured process toidentify the interface risks between various parts of the project design and execution and is discussed in more detail later in the paper. The normal monthly risk review process took placevirtually until the project gate review took place in December 2020. Weekly telephonic discussions between the project manager and risk specialist ensured that the risks were updated regularly.

2.3 Preparation of results

The next step in the process was to review and clean-up the list of risks and then to appropriately categorise them. This is discussed in Section 3.1. Some of the outputs from this process were then used to present a list of lessons learned, which is discussed in Section3.2.

3 RESULTS

The results are presented in terms of the proposed checklist which can be used for risk identification during the feasibility phase of a restarted tank farm projects, as well as some lessons learned during this risk management process.

3.1 Proposed checklist

This section contains the list of risks which were identified as part of the case study. The structure used is presented in the form of a risk breakdown structure (Figure 1), using the business case risks as an example. It has 4 levels, of which level 1 is related to the project

phase, level 2 to high level scope, level 3 to various risk categories and level 4 to the risks themselves. Each of these are discussed later in this article. This structure was selected as it enables easy navigation between project phases and engineering disciplines.

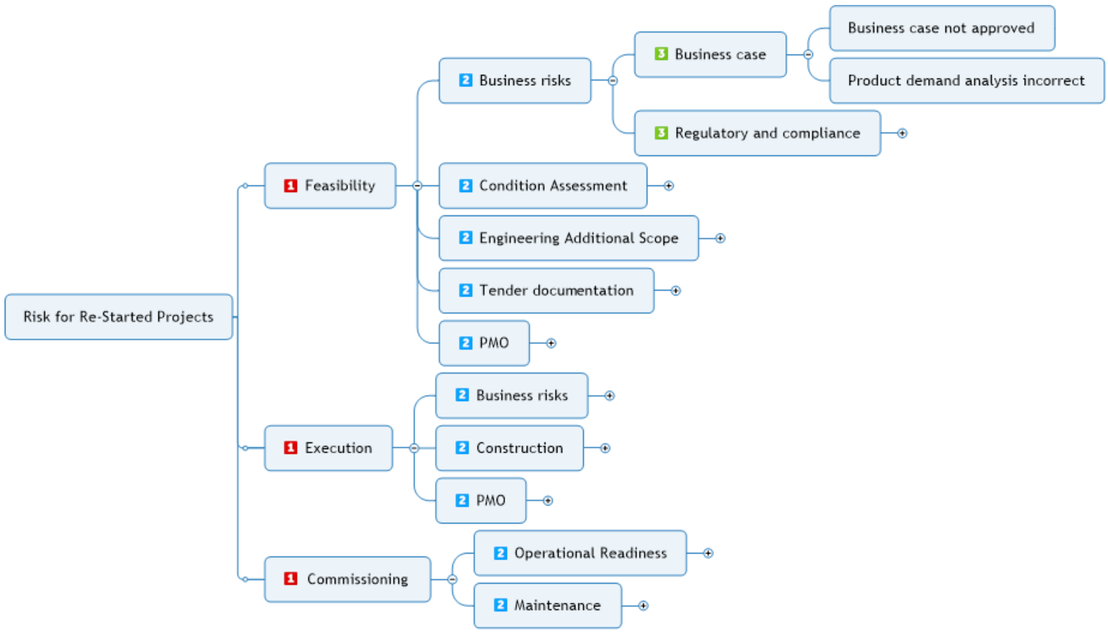

Figure 1: Risk Breakdown Structure

Table 3 contains a list of levels 1 and 2, with the number of each risks identified.

Table 3: Overview of risks identified

Level 1	Level 2	Number of risks
Feasibility phase	Business risks	4
	Condition assessment	13
	Engineering additional Scope	3
	Tender documentation	33
	PMO (Project Management Office)	38
Construction	Project owner	3
	Construction	51
	PMO	32
Commissioning	Commissioning	10
Total		187

3.1.1 Feasibility phase risks

These risks relate to meeting the objectives of the feasibility phase, which included the project owner's business risks, completing the condition assessment of previously completed and mothballed works, and completing additional designs as well as a list of PMO risks. A total of 91 risks appears in Table 4.

Table 4: Feasibility phase risks

Level 2	Level 3	Risk Name
Project owner	Business risks	• Business case not approved • Product demand analysis incorrect
	Regulatory andcompliance	• Regulatory universe unclear • Stakeholder identification incomplete
Condition Assessment	Civil / structural	• Civil works previously completed quality problems • Extent of civil materials for re-use overestimated
	Contaminated soil	• Extent of soil contamination (hydrocarbons) underestimated
	Fire fighting & protection	• Foam Equipment functionality and capacity • Previously installed fire main ring condition
	Instrumentation / control / electrical	• Extent of E&I equipment for re-use overestimated
	Mechanical	• Extent of mechanical equipment (pumps, valves) for re-use overestimated
	Piping	• Datapack traceability problems • Extent of Piping equipment for re-use overestimated
	Tanks	• Extent of internal floating blankets / geodesic domes for re-use overestimated • Stored structural steel components incomplete
	Security & ICT	• Extent of Security & ICT equipment for re-use overestimated

Level 2	Level 3	Risk Name
Engineering AdditionalScope	New tanks	• Additional tank design costs underestimated • Additional tank design late • Wind load on tanks underestimated
Tender documentation	Civil / structural / geotechnical	• Civils/structural design review costs underestimated • Civils/structural design review late • Geotechnical strategy inappropriate • Geotechnical survey delays
	Fire fighting & protection	• Fire Suppression design review costs underestimated • Fire Suppression design review late
	Instrumentation / control / electrical	• Bulk electrical supply capacity inadequate • Instrument IS calculations inaccurate • Instrumentation / control / electrical design reviewcosts underestimated • Instrumentation / control / electrical design reviewlate
	Mechanical	• Corrosion protection philosophy ineffective • Mechanical design review cost underestimated • Mechanical designs reviews late • Mechanical equipment lists incomplete
	Piping	• 3D model compatibility • Changes in design codes on piping designs unknown • Piping design review costs underestimated • Piping design review late
	Tanks	• Existing tank design review costs underestimated • Existing tank design review late • Tank budget quote accuracy • Tank design changes triggers a listed activity
Level 2	**Level 3**	**Risk Name**
	Security & ICT	• Groundwater / unground cabling cost underestimated • Security and ICT design review costs underestimated • Security and ICT design review late
	General designs	• Project owner drawing requirements not met by EPCM • Designs not aligned with future project owner requirements • Late design changes required by Project owner • Late handover of existing designs by project owner • Operations philosophy and basis of design unclear • Safe design requirements inadequate
	Process engineering	• Process engineering design review costs underestimated • Process engineering review late
PMO	Change management	• Design configuration management inadequate • Variations and change management inadequate
	Cost management	• Bill of Quantities quantities inadequate/incomplete • Contingency allowances inaccurate • Cost estimate rates incorrect • Currency provision uncertainty • Equipment by sole supplier costing inflated • Escalation allowances inaccurate • Feasibility phase funding shortfall • Labour cost underestimated • Overtime cost underestimated • Travel cost underestimated
	Environmental management	• Validity of cost agreements made during previous construction phase • Environmental authorisation appealed by interestedand affected parties • Environmental Authorisation not granted • Environmental authorisations late due to authority delays

Level 2	Level 3	Risk Name
		• Environmental permitting procedures flawed • Public participation processes inadequate • Water Use Licence not granted • Water Use Licence requirement uncertainty
	EPCM consultant appointment and management	• Client ability to manage Consultant compromised • Consultant control systems inadequate • Consultant scope unclear
	Gate review	• Consultant Task Order and Client gateway requirements not aligned • Feasibility phase close-out report late • Gate review not passed • Gate review requirements unclear
	Health & safety management	• Corona virus
	Procurement &logistics	• Logistics study late • Procurement package plan incomplete • Procurement package plan late • Procurement package plan sub-division inappropriate
	Project setup and documentation handover	• Client document management system capacity
Level 2	**Level 3**	**Risk Name**
	Risk management	• Project risk management capacity
	Schedule management	• Project execution schedule late
	Roles & responsibilities	• Design and construction liability unclear • Roles and responsibilities between client and consultant unclear

The execution and commissioning risks appear in Appendix 1 and 2.

3.1.2 Risk breakdown structure

A RBS is a high-level process map which may be used during risk identification [4] and is organised in a hierarchy by risk and risk sub-category. These structures identify the various areas and causes of potential risks [5]. The data gathered can also be used to create a risk breakdown structure for similar projects, as displayed in Figure 2.

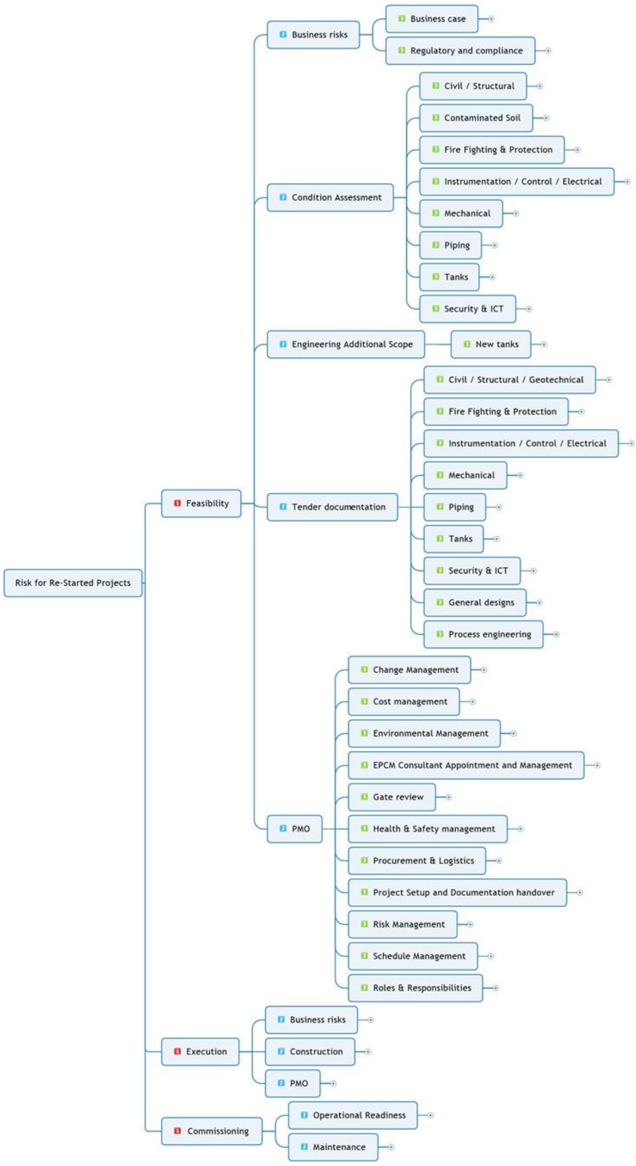

Figure 2: Risk breakdown structure for similar feasibility phase projects

3.2 Lessons learned

The lessons learned during the risk identification process are discussed in this section in termsof the importance of identifying and managing feasibility phase risks, the focus of risk identification, and the importance of identifying interface risks.

3.2.1 Focus must be on aspects which caused previous project to fail

During the risk identification process, one of the first tasks was to review the project tender and context information to identify the objectives of the feasibility study and execution phaseof the project. This is aligned with the recommendations by Hunsberger [19], the IPA [20] andTsongas [21]. One of the first objectives was "Avoid design and construction issues as experienced with the previous tanks." These risks caused significant reputational damage, significant financial losses and lengthy and expensive litigation to the previous contractors. The risks in the Table 5 below were identified during for the feasibility and construction phasesof the project.

Table 5: Risks related to project causes for project stop

Feasibility phase	Execution Phase
• Tank foundation stability • Piling might be required for some tank foundations • Wind load on tanks underestimated • Civil works previously completed quality problems	• Tank foundation compaction quality control • Tank civil contractor rejects existingfoundation designs • Existing tank foundations might need to be reconstructed

3.2.2 The identification and management of the feasibility phase risks are material

Since the feasibility phase contract between the project owner and the consultant was a fixedprice contract on a project which was stopped and mothballed, appropriate attention was placed on risk management and risk management resources from the time when the tender documentation was created for the feasibility phase. The tender documentation had clear requirements regarding the management of risk. The feasibility project risk management wasalso supported by the project owner representatives which were part of the owner's team during the previous project execution phase. At the end of the feasibility phase, 91 risks associated with the phase had been captured in the risk register. These risks were also identified earlier during the feasibility phase, as focus was placed on understanding and treating the feasibility phase risks over the construction risks.

The identification and management of interface risks formed part of the consultant's scope of work and was also employed by the author on a similar project [28]. Since the constructionwould take place on an existing congested site, with different work packages planned for early works, civil / structural works, erection of tanks, mechanical works, piping, fire fighting& protection, instrumentation / control / electrical and piping, two interface risk workshopstook place during August and October 2020.

The method used was similar to conducting a HAZOP study [29, 30]. These studies are structured and systematic examinations of a procedure, process or system and employ deviation guide words (low flow, high flow, reverse flow etc.) and design specific nodes to identify hazards associated with the operation a process or system. The methodology was adapted by exchanging the HAZOP study nodes with combination pairs of input packages (i.e. Early Works / Civil Structural Works), and by replacing the normal HAZOP guide words with guide words connected to interface types which may realise during construction.

Four sets of guide words were used:

- Design: New Designs / Existing Equipment / Refurbishment
- Design: Mechanical / Civil / Geotech / E&I / Fire / ICT
- Design: New Design / Technical information exchange / Approvals
- Execution: Laydown areas / Traffic / Site access
- Execution: Schedule / Sequencing / Tie-ins
- Execution: Operating terminal / Surrounding facilities
- Procurement: Free issue / New Items / Roles & Responsibilities / Quantities
- Resources: People / Materials / Equipment

During these sessions, questions such as "When looking at the early works and the civil package, are there any *Laydown areas / Traffic / Site access* risks?" were asked. If the teamidentified a risk, the risk was further developed. If not, the question "When looking at the early works and the civil package, are there any *Schedule / Sequencing / Tie-ins* risks?" wasasked. The process continued until all the input package pairs and guide words were coveredand typical risks like the following were identified:

- Late handover of tanks by early works contractor to civils contractor.
- Tank / Piping contractor battery limits unclear.
- Tank construction sequence not optimised.

At the end of the feasibility phase, there were 86 construction phase risks, of which 46 were identified during these interface risk workshops.

4 DISCUSSION

The results are discussed in terms of the validity of the RBS, unique risks associated with restarted projects as well as the benefits and shortcomings of the research.

4.1 Validity of checklist and RBS

Lookup methods of risk identification, which includes checklists, are useful since they assist in identifying common problems and may be used by non-experts [31]. One should however, not ignore potential limitations such as potential limits to imagination during risk identification and the potential to overlook “unknown unknowns”. The checklist of 187 risksis seen as appropriate and valid since it was created as part of a collaborative effort betweensuitably experienced subject matter experts during an actual feasibility study of a restarted tank farm project, which formed part of a defined research process.

Additionally, systemic project construction risks can be found in the research published by Chan, et al. [32], Karim, et al. [33], Rezakhani [34], Zou, et al. [35] as well as Tam and Shen[36]. This adds to the confidence in the developed checklist as it is partially based on previousreviewed research.

4.2 There are risks which are unique to restarted projects.

To identify the case study risks uniquely associated with restarted projects, the list of 187 projects was reviewed and systemic project management risks were identified. The rest of the risks were then reviewed and 38 risks specifically related or enhanced by being a restartedproject were identified. These 38 risks were then further analysed to identify commonalities between the various risks. Table 6 contains this list of 11 project specific risks which may beused during the risk identification of restarted projects:

Table 6: Risks related to restarted projects

Category	Risk name
Information availability	1. Availability of information from previous stopped project
Design risks	2. Not all the new client design and scope changes taken intoconsideration 3. Changes in design codes since completion of previous designs 4. Design review costs during feasibility phase underestimated 5. Interface issues between old and new designs and equipment 6. Late completion of design reviews

Condition assessments	7. Extent of re-usable equipment overestimated 8. Quality problems with previously completed works 9. Uncertainty regarding status and condition of previously installed equipment
Contractual and legal	10. Design and construction liability unclear between old andnew designs 11. Status of contracts agreed during previous project

One should also note that there might have been significant context changes since the projectwas stopped. These context changes may include changes to project scope, project stakeholders, project funding and so forth, and should be reviewed as part of the normal riskmanagement process.

4.3 Benefits

The benefits and applications of the offered checklist of 187 risks and RBS include the following:

- Since the checklist covers the feasibility, construction and commissioning phases of a restarted tank farm project, it may be used for similarly scoped projects, or projects which covers only part of the scope to assist in ensuring that appropriate risks are identified.
- The RBS may be useful during risk identification, risk assessment and risk reporting for comparable feasibility phase projects. This RBS can also be employed in tender documentation for similar projects to present risks in a consistent format [37].
- The list of 11 risks related to the feasibility phase of a restarted project is useful as it fills a research gap and adds to the work by Hunsberger [17], the IPA [18] and Tsongas [19].
- The lessons learned section provides some insights regarding the risk management process, which other subject matter experts might find useful.

4.4 Shortcomings

Since this list of risks was created as part of a case study which involved a single project, thelist makes no claims to being complete, for the following reasons:

- The scope of the article is limited to the risks identified and managed by the consultant.It therefore excludes the project owner's commercial, project and operational risks.
- Since this article was completed before the start of the execution phase, it is expectedthat additional risks will be identified during construction.
- It is acknowledged that although tank farm projects generally follow an established work breakdown structure, other restarted tank farm projects might include scope which wasnot covered in this article. This however, does not detract from where the scope is similar and where this article may be used as a checklist to identify risks in similar projects.

5 CONCLUSION

This paper presented the process followed and lessons learned while conducting project risk management work during the feasibility phase of a restarted tank farm project and answers the questions "What does a checklist of risk for such a project look like?", and "What lessonswere learned during this risk management process?" The list of 187 identified risks was usedto produce a RBS for similar projects, and to derive a list of 11 project specific risks related to restarted tank farm projects. Since the checklist covers the feasibility, construction and commissioning phases of a restarted tank farm project, it may be used for similarly scoped projects, or projects which covers only part of the scope to assist in ensuring that appropriaterisks are identified. The lessons learned section provides some insights regarding the risk management process, which other subject matter experts might find useful when implementing similar projects.

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APPENDIX 1: CONSTRUCTION PHASE RISKS

The table below contains a list of 86 risks which might realise during the construction phase of the project and contains systemic risks such as "Design freeze not implemented", and project specific risks, which include "Pipe bridge construction sequence" and "Access afterbund wall closure".

Table: Construction phase risks

Level 2	Level 3	Risk Name
Project Owner	Regulatory and compliance	• Construction licence not granted • Local authority permitting delays • Operating licence not granted
Construction	Early works	• Cathodic protection might need to be replaced • Cathodic protection removal clashing with foundation repairs • Delayed Demolition Works • Early works contractor delays removal of piping • Incomplete as-built drawings for demolition drawings • Site office requirements unknown • Tank contractor rejects tank foundations completed by civils contractor • Tank foundation compaction quality control • Tank foundation completion delay • Unknown live services
	Civil / structural	• Access after bund wall closure • Catch basin contamination • Construction/contractor schedule integration issues • Damages to below ground piping during road layer works construction • Damaging neighbouring fire protection system during construction • Foundation works completed late • Late handover of tanks by early works contractor to civils contractor • Late site access for completion of civil works • Piling might be required for some tank foundations • Pipe bridge construction sequence • Scope uncertainty of works after bund walls are completed • Stormwater design and management capacity • Tank foundation completion delays • Top of road and manhole levels misaligned
	Tanks	• Clashes between tank and early works contractors • Existing tank foundations might need to be reconstructed • Incomplete tank and equipment design information given to tank contractor • Insufficient potable water for flushing of tanks and pipes • Piping and sleepers blocking site access to specific tanks • Tank civil contractor rejects existing foundation designs • Tank completion delays • Tank foundation stability
	Instrumentation / control / electrical	• Electrical and instrumentation installation delay
	Fire fighting & protection	• Compatibility issues between new and old fire protection system • Fire water system not completed in time
	Piping	• Hydrotesting not done on existing installed pipes
	Planning and logistics	• Constructability review not completed in time • Construction traffic congestion • Laydown area for removed electrical and piping too small • Laydown area planning • Logistics plan detail planning insufficient

Level 2	Level 3	Risk Name
		• Position of dual site access point unclear • Security during tie-in • Site accountability / ownership • Site logistics delays due to congested site • Specialised equipment availability • Tank / Piping contractor battery limits unclear • Wet weather site access
	Integration	• Existing and new equipment integration • Old and new tank design integration • Project design and construction interfaces not identified
PMO	Change management	• Design freeze not implemented
	Environmental management	• Air emissions licence not granted • Environmental management non-compliance • Water use licence for discharge of hydrotest water not obtained in time
	Consultant appointment	• Consultant changed before construction starts
	Health and safety management	• Asbestos found during construction • Damages/disruptions to existing services • Exposure to explosive environments • Inadequate safety management • Public protests interrupting construction • Site security inadequate • Site visitor injuries • Trench collapse
	Procurement and logistics	• Project owner late award of contracts • Construction contractor contracting strategy inappropriate • Contractor appointment not aligned with schedule requirements • Contractor procurement management inadequate • Imported equipment/material availability • Laydown areas insufficient • Long lead management inadequate • Supplier development requirements not aligned with contractor availability • Tank contractor with sufficient experience not available
	Project controls	• Governance structures and controls not in place
	Schedule management	• Project owner approval delays • Contractor planner competency • Design approval delays • Tank construction sequence not optimised
	Skills & resources	• Project owner engineering resources insufficient • Project owner project management resources insufficient • Design and engineering skills insufficient
	Constructionquality management	• Contractor quality management inadequate • Contractor site supervision inadequate

APPENDIX 2: COMMISSIONING PHASE RISKS

As commissioning risks are a known entity with petrochemical projects [38, 39], these risksare included as a separate part of the RBS. These risks contained in table below:

Table: Commissioning phase risks

Level 2	Level 3	Risk Name
Operational Readiness	Plan performance	• Performance criteria not met
	Planning	• Budget for Commissioning, Handover and Close -Out inadequate • Commissioning and handover systems and procedures inadequate • Inadequate budget for support during guarantee period(12 months) • Time frame for commissioning and handover inadequate
	Skills & resources	• Commissioning personnel skills inadequate • Operator training late
	Maintenance	• Spares requirements unknown • Maintenance contracts late • Maintenance training late

IMPROVING THE SURVIVAL RATE OF SMALL MEDIUM AND MICRO ENTERPRISES THROUGH 4IR DESIGN PRINCIPLES IN THE CONTEXT OF BUSINESS INCUBATORS

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ABSTRACT

Business Incubators (BIs) have been shown to improve the survival rate of Small Medium and Micro Enterprises (SMMEs) in South Africa from infancy through to inception. There is still however a large deficit of failing SMMEs despite the future of industrialisation being heavily marketed to stand on both the fourth Industrial Revolution (4IR) and the success of SMMEs. In this paper, a conceptual framework is developed on how 4IR design principles can be leveraged in the business incubation space to better their operations and outputs leading to improved survival rates of SMMEs.

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1 INTRODUCTION

There is very limited research especially within South Africa as to how BIs actually go about executing their roles especially since they are influenced by several impactful external factors as shown in Figure 1 below.

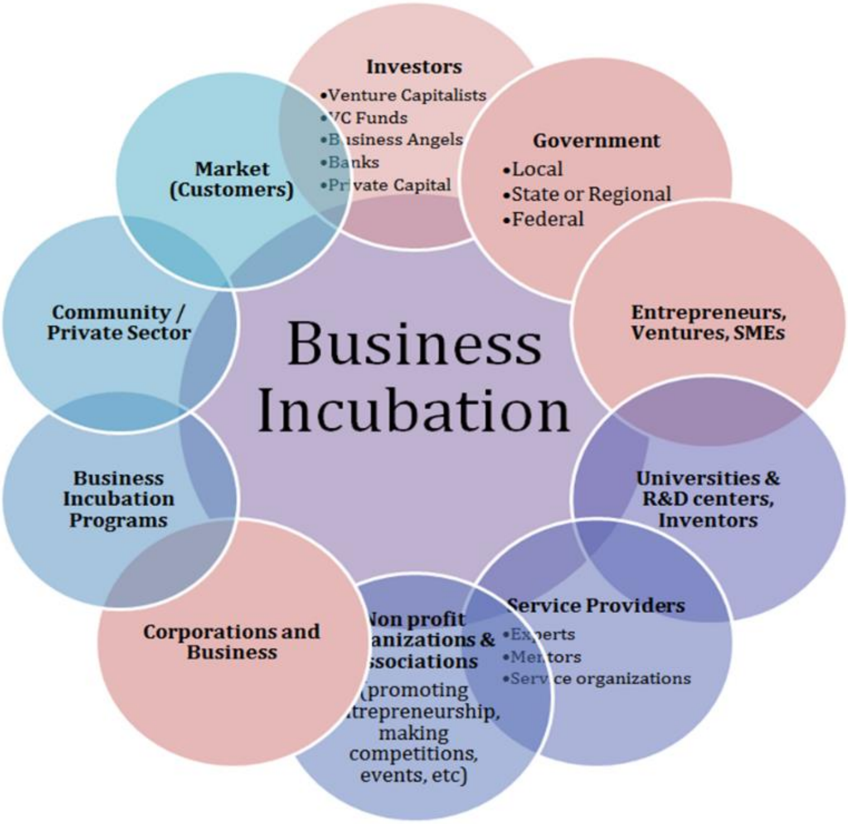

Figure 1: Multi-external environment of Business Incubators [1]

Considering the complexity of the environment in which BIs operate and the importance of SMEs in the South African economy, it is imperitive that the operations and efficacy of incubators in South Africa are explored in more detail, and suggestions are made for the improvement of their operation. This paper seeks to develop a conceptual framework for how 4IR design principles can be leveraged in the business incubation space to better their operations and output leading to improved survival rates of SMMEs.

2 LITERATURE REVIEW

The development of the Small Medium and Micro Enterprise (SMME) sector is globally considered to be a key strategy for economic growth [2]-[3]. In South Africa, SMMEs are acknowledged as having a significant role to play in achieving a variety of objectives: social (poverty alleviation), economic (employment creation, increased incomes, and economic growth), and political [4]-[5].

Multiple studies have shown that the survival rate of SMMEs in South Africa is considerably low [6]-[7]. According to the 2017 Global Entrepreneurship Monitor report, the discontinuance rate of SMMEs in the country is markedly higher than the rate for established business. Some studies estimate that 40% of new businesses in the country fail within their first year, 60% in their second year and 90% within the first 10 years [8]-[9]. Other studies have shown failure rates higher than 75% among SMMEs in their first two to five years, suggesting a level of stagnation in early entrepreneurial activities in the country [2].

While the importance of SMMEs as a channel for the creation of jobs and the reduction of poverty and income inequality has long been recognised, the paths to successful SMMEs remain partially unknown [10]. The upper end of the SMME range is comparable to the small and medium-sized enterprises (SME) segment found in developed countries and is generally stable and successful [11]. The issue lies in the majority of SMMEs which are concentrated on the lower end, where survivalist or 'early stage' enterprises are found. These can take the form of street trading enterprises, backyard manufacturing and services, and occasional home-based jobs [12]. Equipping these businesses with knowledge, technical skills and a way into sustainable value chains is what is required for them to succeed economically and help to boost their productivity [13]. It is important to note that 'early stage' is not a measure of time, but the extent by which a business has developed. For example, an SMME can be five years old, but still struggle to get customers and secure revenue (early stage). At the same time, an SMME can be one year old and already be very profitable and financially sustainable (growth stage)[20].

The increasing number of business incubators (BI) shows that the right kind of business environment is increasingly acknowledged as an important factor contributing to the success of competitive SMMEs and diversified local economy [14]. The promotion of business incubation to reduce the failure rate of these SMMEs has, thus, been and still is an issue of policy concern [8]. A business incubator is a physical or virtual institution that aims to equip SMMEs with the necessary skills needed to grow sustainable businesses and create jobs. The type of support that most SMMEs receive from incubators is: Business Development and Strategic Management, Financial Management, Leadership and Training. This is done by providing business development and training support services, creating linkages and networks and providing infrastructure support services to SMMEs [15]-[16]-[17].

In the literature, BIs are seen to operate based on a linear model according to Figure 2.

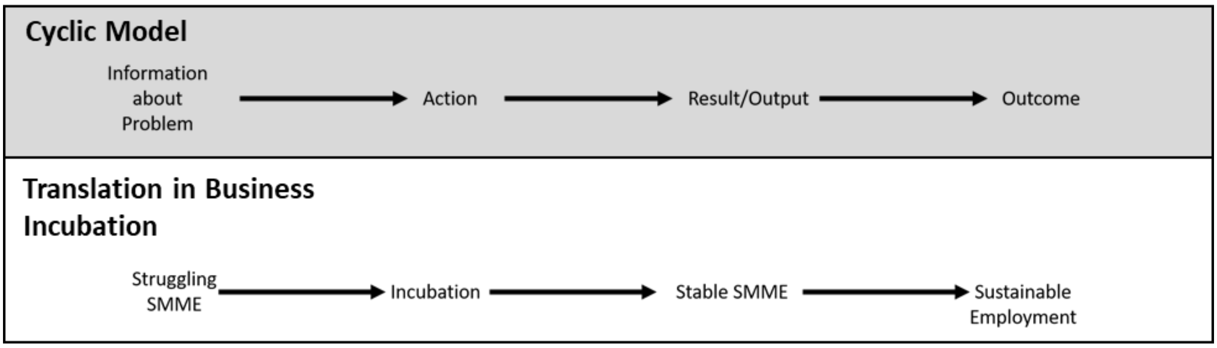

Figure 2: Incubation through the perspective of a linear model [20]

Essentially what is expected of the BI space is a cohesive flow, with struggling SMMEs being the input resulting in stable SMMEs as the output, with the outcome of sustainable employment in society. Recently the question of the efficacy of BIs has been highlighted, as the outcome of business incubantion has not produced the anticipated results. Particularly, SMMEs have not contributed as expected to reducing the high unemployment rates within the country. This has brought about a more circular notion of the BI space as depicted in Figures 3.

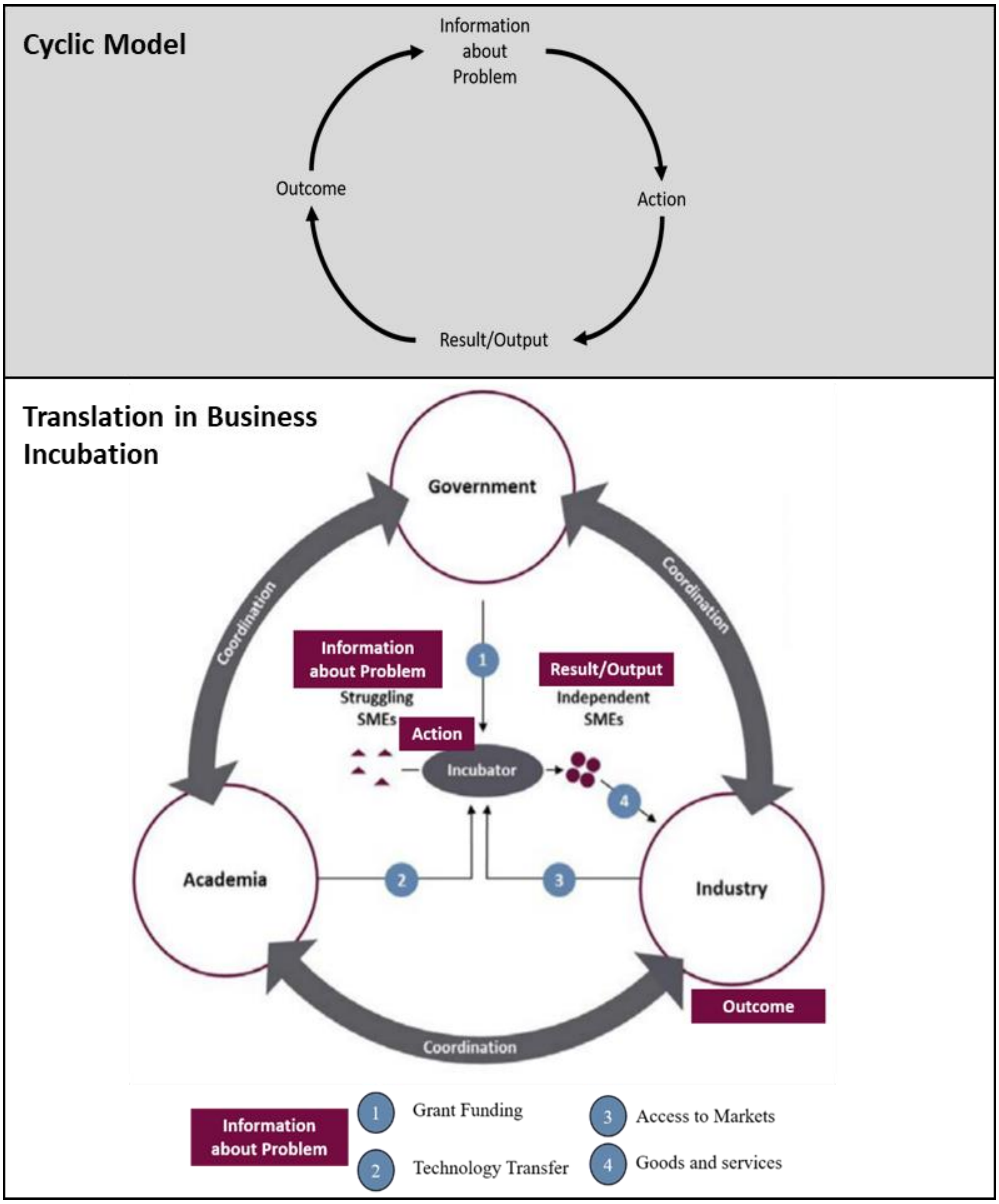

Figure 3: Incubation through the perspective of the cyclic model [20]

The question of the efficacy of BIs has, however, still not been adequately addressed as studies have focused on the "What" and "Why" questions with research such as;

- Investigating the role of BIs [31]- [33]
- Investigating the benefits of BIs [17]
- Discovering the current challenges of business incubators [33]
- Investigating and comparing the performance of varying incubator models [15]

3 RESEARCH METHODOLOGY

The method adopted for the development of the conceptual framework was a systematic literature review. This qualitative approach allowed for a high level view of the research area, while simultaneously allowing the research to produce a comprehensive review of the academic literature in the selected fields. The review entailed collecting and obtaining accurate, clear, and relevant industry and academic literature that gave insights to the study. For the identification of relevant articles and papers, reliable and reputable multidisciplinary databases were used as well as government and industry sites and annual reports.

Table 1: Multidisciplinary databases used in the search

Multidisciplinary databases	
Scopus	SEDA Publications and audio visuals
EBSCO Host	South Africa DTI Publications
Wiley Online Library	South Africa DSBD Publications

Key words and phrases (Table 2) were based on the problem outlined in section 1 above and were used to search in various databases in Table 1 above:

Table 2: Key words and phrases searched in databases

Business Incubators	Fourth Industrial Revolution
Business Incubator Space in South Africa	Components of 4IR
Performance of Business Incubators	Characteristics of 4IR
Best Practices in Incubation	Design Principles of 4IR
Challenges facing Incubators	

Relevant articles were downloaded into Zotero and eliminated iteratively based on relevance to whether they gave insight to how incubators operate, relevance towards the design principles of 4IR and how recent the articles were. This is depicted in Figure 4.

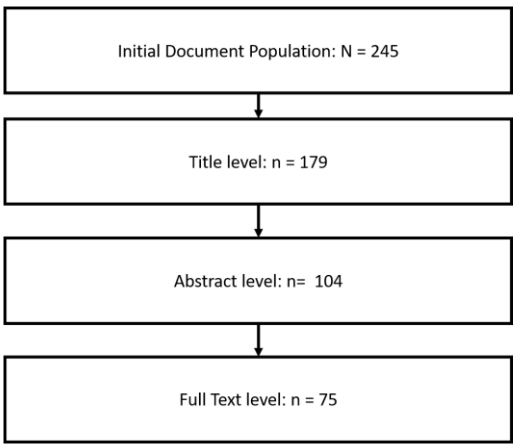

Figure 4: Process to eliminate articles

4 DISCUSSION OF RESULTS

A number of key themes and areas of interest that emerged from the systematic literature review are elaborated below culminating in a preliminary conceptual framework.

4.1 Business Development Support in South Africa

After the end of apartheid in 1994, the government directly tried to uplift SMMEs [14]. In 2001 there were only three public sector business incubators in South Africa [31]. By 2004 there were four incubators, rising to 37 by 2011 [32]. By 2013 the total number of incubators had escalated to 51 in total [31]. Currently, the government operates approximately 57 business incubators through the Small Agency Development Agency (SEDA). These business incubators are predominately sector focused and operating within different provinces across the country [8]. There are also private business incubators thereby suggesting the number of incubators in the country is slightly higher [31]. Never the less, they all generally follow the same generic incubation model (Figure 5) with the main varying factors being the target business' age and time spent in incubation.

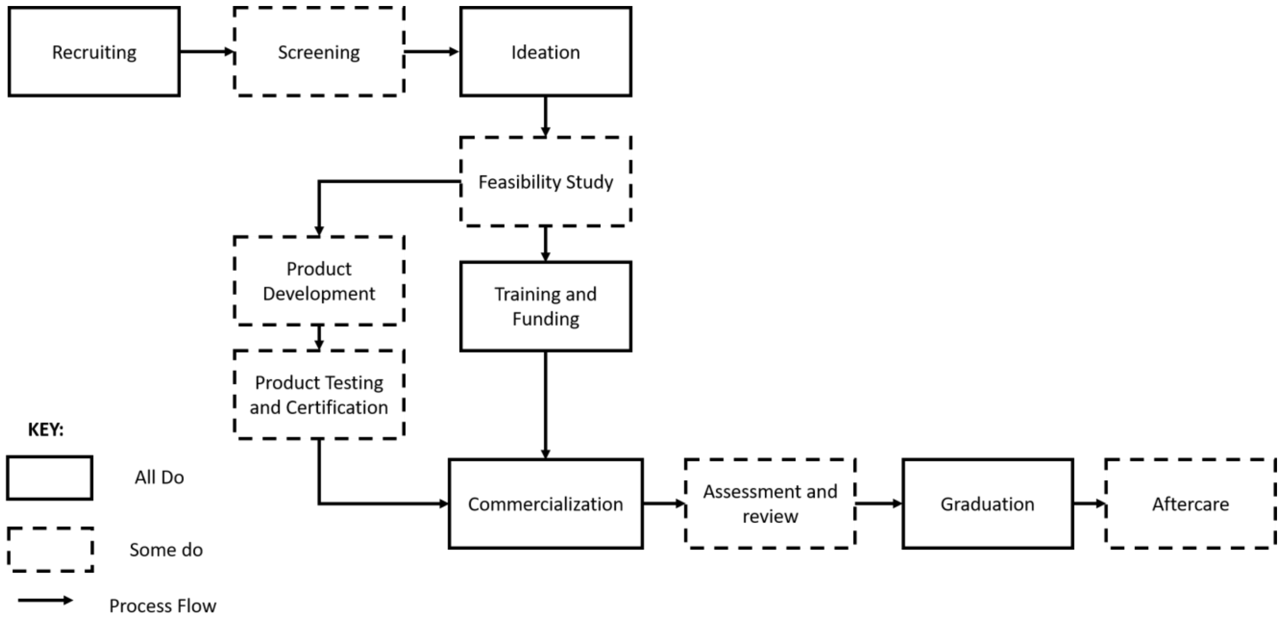

Figure 5: Process Flow in Business Incubators in South Africa (Authors own composition)

Generally, either SMMEs or individual entrepreneurs apply to or are recruited by BIs with some undergoing screening processes for acceptance into BI programs. The next step in the process is ideation, where incubatees are taught how to either come up with ideas or test the core idea of their business. Most then got through business training under coaches and classes while receiving funding with the aim of commercialisation. Once the incubatees have either reached the end of the program or are financially stable, they then graduate from the program. Some BIs offer aftercare by regularly checking on their alumnis' progress.

4.2 Business Development Support Challenges

There are limited studies exploring and highlighting the challenges facing BIs in South Africa. Agreed upon challenges can broadly be listed as below [2]-[19]-[32];

Table 3: Challenges BIs Face [2,19,32]

Challenge	Description
Access to qualified staff	Management functions play a pivotal role in keeping BIs alive, however, a lack of certified staff within the programmes restrict the services offered to the incubatee.
Mismatch in BI value offering and SMME expectation	There exists a mismatch as to what SMMEs expect out of BIs. Some expect training and skills development in a particular area in business while the BI offers training in other areas.
Lack of entrepreneurial skills in SMMEs	Some incubators struggle to assist incubatees because they offer services within their capabilities with the expectation that SMMEs going to them have fundamental entrepreneurial skills.
Access to funding and sponsorship	Depending on the programme and the funder goals/motives, BIs may lack access to funding and this makes it difficult for them to remain operational and support entrepreneurs.
Geographical areas	The geographical area where BIs are located, are not always favourable to incubatees. This makes it difficult for them to offer their service at large and makes it difficult for incubatees to be part of the programmes.
Lack of commitment of entrepreneurs	Some entrepreneurs lack commitment.This becomes a challenge to BIs because they end up utilising their resources to assist entrepreneurs that are not committed.
Government policies	The ineffective implementation of policies such as Broad-Based Black Economic Empowerment (BBBEE) and Protection of Personal Information Act (POPI) create negative incentives within the BI space limiting the operations of the programmes.
Mentorship and Training of BI trainers	There is limited training available in terms of business management, marketing processes, administrative management and public relations offered to managers and trainers within BIs.
Stakeholder support	There is a gap in the relationship between stakeholder endorsements and BIs. This could be caused by the discipline of either the BI or the stakeholder involved.
Reporting pressure from Funders	Given that funding is often dependant on results and outcomes, BIs are incentivised to inflate and misreport outcomes. This makes it difficult to accurately report outcomes which in turn has a knock on effect in available funds for other programmes.
Changes in leadership	BIs have stated a change in stakeholder leadership. Parent Companies, Universities, Funders etc, may affect their operations as Key Performance Indicators, goals and motives change with the leadership.

It should be noted that these challenges are not technological in nature or rather cannot be solved using technology alone. This is because most of the challenges are ***people*** related. Rather than heavily relying on a technology to solve the challenges, the focus should be placed on implementing an effective framework to draw out the value, efficiency and effectiveness from the people in the space. The challenge thus is creating this framework in the context of the Fourth Industrial Revolution (4IR) that is the current and future reality for business.

4.3 Innovation

The BI space is synonymous with innovation and in the day and age we live in, that almost inherently ties in with 4IR.

Innovation has been and continues to be an important topic of study for a number of different disciplines, including economics, business, engineering, science and sociology. Despite the fact that innovation has been studied by a variety of disciplines, the term is often poorly understood and can be sometimes confused with related terms such as change, invention, design and creativity [34]. Among academics there is a difference of opinion about what the term innovation really means. One definition of innovation according to O'Sullivan D. & Dooley L. [34] that aligns with this paper is the following;

> *"The process of making changes, large and small, radical and incremental, to products, processes and services that results in the introduction of something new for the organisation that adds value to customers and contributes to the knowledge store of the organisation"*

This definition does not suggest that innovation must be exclusively radical nor limited to products, nor is it limited to certain kinds of organisations. The term customer is also very flexible as it means the end user of a process, service or product.One can even argue that innovation is at the heart and core of every Industrial Revolution.

4.4 The Fourth Industrial Revolution (4IR)

The concept of 4IR is meant to help individuals and organizations make sense of the interplay between humans and technology at a time when advances in computing power, biotechnologies, artificial intelligence, renewable energies, additive manufacturing, and many other emerging technologies threaten to overwhelm us with complexity [ref]. Therefore, the important work with regard to 4IR is not around defining its further, but rather understanding and shaping its impact. It has a vital focus on the relationship between digitization, organisational transformation and productivity enhancement.

One of the challenges in defining 4IR is that there is no generally accepted definition amongst academics [37]. To better understand the concept of 4IR from an academic point of view, Hermann, Pentek and Otto [37] conducted a comprehensive investigation into the fundamental design principles of Industry 4.0. It was found that there are four fundamental design principles of industry 4.0 which are elaborated below:

Principle 1: Interconnection

The first design principle, which is arguably the most important, is interconnection. The connection of people, machines, devices and sensors provide the means for 4IR [37]. Without interconnection, information transparency, decentralised decision making and technical assistance would be difficult to achieve. Interconnection allows people and objects to share information in real-time, creating an environment where the real world and the cyber world interact instantaneously. Interconnection allows for collaboration in three ways, human-human, human-machine and machine-machine interconnection [37].

Principle 2: Information Transparency

The design principle of information transparency is driven by the increasing number of interconnected objects and people. The merger between a physical world and a virtual world enables information to be shared in new ways and at an almost instantaneous speed. It is this ability to freely share information without delay that unlocks the real-time capabilities of 4IR and makes information transparency a core design principle.

In an ideal 4IR state, data is captured by hundreds of sensors and linked to digital plant models resulting in a virtual copy of the physical world. This virtual copy is filled with "context-aware information", which allows other participants in the network to make correct decisions through data analytics [37]. Two key components that are closely related to information transparency are Big Data and Cyber Security.

Principle 3: Decentralised Decision Making

The third design principle builds on the first and the second. Once there is interconnection between objects and people as well as information transparency, decision making can be automated to a higher degree and executed independently [37]. Decentralised decision making systems make use of both local and global information for improved decision making which leads to an increase in over-all productivity [38].

Principle 4: Technical Assistance

The fourth design principle focuses on the interaction between humans and a digital environment. During the 4IR, people will shift from being operators to strategic decision makers who can flexibly solve problems [37]. An increase in complexity, due to the numerous links between cyber-physical systems and other networks, human will require support by technical systems. Assistance systems will aid in the visualisation of information so that people are able to make correct decisions and solve the problems in front of them without excessive delay [39]

4.5 Principles vs Technology

There is no agreed process as to what 4IR tool should be used within the BI space to improve its efficacy and effectiveness. In order for this to be established, there needs to be a change in implementation strategy of 4IR in the space; shifting from looking at the tools and technologies to looking at the principles that underpin these technologies.

There are many theories of change, but one that is particularly relevant to innovation is centred on the S-curve. It is a way of depicting incremental, disruptive and radical innovation [41]. The S-curve (Figure 7) shows the innovation from its early beginnings as the technology or process is developed, to an acceleration phase (a steeper line) as it matures and, finally, to its stabilisation over time (the flattening curve), with corresponding increases in performance of the item or organisation using it. At any point, there may be a step change in the technology (a radical innovation) resulting in a new S-curve.

The S-Curve pattern of innovation highlights the fact that as an industry, product, or business model evolves over time, the profits or performance generated by it gradually rise until the maturity stage. If an organization can pinpoint its position on the life cycle curve (S-curve), and it has a sense of the slope of the curve, it has an excellent mechanism for determining where its performance is headed [41].

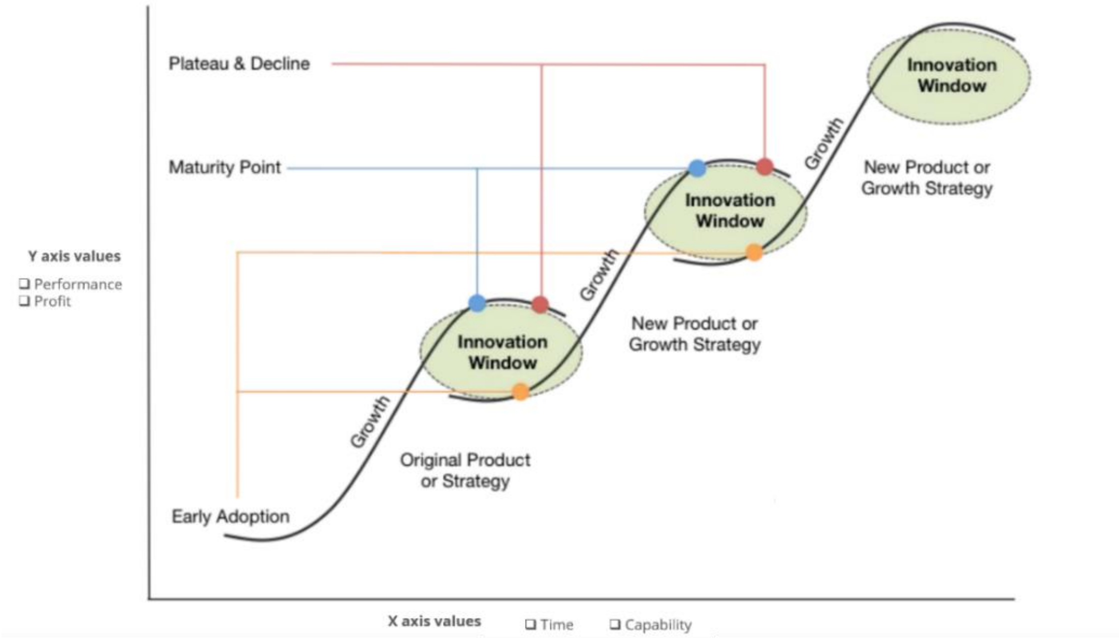

Figure 6: Growth Trajectories of S-Curves [41]

In a study conducted by Manabu Sawaguchi on innovation activities based on S-Curve analysis and patterns of technical evolution, four innovation patterns emerged using "Affinity Diagramming" (See Figure 8 below). The categories of the patterns are based on Christensen's aspects of innovation [42]-[43].

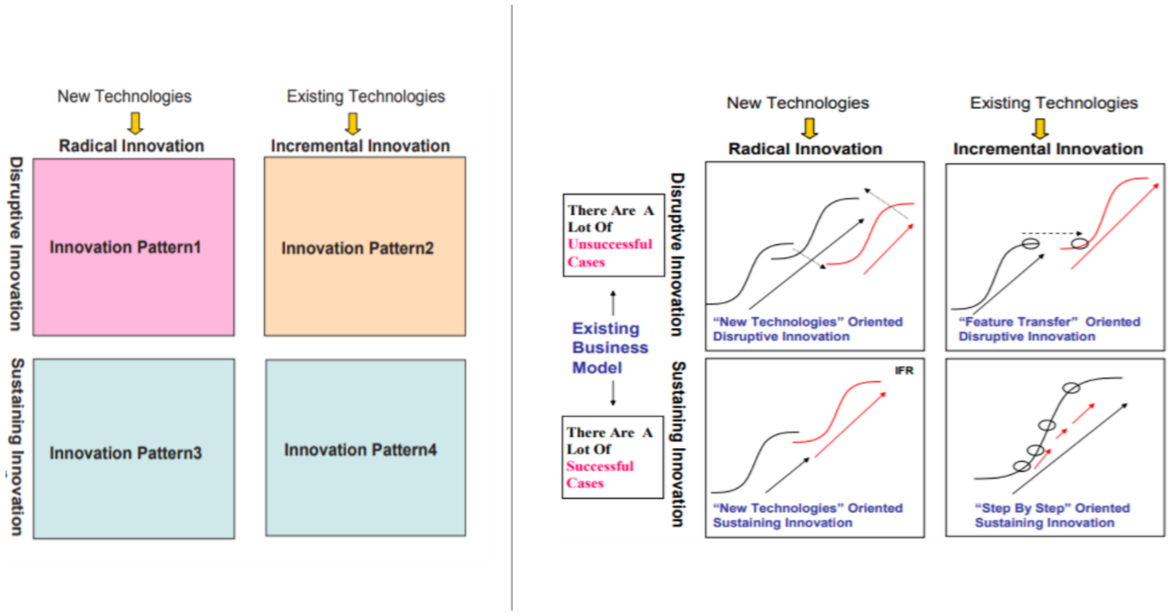

Figure 7: The relationship between "S-curve" and "Four innovation patterns" [42]

- **Innovation Pattern 1-** The purpose of this pattern is to create new S-curve for the next generation product/process by utilizing new technologies. If the core technologies (i.e. sophisticated technologies in established market or space) of this innovation are in the "maturity to deadline stage" and have exceeded the "Customer's requirements in established markets", this innovation actively "encourages companies to look to other markets" to create "new products". Consequently,
- **Innovation Pattern2-** This pattern is based on the same powerful strategy as "Innovation Pattern 1". This strategy is designed to destroy the products/processes of

"traditional companies" produced before those companies focus on new innovation, which will aid in the establishment of new markets.

- **Innovation Pattern 3-** This Innovation Pattern is based on new technologies which create the next S-curve after obsolescence of core technologies on a previous S-curve. Therefore, industrial strength in previous markets is basically unchanged, even on a new S-curve.
- **Innovation Pattern 4-** The purpose of this Innovation Pattern is to utilize "the existing core technologies" comprehensively to extend an existing S-curve. Accordingly, this innovation is based on the detailed understanding of established customer requirements which enhance customer satisfaction. Essentially, this innovation corresponds to "Gradual Innovation (Improvement)" .

In the context of BIs in South Africa, it is agreed that BIs fall in the space between early to growth stages [14]. On top of that, given the questioning of the efficacy of incubators, it can be inferred that the space is still not operating at its best capability [14].

Changing the technology without optimising the operational process performance does nothing but create a new S curve. This gives the illusion of improvement under the current operations capability, whereas in reality a new operational capability functioning under the same process has been created. It also does not ensure sustainability in improvement, as technology costs are incurred. Solidifying and ensuring that the operational processes are right before infusing technology is a much more sustainable and proven way of ensuring performance improvement and operations are improved on principles. This is detailed in Figure 8.

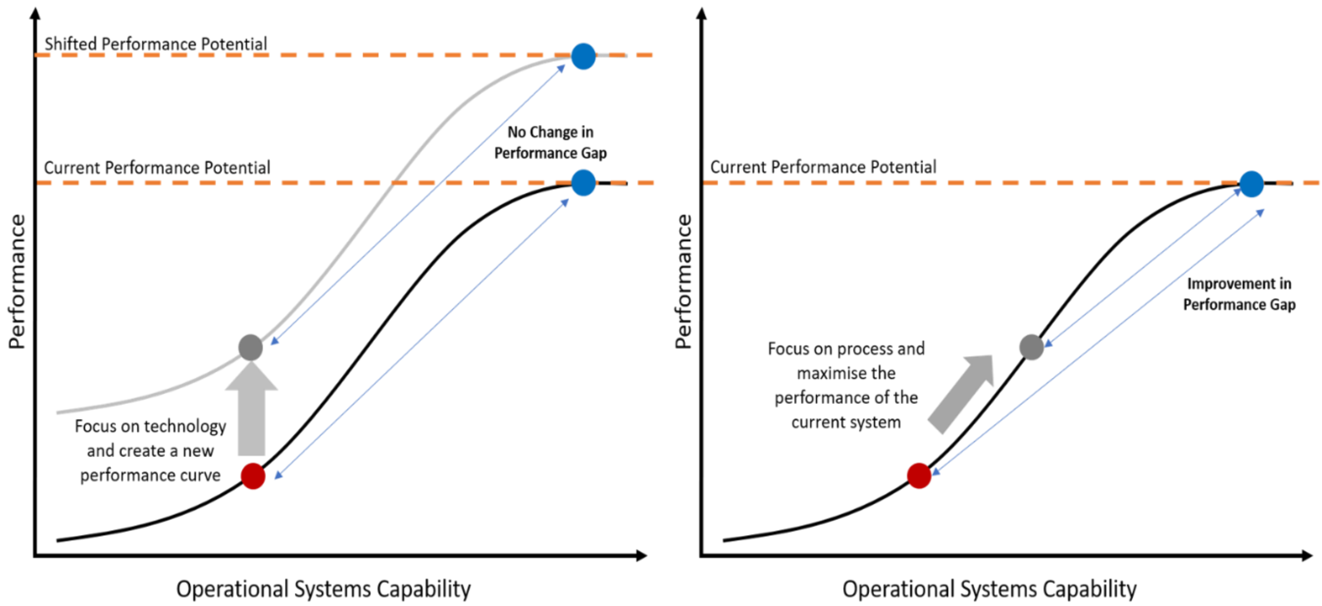

Figure 8: Changes in the performance gap based on focusing on improving processes vs focus on changing technologies [42]

5 THE CONCEPTUAL FRAMEWORK

As highlighted by its design principles, the pivotal aspect of the 4IR is the sharing and distribution of information and knowledge. By leveraging these principles; Interconnection, Information Transparency,Decentralised Decision Making and Technical Assistance , BIs could help more SMMEs stand a better chance at survival. This would primarily take the form of a shared system that gives BIs better access to solutions to the challenges they as BIs face. Some of the suggestions made to improve the BI space already see the opportunity that 4IR presents and focus on achieving a wider reach while promoting collaboration [40].

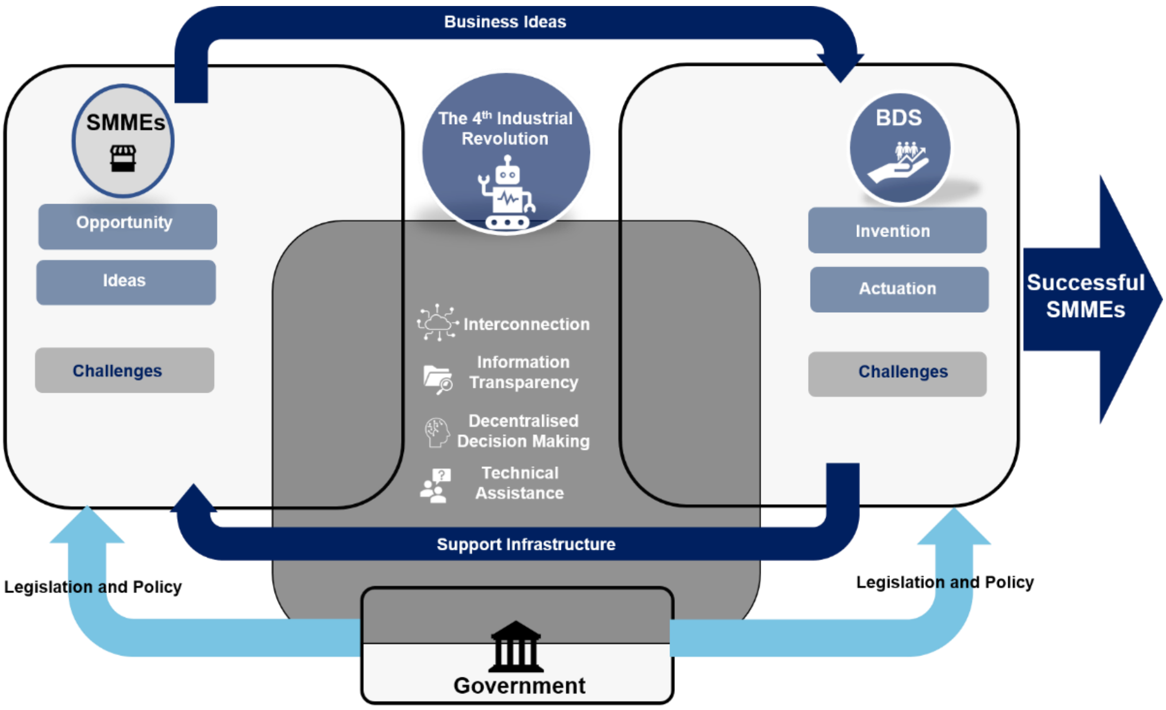

Figure 9: Conceptual Framework of the possible interaction of 4IR Design Principles in the BI space

The framework (Figure 9) suggests that the 4IR design principles can be used in four primary ways to unlock value and increase the efficacy of BIs;

- to harness and expedite the opportunities and ideas SMMEs bring to the BIs
- to improve the invention and actuation processes within BIs
- to address the challenges faced by both SMMEs and BIs face within Incubation
- to enhance the implementation of legislation and policy within the BI space

Its important to note that this diagram shows “the what” but again not really showing “the how”. It is a point of departure conceptual framework for future investigation.

6 CONCLUSION

In the study of BI efficacy in South Africa, it is time to reach beyond the ‘what’ question – what do successful incubators do, what challenges do they face—and instead respond to the questions: ‘how,’ ‘why,’ and ‘in what context’? A conceptual framework that provides a starting point for this has been presented in this paper. The framework supports the integration of 4IR design principles in the operations of BIs to enable them to compete in today’s global economy.

The successful development of business incubation programs is often measured in terms of impacts, effectiveness and sustainability and depends essentially on five inter-linked rings: public policy, private partnerships, knowledge affiliations, professional networking and community involvement [44]. It’s the realisation that these success measures are not dependant on technology but people, and how they intergrate with each other, that makes it essential to rely on the principles of 4IR rather than its technologes to develop the framework.

This paper outlines the complexity that currently exists in the space and highlights the global history of business incubators and industrial revolutions with the aim of understanding their essence and drives. The key takeaway from the above is that by looking back and establishing principles, it is then possible to take a step forward towards sustainable continuous improvement.

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THE RECORDING MUSIC INDUSTRY SUPPLY CHAIN AND INDUSTRY 4.0

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ABSTRACT

This paper explores the impact technological innovations have had on the music supply chain. The study investigates how these changes have affected the management of the South African music industry in the advent of the Fourth Industrial Revolution (Industry 4.0). The study focuses on four supply chain dimensions; the structure of activities, the choice of players, the governing mechanism and co-ordinating structure of supply chains. An exploratory research design was chosen to investigate and gain greater knowledge of the technological advancements in the South African recorded music supply chain. The data was collected by means of a document review and semi-structured interviews. The results indicate that the advent of the Internet has reorganised the industry and affected the way music is consumed. Technological innovations have opened new markets, created new opportunities for new entrants into the market and offer a mix of new and already known services. New offerings often require new partnerships, which in turn may change the network structure in the supply chain. With Industry 4.0, breakthroughs in innovations have progressed at an exponential rate, bringing entirely new capabilities and possibilities for change.

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1 INTRODUCTION

Music has been around for thousands of years.It has been a part of every culture and has pervaded every level of society, listening to music is a source of great entertainment for most people in today's era. However, music is a very serious business for the global music industry, with global recorded music sales equivalent to US$20.2 billion in 2019 [1].

During the 20th century the music industry saw a significant growth.The advance of music recording technologies, in the form of cassettes, CDs, DVDs, vinyl records, for example, have made music more accessible and created a global industry [2]. According to Graham *et al*. [3], while music as a physical product has changed significantly over time, the distribution mechanisms and division of labour within the industry have largely remained the same: musicians create music, record labels market, and distribute it, and listeners consume it. While this is the case, over the past few years, the way corporations have conducted and handled their business activities has undergone dramatic changes [3].

Technological innovations of the 20th century have enabled new intermediaries and entrepreneurs to enter the music market and deliver a combination of new and existing services [2]. Unique services also necessitate new alliances, which can alter the business model and network structure of thesupply chain, impacting the stakeholders in the network. To cope with changes, gain a competitive edge, and react quickly to changing marketplaces, business leaders are increasingly adjusting to new business paradigms that allow them to work more closely with their traditional and new business partners, including customers, throughout the supply chain [4].

Technological advancements have transformed the environment of the music industry along with the rules of operation and competition. Businesses are now competing on a global scale, most especially now that the music chain of physical product circulation has become less essential [3].

This study soughtto develop a more detailed understanding of how historical technological innovations have shaped the music recording industry in South Africa and how these innovations have affected the supply chain of music and the players within the industry. Similar studies indicate that the digital age has brought about major changes to the structure and operation of the music industry’s supply chain. The issue is that there has not been a comprehensive analysis of the impact of newer technologies and the companies that are pioneering these game-changing inventions. The research also investigated how these developments have influenced the management of the South African music industry's supply chain and how it is presently working, especially in the age of Industry 4.0.

2 LITERATURE REVIEW

2.1 The Music Industry Supply Chain

Porter [8] described a supply chain as a collection of interconnected suppliers and customers, referred to as links, actors, or players. In a supply chain, organisations form a network where upstream suppliers provide input, which the business then adds value to before moving it downstream to the next player, which may be another company or the end consumer [8].

Music, in all its forms, has become a product that can be sold and consumed, a way of generating money, so examining music as an industry from a business perspective makes sense [9]. Porter [8] was the first to introduce the value chain concept by considering an entity as a system consisting of subsystems, each with inputs, processes of transformation and outputs, all of which seek to add value to the provided product or service.

According to Hardaker *et al*. [11], the design of supply chains involves four interrelated dimensions, namely, the structure of activities, the choice of players, the governance mechanism; and the co-ordination structure.

Therefore, in this study, these four supply chain dimensions and the definition of the value chain were used to outline the developments in the structure and evolutionof the recording music industry's supply chain's design.

2.1.1 The structure of activities

As in the manufacturing process;the series of processes involved in getting the product from the suppliers of raw materials to the distribution of the final product to the customer, determines the supply chain structure [11]. Waltman [12] observes that, when it comes to cultural products such as music, this chain begins with an initial creative concept, which is then combined with other inputs to produce a cultural good or service. This includes a series of different players and activities that take the form of business units within a sector, within a corporation, or a company. In the case of the music industry, to reach a customer, music must be developed, generated, processed, replicated, and distributed, thereby constituting the value chain, as can be seen in Figure 1.

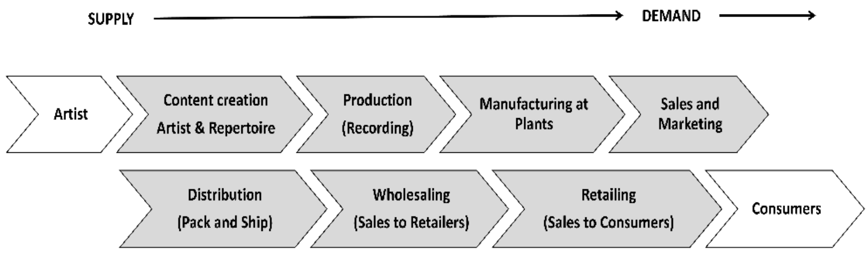

Figure 1: A traditional music industry value chain [3]

The Internet has changed the way record labels carry out their business operations dramatically. A comparisons to how the Internet has influenced the supply chain of music, listing the characteristics of both the core traditional and Internet supply chains activities, can be seen in Table 1 below.

Table 1: Structure of activities supply chain characteristics

Traditional Supply Chain	Internet Supply Chain
• Activities are serial interdependent • Sequential logic of activities in a linear value creation process • High vertical integration of activities/ resources • Physical goods/marketplaces (physical value activities)	• Simultaneous, parallel activities associated with multiple value creation processes • Focus on core competencies • Partnerships/collaborations allow sharing resources and capabilities • Increasing digital goods/marketplaces (virtual value activities)

The Internet, above everything else, has had a significant impact on how music is distributed. Music is increasingly being distributed in digital format. This disruption has allowed businesses to change their strategies and has promoted partnerships between traditional music companies and specialised online distribution companies. These online distributors are now commonly used to manage online sales and delivery operations [10].

Also, since the advent of the Internet, it has become much easier for record labels to enlist the help of third parties to enhance their product's value. According to Graham *et al.* [3], company operations now tend to be more networked than ordered in sequence, as can be seen in Figure 2. Operations seem to be more dynamic and flexible as well. Therefore, the invention of Internet has changed the framework of activities in the music industry, in terms of virtual structures replacing physical ones, and network structures replacing sequential ones [3].

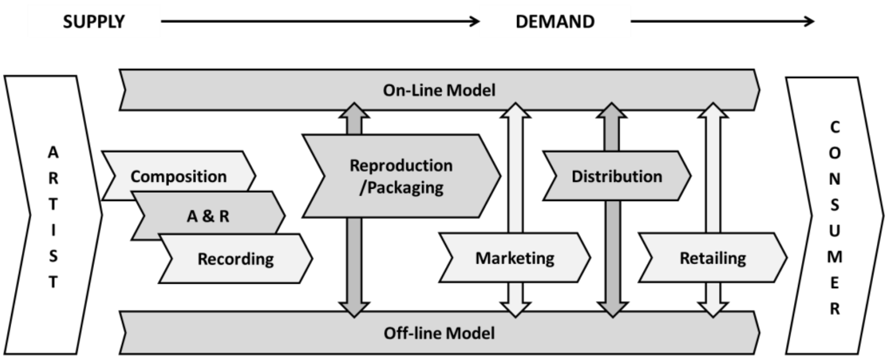

Figure 2: An Internet music industry value chain [3]

This dimension is linked to the degree of dynamism in a supply chain's selection of players [11]. Hardaker [11] further explains that the chain is very static when stakeholders in a chain are well well-known. Alternatively, the chain is very fluid if the participants in the chain change from one business opportunity to another. In between, there are variable degrees of flexibility in the choice of supply chain partners that are involved in the production and distribution of music. When all players belong to the same organisation, a supply chain is vertically integrated. Vertically integrated chains typically show a high degree of rigidity, since businesses can only select from companies they own or are willing to buy [3].

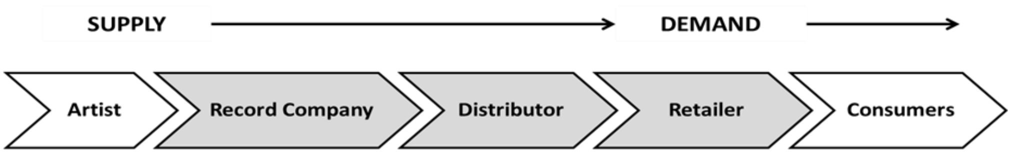

Figure 3: Traditional Music Industry Players [3]

Figure 3 shows the stakeholders in thetraditional music value chain. However, according to Ricardo [9], this picture is limited because it only depicts the system's core stakeholders. The supply chain for the music industry has historically been inflexible and fixed. Traditionally, players were well-known, and the number of players available in the music supply chain was small[9].

The Internet has removed the need for products to be physically distributed and retailed. It also makes it easier for both consumers and those involved in making and distributing music to communicate. Therefore, new specialist companies enter the market as entry barriers are removed, creating a greater variety of potential partners and new customer and supplier combinations [3]. As new combinations of organisations come together, the traditional, static music industry supply chain has therefore become increasingly dynamic, see Figure 4[13].

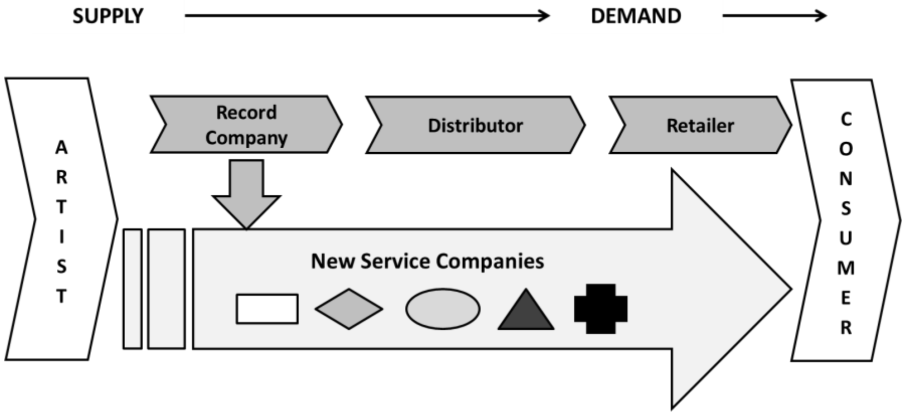

Figure 4: Internet Music Industry Players [3]

2.1.2 The governing mechanism

The governance dimension is concerned with the ownership and control of various supply chain players [11]. In a vertically-integrated supply chain, the dominant force is usually the company that links the other companies to produce the final product (Figure 5)[13]. The company would also have leverage over the chain's main resources and value measures. Otherwise, in the absence of vertical integration, each company can operate independently of others, with only a limited relationship with them.

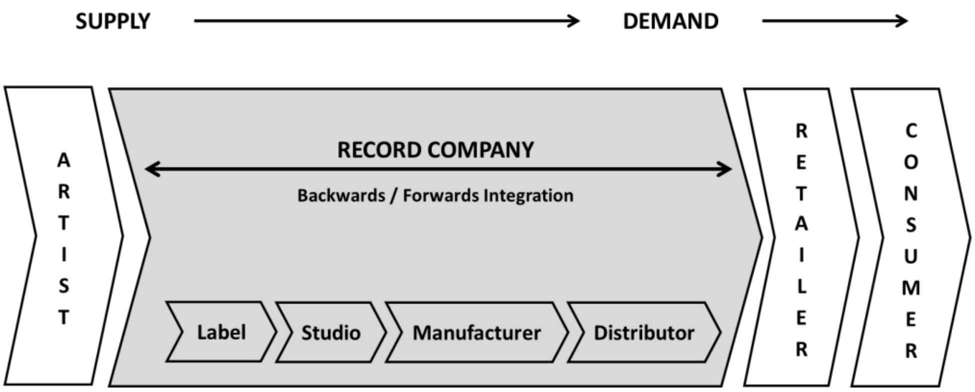

Figure 5: Traditional Music Industry governance [3]

According to Graham *et al.* [3], high market entry costs and a scarcity in the number of distribution channels have been characteristics of the music industry. These high costs are linked to the need for a strong market position to justify the initial operating expenses in Artist and Repertoire, recording, and manufacturing, as well as marketing.

As a growing number of musicians produce and sell music on their own, recording companies exhibit less governance through their supply chain [3]. While artists have become more self-sufficient, to benefit from their marketing knowledge, some artists continue to sign up with big record companies. In the digital age, Figure 6 shows the music supply chain, distinguishing between artists who try to sell directly to their fans and others who use the record labels [3].

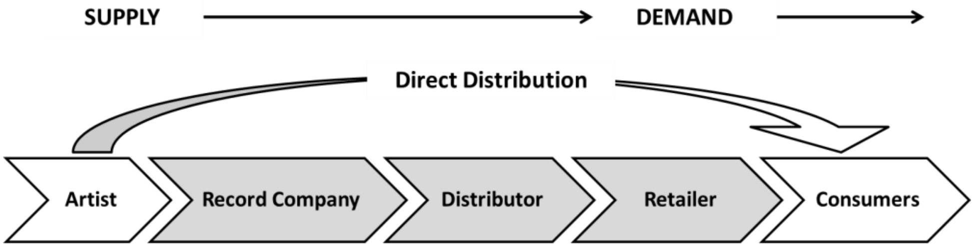

Figure 6: Internet Music Industry Governance [3]

Table 2 below, shows a contrast between conventional and digital era industry governing mechanisms.

Table 2: Conventional vs. Digital Governing mechanism comparison

Traditional Supply Chain	Internet Supply Chain
Major record labels hold a dominant position because of: • Entry barriers owing to high business and production costs • Economies of scale and scope (competitive advantage due to high vertical integration) • Complete control over distribution and marketing channels • Artist dependantthe on the record label • Consumers are limited (in terms of choice of music)	Elimination of record companies' monopolistic position: • Low entry barriers due to decreased business and production costs. • Economies of scale and scope are not applicable (vertical integration means no more competitive advantage) • Loss of the rank of gate keeper • Artists gain more controlover music and production activities • Consumers gain bargaining power.

Therefore, the Internet to directly link artists and customers, who have both gained greater bargaining power [3]. This declaration supports Porter's [15] assertion that: ". . . the Internet eliminates powerful channels and shifts bargaining power to consumers".

2.1.3 The co-ordination structure

The flow of knowledge, according to Bowersox *et al*. [14], is one of the most critical processes for supply chain co-ordination. Co-ordination takes place, for example, when orders for services and goods are communicated, stock levels are recorded, and demand for specific products and services is expressed [11].

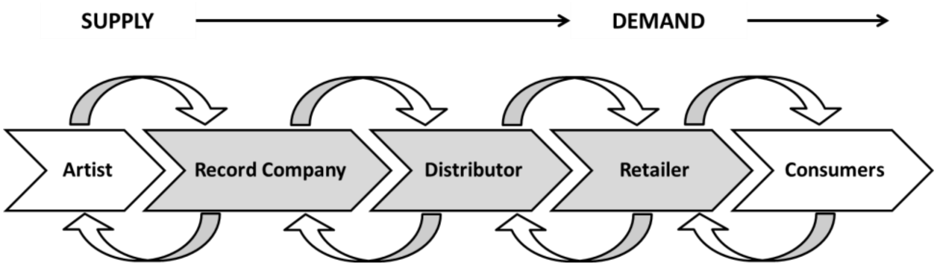

Figure 7: Traditional Music Industry co-ordination [3]

Traditionally, co-ordination in the music supply chain takes place in a hierarchical system and is largely between two groups (see Figure 7), as shown by the communication of goods orders between record labels, producers, and retailers.

Graham *et al.* [3] suggest that to support the knowledge needed to handle the selling of digital music, the existing coordination processes and frameworks would need to be modified significantly. The advent of Internet-based network technologies has empowered bodies in the industry to function in a cyber environment and interact with various suppliers and customers (see Figure 8). Nevertheless, doing business over the Internet presented a new challenge. When the number of product offerings increased, so did the need for digital coordinators to help parties locate each other. To meet the digital user's needs, music labels and artists have had to form relationships with these online outlets [3]. Digital coordinators will easily replace the coordination role of conventional intermediaries in digital marketplaces, i.e., a service that directs businesses and people to the data they need [3]. The number of physical intermediaries between the artist and the consumer has decreased, major labels have outsourced operations, and marketing and Artist and Repertoire roles have been reorganised to increase the ability to respond rapidly to market developments and new business opportunities.

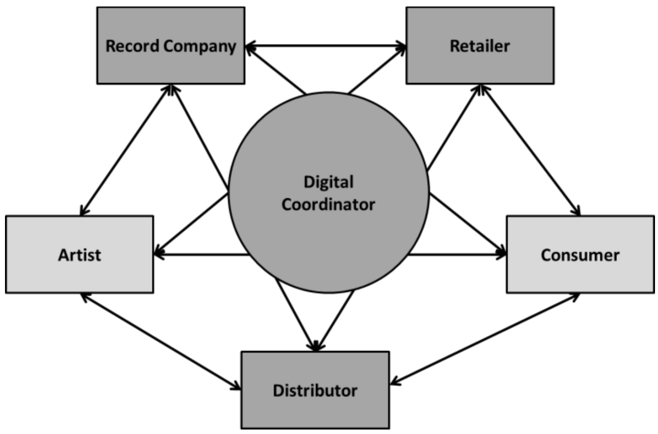

Figure 8: Internet Music Industry co-ordination [3]

2.2 The Fourth Industrial Revolution and Music

The World Economic Forum [16] describes the Fourth Industrial Revolution (Industry 4.0) as the advent of “cyber-physical systems” involving entirely new capabilities for people and machines. [17].

The arrival of Industry 4.0 is signalling the next era in supply chain management. Supply chain management, defined by Jacobs *et al.* [18], as “… a total systems approach to managing the flow of information, materials and services from raw material suppliers through factories and warehouses to the end customers”. This new age would put suppliers and clients together in an entirely new way, blurring the borders between the digital and physical worlds with Industry 4.0 technology and erasing conventional organisational boundaries [19].

Similarly, in the music industry, there are studies and projects in the technology world aimed at changing how music is created and consumed.

2.2.1 Artificial intelligence and Machine Learning

The science of teaching computers to perform human tasks is known as artificial intelligence (AI). Machine Learning is a branch of artificial intelligence that teaches machines how to think.

In the music technology world, there is a clear drive to make computers and robots create music. The most recent advancement is the creation of music using AI. The area of AI-assisted music has seen a dramatic growth in capacity and performance over the last two years. Projects like Google's Magenta, IBM's Watson and Sony's Flow Machines have taken their own shot at feeding musical laws and information into machines to teach them how to imitate human imagination and produce original music [20]. Algorithms and machine learning are also used by music streaming platforms like Tidal, YouTube Music, and Soundcloud to figure out their users' music preferences and listening habits.

2.2.2 Big Data Analytics

ORACLE [21] defines big data as data that contains greater variety arriving in increasing volumes and with ever-higher velocity. To simplify, Big data, is data from completely new data sources, is larger, and more complicated. Latest technological breakthroughs have reduced data storage and processing costs exponentially, making it simpler and less costly to store more data than ever before. More detailed and reliable business decisions can be made with an increased amount of big data that is now cheaper and more available [21].

In the age of streaming services, with tens of millions of users listening to music every minute of the day, music streaming services collect a mountain of implicit consumer data consisting of song preferences, keyword preferences, playlist data, geographic location of listeners, most used devices and more [22]. Big data analytics also helps to produce data on what motivates a listener, so that digital marketers understand why certain artists are more successful than others. This helps businesses recognise which of their business models are becoming redundant [23].

2.2.3 Blockchain

In today's digital age, storing, authenticating, and protecting data presents serious challenges for many organisations [23]. Blockchain technology is a type of distributed ledger or database that holds digital transactions records. Rather than providing a central administrator like a traditional database, a distributed ledger offers a network of chronologically evolving replicated databases that are coordinated using the Internet and open to anyone within the network (e.g., banks, governments, and checking companies).

Music can currently be streamed and downloaded at the click of a button, but payments can be slow and invisible to the people who make the music. In contrast to a world of non-disclosure agreements and black boxes, Blockchain technology provides transparency throughout the supply chain, enabling artists and their managers to see precisely how much money they are owed [24]. Blockchain's distributed, transparent, and cryptographic design enables people to trust and transact P2P with each other, rendering the need for intermediaries obsolete. This offers possible security advantages as well. While some of the predictions made for Blockchain technology are premature, it seems to have the potential to change the music industry at least [24].

2.3 Technology Companies in the Music Industry

Large technology firms have also started to exert leverage over some aspects of the music industry by acting as distributors. Companies like Amazon, Google, Apple, and Spotify make a lot of money even though they do not make their own content because they have established themselves as trustworthy music retailers [25].

Technology companies have recently shown signs of shifting their focus to content development as a complement to their distribution channels [25]. Businesses like YouTube, Apple, and Spotify, like a record label, have all the resources at their disposal to find, record, create, and sell original material for their own artists, and all have taken measures that show they are moving in this direction [25].

2.3.1 Google and Youtube

YouTube developed a data resource called "YouTube For Artists" with the aim of providing musicians with analytics on how people are reacting to their music [26]. As the world's largest streaming service, YouTube has access to an unprecedented amount of data, allowing the company to excel at artist discovery and create original content with a potential unmatched by any record label [25].

Google and YouTube have vast resources in a variety of fields related to the music industry. If Google or YouTube decides to make original music, they will be able to find, record, distribute, and publish music faster and more efficiently than any other record label [25].

2.3.2 Apple

Apple has started to work on original music, but it is their proprietary material that most closely resembles that of a record label [25]. Apple is looking for people with "senior level entertainment and media experience" to devise, build, and manage a multi-faceted original content and live projects program for Apple Music, iTunes, and the App Store [25].

Apple Music is now cultivating partnerships with musicians and other stakeholders in the music industry. Apple has signed exclusive distribution agreements with major artists and major independent record labels. They have also recruited several major label and music industry executives, including Jimmy Lovine, the co-founder of Interscope Records, to help them establish relationships with artists in the same way that a record label would [27].

2.3.3 Spotify

Spotify also launched two new programs: Spotify Singles and Spotify Live, both of which produce original material [25]. Artists on Spotify Singles record original music as well as cover other artists' songs, which are new performances or recordings of a song by someone other than the original artist or composer. These songs were recorded at a Spotify-owned studio in New York City and are only available on Spotify. Artists performing live in-studio shows are featured on Spotify Live.

According to Stabnau[25],Spotify is the most like a record label of the three. They have a wealth of analytic data, including weekly playlists featuring viral songs and artists, which can be used in artist discovery. They have the financial resources to record music, either by their own studio or through investing in an artist's album. They have one of the most used distribution systems on the planet.

2.4 Preliminary Conceptual Framework

A conceptual framework base on the literature is provided to guide data collection and analysis. The conceptual framework specifies who and what will be studied. Figure 10. is a preliminary attempt at listing the influences and players in the music industry's supply chain.

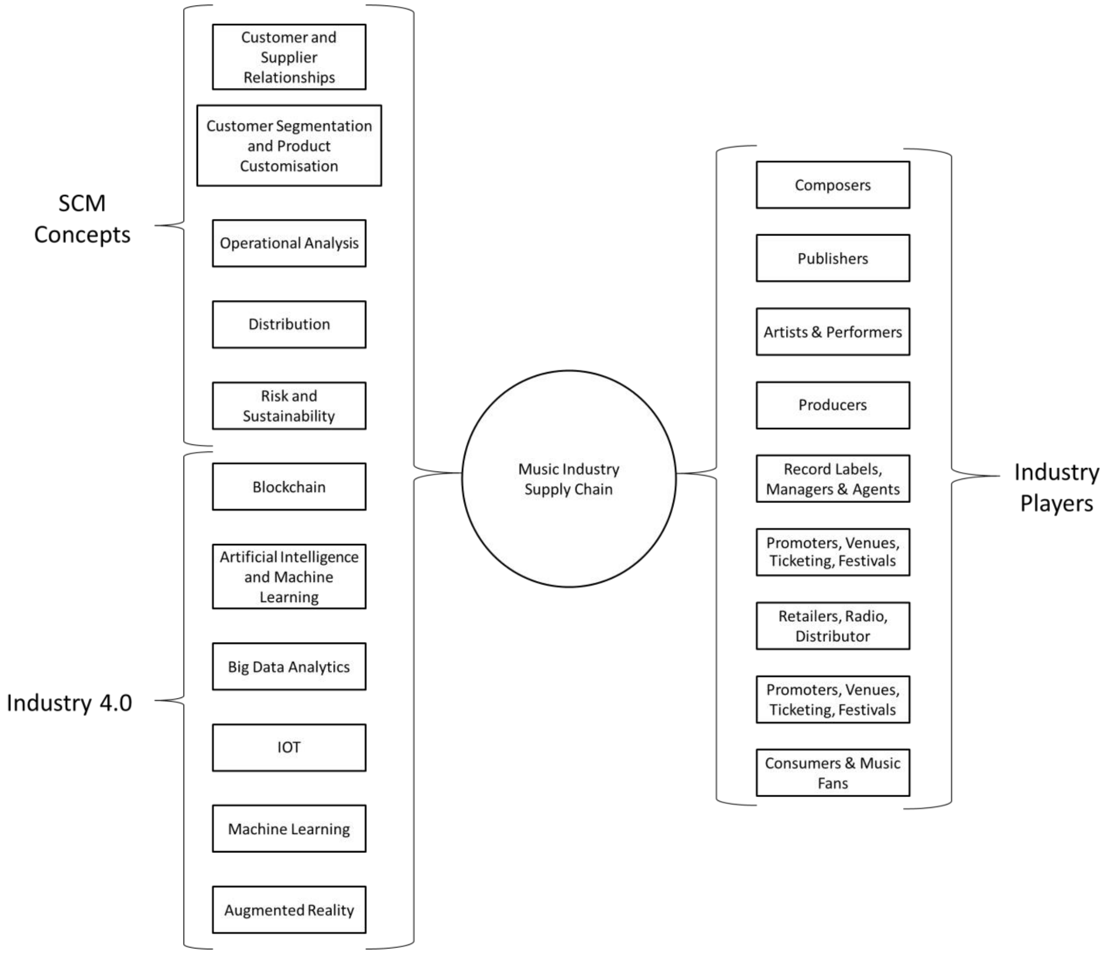

Figure 9: Preliminary conceptual framework for the music industry and the influences on its supply chain.

The illustration in the Figure 10 identifies the people and the variables identified as influential on the supply chain of music. Miles et al. [31] describe a preliminary conceptual framework as aninitial guide to the topic being investigated. As the study progresses,knowledge of the topic improves and the conceptual framework evolves.

3 RESEARCH AND DESIGN METHODS

The research studies the South African music industry, and its main aim is to understand the impact new technologies have had on the supply chain for music. Since this is a focus on investigating occurrences within a real-life context, an explorative qualitative approach was chosen to answer the research questions posed [5].

3.1 Data Collection

3.1.1 Primary data collection

The primary data was collected using semi-structured interviews with participants from organisations that are related to the study.These interviews were employed to obtain a perspective of the networks and business model types of the different industry participants. This was an appropriate method for determining the future state of the industry's supply chain from the perspective of the players because it allows for the collection of detailed information in an exploratory manner. According to Wahyuni [30] semi-structured interviews are usually chosen because they encourage two-way communication and can confirm what is already known and provide opportunities for learning.

Wengraf [6] states that lightly structured interviews are also appropriate for testing highly developed theories, most especially when those theories require data that a heavily structured interview schedule discourages.Wengraf [6] outlines an algorithm which can be used when designing and analysing interview material shown in the Figure 9 below. The algorithm is based on the primary research question and on the distinction between theory-language used in research questions and the interview-language to be used in interviews.

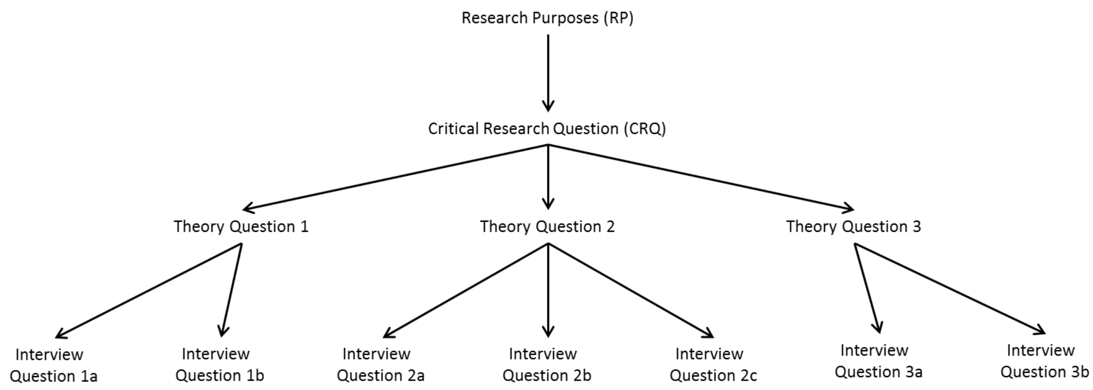

Figure 10: CRQ - TQ - IQ: Pyramid Model [6]

To structure the interview, open ended questions were developed and administered, using the algorithm in Figure 9. The list of questions to guide the interview process can be seen in Appendix A.

Twelve semi-structured interviews were conducted. Due to timing issues and the COVID-19 pandemic, the interviews were conducted over the Internet using Microsoft Teams and Skype videoconferencing platforms. The interviews were recorded.

Since the interviews were designed as semi-structured and semi-guided, each interview was approached more as a conversation rather than a questionnaire. Broad points which were also discussed included exploration of participants' prior understanding of Industry 4.0 technology, their experiences in the industry, their operational environments, and their strategies and outlook of the future. The propostions put forward by Graham et al. [3] and Hracs [28] are used to guide the exploration of the developments to the four supply chain dimensions and provide the broad basis the interview schedules followed, as can be seen below:

- Explore participants understanding of Industry 4.0
- Explore participants experience with the analogue to digital music transition; compare,
- Ask about the environment in which the participant operates.
- Explore thoughts on the Major labels' control over the supply chain,description, and feelings.
- Explore thoughts on technology companies creating more value than incumbents in the supply chain, even though music is not their core competency.
- Use participants experience to ascertain their recommendations for the payment of royalties and facilitation.

The semi-structured nature of the interviews allowed for more questioning and digression from the main topics while also allowing for exploration of the given answers. These topics and questions arose from the secondary data collected as outlined below.

3.1.2 Secondary data collection

The second type of data, secondary data, refers to information that is obtained from sources that already exist [7]. Data was gathered from the literature and the previous works of other scholars. Textbooks, journals, records from public agencies or phonographic societies, and the Internet were gathered as secondary data for this research in the form of a literature review.

3.2 Sample selection

In this study the sample is comprised of participants from record companies. In Johannesburg, the "big three" record labels have a headquarters or at least a main subsidiary. This city was chosen as a symbol of the music industry to draw broad conclusions. Participants in the interviews who worked for one of the "Big Three" were targeted. Participants from independent record labels that have entrepreneurial backgrounds were also sought out, as these participants were assumed to be innovative because of their entrepreneurial nature.Snowball sampling was used in this study to find interview participants. According to Cooper *et al.* [7], snowball sampling is a widely used tool in qualitative analysis. Cooper et al [7] further state that, snowball sampling is a good option when it is difficult to find the desired number of interviewees or when the respondents are hesitant to participate in the study. To find respondents, this strategy employs a referral approach: people from the target population were asked to provide information on how to locate other members of that population they know. As a result, the respondents assisted in identifying colleagues, acquaintances, or friends.A total of twelve (n=12) participants were interviewed in the study and the main characteristics of the participants are shown in Table 1 below.

Table 3: Main characteristics of the participants interviewed in the study.

Status	Particpant Category	Age	Education	Years in industry	Interview Method	Duration	Code
Artist	Major	27	Honours	10 +	Interview conducted via videoconferencing	1h5min	P1
Artist	Independent	23	Matric	4-6	Interview conducted via videoconferencing	40min	P2
Director of Indie-label	Independent	38	Honours	10 +	Interview conducted via videoconferencing	1h6min	P3
Music Technology Entrepreneur	Other	26	Bachelors	7-10	Interview conducted via videoconferencing	55min	P4
President of Indie-label	Independent	37	Honours	10 +	Interview conducted via videoconferencing	59min	P5
Radio Station Founder/Owner	Independent	30	Bachelors	10 +	Interview conducted via videoconferencing	49min	P6
Record Producer/Author	Independent	37	Honours	10 +	Interview conducted via videoconferencing	1h18min	P7
Studio Founder/Owner	Independent	37	Bachelors	10 +	Interview conducted via videoconferencing	47min	P8
Studio Manager	Major	32	Honours	7-10	Interview conducted via videoconferencing	1h24min	P9
Studio Manager	Major	30	Honours	7-10	Interview conducted via videoconferencing	1h11min	P10
Studio Manager	Independent	29	Matric	10 +	Interview conducted via videoconferencing	1h10min	P11
Supply Chain Business Consultant	Major	52	Honours	10 +	Interview conducted via videoconferencing	1h40min	P12

4 RESULTS ANDDISCUSSION

4.1 Industry Knowledge

A general divide in expertise was discovered as a common factor during interaction with the participants. In terms of how technological advances have changed the industry's supply chain, it seems that artists are the segment with the least awareness of the industry. In addition, four out of the twelve participants had previous knowledge of the supply chain's Big Data and Blockchain implications. Other interview participants had no previous knowledge of Industry 4.0 related innovations and their potential implications on the network and operations, as this participants explain:

> *"I have heard of the Fourth Industrial Revolution but did not know what it was. I remember the government setting up some sort of a commission, but I did not pay it much attention…" (Interview: P9)*

There is some information procured from the informants that had little or no connection with what was written in the literature. Some of these misunderstandings are trivial and have no bearing on fact, but a few are critical to understanding the supply chain's current state.It was discovered that even the most experienced sources did not have all the necessary details. This is an intriguing concept, but it also demonstrates that "errors" do occur while interacting with people.

There were also a varryingopinionis on how deeply technology companies were embedded in the industry. Large technology companies have started to exert leverage over some aspects of the music industry by acting as distributors. These technology companies have recently shown signs of shifting their focus to content development as a complement to their distribution channels as stated by Stabnau[25]. Most of the participants were unaware of Artificial Intelligence and machine learning research and development that technology companies were doing. Many of the participants were opposed to the concept of computers ever replacing artists and creators in the supply chain, but they had a limited understanding of how robots, computer systems, and algorithms were already a part of their daily routine. One participant, for example, denied that machines could make music on their own, but acknowledged that they had already taken over some of the artist's creative processes:

> *"I do not think computers will make music like people because they lack the feeling that goes into a piece of art." (Interview: P2)*

When asked about computers aiding his production process:

> *"I admit sometimes I am lazy, and I use programs to finish up a piece of music or an idea that I have… The Digital Audio Workstation that I work with has this interface that can complete a chord progression for you… It is like a cheat sheet." (Interview: P1)*

When asked if that idea was a form of artificial intelligence that, if further developed, could enable computers to start and finish pieces of music entirely without human intervention. The respondent replied:

> *"I hadn't thought of it in that way. Maybe computers can write music…. Can they really do that?" (Interview: P1)*

4.2 Industry 4.0 and the Supply Chain of Recorded music

The rate at which new technological innovations are developed and implemented has had a significant impact on the South African music supply chain. Technological advancements will fuel growth, making the music industry more efficient. Massive technology companies will disrupt and replace major record labels, which have long dominated the industry, by behaving like record labels; discovering, recording, and promoting artists as well as producing original music content on their own digital platforms. The implication of these disruptions on the supply chain of music is outlined in the following sections.

4.2.1 Structure of activities

In line with the global industry, the South African music industry's supply chain and activities have been drastically altered because of rapid technological advancements. The way record companies do business has been influenced by digital technology, which has been made easier to introduce thanks to the Internet's widespread impact. The amount of data being transmitted, as well as the variety and speed at which it can be transmitted, has created a gap in the network for big data intermediaries. Most interviewees (n = 7) agreed that they are increasingly seeking help from outside organisations and other people in their network to interpret the large amounts of data available on the Internet and better communicate with customers. This has been brought about by understanding the range of possibilities posed to them using Big Data Analytics.

Technology companies have successfully developed online sales services in the form of music streaming platforms in response to the increased digital consumption of music, both legally and illegally, a feat that the major labels have struggled to achieve. The majors' approach has also shifted to working with specialised distribution networks, which is now seen as a more competitive online distribution business model.

The South African networked system of business operations has grown in size and variety, displacing the sequential structure entirely. Physical bodies have been replaced by virtual entities. These findings correspond with Graham *et al*.'s [3] predictions that the framework of operations beyond the internet age will be a dynamic constellation of virtual operators in a digital product and service market.One of the factors that enables the dynamic network of actors is the advancement of digital technology.The findings are in line with Graham *et al*. [3] and further emphasise Hracs' [28] view that the music industry will be restructured as technology transforms independent music production from a niche market to a commercial model.

4.2.2 Choice of players

The need for physical music delivery is decreasing rapidly. The internet, e-retailers, and streaming platforms have made it easy for consumers to connect with those involved in music production as well as supply chain intermediaries. This result supports Graham *et al*.'s [3] assertions that as entry barriers are removed, new specialty companies will enter the market, and a wider variety of potential partners will arise; new combinations of customers, suppliers, and business partners will emerge to overtake incumbents' dominance.

In the current supply chain setup, relationships range from tight alliances to loose collaborations. Examining the latest online distribution approach of major record labels provides further support for the preference for long-term relationships. Most record companies do not sell their artists' music directly on their websites, instead providing links to stores that take a cut of the sale, such as Amazon (15% commission), iTunes (30% commission), and Google Play (30% commission) [25]. Even though they all license content to various music streaming sites, all the participants (n = 12) agreed that record labels do not want to fully relinquish ownership of their content. This finding was in line with Graham *et al*.'s [3] assertions.

Furthermore, record labels collaborate with several technological partners on strategies for digital distribution and copyright security; as all the participants (n = 12) pointed out, these relationships are more long-term than short-term in today's supply chain setup. According to Hracs[28], the music industry is going through a supply chain deconstruction phase, which will result in a multitude of potential players participating in the music supply chain, each with their own specific source of competitive advantage partnerships. This is reinforced by the fact that large technology companies have also started to exert control over some aspects of the music industry by acting as distributors. Even though Amazon, Google, Apple, and Spotify do not create their own content, they make a lot of money because they have established themselves as reliable music retailers [25].

4.2.3 Governing mechanism

According to Graham *et al*. [3], as more musicians produce and sell music on their own and become more self-sufficient, record labels will show less governance over their supply chain. This is something that all the participants (n = 12) agree on. The number of self-released or independent artists is growing, and the intern*et al*lows them to distribute their work worldwide. The gap between their product distribution and that of major label artists could not be determined, but South Africa is a nation where 56.3% of the population is expected to be online by 021, with that figure expected to rise to 62.3% in 2025 [29].

According to the findings, the Internet now allows consumers and artists to communicate directly, and both parties are gaining bargaining power. This appears to back up Porter's [15] argument that the Internet undermines strong networks and transfers bargaining power to customers.

The consensus (n = 12) from the interviews was that governance processes will evolve in the future. This is due to the emergence of a new type of record label: technology companies are increasingly replacing record labels as a means of discovering, recording, and promoting artists, and they are also starting to create original music material. According to the results of the study, this trend will continue, potentially replacing major labels as the leaders of the industry.

As a result, all the participants agreed (n = 12) that record labels are unlikely to remain the strongest player in the music supply chain, and the participants also indicated that the recording companies' dominant role would be undermined. This finding contradicts Graham *et al*.'s [3] arguments.

4.2.4 The co-ordinating structure

To support the Big Data required to handle the selling of digital music, all the respondents (n = 12) agreed that conventional coordination processes and systems would need to be significantly altered. Music industry companies can now operate in a virtual world and negotiate with many suppliers and consumers thanks to the advent of Internet-based digital distribution technologies [3]. Graham *et al*. [3] and Hracs[28], on the other hand, cited the difficulty of conducting business over the Internet. When the number of product offerings grows, so does the need for virtual navigators that can help stakeholders locate each other. Artists and music labels have started to develop partnerships with streaming platforms to reach out to the digital audience. In virtual marketplaces, these intermediaries are rapidly replacing traditional intermediaries' coordination position, addressing Graham *et al* [3] and Hracs' [28] concerns.

In terms of coordination, the results show that there has been a significant decrease in the number of physical intermediaries between the artist and the customer, as well as a rise in major label outsourcing of activities. The streaming services, which allow major labels to coordinate their operation with customer demands, are viewed as the most important elements in these new network architectures by all the participants (n = 12).

Traditional intermediaries, such as physical stores, are losing ground, if not completely disappearing. In the music industry, the Internet is now the primary infrastructure for conducting business electronically. According to Graham *et al*.'s [3] predictions of a potential future supply chain, communication and coordination in the music industry will no longer be hierarchical and dyadic, since anyone will communicate with everyone, this is directly in line with the findings. Consumers, as well as artists and record labels, have begun to connect. As a result of the interviews, the streaming platform has gained widespread acceptance for music sales and distribution.

5 CONCLUSIONS

The aim of this paper was to look at how technological advancements are changing the South African music industry supply chain. Based on literature review and semi-interviews with a variety of stakeholders, it was determined that the music industry's network is evolving, and that technology is playing a significant role in restructuring operations.

Historically, the major record labels used to control the production, distribution, and consumption of music; however, the Internet, increased digital distribution, and the music streaming business model have changed that. More and more business is being conducted out electronically and many different types of business models have emerged because of new partnerships. This has also brought the era of physically distributing music to an end. Therefore, the old structures of physical intermediaries are being replaced by new virtual ones. The research also discovered that the vertically integrated supply chain has been replaced by a more complex and versatile network system, reducing the dominance of big record labels that no longer own and manage the major distribution networks.

The South African music industry is made up of a variety of players who are gradually forming an interconnected network, a flexible spider-web-like network that varies significantly from the conventional horizontal chain of actors. According to the research, the number of actors is increasing, and independent artists now have full creative control over the direction and quality of their music and related goods. They have complete control of how they function and can now make music almost anywhere. Technology enables artists to reach the market and sell directly to customers, fully disseminating the conventional music supply chain through the various channels available to independents. On the other hand, to take advantage of these possibilities, musicians must first conquer a new and complex set of obstacles. Even though barriers to entry such as the high market entry costs and a scarcity in the number of distribution have been greatly reduced,the market is still rife with complexity and competition.

By acting as distributors, large technology companies have begun to exert influence over certain aspects of the music industry. As a complement to their distribution channels, these technology companies have recently shown signs of shifting their focus to content development [25]. If this prediction comes true, the Big 3 record labels (Universal, Warner, and Sony) will be replaced by a new group of digital media labels, which will include Apple, Google and YouTube, Spotify, and possibly Amazon and Facebook. These new labels will be more competitive and capable of responding more quickly to changing consumer conditions [25]. These businesses' entrepreneurial, risk-taking mindsets, combined with a wealth of analytic data that can be used to gain a significant competitive advantage over their competitors, will provide them with more room for growth and longevity than traditional record label models [25]. As this respondent states:

6 RECOMMENDATIONS

An opportunity for further research is to seek out new stakeholders who have held executive positions in major recording companies. These participants could provide a lot more insight into the majors' strategies in an increasingly competitive market. Engaging with more experienced stakeholders may assist in further developing a research area or topic. In view of the skewed record number of publications across countries other than South Africa, a future study could investigate if there is a shortage of knowledge or interest in the subject.

During the interviews, a common theme that arose was the degree of government intervention in the sector. The government can play a variety of roles in the music industry, but whether by commission or omission, it still influences the network's outcome. Since private funding is difficult to come by, stakeholders exposed an over-reliance on their own money and labour to build and manufacture, rendering their career a high-risk one. They also mentioned a shortage of public funds or their distribution. An inquiry into government involvement in the industry, including how much public support and regulation is needed to keep the industry going and promote education, creativity, and innovation, is one direction the research could go.

7 LIMITATIONS AND DELIMITATIONS

The sample size was more than adequate, and the responses yielded insightful results; however, some limitations of this study include the fact that the sources for this paper's interviews are from the Johannesburg region, which was assumed to be representative of South Africa’s music industry. Also, the participants are mostly in lower positions within their respective companies and a lot of the respondents work for similar companies, raising concerns that the image of the companies is too restricted. The companies profiled in this research are just one link in the chain. For example, only respondents from major and independent labels were interviewed, even though many other types of business models may provide more innovative perspectives outside of these companies.

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APPENDICES: THE RESEARCH INTERVIEW MODEL

Since the interviews were designed as semi-structured and semi-guided, this was approached more as a conversation and not as a questionnaire.

The questions posed in the interviews, sought to gain insight into the music industry, technological innovations in the industry and the effect of the fourth industrial revolution on the industry. To illustrate, the participants' understanding of the following points were sought.

- The potential impact on business and the supply chain presented by new technologies.
- The Impact on the different players and how these technologies are shaping the future of the music industry

Questions

Players in the industry

1. How important have different players and/or services been to the operation and development of your businesses/craft over the past five to ten years (List the players).
2. Who are the players with whom you currently interact with the most?
3. What about the players with whom you expect to interact with the most soon?
4. What would you say the strengths and weaknesses of the sector that you currently operate in are?
5. Who do you think are the strongest and weakest players in the industry now?

The Internet's transformation of the music industry supply chain, with some of the major changes being the electronic distribution of music, piracy and artists bypassing the record labels and marketing their own music. This also resulted in increased information reach and which provided an extra boost to the growth of the music industry.

6. Do you see Industry 4.0 technologies having the same kind impact on business activities as the Internet and digital technology did?
7. How do you think this change has impacted the roles of the major labels in the music supply chain? Do you see labels remaining the strongest players in the industry? Or greater influence continuing to shift to independents or other players? 115
8. How does your label choose and sign new artists? Is there a criterion you follow? Or do you have any idea how this is done?
9. What about the physical music chain stores, like Musica, Look & Listen etc. that have dominated the industry on the consumer end of the supply chain for a long time, closing even as recorded music sees its highest sales since 2014. Do you see an end to the music retail store? Why do you think they could not just move their models to internet-based retailing or distribution?
10. Do you think technology companies will have even greater roles in the future?
11. In your opinion, do you see independents forming their own networks, outside of the major labels influence?
12. Do you think big labels will bring Industry 4.0 specialists in-house or sub-contract and focus on their core competencies? What are your views? What is your company's view? In terms of partnerships, what will the nature of these relationships be? Long term to short term? Formal or informal?

Music streaming platforms, such as YouTube, Spotify, Deezer, Tidal, and Apple Music; at one point seen as disruptive to the industry, are now among the most used tools to access music nowadays.

But with the advent of Blockchain technology, innovators such as the British singer and songwriter Imogen Heap, are building what they call a "fair trade" music industry that aims to sidestep "middlemen" platforms like iTunes and Spotify to give musicians more ownership over the money and data produced by their work using Blockchain technology. Blockchain technology essentially offers transparency through the value chain, allowing musicians and their managers to see exactly how much money they are owed, as opposed to a culture of non-disclosure agreements and black boxes.

13. What are your thoughts around the idea of musicians having more control and ownership?
14. Do you know how revenue is distributed through streaming platforms?
15. Do you think a platform based on Blockchain technology has the potential to undermine and maybe render the existing streaming platform model obsolete?
16. Based on this premise, how viable is a technology like Blockchain? Is it a pressing need or something that would just be cool to have as an option? 116
17. With the promise of unrivalled transparency. Could this be the end of music piracy as we know it? Do you see other problems or forms of piracy emerging?
18. Blockchain technology might be premature, but it seems to have the potential to change the music industry and render intermediaries like SAMRO and CAPASSO obsolete. Do you see this happening in the future?

Computers and music

19. Do you have any experience using analogue music equipment?
20. In the digital age, it is a lot easier for artist to make music themselves as opposed to booking sessions in the more established studios. Similarly with marketing, today's artist can literally do what traditional labels di a long time ago all by themselves now. Do you think it advantageous for an artist to be a jack of all trades?
21. Have computers made the process of making music easier? Do you see a greater dependence on computers in the future?
22. There is a strong push in the music technology world, to have computers and robots produce music. The most recently it has been AI, or Artificial Intelligence, getting involved in the music production. What are your thoughts, do you ever see computers replacing the music producer and composer in the value chain? A restructure was required to support the information necessary to manage the sale of digital music. Conventionally, information flow was sequential Artist-record company-distributorretailer-consumer. The Internet changed that, now everybody can communicate with everyone in real time.
23. Was there ever a point where you thought you need to change your operational/process/marketing/distribution strategy? What event inspired this?
24. With bigger and larger data sets do you see another restructure for coordinating the SC in the future? Do you see an opportunity for companies that can process the vast information flowing that is now available to music companies? 25. Music streaming platforms are on the rise and stronger before, a lot of the consumers information will now flow through the platforms, do you think the control and understanding of data will yield competitive advantage for the streaming platforms?
25. Traditionally major labels have sought to control the distribution infrastructure of music, through acquisitions etc. Do you think labels will one day control the biggest streaming platforms? Or ever pursue such a strategy? 117 27. What role do you think the consumers will play in the future? Where AI, social media and technology can be effectively be used to market and influence what the consumer listens to? Do you think the platforms will be used to push certain artists/musicians to the forefront? What about the small labels?

IMPLEMENTATION OF WAREHOUSE LEAN TOOLS FOR THE IMPROVEMENT OF PROCESS CYCLE EFFICIENCY. A CASE OF 3PL SERVICES

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ABSTRACT

The implementation of Lean in the warehousing environment is gaining attention due to its contributions in third party logistics and total supply chain operations. The study aimed at examining process cycle efficiency in the warehouse processes of a third-party logistics (3PL) company. The study is case study in nature considering a real-time problem of both management and customer's dissatisfaction. Value stream mapping and warehouse Lean tools were used to carry out the evaluation. The evaluation shows the present value added and non-value-added time, process cycle efficiency as 92700 s, 140460 s and 40 % respectively. After the implementation of the warehousing Lean tools, there were improvements in the parameters as process cycle efficiency increases to 70% while the non-value-added time deceases to 39069 s. An improvement framework was proposed for the improvement of process cycle efficiency across the warehouse processes.

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1 INTRODUCTION

There has been increasing competitiveness among companies which is becoming peculiar in warehousing environment both at third party logistics and total supply chain operations [1-2] using Lean approaches without compromising productivity [2-5]. Related to this kind of operations are inbound and outbound operations that if properly managed, can enhance productivity of the entire business [6-8]. Organizations into logistics and warehousing have been searching for effective tools and techniques that would enhance the productivity of their operations [9]. This can be achieved leveraging on Lean Manufacturing [9]. Lean has been one of the most powerful managerial philosophies in recent history [10-13]. At the heart of successful implementation of Lean, comes the concept of non-value adding activities in a particular system [6-9]. Warehouse wastes reduction practice is defined as the set of activities undertaken by an organization to increase the overall efficiency of the system. According to Abushaika *et al* [9] waste is referred to as anything less than the optimum activities necessary to perform a particular process. Lean was introduced as production strategy which is now widely accepted by several industries [9]. Major areas of research where productivity improvement has been given utmost attention is within the field of logistics and supply chain management [9]. Research has been carried out in the areas of Lean Transport [14], Lean Purchasing [15] and Lean Supply Chain [15-16]. However, the focus on warehouse operations from Lean perspective received less attention compared to other logistics functions [13, 17]. The target of Lean Warehousing (LW) implementation is that productivity optimization in the warehouse operations will ultimately be reflected in the logistics performance of the supply chain [18-20].

Despite the great importance and relevance of Lean techniques to warehouse processes, few papers have been published about this topic and there are several plausible research gaps to be explored [21-22]. For Bozer [23], the use of Lean in warehouses does not present the same level of maturity of the application observed in the factory environment, and there is ample possibility for research that develop new tools, models, etc. Few that have contributed to improvement of warehousing operations are Bowersox *et al.* [24]; Moussa *et al.* [25]; Phogat [26]. The focus of their studies was on productivity improvement based on location and storage strategy of warehouses and study of more efficient techniques of material handlings. By reducing the existing waste in these activities, values can be added to customers' demand likewise improvement in the whole warehouse processes [27]. Lim *et al.* [28]; Luo *et al.* [29] and Moussa *et al.* [25] also worked on productivity improvement in warehousing focusing on technologies advancement implementation.

Non-value adding activities have tendency to be much in warehouses due to the nature operations they undertake [30-31]. The principles and managerial tools of Lean philosophy have been typically applied to improve the internal logistics of the organization and not the main warehouse [32]. Thus, there is an opportunity to minimize non-value adding activities of warehouses through identifying waste activities. The few scholarly works on LW have mostly centred on efficiency improvement in a specific operation in the warehouse environment to reduce the time and cost of this operation. However, literature still dearth in the application of warehouse Lean tools to assess the level of wastes or non-productive practices across all the warehouse processes. Therefore, development of assessment tools is particularly necessary, as the implementation of any LW activities should start by evaluating the level of non-value adding activities in the current system [17]. The novelty of this research addresses this gap in literature and propose a framework to improve productivity across warehouse operations. Therefore, the purpose of this study is to empirically examine process cycle efficiency in the warehouse environment considering all the warehouse processes with objective of improving on the productivity to meet up with the warehouse Lean standard.

2 RESEARCH METHODS – CASE STUDY RESEARCH

The methodology adopted in the study is case study. This method illustrates how LW is used to evaluate the existing warehouse processes in a 3PL operated company in South Africa based on productivity. The study also presented lessons learnt and managerial implications of LW implementation. The case study method was chosen because it offers flexibility in design and implication by allowing both quantitative and qualitative analyses, which are more sensitive to organization complexities phenomena [33-36]. A case study method offers a means of investigating complex and critical functions of the value chain [37-38]. Another advantage of the method is that it makes direct observations, collect data in a natural setting [37; 39]. In this study, a real-time problem of warehouse inefficiency was considered. The gathered data were based on suppliers', customers' and warehouse operations. The assessment of the warehouse productivity in terms of process lead time focus on the core warehouse processes of receiving, put-away, storage, picking, packing and shipping, using value stream mapping and warehouse Lean tools like supplier involvement, customer involvement, 6S, process confirmation, structured communication, performance management, Plan-Do-Check-Act (PDCA), problem solving, work instructions and warehouse visualization. These tools are valuable for diagnosing and resolving sets of warehousing problems [39-40]. Qi Macros application embedded in Microsoft Excel is used to design the value stream mapping for the process value chain. The overview of the Lean tools is presented thus:

2.1 Value Stream Mapping (VSM)

It is a Lean Manufacturing tool suitable for the analysis and design of the flow of materials/ information that is required to deliver products to customers [41]. Also, it assists in highlighting the problem areas.

2.2 Process Cycle Efficiency (PCE)

It is defined as the ratio of value-added time to total time of a process [42]. This is expressed as equation 1.

$$PCE = \frac{VDT}{TT} x100\% \qquad (1)$$

Where:
PCE is the Process Cycle Efficiency
VDT is the Value-Added Time (s)
TT is the Total Lead Time = VDT+NVDT *(2)*

Tables 1 to 11 present the Lean tools and their corresponding Lean practices used for the assessment of the warehouse's productivity. They are used to establish warehouse lean maturity.

Table 1: Suppliers Involvement construct and measurement Items

Construct	Description	Measurement Item
Sup. 01	The lean practice is aimed at good relationship between suppliers and warehouse operator in terms of supplier's feedback, Just-in-Time delivery and supplier's development	Is the warehouse in close contact with suppliers
Sup. 02		Is there feedback to the suppliers on the inbound delivery performance
Sup. 03		Is there any attempt to establish long-term relationship with suppliers

Construct	Description	Measurement Item
Sup. 04		Is there any standardized supplier certification method
Sup. 05		Is there provision of information on inventory position to suppliers
Sup. 06		Is there provision for efficient material handling and flow by using appropriate means

Table 2: Customers Involvement construct and measurement Items

Construct	Description	Measurement Item
Cust. 01	The lean practice is aimed at good customer-client relationship in terms of customer feedback and Just-in-Time delivery	Is the warehouse in close contact with customers
Cust. 02		Is there feedback from the customers on the outbound delivery performance
Cust. 03		Is there any active involvement in current and future value-added logistics offerings by the customers
Cust. 04		Is there frequent sharing of current and future demand information with planning department

Table 3: 6S Involvement construct and measurement Items

Construct	Description	Measurement Item
Select 01	it aimed at systematic way of ensuring and improving orderliness, cleanliness, visualization and safety in the warehouse	Are unnecessary, unused and defect things, accessories, materials, equipment, tools, storage bins and others removed?
Select 02		Is all unneeded and old information in the working area removed? (Bulletins, work instructions, orders, target deployments, working results, etc.)
Sort 01		Are things at workstation arranged by usage frequency and according to ergonomic aspects?
Sort 02		Are there markings within the working areas?
Shine.01		Are workstations and machines properly cleaned and therefore free of dirt and tidy?
Shine 02		Is the working environment free of dirt?
Shine 03		Are there cleaning schedules and/or checklists (are in the cleaning schedules/checklists all relevant tasks defined by name, described and scheduled?)

Construct	Description	Measurement Item
Shine 04		Is all relevant cleaning equipment available and at the designated place (cleaning board, cleaning trolley, cleaning cupboard, etc.)?
Stand 01		Are there only the corresponding things at the marked places? (floor spaces, shelves, working spaces, cupboards)
Stand 02		Are the associates of all shifts informed about targets and procedure of 5S? (5S standard process, checklist cleaning rules, process confirmation, etc.)
Stand. 03		Are the existing cleaning schedules visualized and verifiably used in daily business? (scheduling and execution)
Sust. 01		Are defined standards met and continuously improved? (Done process confirmations, filled-in task cards, etc.)
Sust. 02		Are the established boards up to date, does the warehouse work consequently and sustainably with relevant tools (OPL, milestone plans, VSM/VSD, problem solving method, etc.)?
Sust. 03		Is a regular monthly 5S self-assessment executed from operational/warehouse manager?
Safety 01		Are safety devices (handrails, balustrades, security devices, etc.) available and ok?
Safety 02		Is the allowed maximum stacking height/weight of transport and loading devices met?
Safety 03		Are fire extinguishers available/at designated place? (only relevant when fire extinguisher movable)

Table 4: Warehouse Process Confirmation construct and measurement Items

Construct	Description	Measurement Item
Inbound 01	It is a lean tool that aimed at checking if defined process standards are followed	Receiving book in ERP within stipulated time?
Inbound 02		Are there discrepancies that were not reported or solved?
Inbound 03		Are the damaged products in receiving area clearly identified?
St.& Hand 01		Are all locations properly labelled?
St.& Hand 02		Is the storage conditions measured, documented and deviation addressed?

Construct	Description	Measurement Item
St.& Hand 03		Is repacking according to work instruction done properly?
Outbound 01		Are items being picked and packed ready for transport as per KPI?
Outbound 02		Are deliveries properly packed and labelled?
Outbound 03		Are there any pending return items
Qual. 01		Are all non-conforming items properly identified and labelled?
Qual. 02		Are stock discrepancies analyzed and addressed?
Qual. 03		Is scrapping process done properly and documented?
Qual. 04		Annual or permanent stock taking completed?
Qual. 05		Contract for services self-audit completed?

Table 5: Warehouse Structured Communication construct and measurement Items

Construct	Description	Measurement Item
SC 01	It is a lean tool that ensures that communications are defined in line with agenda, participant, in accordance to schedules	Is there clearly define communication route with regards to agenda, participants, contents, duration and frequency per meetings
SC 02		Are there display of standardized communication schedule on CIP board, pentagon or other official information board?
SC 03		Is there usage of CPI to regulate actions to be taken?
SC 04		Is there involvement of all associated by ensuring information flow top-down and bottom-up through meeting schedule?
SC 05		Is there design and execution of internal customer survey?
SC 06		Is feedback shared with associates for correction, action in PCDA format and closure of PDCA loop?

Table 6: Warehouse Performance Management Implementation construct and measurement Items

Construct	Description	Measurement Item
PM 01	It is a lean tool that monitors both performance and improvement measures and to manage deviations from standards on a daily basis	Is there any established and usage of mandatory KPIs to be measured at least monthly as reported to logistics Department?

Construct	Description	Measurement Item
PM 02		Are all monthly KPIs (inbound and outbound quota, productivity, customer claim and warehouse cost) results displayed on the performance board for visualization?
PM 03		Any assigned findings from review addressed in OPL format and establishing of regular meeting time, participant and agenda?
PM 04		Is there documentation of daily delivery performance as well as tracking and prioritization of deviation to be displayed on performance board?
PM 05		Are corrective measures defined in PDCA format; deadline and responsibility assigned as well as documentation of follow up and corrective measures?
PM 06		Any design and use of active cockpit to monitor KPIs?

Table 7: Warehouse PDCA Implementation construct and measurement Items

Construct	Description	Measurement Item
PDCA 01	It is a lean tool that aimed at deviation management. It's a cycle of process steps that enables continuous improvement when implemented consistently	Is there any definition of progress indicators showing various stages as well as agreed times for updating progress topics?
PDCA 02		Any documentation of implemented action points, responsibilities and deadlines from PCDA?
PDCA 03		Any regular periodic review of PDCAs and documentation of outcomes?

Table 8: Warehouse Waste Analysis Implementation construct and measurement Items

Construct	Description	Measurement Item
WA 01	It is a lean tool aimed at reducing of non-value-adding activities in processes, operations and resources	Any established and well-defined waste analysis method and template for use in warehouse?
WA 02		Any documentation of use of waste analysis template and definition of various responsibilities?
Construct	Description	Measurement Item
WA 03		Any identification of findings in OPL format and addressed to the right personnel?
WA 04		Is there periodic process-focused waste analysis (good receiving, put-away, picking, packing and dispatch) as well as

		periodic training of shop floor employees carried out?
WA 05		Is there definition implementation and documentation of corrective measures, progress action and follow though in PDCA format with responsibilities and deadline definition

Table 9: Warehouse Problem Solving Implementation construct and measurement Items

Construct	Description	Measurement Item
PS 01	It is a lean tool that ensures systematic approach to finding unknown root causes for problems, define and implement respective solutions	Definition of systematic problem-solving approach and root cause analysis as well as provision of problem-solving chats?
Construct	Description	Measurement Item
PS 02		Identification and implementation of corrective measure, written and followed in PDCA format with responsibilities and deadlines assigned
PS 03		Usage of problem-solving standard approach in all value stream areas?

Table 10: Warehouse Work Instruction Implementation construct and measurement Items

Construct	Description	Measurement Item
WI 01	It is a lean tool that ensures define standard for shop floor operations are available in a step-by-step written form.	Making written work instruction available on the information board in an easy-to-grasp format for all relevant processes
WI 02		Design and use of visual and label for clarity
WI 03		Documentation of training plan and schedule for new associates and skills update for old associates
WI 04		Review and sign off respective schedule, training plan and actual training

Table 11: Warehouse Visualization Implementation construct and measurement Items

Construct	Description	Measurement Item
VI 01	It is a lean tool that ensures transparency of warehouse processes	Availability of updated warehouse layout including functional areas
VI 02		Marking of areas to indicate position of materials and machines

VI 03		Indicating pathway for pedestrians or machines to avoid collision
VI 04		Marking all inventory outside of racks and shelf location with a unique identifier including destination and material status

3 CASE-STUDY BACKGROUND

This case study was undertaken in a 3rd-party logistics company managed as Private Limited Liability Company. It was established in 1980 as a manufacturing logistics and warehousing company, located in Gauteng, South Africa, currently employing 750 people. Of the total workforce, 70 % is allocated to the warehouse and depot operations Department. The company receives products through the warehouse (inbound) and makes deliveries of orders (outbound) daily. The warehouse has varying amount of stock keeping units (SKUs). Figure 1 shows the Value Chain of the warehousing process. The Value Chain indicates that the process is composed of other sub processes, each with input, transformation activities and their respective output [43-44]. It is a systematic approach to examine the development of competitive advantage [44]. The value chain of the warehouse is described as:

i. receiving
ii. put-away
iii. storage
iv. picking
v. packing
vi. shipping

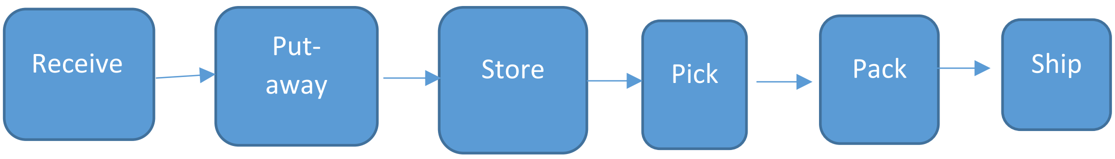

Figure 1: Value Chain of the Warehouse

3.1 Business Case

In the bid to maintain a good customer-client relationship by the management of the company, there is a need to improve on the warehousing productivity by evaluating the process cycle efficiency. The management decided to engage Lean Six Sigma practitioners to evaluate the current warehousing processes. The Lean Six Sigma (LSS) team included a researcher that specializes on quality management and a university senior lecturer, who is also a Black Belt certified.

The team conducted a review of relevant company documents, one-on-one interviews and questionnaires attestation with some selected staff from the warehousing Department (Warehouse Managers and two (2) other Asst. Warehouse Managers). These were further supported by self-observations on the shop floor for a period of six months to study the warehousing processes.

3.2 Data Collection

Data used in this study were gathered from both primary and secondary sources. The primary data collected were via structured interviews, questionnaires and observations. The assessment tools (Tables 1-11) used were developed by two Lean specialists as secondary data collected from the literature, internet and from the company's archive for Lean maturity assessment in the warehouse environment. The assessment tools are limited to standard basic Lean maturity tools.

4 RESULTS

The results of the evaluation are presented in this section.

4.1. Present VSM of the Warehouse

The present VSM of the warehouse is revealed from different activities which emanated from different stages of operations. The data necessary to develop the existing VSM were presented in Table 12 with other important data like number of pickers (PI), packers (PA), and other truck pushers were presented. The estimation of the completion of the present VSM involved the introduction of the value added and non-value-added time. The VSM is a function of the class of the stock keeping units (SKUs) which can be mono or mixed pallets. More time is required to carry out the process in the case of mixed pallets due to sorting action before proceeding to the next process.

Table 12: Existing Value Added and Non-Value-Added Time of the warehouse

S/N	Processing Stage	Nature of SKUs	Average VDT (s)	Average NVDT (s)
1	Receiving	Mono-Pallet Mixed-Pallet	7 200 18 000	10 800 27 000
2	Put-away	Mono-Pallet Mixed-Pallet	1 800 7 200	2 700 10 800
3	Storage	Mono-Pallet Mixed-Pallet	10 800 21 600	17 280 34 560
4	Picking	Mono-Pallet Mixed-Pallet	1 200 2 400	1 920 3 840
5	Packing	Mono-Pallet Mixed-Pallet	2 700 5 400	4 320 5 640
6	Shipping	Mono-Pallet Mixed-Pallet	3 600 10 800	5 400 16 200
	Total		92 700(39.8%)	140 460 (60.2 %)

The present VSM of the warehouse shows the flow of order (SKUs), labour, information, value-added time and non-value-added time. Aids in the computation of the required processes and customer order. By examining the present VSM of the warehouse, the question of level of waste generated, value added time, non-value-added time as well as any improvement measure to be carried out should be asked as these would help to determine PCE. Figure 2 shows the present value stream mapping of the warehouse which was actually managed by three (3) representatives. Orders are received from customers for processing and further shipping. As observed, there are so many non-value-added time reflected from each unit. The implementation of Lean tools is expected to improve on the non-value-added time.

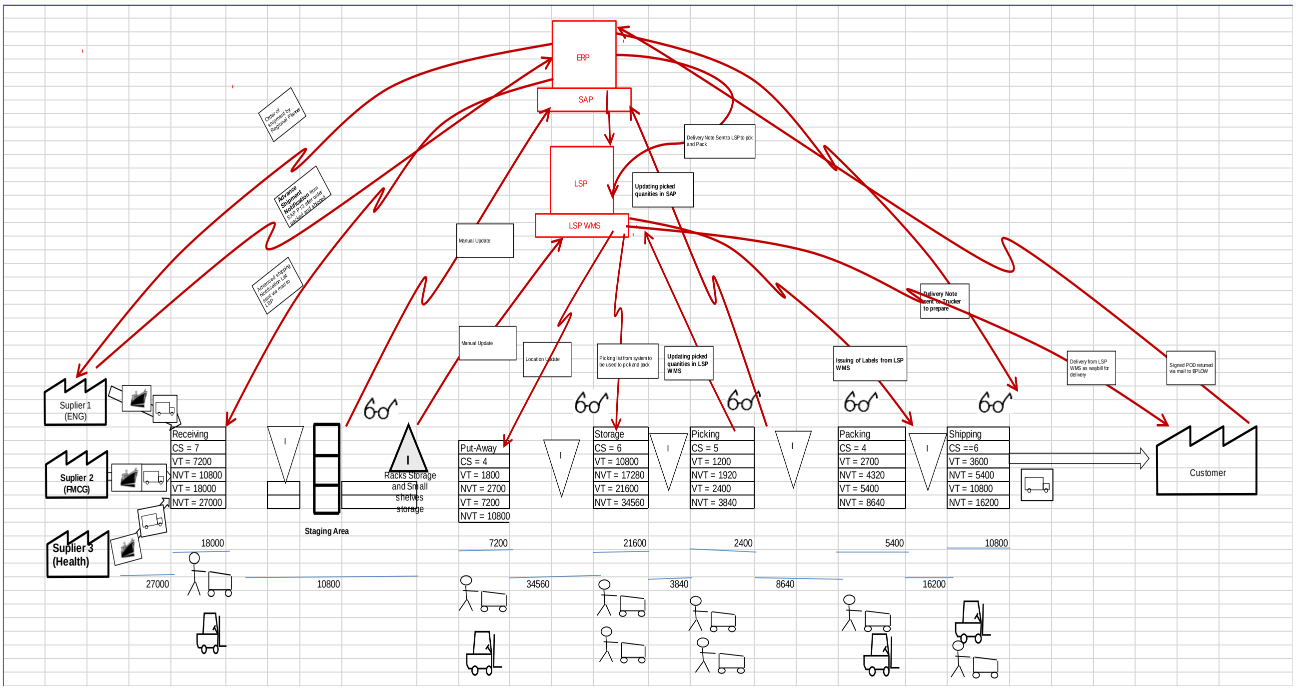

Figure 2: Present Value Stream Mapping of the Warehouse

4.2 Present PCE of the Warehouse

Value Added Time = 92700 s
Non-Value-Added time = 140460 s

Present Lead Time = Value Added Time + Non-Value-Added time *(3)*

= 92 700 + 140 460 = 233 160 s *(4)*

$$\text{PCE} = \frac{Value\ Added\ Time}{Lead\ Time} x100 = 39.8\% \qquad (5)$$

From the above calculations, it is estimated that the PCE is 39.8 % which falls below the warehousing benchmark of 40 % [42].

4.2.1 Root Cause and Effect Analysis of the Problem

The root causes and effect analyses of the productivity problems were done through brainstorming session by the LSS team using Ishikawa Diagram as presented in Figure 3, so as to design improvements and subsequent framework [45-47]. The causes were grouped into seven main categories, namely: management, machine, method, environment, materials, measuring equipment and man.

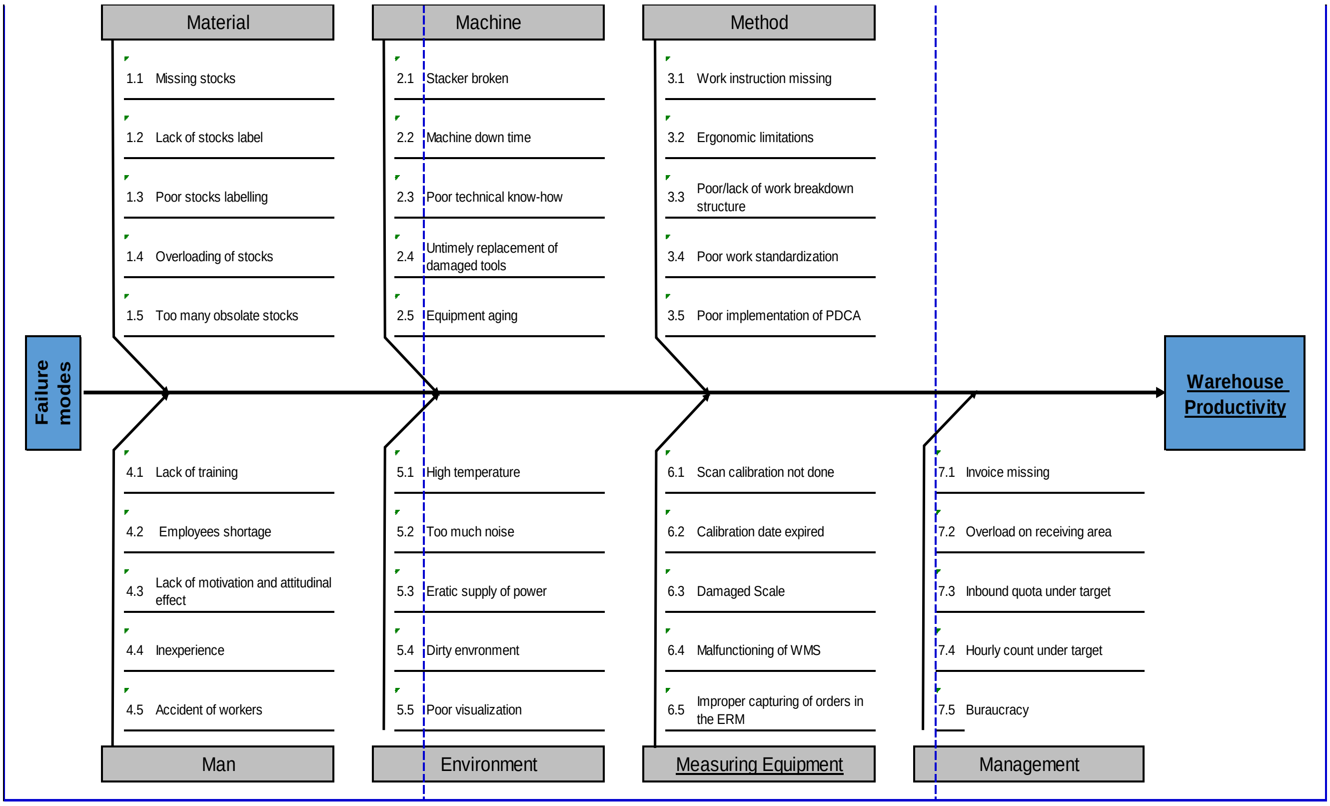

Figure 3: Ishikawa Diagram of the Productivity of the Warehouse

4.3 Implementation of Warehouse Lean Tools

There are some improvement points which differ by process stage in the present VSM. The present VSM of the warehouse with improvement points is presented in the Figure 4.

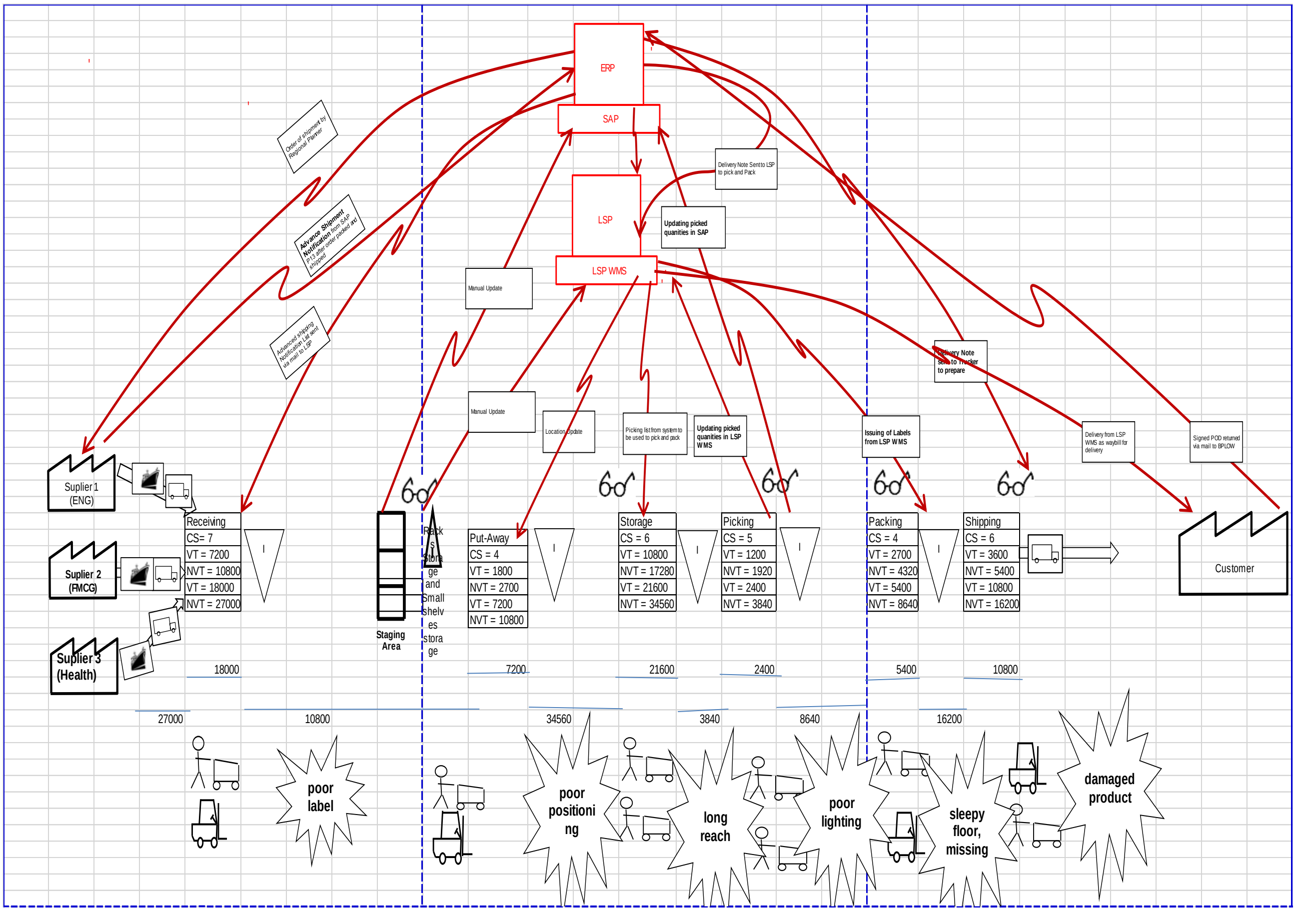

Figure 4: Present VSM of the Warehouse with Improvement Points

4.4 Future Value Stream Mapping of the Warehouse

The future VSM of the warehouse, after implementation of appropriate Lean tools reflected improvements in Non-Value-Added time as presented in Table 13.

Table 13: Future Value Added and Non-Value-Added Time of the Warehouse

S/N	Processing Stage	Nature of SKUs	Average VDT (s)	Average NVDT (s)	Lean Tools Implemented
1	Receiving	Mono-Pallet Mixed-Pallet	7 200 18 000	3 240 8 100	SUP, PM, WA, 6S, PC, SC
2	Put-away	Mono-Pallet Mixed-Pallet	1 800 7 200	810 3 240	WA, PM, WI, 6S, PC, PDCA
3	Storage	Mono-Pallet Mixed-Pallet	10 800 21 600	4 212 8 424	WA, PM, PS, WI, 6S, PC, PDCA
4	Picking	Mono-Pallet Mixed-Pallet	1 200 2 400	468 936	WI, PM, WA, 6S, VI, PC, PS, PDCA
5	Packing	Mono-Pallet Mixed-Pallet	2 700 5 400	1 053 2 106	PM, WA, WI, 6S, VI, PC, PDCA
6	Shipping	Mono-Pallet Mixed-Pallet	3 600 10 800	1 620 4 860	PM, WA, CUS, 6S, PC, SC
	Total		92 700(70.4%)	39 069(29.6%)	

From Table 13, there is a decrease in non-value-added time to approximately 30 %. Figure 5 shows improved VSM of the warehouse.

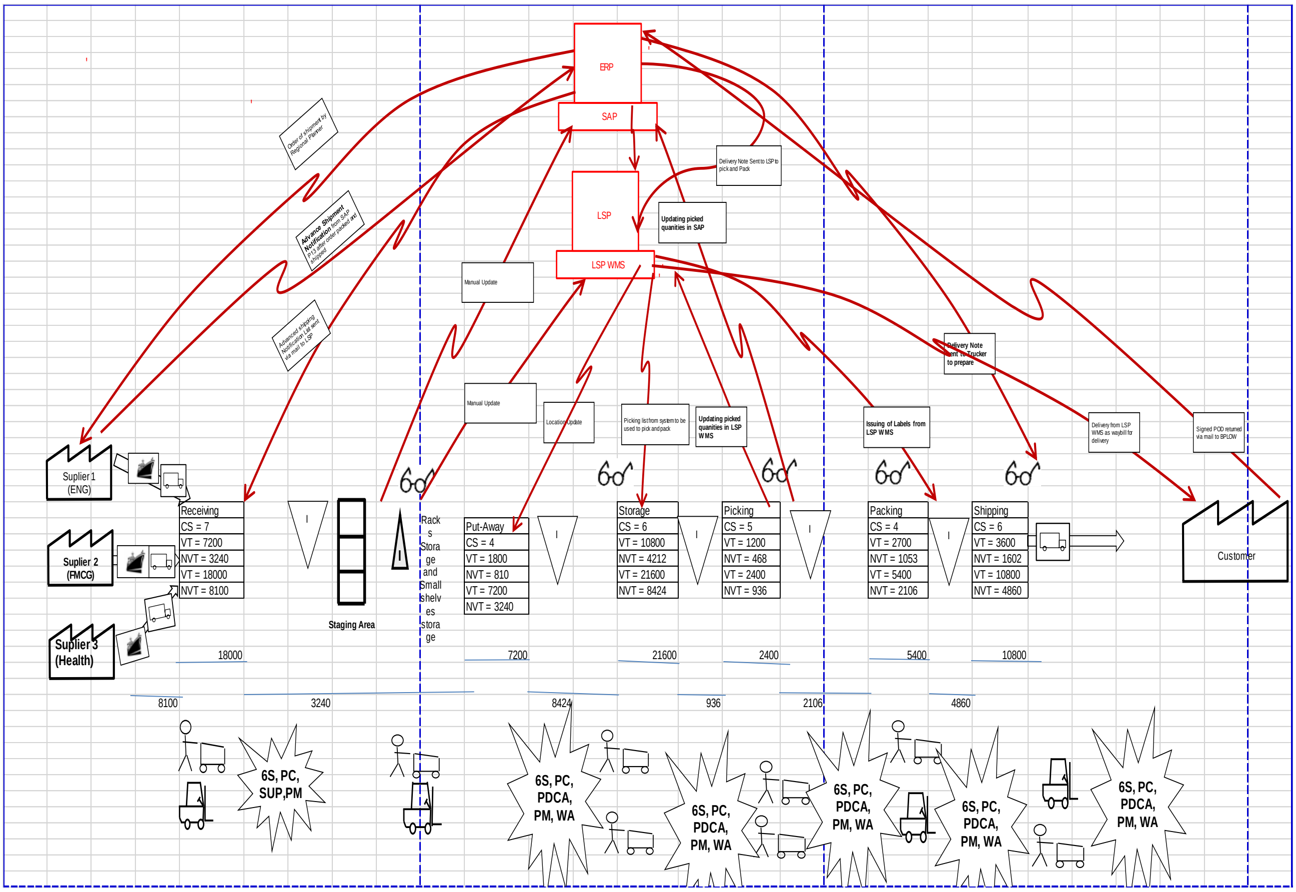

Figure 5: Improved VSM of the Warehouse

4.5 Improved PCE of the Warehouse

The improved process cycle efficiency of the warehouse is estimated to be approximately 70 %. This also results the lead time to reduce to 131769 s.

Value Added Time = 92 700 s

Non-Value-Added time = 39 069 s

Future Lead Time = Value Added Time + Non-Value-Added time *(6)*

= 92 700 + 39 069 = 131769 s *(7)*

$$\text{Improved PCE} = \frac{Value\ Added\ Time}{Lead\ Time}\ x\ 100\% = 70.4\% \quad (8)$$

5 RESULTS DISCUSSION AND LESSONS LEARNT

The results discussion and lesson learnt were presented in this section.

5.1 Analysis on PCE

It was deduced from the result that PCE before implementation of warehouse Lean tools was 40%, which improved to 70% after the implementation of warehouse Lean tools. The problem of low PCE was traceable to processing method, material (stock) movement, machine/equipment usage and the attitude of the employee.

In terms of processing methods, there was no provision for efficient material handling and flow using appropriate means, lack of process standardization and poor process ergonomics. These resulted to undue congestion and work-in-progress in the dispatched area in the course of receiving and storage processes thereby much time were spent on the offloading from the truck to the inbound area and movement of goods to the storage area.

Unnecessary movement of the operators whereby stock was not stored at the right location level, and operators needed to reach or bend over in awkward positions to pick the items or due to non-logical and sequential storage of goods were observed from the put-away and storage processes. In the case of machine/ equipment usage, prolonged machine downtime was observed due to mishandling of the equipment by the operators, equipment aging and lack of maintenance culture. In the case of stock movement, there were overloading of stock in the inbound area, poor labelling or poor arrangement of stock in the storage area sometimes led to stock being missing.

Damage of stock were observed from all the processes due to wrong picking or shipping of order and mismanagement of goods during receiving.

Also, insufficient implementation of control system was found in the organization. The poor control system resulted in attitudinal behaviour of the pickers, packer and truck pushers.

The improvement of PCE was achieved by implementation of kaizen (continuous improvement) on all the processes. It is systematic approach to improving efficiency and quality by gradual or incremental changes [43; 48]. The implementation of kaizen reduced unnecessary inventory, reduced process lead time and defect products in the shop floor. Also, implementation of kaizen involves intermittent training and re-training of the operators for skills and multi-skills on the job. Operators were made to understand the importance of teamwork.

Another Lean tool implemented to improve PCE of the process was work standardization. It was used to organize processes in such a way that they were being executed in the most effective way [49] by achieving accurate staff balancing, minimizing undue work in process and serious reduction in non-value-added activities especially in the non-machine running processes [50].

6 CONCLUSIONS

This article has contributed towards the implementation of Lean in warehousing. Application of Lean in this case has been able to solve real-time problem of productivity in warehouse environment which has direct implications on management and customer's satisfaction. It has also presented some implications by establishing a Lean framework for warehouse processes when it is applied to improve real-time Lean problems as listed:

i. PCE was improved from 40% to 70 % by implementation of value stream mapping, 6S and other warehouse Lean tools

ii. The application of Lean in the presented case-study was an indication that it can be successfully adapted to other process metrics like quality, responsiveness, total turnaround time and so on.

iii. Involvement of a Black Belt certified expert alongside with university resources and quality management students, was leveraged during the execution of the project. In view of this, academic-industry collaborations are encouraged.

6.1 Limitation and Recommendations

i. The research was limited to a case of Lean warehousing in a third-party logistics (3PL) environment only. It cannot be generalized for a case of total supply chain.

ii. The assessment of the warehouse processes was based on the application of warehouse basic Lean tools. The tools can still further be extended to warehouse advanced tools.

iii. The established framework can be validated by modelling tools like system dynamics or Anylogic.

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SYSTEMS ANALYSIS OF MUNICIPAL WATER SUPPLY POLICIES IN THE LIMPOPO PROVINCE OF SOUTH AFRICA

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ABSTRACT

Water is a very scarce resource in the Limpopo province of South Africa affecting particularly rural areas. The policies of the municipalities in the province over the years has a high influence on the availability and affordability of potable water in the province. This paper examines the policies and initiatives implemented to address the challenge of water shortage. A systems analysis model for water supply policies is developed to test the effectiveness of these policies in the delivery of potable water. The model shows poor synergy in the system and lack of commitment on the part of municipalities particularly concerning potable water supply in the province. This paper recommends a review of municipal water policies to ensure better distribution of potable water to communities. More diversity in water sources use, review of water pricing policies and a possible introduction of lean management to reduce wastages in the system are recommended.

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1 INTRODUCTION

The Limpopo province is the hottest region of South Africa with less rainfall ranging between 100mm to 1000mm annually [1, 2]. Shortage of rainfall has placed the province under a water crisis. Previous researchers have recorded that three (3) million people nationally do not have access to basic water supply services and 14.1 million do not have access to safe sanitation [3]. The province is largely rural and its people suffer from a high level of unemployment. As a result, the cost of potable water supply is beyond their affordability. The biggest challenge of water service is payment of water services and sustainable supply of these services to the consumers. Though there are challenges with payments of services, the municipalities still try to meet water demand in the province [4]. The rural communities make use of a self-supply strategy to access water for multiple purposes amongst them including domestic use, irrigation and livestock [5, 6].

According to Koppen, et al. (2019), dependency on self-supply services improved access to water faster, is more cost effectively and sustainable than public services do. Limpopo province has five (5) municipalities and there are executive authorities in each municipality to provide water services within its area of jurisdiction. According to the Water Services Act (No. 108 of 1997), municipalities are Water Service Authorities (WSAs) because they are responsible for water service provision functions in the province [7]. The municipal responsibilities are to ensure that communities have functional potable water systems and domestic waste-water and sewage disposal systems [7, 8]. In addition, Lepelle Northern Water is a water utility in the province and is amongst the nine (9) Water Boards that were converted to Regional Water Utilities (RWUs) by cabinet during approval of the National Water Policy. The policies were revised to improve the water management and supply in the province [9]. Development of water infrastructure promises clean and safe drinking water to the consumers to comply with SANS standard (SANS 241:2015) and reduce the burden of common illnesses [10].

The South African constitution states that it is a right to everyone to have access to water and food. For this reason, government has invested public resources to infrastructure in low-income areas. Despite the water sector’s policy commitments and allocation of funds to develop and manage water infrastructures, it is still known that people with agriculture-base and diversified livelihoods do not have access to potable water [3]. In the Limpopo province, only 14% of water infrastructure implemented is fully functional, 15% is sub-functional and 71% is dysfunctional. In this paper we examine policies and initiatives to address the challenge of water shortages [3]. The systems analysis model for water supply policies is developed to test the effectiveness of existing policies in delivery of potable water. In this paper, the impact difficult matrix is used to identify priority of water sources, water supply and use of water across the province. The following diversity in water sources are recommended in this paper;

- Review of municipal water policies,
- Review of water pricing policies,
- Development of systems analysis to test the effectiveness of policies in delivering potable water,
- Introduction of lean management to reduce wastages in the systems.

2 METHODOLOGY

2.1 Conceptualization

A multiple method was used to identify potential water supply and the use of water policies to manage water supply in the Limpopo province. A review of grey and white literature was undertaken to identify the challenges of water supply and water policies use in the Limpopo Province. A systems analysis model for water supply policies is developed to test effectiveness of water policies in the delivery of potable water. In addition to solution of water supply challenges, lean impact difficult matrix of water supply is introduced. A representative sampling frame of water supply was used to develop the lean impact difficult matrix based on policies used to manage water supply. Lean management is a technique used to manage and improve management systems and company assets or resources. It also helps with developing management team to maintain public resources. It helps with setting objectives that can help government to effectively manage and maintain water infrastructures [11]. The amount of water used in Limpopo province increases much faster every day than population growth. The risk of water shortage facilities faced vary from water shortages and reliability issues, water quality issues, increasing water costs, and supply chain disturbances [12].

2.2 Mapping Water Supply onto Systems Dynamic, Water Policies and Lean Impact Difficult Matrix

System analysis model for water supply policies is developed to test the effectiveness of these policies in the delivery of potable water. The purpose of the water policies is to identify and evaluate effective strategies to achieve water management objectives and ensure safe and reliable potable water. In addressing the issue of water, supply and demand are main policy variables. Introduction of lean management to reduce wastages in the municipalities' water system is recommended. Lean contributes to water delivery to customers in a manner that minimizes waste and risks from unnecessary water use. Lean implementations creates significant value to deliver water quality services to consumers. Lean implementation creates significant value to ensure that quality water services are ~~is~~ delivered on time to consumers. The municipalities in the province can benefit~~s~~ and improve water services in the province by addressing water with lean. Research sponsored by EPA reported the three key elements that can be used to address water using lean as follow [12];

- Under cost savings and operational improvement,
- Reduce water related business risks,
- Deliver value for customers and employee.

Lean tools provide means to effectively implement water policies and ensuring that communities have access to potable water. Shortage of water supply in Limpopo Province is sign of inefficient production, non-valuable added activities and indicates opportunities for saving cost and time. Lean gives an opportunity to improve service water delivery and provide opportunity to reduce facility water use. While other places struggle with paying municipal water facilities, there are other cost of water which includes cost to purchase water, cost associated with water treatment and regulation compliance.

3 RESULTS AND DISCUSSION

3.1 System Analysis and Water Policies

Systems Analysis deliberates systematic methodologies to the mathematical modelling of various water resources issues, which helps decision-makers allocate water effectively and efficiently (Figure 1). Water systems analysis is complex, as it requires attention and planning co-ordination between Water Service Authorities (WSAs) and provincial boundaries for ensuring safety and consistent potable water. Policy analysis process focuses on water demand and water supply. The strategies express the sense of specific actions which are required for implementation of water policies [13].

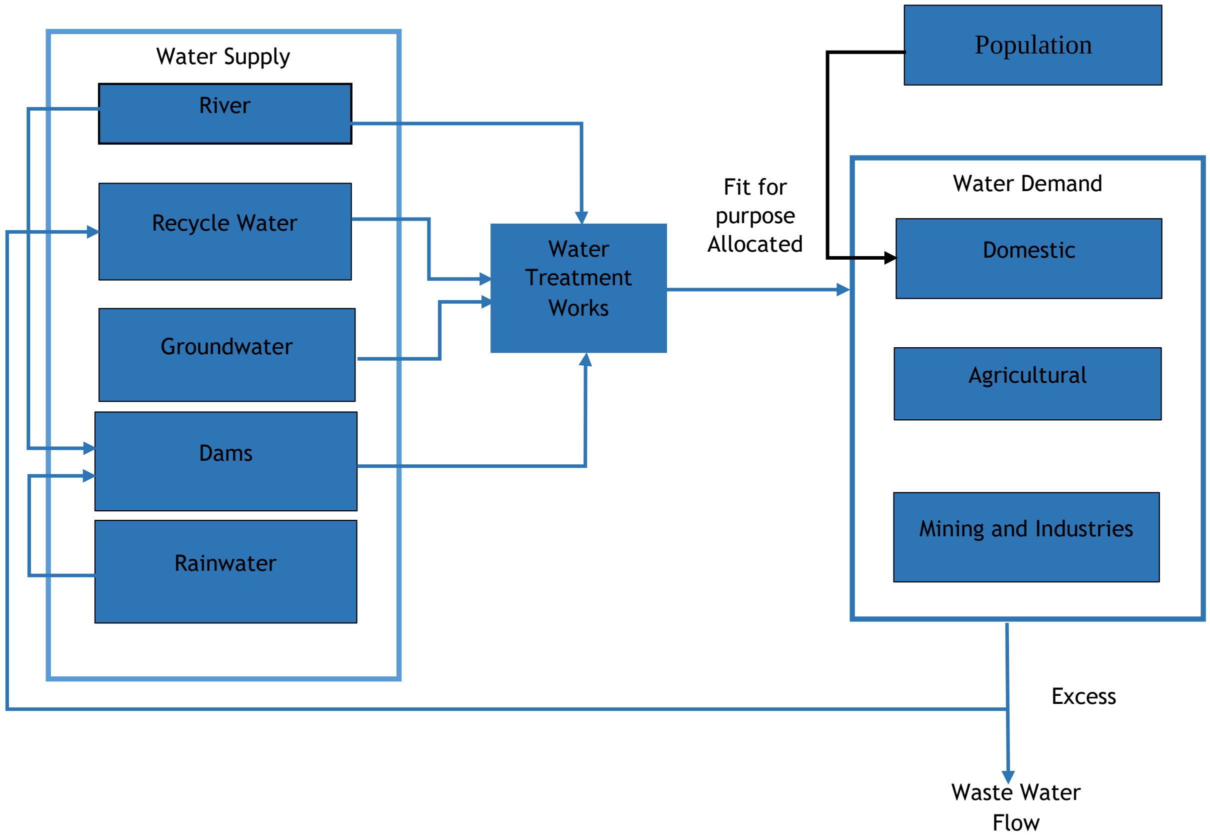

Figure 1: Water System Dynamic Model

At the same time, the government has a right to regulate the proper use of water in the country. The regulation of water use benefits all South Africans in a way which takes into account the public nature of water resources and the need to make sure that there is a fair access to the resources. The benefits of water regulations are to ensure that these scarce resources are used for public interest [14]. The aim of water resource regulation strategy is to support the following criteria;

- Alleviate poverty by growing the economy, decent work and sustainable livelihoods,
- Rural development, food security and land reform,
- The fight against crime and corruption,
- Sustainable resource management and public service improvement.

This paper reports on various polices governing water supply, water demand, maintenance services of water infrastructure and recycling process of water in Limpopo Province.

3.1.1 Water Supply Policy

Water is supplied by means of pumping systems infrastructure. Several pumping systems are due for upgrade and new pumping systems are being planned and developed. Pumping systems are complex, require long planning and are expensive to build. Water infrastructure in the province requires dedication and planning co-ordination between Water Service Authorities (WSA) and province boundaries [13]. Water Policy Position of 2013 (Gazette No 36798) states that access to basic water is achievable and infrastructure is necessary to supply potable water to a formal connection at boundary of stand. The policy further states that “Water Service Authorities (WSAs) should plan for basic yard connections, as well as for higher levels of service, which includes productive water use where applicable” [14].

3.1.2 Water Demand Policy

Total water requirements are projected to increase from 4595.99Ml/d in 2015 to 6306.13Ml/d in 2045, a 37% increase. This requirement can be maintained by continuously maintaining water infrastructures across the province The water demand in the province between 2014 to 2045 are represented in Table 1 [13].

Table 1: Water Demand in Limpopo Province [13]

Section	**Volume Ml/d (2015)**	**Volume Ml/d (2045)**	**Total Water Demand (%)**
Domestic	678.3	1278	15.1
Agricultural	3314.8	4099.7	78.5
Mining and Industrial	255.7	813.96	6.0
Wildlife	22.2	23.02	0.5
Total	4507	6214.87	

3.1.3 Maintenance Service Policy

According to the Maintenance Service Policy [13], refurbishment and preventative maintenance of the existing water infrastructure must be prioritized. Access to basic water infrastructure is necessary to supply potable water to a formal connection at the boundary of a stand. Maintenance Service Policy states that Water Services Authorities (WSAs) should plan for basic yard connections, as well as for higher level of services, which include productive water use where applicable. It is recommended to build up settlement demographics with warren and future level of water supply [13].

3.1.4 Recycling Policy

Waste Water Treatment Works (WWTW) and mine water must be recycled and re-used in the water cycle to save water [13]. Households in the Limpopo province get food from farming which uses lots of water. During rainy season, farmers depend on rainfall as the source of water for their gardens [3]. Irrigation and Conservation of Water Act (Act 8 of 1912) was promoted by South African government to consolidate and amend the provincial laws in the Union of South Africa rated to use of water for domestic, irrigation and industrial purposes [15]. Since irrigation required bulky capacity of water, therefore, there is a need to improve water supply systems for more efficient use [13]. Implementation of integrated water resources management (IWRM) is a way to sustainable development and food security especially in improving the livelihoods in small communities [16].

3.1.5 Review of Policies

Review of future water demand for domestic, irrigation, mining, industrial, livestock, game and forestry needs to be obtained accurately so that proper planning can be introduced [13]. The policies are effective in the delivery of potable water in the province. In the existence of these policies, other regions of the province, especially rural communities remain under stress of potable water. This is due to poor interaction and lack of commitment on part of Water Service Authorities (WSAs) and municipalities particularly concerning potable water supply. Lack of dedication and planning co-ordination between WSAs and province boundaries affects proper implementation of the policies. In addition, lack of effective water rights has contributed to lack of water supply [17]. Ineffectiveness of the policies in the province resulted in 93% of communities in the province to experience functional problems with water supply systems. Dysfunctional nature of the water infrastructure is due to lack of effectiveness Operation and Maintenance which are caused by the operational issues, functional and financial aspects. Vandalism and thief of government properties is decreasing the water supply capacity. Poor selection of service providers and illegal connections also contributes to inefficiency of the water policies in the province.

3.2 Water Supply Lean Management

3.2.1 Lean and Water Strategies

Reducing nonvalue added water use is a key strategy for mitigating water risk in the province. The municipalities can make use of Lean and water strategies to implement practical solutions that supports multiple business objectives such as increasing efficiency, reducing cost, improved consumer awareness and decreased water and energy use. Water Authorities Service alongside provincial government need to work together to identify and eliminate source of water waste in the water facilities. If the production water is such as overspending, over processing, defects and delays are eliminated, water infrastructures can proactively supply enough water volume. Lean impact difficult matrix is developed for the identification of priority water sources, water supply and use of water across the province (Figure 2). The matrix shows the current situation of potable water supply in Limpopo Province. Implementation of lean in the province contributes to water satisfaction of consumers and helps with executing future plans that will positively help with saving water. Lean and water strategies make the water facilities less susceptible to risk instead better positioned to succeed given changes in water supply demand and quality. Lean helps with saving costs, time and energy, and water for future use.

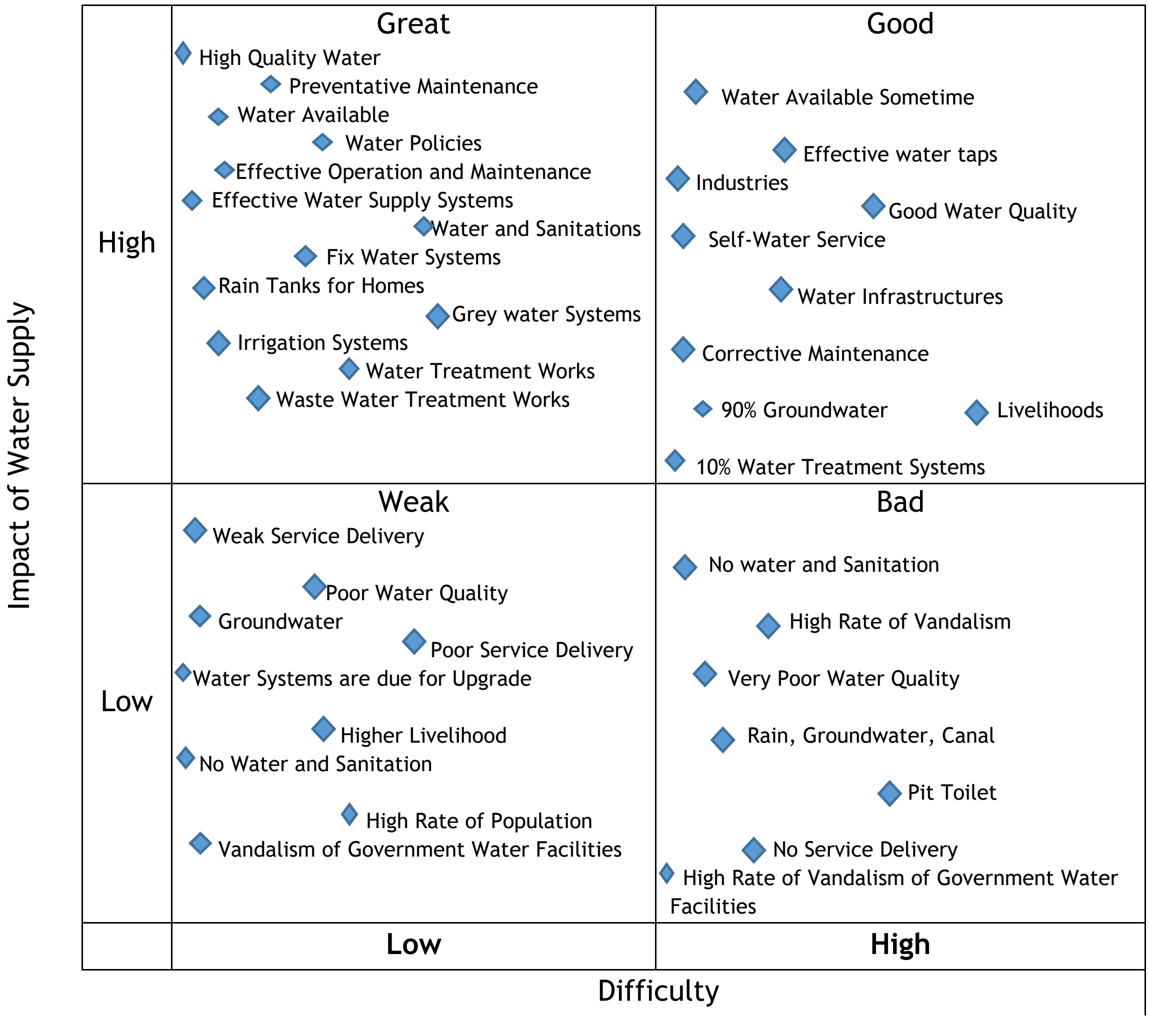

Figure 2: Impact-Difficult Matrix of Water in Limpopo Province (Adopted from Kneebone, et al. 2017)

The challenge of water shortage can be addressed by deploying effective management and visionary leadership that will effectively implement water policies to ensure the province does not experience stress of water. Municipalities find it difficult to manage, regulate and control water uses because of limited water systems available to monitor the actual water consumption. Inappropriate water use and illegal connections limits municipalities to efficaciously execute water policies to ensure that potable water is available to use. Implementation of lean and water strategies helps with water management, saving cost and time. Lean impact difficult matrix in Figure 3 shows opportunity for future engagement to improve water supply in the Limpopo province. The areas that can be considered to improve the water supply in the province include, review water policies, installation of water of water saving devices to monitor the amount of water supply, introduce habit of saving water, implement efficient operation and maintenance, and monitoring of water quality.

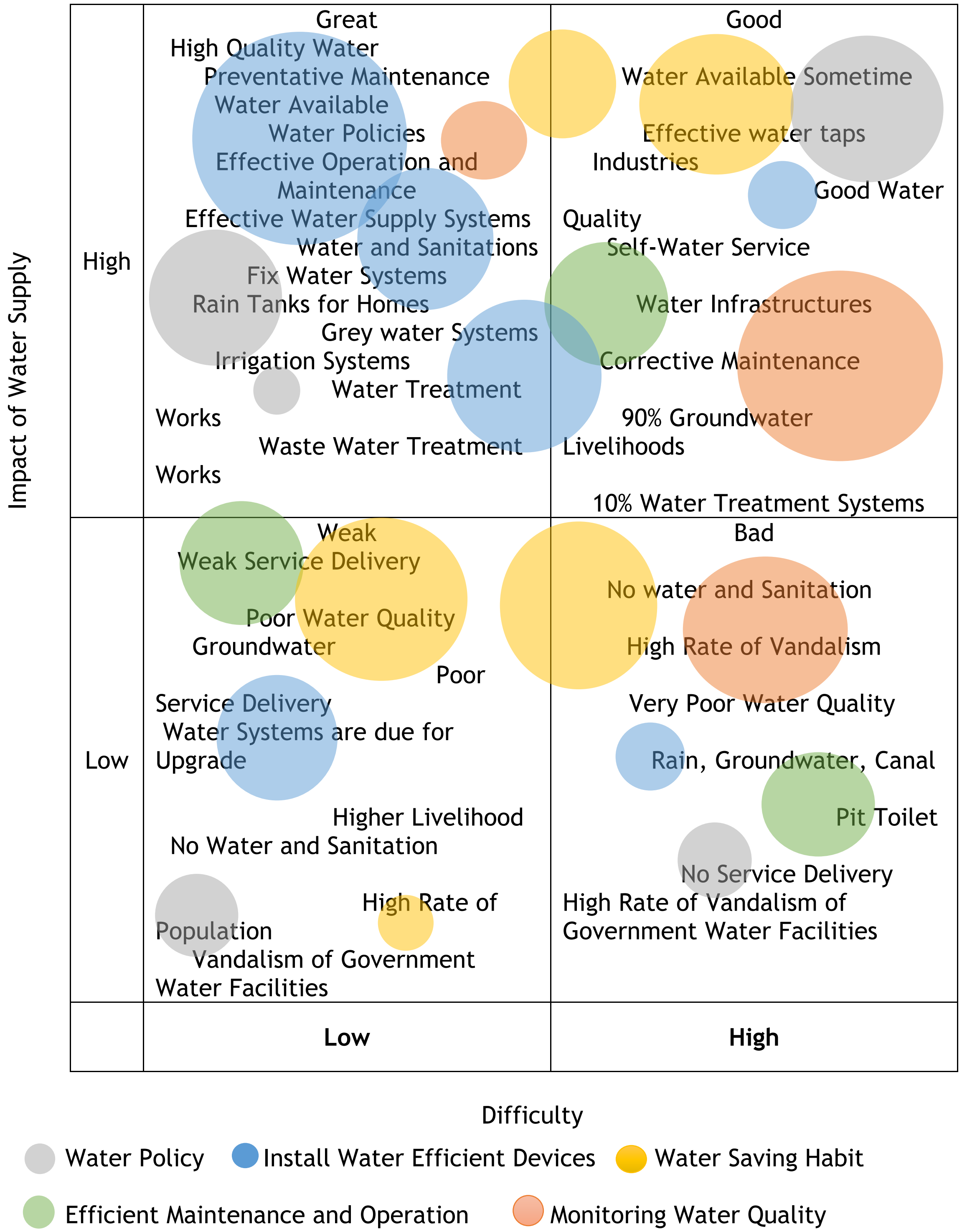

Figure 3: Prioritization Matrix Created from Observation of Water Supply in Limpopo Province, Illustrating Opportunities for Future Water Supply, Water Source and Quality (Adopted from Kneebone, et al. 2017)

4 CONCLUSION

The challenge of water supply can be solved by improving water resources management. Water regulation is a strategy that can be implemented to improve water resource management. Key element of water resource management include:

- Infrastructure operation,
- Maintenance and development of water infrastructure,

- Monitoring and assessment of water quality and infrastructure,
- Research and,
- Design.

Access to basic water supply and sanitation can be achieved should the policies be implemented and not compromised. The level of upgrading of infrastructures should be prioritized. Technical and water resources solutions should be implemented with proper strategy to meet water demand and supply. Introducing of lean and water strategies also improves water supply, saves time, cost and ensure water quality to the consumers. The aspects that contribute to water supply include; review water policies, installation of water saving devices to monitor the amount of water supply, introduce habit of saving water, implement efficient operation and maintenance, and monitoring of water quality. Integrated water resources management (IWRM) is a key in managing water and regulations. 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 with IWRM. IWRM provide a broader context through which to achieve an objective of ensuring potable water is supplied and saved for future use.

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SYSTEMS DYNAMICS OF MUNICIPAL WATER SUPPLY POLICIES IN THE MPUMALANGA PROVINCE OF SOUTH AFRICA

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ABSTRACT

In this paper, systems dynamics tools are used to evaluate the dynamic performance of water supply system and identify the most suitable period for future water planning in the Mpumalanga province of South Africa. In planning water use strategies over the long term, economic cost minimization is the main consideration of the municipalities in the province. The policies which integrate supply and demand of water were deployed to address the water stress issues faced by Mpumalanga Province through a systems dynamic model. A strategy was developed to review long term management of water supply systems. Policies for reducing residential indoor and outdoor use and increase supply to rural areas were looked into at the level of reasonable price so that households with lower income can have access to potable water. The developed systems dynamic model is capable of monitoring cost effect, consumer effect and period effect that can sustain potable water availability in Mpumalanga Province. The model includes the financial state of water supply system, water recycling system, water transmission and water treatment works. Water supply in Mpumalanga province was simulated from 2015 to 2050, a 35-year period for effective projection. Policies tested shows potential for reduction in municipal demand, reduction in wastages in the system and the potential increase of supply to rural areas arising from savings in the system.

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1. INTRODUCTION

The study focuses on rural areas, urban areas, towns and cities of the Mpumalanga province. The province has three (3) district municipalities which are: Enhlanzeni, Nkangala and Gert Sibanda municipality (Figure 1) [1].. Each district municipality has their own local municipalities who in turn have their own dams, boreholes and water treatment works to supply water to the citizens across the province. The rivers that run through Mpumalanga province are Usuthu, Crocodile, Sabie-sand and Komati. The province experiences water stress because of limited water supply and water catchments [1].

Figure 1: Location of Mpumalanga Province *[2]*

This means that Mpumalanga province has to build more dams and commission water-treatment plants to supply to their communities and secure more water for future use [1]. There has been a decrease with access to water across the area [1]. Research shows that in 1996 there was a water supply decrease of 80.19%, in 2001 it was 74.58% and in 2011 there was further decrease of 61.77% [3]. Water supply in the province is rated as, 60% without tapped water and 75% without yard water connection [4], while 70% of the population still rely on water from boreholes even though this water is heavily contaminated due to ~~back~~ its proximity to pit toilets used in rural areas of the province [4]. Pit latrines cause human and ecological health impacts associated with microbiological and chemical contamination of groundwater [3, 4].

The factors that contributed to the decrease of access to water amongst the communities include the increase of population, illegal connections from the bulk pipelines that supplies water from the treatment plants, lack of proper maintenance and failure of water pumping systems. Access of water through illegal connections also overloads the water pumping system and as a result, the system does not last as planned [5]. The province is a mining industrial region with old mines that pollute groundwater through the production of acid mine drainage [6, 7, 8]. The need for efficient and effective operational management of water distribution networks has never been looked at. Water policies meant to ensure the citizens have enough potable water are inadequately implemented. Systems dynamic tools are used to evaluate the performance of water supply systems and to develop future water planning. Water policies are looked into for reducing residential indoors and outdoors water use and increase supply to rural areas at reasonable cost so that the houses with lower income can have access to potable water. The use of systems dynamics approach contributes significantly to inform policy of water in South Africa in a more effective way so that the communities with low income can access enough potable water.

2. WATER POLICIES

The objectives of implementing water policies are to ensure all communities have access to water services. The Water Service Authority monitor and regulate water supply to achieve optimum, long-term, environmentally sustainable social and economic benefits for society [9]. There is a need for provision of water services which will enable water users in the province to use water resources on a sustainable basis. In 1994 South African government implemented water policies with a non-racial and non-sexist democratic system based on fundamental principles to replace policies that was focused on white supremacy and racial segregation which was active till 1994. Water Security (Section 27) states that all persons have the right to have access to access water [9]. The government of South Africa established National Water Policies to ensure that all areas in South Africa including rural areas have access to potable water. National Water Policies of South Africa was established and reviewed based on the following four documents [10];

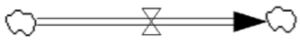
- White paper on water supply and sanitation (1994),
- White paper on a national water policy for South Africa (1997),
- White paper on basic household sanitation (2001),
- Strategic framework for water services (2003).

The National Water Policy states that any authorized water use which is not utilized for a specified period should be managed as custodian of the nation's water resources and no transfer between authorities of water. There will be no form of temporary or permanent trading between authorized water users. The policies further states that there should be prioritising social and economic equity in the reallocation of water. Priority in this regard is only given to water use authorisation. National Water Policy further states that there is a need for multiple use approach in planning infrastructure to incorporates all water use including water supply which must be catered for in planning of bulk water infrastructure. Water Authority Services in the province is given a mandate to ensure high level of water supply to all households including rural areas. Free basic water supply is granted to every community member. Minimum of 25 litres per person per day must be supplied to every person in the communities [10]. Even though there are policies to ensure accessibility to water, shortage of water is still existing due to ineffective and inefficient water management.

3. METHOD

Systems dynamics is used as a methodology to address and solve dynamically the complex problems in water resources management and supply in the province. Systems dynamic modelling helps with solving systems problems by means of using flow, internal feedback loops and time delays. The first step in any systems dynamics modelling is to determine the system structure between variables, feedback loops, system archetypes and delays. The involvement of stakeholders helps with ways to address the issue of water management effectively. In this paper, a systems dynamic model is developed to evaluate dynamic performance of water supply systems of Mpumalanga province. Systems dynamics model is introduced because Mpumalanga water supply services requires sustainable water resources management approaches that accounts for dynamic connections between cost of water, consumer effect and period effect, among others [11, 12, 13]. The model also helps with testing the real world behaviour in an artificial setting [13, 14, 15]. Dynamic simulation helps to observe the behaviour of a modelled system and response to interventions over time. Table 1 portrays the basic elements that are found in all systems dynamics models and provides a description for each system components [13].

Table 1: Components of System Dynamics Models (Niazi, et al., 2014)

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.
Level	Stock/ Level	Represents accumulation

4. THE DEVELOPED SYSTEMS DYNAMIC MODEL

The stock and flow diagram of the computer model is built using Vensim PLE 8.0.9 (Double Precision). The aim of developing a systems dynamic model is to monitor the cost consumer and period effects that can sustain potable water availability in Mpumalanga province. Water policies are looked into for reducing residential indoor and outdoor water use and increase supply of water to rural areas at a reasonable price so that houses with low income can have access to potable water. Mpumalanga Province covers a total land area of 76,495km^2 which is 6.3% of South Africa's land area. Mpumalanga Province recorded a population of 4,6M in 2020, the sixth most populous region in the country. This study chooses the period 2015 to 2050 as the simulation period. However, before changing the key variables, an evaluation of the model's effectiveness is necessary. The starting time of the model is 2015 and the historical data collected from 2015 to 2020. We have first tested the system during this historical period to establish the causes of the poor water supply in the province. The level of variables chosen for the Systems Dynamics model are cost of water, Domestic Demand and Annual Demand (see Figures 4-6). The factors that affect the data range in the future include an increase of population, climate change, mismanagement of water infrastructures and shortage of funds to upgrade, operate and maintain infrastructures.

4.1. System Dynamics for Water Supply

The use of dynamic simulation models in water management has a long tradition due to the complex nature of the problems addressed. The development of a systems dynamic models in this paper is represented in two ways, casual loop diagram (Figure 2) and stock flow diagram (Figure 3). Casual loop diagram is created to capture the interactions between population growth, potable water demand and other factors that contribute to the supply of potable water.

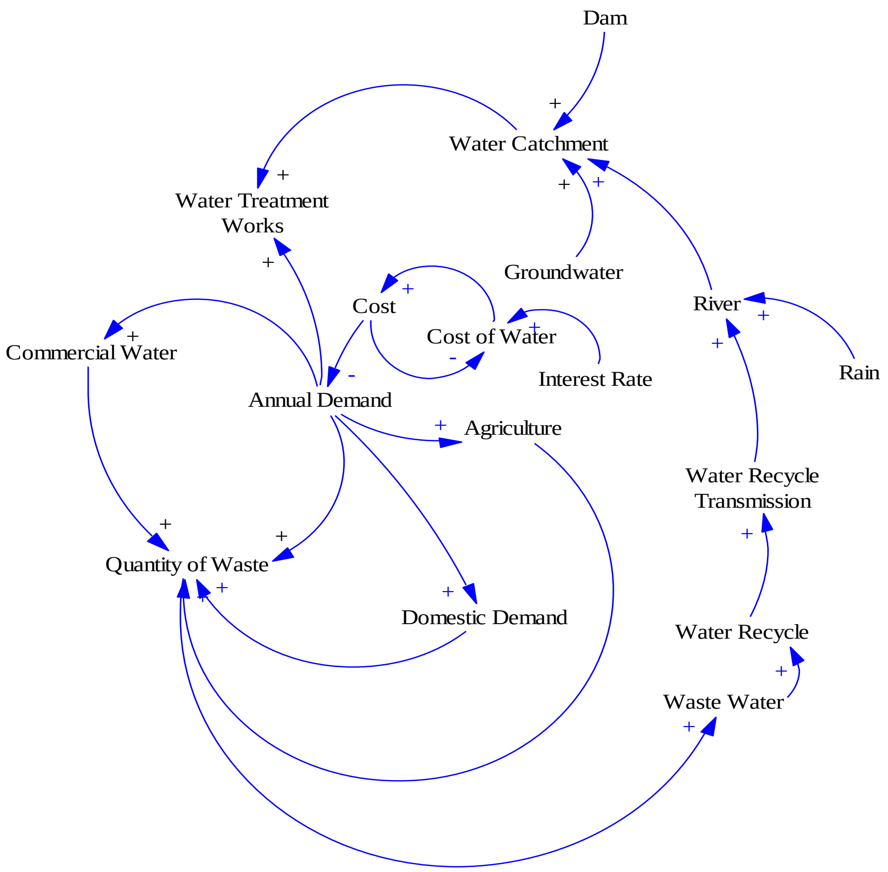


Figure 2: Casual Loop Diagram for Water Supply

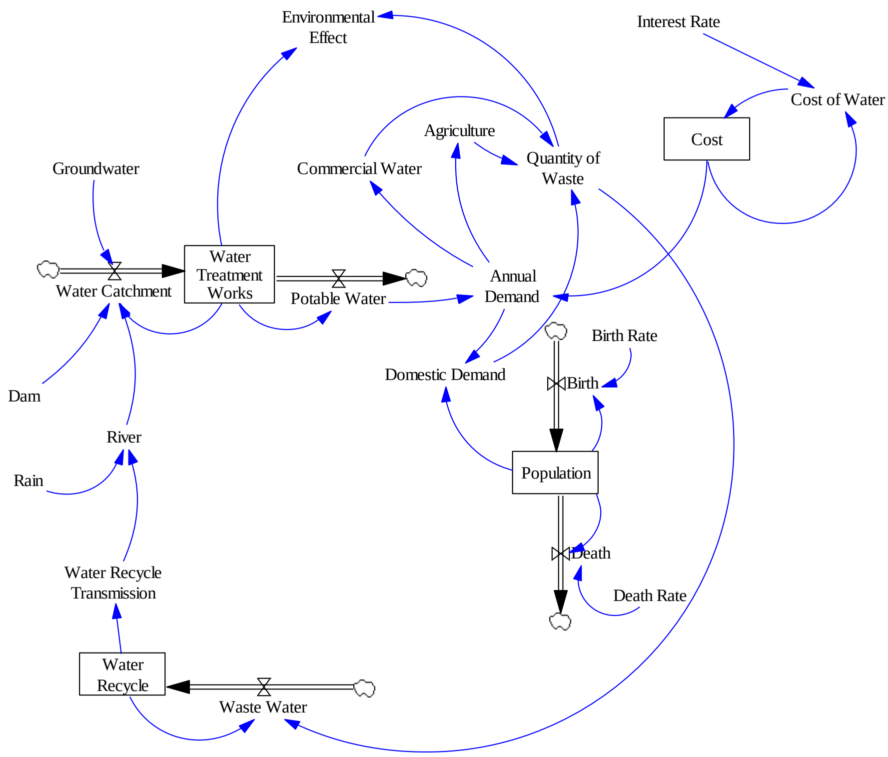


Figure 3: Stock and Flow Diagram of Water Supply for Mpumalanga Province

5. RESULTS OF THE MODEL SIMULATION

The simulation results of the systems dynamic model were determined focusing at two (2) conditions: low cost of water (1) and high cost of water (2). The results are represented in Figure 4 to Figure 6 with the blue trend representing high cost of water and red trend illustrating low cost of water. The interest rate of 5% for low cost and 16.8% for high cost were compared to determine the access of potable water use in Mpumalanga Province of South Africa [3]. The trend in the first 5 years when the two trend lines that are close in Figures 4-6 show that in that previous years challenge of water shortage was less and large amount of population had access to enough water.

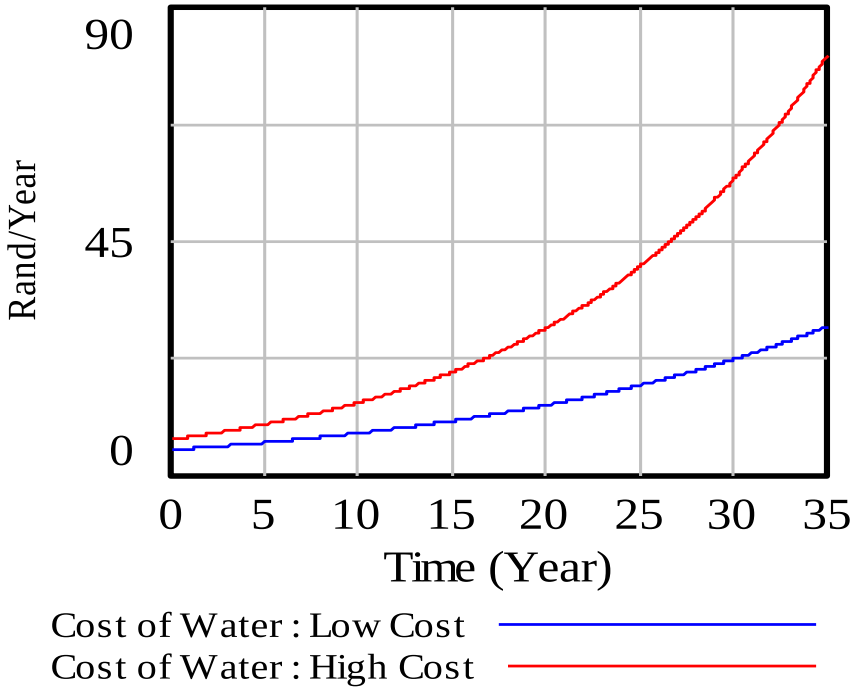


Figure 4: Comparison between Low and High Cost of Water

In Figure 4, it can be observed that if the cost of water is low (red trend) the province will have large amount of potable water for domestic use (Figure 5) and also increase the water demand (Figure 6). It can also be observed that at high cost of water (blue trend), water demand gets affected negatively as a result only communities with high income will have access to potable water because they can afford to pay the municipal water services. It is therefore, recommended that the cost of water needs to be reduced to ensure that communities with low income can have access to potable water. Unpaid water has an impact on the operation and maintenance of the existing water infrastructure. In Figure 5 and 6 it can be observed that domestic and annual water demand at lower cost (blue trend) will increase than domestic and annual water at higher cost (red trend). This will mean that communities with high income will have enough potable water than the communities with low income. It is therefore, recommended that affordable potable water is supplied to accommodate rural communities in the province.

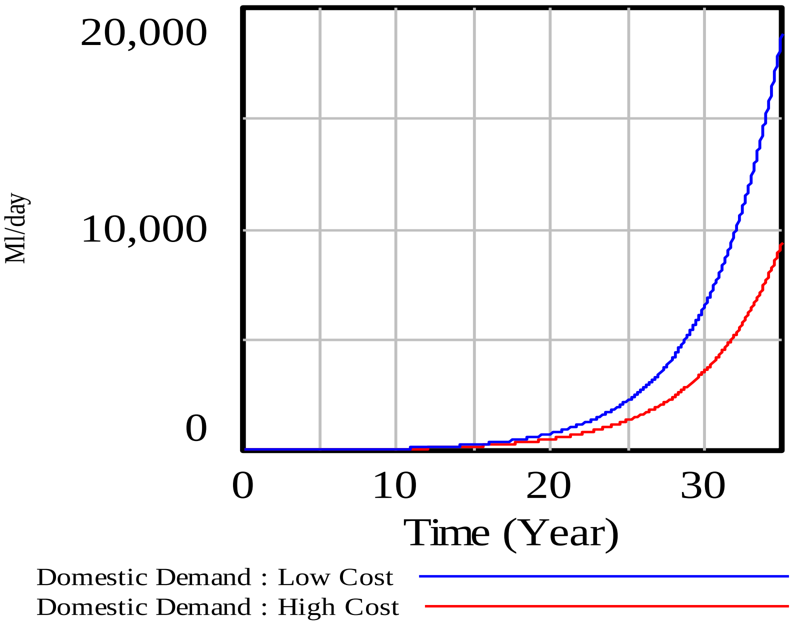


Figure 5: Impact of Low and High Cost on Domestic Water Demand

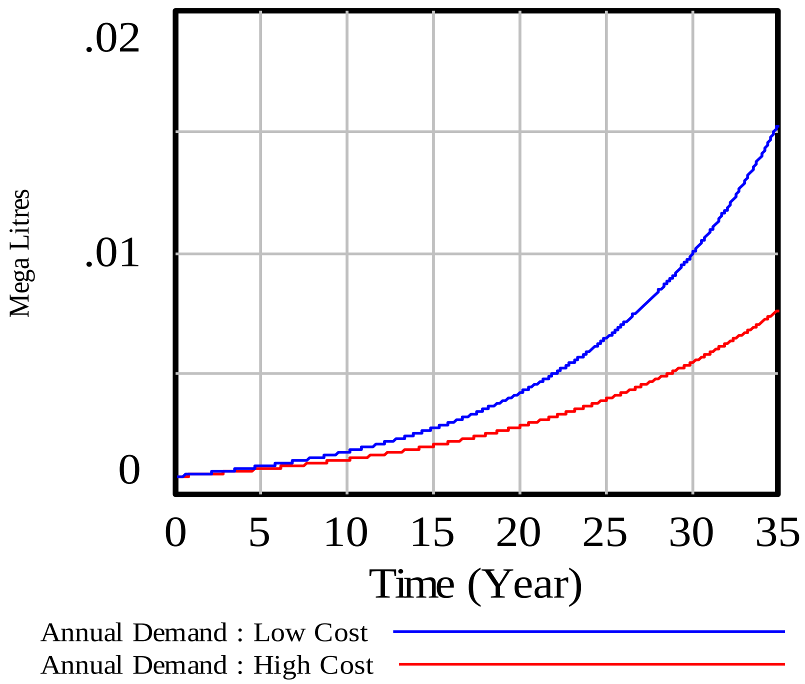


Figure 6: Impact of Low and High Cost on Annual Demand

6. CONCLUSION

In this study, a systems dynamic model was developed to elucidate the complicated interactions in water supply systems in the Mpumalanga province of South Africa. The results of the model show that reducing cost of water will increase access to potable water. At high cost of water (blue trend), water demand gets affected negatively as a result only communities with high income will have access to potable water because they can afford to pay for municipal water services. In addition, the study shows that if no type of water management policy is implemented, the province will continuously experience shortage of water. There is a need to implement water management and demand policies to ensure that even communities with low income have access to potable water. Despite the implementation of water management policies, effective maintenance and operation of supply systems is essential to ensure that enough water is available to consumers and prevent possible damages of water infrastructure in the near future. The shortage of water can be solved if the municipalities reduce the cost and ensure that communities with low income pay water services. The municipalities need financial support to ensure proper administration of water demand and availability, water resource planning, water resource development, the treatment of water, safety of dams, control over the abstraction of public water management, monitoring of water quality, provision of technical and financial assistance to the private sector and water authority. Long term value of using the systems dynamics approach will be to update policy in the sourcing, management, purification and distribution of water in South Africa in a more effective way.

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THE APPLICATION OF LEAN PRINCIPLES IN THE BREWERY INDUSTRY

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ABSTRACT

While there has been significant research focusing on the application of lean principles to the discrete manufacturing of items, there is a sparsity of literature that addresses process industries. This study closes this gap by applying lean principles in the brewery industry. The study identifies areas of improvement at a case study company and provides recommendations for production line improvement. The study starts with a conceptual phase, which comprised a literature review, interviews, and observational analyses that formed the case study of the project. The second phase is concerned with developing and applying lean manufacturing analysis techniques in the context of the breweries production line. The study concludes with the evaluation phase of the project, where recommendations are made to improve the production wastes identified on the production line.

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1 INTRODUCTION

The application of lean principles in process industries is scarce. Although there is plethora of literature regarding lean application to the discrete manufacturing of items, there is limited research addressing process industries [1]. In the cutthroat brewery industry, it is imperative to gain a competitive advantage as an enterprise. Since the commercialisation of beer brewing in South Africa in the early 1900s, the industry has been almost entirely controlled by South African Breweries (SAB) [2]. Cape Brewing Company, a craft brewery founded in 2012, is looking to transition into a premium beer brand. For this to be possible, their current production operations at their Paarl based brewery need to be further optimised to clear the path for future growth. With craft beer accounting for only a 1% share of the beer market in South Africa [3], the aim is for these smaller craft breweries to get a foothold in the South African market. Applying lean manufacturing principles to the industry appears to be a good foundation to initiate further growth in the market, to ensure that they produce as efficiently as possible.

The research problem is to identify production wastes on the CBC production line to recommend improvements to CBC management. The research objectives are:

- To understand the current production operations of the craft brewery
- To analyse the breweries production processes to identify areas of improvement
- To apply appropriate lean manufacturing principles to the identified areas of improvement
- To recommend improvements to CBC management

The lean manufacturing tools used to analyse the CBC production line are value stream mapping and a Lean Assessment Tool found in literature. A time-motion study and interviews conducted with CBC management provide the data and information required to apply the lean tools mentioned.

2 BACKGROUND

2.1 History of lean manufacturing

A significant shift in the manufacturing sector was initiated by Henry Ford, the founder of the Ford Motor Group, in 1913. He is the first person to fully integrate a manufacturing process by creating a moving assembly line for mass production [4]. The assembly line consisted of conveyors, standardised processes, and interchangeable parts, controlled by narrowly skilled workers [5], to facilitate the Ford Model T automobile production. Ford was thus able to maximise the utilisation of its inventory in relatively short periods of time.

While Ford was able to optimise the flow of a product throughout its assembly line, the firm could not offer a variety of products due to its assembly line being in a product layout. Each Model T automobile was manufactured using identical chassis and was available in one colour until the end of production in 1926 [6].

This stoked the interest of Japanese engineers Kiichiro Toyoda and Taiichi Ohno at Toyota in the 1930s. They decided to use the foundation of Ford's product flow concept to try and perfect the flow of a product through their entire system, the now better-known Toyota Production System. The Toyota philosophy is centred around integrating the people, equipment, time and money of complex manufacturing systems [4]. They believed that relatively few steps in the production process contributed to the value of the final product [5]. Their main objective was to eliminate any form of waste in Toyota's manufacturing line, where waste was defined as anything that did not add value to the product that the customer receives. By implementing a lean philosophy company-wide, Toyota has remained as the top producing automobile manufacturer worldwide based on sales and diversity in market shares, causing great curiosity in the field of lean thinking [7]. Furthermore, lean thinking has started to be adapted to each sector of the supply chain whilst being used in the process improvement in logistics, healthcare, retail and construction, to name a few [5].

2.2 Lean manufacturing in South Africa

A study by Chiromo et al. [8] investigated a publication on the factors affecting the implementation of lean production in South Africa, where a government-run apparel company was studied. It was discovered that the development of general lean implementation frameworks was common in South Africa. In contrast, a country such as Germany preferred to focus on lean implementation that is company-specific. It is also known that Germany is dedicated to developing more sustainable manufacturing systems in which raw material and process waste are minimised [9]. In contrast, local South African firms have attempted to apply lean principles to product design and mineral industries, which are not explicitly relevant to lean implementation [10].

In research conducted by Dondofema et al. [11], the gaps between the implementation of lean manufacturing practices in South Africa were compared to Germany. This country is considered to be one of a select few countries that have prioritised lean manufacturing [12]. The country has historically taken a holistic stance on lean manufacturing. The vast majority of lean implementation projects have prioritised the training of staff towards lean thinking to adopt a lean company culture before implementing any lean tools [13]. Therefore, the existing gap between the two countries is that South Africa is still starting its lean manufacturing journey. Up to this point, lean manufacturing implementation in South Africa has been done using lean manufacturing tools and frameworks without developing a lean culture within the respective firm beforehand [11].

2.3 Principles of lean manufacturing

The book 'Lean Thinking' by Womack & Jones [14] defined the five main principles of lean manufacturing shown in the table below.

Table 1: Five principles of lean manufacturing

Principle	Interpretation
1. Specify the value of the product	The customer should specify the value of a product. Hence, the benefits of acquiring the manufactured product must outweigh the cost to the customer.
2. Identify the value stream for the product	The value stream of a product consists of all processes that occur from customer order to delivery to the customer (i.e. consisting of value-adding (VA), required non-value adding (RNVA) and non-value-adding (NVA) processes). To eliminate process waste, non-value-adding process steps need to be removed.
3. Generate product flow	The product should flow continuously through the resulting value-adding processes. The system should then be managed such that the resources used to complete customer orders are continually reduced where possible.
4. Respond to customer pull	Production should only proceed once a customer order is received, also known as a 'pull' on the system.
5. Strive towards perfection	Repeat Kaizens to strive for perfection, although an entirely waste-free system of processes is unattainable.

2.4 Types of waste in lean manufacturing

According to Melton [5], there are several expected benefits of implementing lean principles in a production environment. Lean principles encourage a greater understanding of cross-departmental processes, which assists in the elimination of various sources of waste. This ultimately results in reduced: inventory levels, lead times and reworks.

In literature by Fercoq et al. [15] on waste reduction techniques to combine lean and green manufacturing principles, the seven general categories of waste found in manufacturing processes are mentioned, along with potential lean solutions. The table below is adapted from several papers [4, 14, 15]. The general wastes shown below provide the categories under which production wastes can be grouped according to their similarities.

Table 2: Sevens wastes of lean manufacturing

Waste	Description	Consequence	Lean solution
Over-production	Production beyond what is required	Waste of resources (i.e. time, material, labour etc.) No value is returned to the company.	Donation of by-products or excess inventory. Precisely following a production schedule.
Inventory	Storage of materials and products due to over-procurement or production	High overhead costs Clustered working area Depreciation of materials and components in inventory	Optimisation of raw material/component procurement
Transportation	Moving of product from production to customer	Repetitive movement of materials during intermediate stages of production Movement of the final product is the only value adding step	Centralisation of production, tasks, delivery and recycling facilities
Motion	Unnecessary transfer of products and information	Whilst a product is in motion, nothing is directly contributing to the production of the product.	Centralisation of production, tasks, materials and information flow
Defects	Errors occurring during production (i.e. rework, discarding)	Customer dissatisfaction Increased operating costs Overtime Disposing and recycling of defects	Clear definition of expected quality, controlling of vital parameters, re-integration of scraps in the form of raw material
Over-processing	Completing more tasks or higher quality than required	Delays of products, documentation. Overall increase in waste	Precise control of raw materials and resources
Waiting	Delaying of work	Potential component damage/spoilage	Reduce WIP inventory

3 CASE STUDY DEFINITION

To identify production wastes and recommend improvements using lean principles, a case study was chosen: the CBC beer production line at their Paarl based brewing facility.

3.1 Defining product value at CBC

CBC is a tried and trusted premium brand of high quality, multi-award-winning craft beers. The product range consisting of a variety of styles and characteristics is suited for all tastes and occasions. The quality of the flavour in the beer is achieved by procuring the highest quality of ingredients and paying attention to detail during each stage of the brewing process.

3.2 Current state value stream map

The current state value stream map of the CBC brewing facility is shown in the figure below. The value stream map visually displays the flow of materials and information in the beer production process. The map allows for suspected system wastes to be identified by exposing the non-value adding stages of the process. The time scale at the base of the map shows the cycle times (top) of each process and the waiting time (bottom) between the respective processes.

The waiting time consists of the time it takes to transfer materials between processes, cleaning time and setup time. The cycle time of each step is considered to be value-added time (VAT), as these steps contribute to the value of the product that the customer will receive. The waiting time is treated as non-value-added time (NVAT). The majority of this time is essential to producing the beer, but these steps do not directly influence the product's value. It is, therefore, the focus of analysis when attempting to eliminate wastes in the production process.

An important key performance indicator (KPI) that can be deduced from the VSM is the production ratio. It is defined as the ratio of value-added time and total lead time [12]. According to the current state VSM, the ratio is around 72%. The higher the production ratio, the less the amount of NVAT is present in the system. Thus, the elimination of as much NVAT as possible will assist in maximising the production ratio.

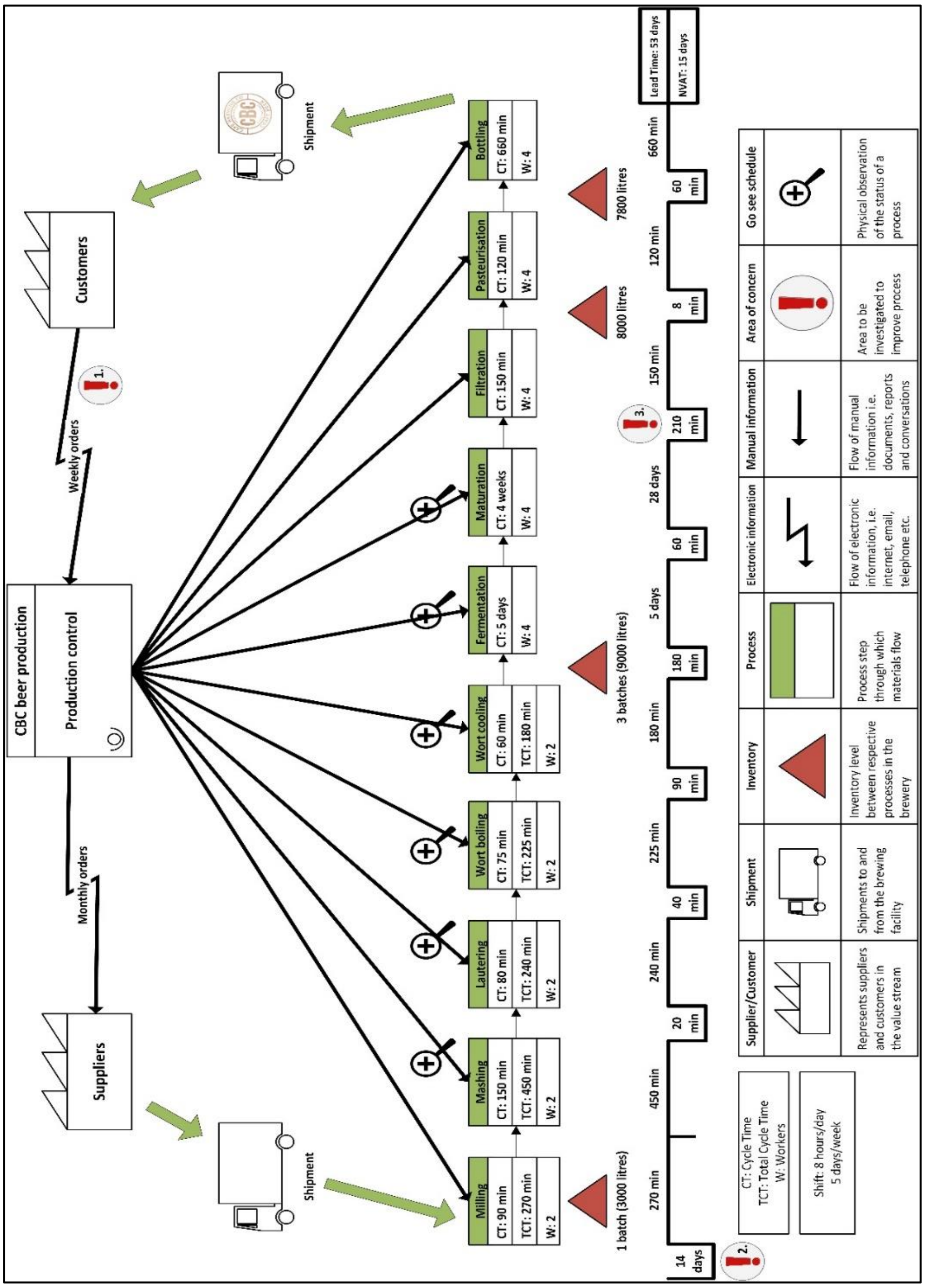

Figure 1: Current state value stream map

3.3 Lean Assessment Tool

In a study by Panizzolo et al. [17], four small to medium enterprises in India were studied to determine the extent to which lean manufacturing principles had been adopted in these enterprises. Subsequently, a Lean Assessment Tool (LAT) was developed which was based on a set of lean manufacturing principles that assist in eliminating waste. The principles that had not been implemented yet were related to occurrences of waste in the respective production processes. An adaptation thereof is presented below, which was applied in the context of the CBC brewery. The relevant functional areas used in the LAT were identified by various authors mentioned in the table below and their operational goals. The functional areas are as follows: Process and Equipment (PE), Manufacturing Planning and Control (MPC), Human Resources (HR), Product Design (PD), Supplier Relationships (SR) and Customer Relationships (CR).

It was revealed that CBC has implemented or at least considered all of the lean principles identified by Panizzolo et al. [17] in their production process. This is a strong showing of the implementation of lean principles in a production environment. However, a third of the listed lean principles have only been applied to a small extent. Therefore, these principles will serve as the focus of the outcome of the LAT.

The table below presents the lean principles applied only to a small extent at CBC, along with the functional areas they find themselves in and the reasoning for lack of further implementation.

Table 3: Lean Assessment Tool outcome

Manufacturing Planning and Control	**Description**	**Reason for lack of implementation**	**Applicable**
Levelled production [18]	Intended to reduce over-production by flexibly producing according to customer demand. This is achieved by operating manufacturing processes as close to the takt time as possible, in turn creating a continuous flow of work.	Considering that CBC currently has no production scheduling or demand forecasting system in place, it was deemed unfeasible to implement levelled production. Accurate forecasting and production scheduling are required to implement levelled production successfully.	Yes
Synchronised scheduling [19]	Production strategy where the onset of production is synchronised with shipments. A shipping due date is established, and production ensues to meet that due date. It is suited to make-to-order industries due to the level of product customisation required.	CBC follows a make-to-stock production strategy, in which enough product is produced to match anticipated demand. Synchronised scheduling requires accurate demand forecasting, which is currently not available at CBC.	No
Human Resources	**Description**	**Reason for lack of implementation**	**Applicable**
Worker training [20]	Increasing the skill levels of employees to enable them to work across the various functional areas of a company.	This empowers workers and encourages worker engagement for the better of the company. However, due to the current size of CBC, this has not been a priority.	Yes
Innovative performance appraisal and performance-related pay systems [21]	An employee performance management system in which good performances are rewarded by encouragement, incentivising or	Although the improvement of overall work quality can be expected, it is currently not a priority at CBC, as they have a	Yes

	allocating greater responsibility.	relatively small staff force.	
Product Design	**Description**	**Reason for lack of implementation**	**Applicable**
Product modularisation [22]	Aids in creating product variety in industries that offer customisable products. It usually involves designing products that contain interchangeable parts to provide different functionalities.	This does not apply to CBC, as they do not offer any customisable products.	No
Supplier Relationships	**Description**	**Reason for lack of implementation**	**Applicable**
Backlog orders [23]	An order that has been requested but cannot be shipped at present. Orders of this nature are often paid for by the buyer in advance.	A backlog order production strategy increases lead time and is suited to a customisable product industry. As CBC does not deal with customisable products, this strategy is not applicable.	No
Supplier involvement in quality improvement programmes [24]	A practice that promotes resource and network efficiency by sharing design expertise between management and suppliers.	This is beneficial to the brewing industry, considering that the quality of the raw materials and components supplied by suppliers determines product quality to a large extent.	Yes
Long-term contracts [25]	A mutually beneficial agreement between buyer and supplier usually over a number of years. It is a sign of commitment to a supplier's product.	This is important in the brewing industry, as it ensures raw material availability, reduced rates and reliability. The COVID pandemic has resulted in demand uncertainty and procurement difficulties. Thus, long-term contracts have not been feasible of late.	Yes

Customer Relationships	Description	Reason for lack of implementation	Applicable
Flexibility in meeting customer requirements [26]	A production strategy aimed at responding to spontaneous requests of customers, creating greater customer retention.	This does not apply to CBC, as they do not offer customisable products.	No
Customer involvement in product design and development [24]	Customers provide valuable feedback to improve product design and development potential.	This has not been prioritised at CBC, as it would require more staff and capital to set up and conduct a rigorous feedback procedure.	Yes

4 ANALYSIS

4.1 Wastes observed at CBC brewery

The various wastes observed during site visits to the CBC brewing facility are shown in the table below. These wastes were identified after inspecting the beer production process and the areas of concern identified on the current state value stream map. The wastes are categorised according to the categories listed in Table 2, which are the seven wastes in lean manufacturing defined by Fercoq et al. [15].

Table 4: Production wastes observed at CBC

Category	Description
Over-production	Excess stock in the form of boxes and cases of beer in the bottle storage area.
Waiting	Filled bottles waiting to be packaged. The packaging machine is unable to keep up with the bottling machine.
Defects	Incorrect labels being placed on bottles and occasionally using the wrong bottles.
Over-processing	Repetitive cleaning and setting up of filter before filtration process.
Motion	Manual placing of stickers onto boxes.
Motion	Excess material (ingredients and packaging) changeovers during production of different beers.
Motion	Manual information transfer regarding stock levels

4.2 Root cause analysis

Root cause analysis is a method of identifying the cause of an issue rather than aimlessly treating the symptoms thereof [27]. The result is a sequential structured framework showing the symptoms that the manufacturing system is suffering from, leading to the ultimate root cause of the issue. The figure below intends to show how the implementation of the lean principles only applied to a small extent could solve some of the symptoms and root causes of the wastes found in the CBC production process. In summary, the LAT revealed the lean principles yet to be fully implemented at CBC, their applicability, and the functional areas in which these principles fall. The time and motion study allowed the various system wastes in CBC's production operations to be identified. The red arrows below depict a pathway to the root causes of some of the wastes that were identified. The reverse paths of the red arrows present possible solutions to the issues identified.

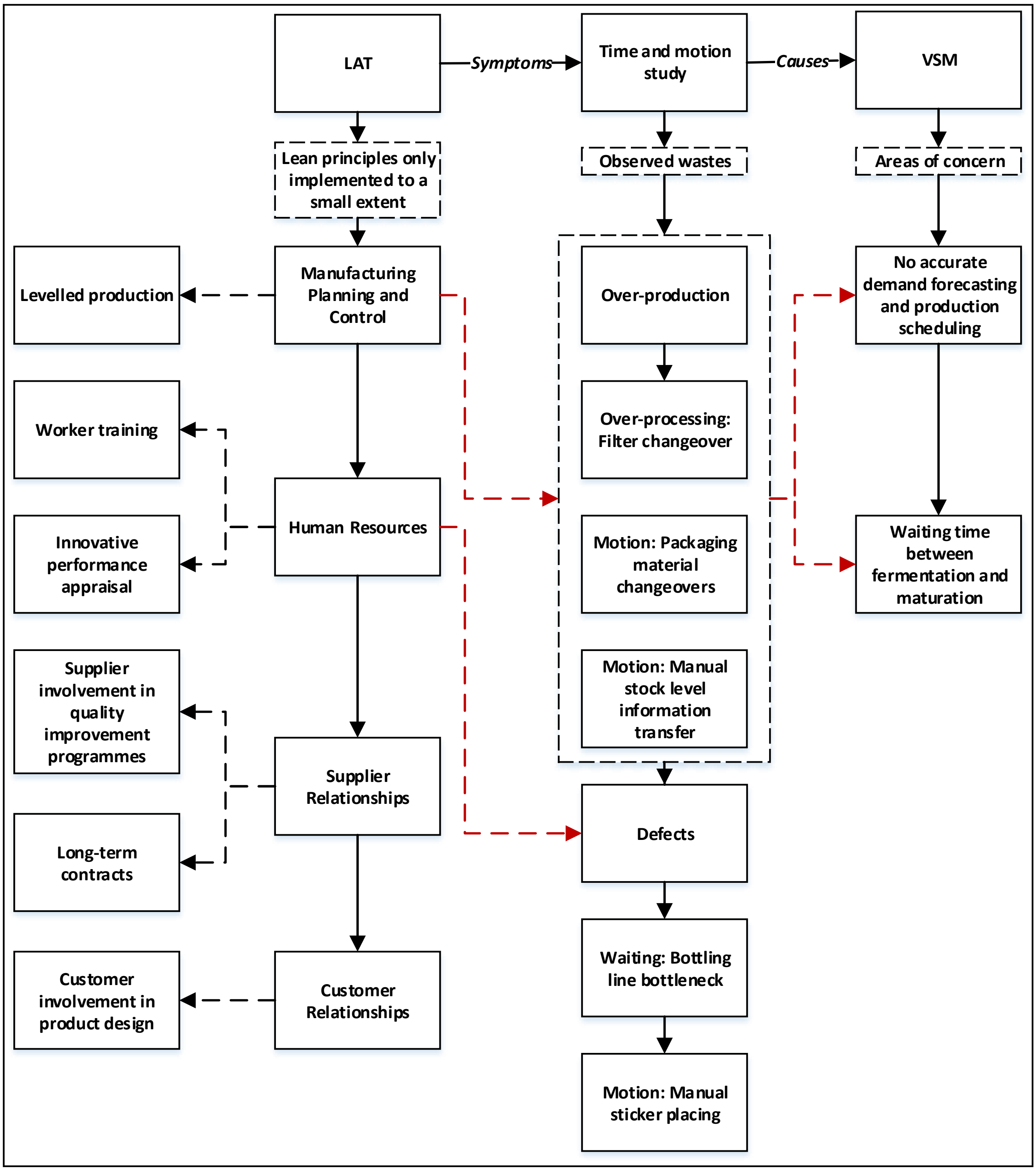

Figure 2: Root cause flowchart

5 RECOMMENDATIONS

5.1 Future state value stream map

The future state VSM below shows the recommended improvements required to address the discussed wastes and areas of concern. The future state VSM shows an improved production ratio of 83% compared to the 72% of the current state VSM. The following recommendations are given from the perspective of CBC aspiring to become a premium beer brand with a larger production capacity.

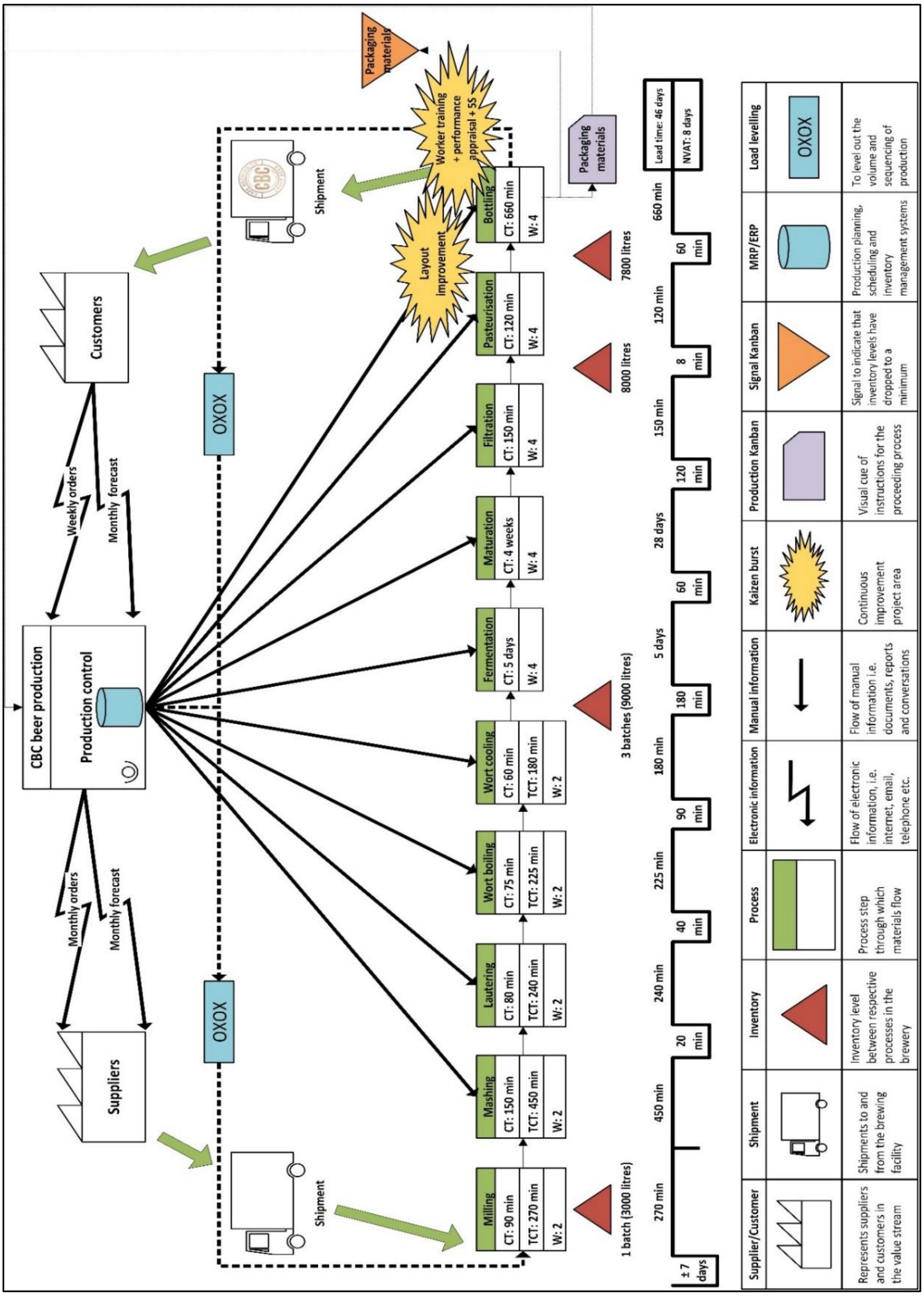

Table 5: Future state value stream map

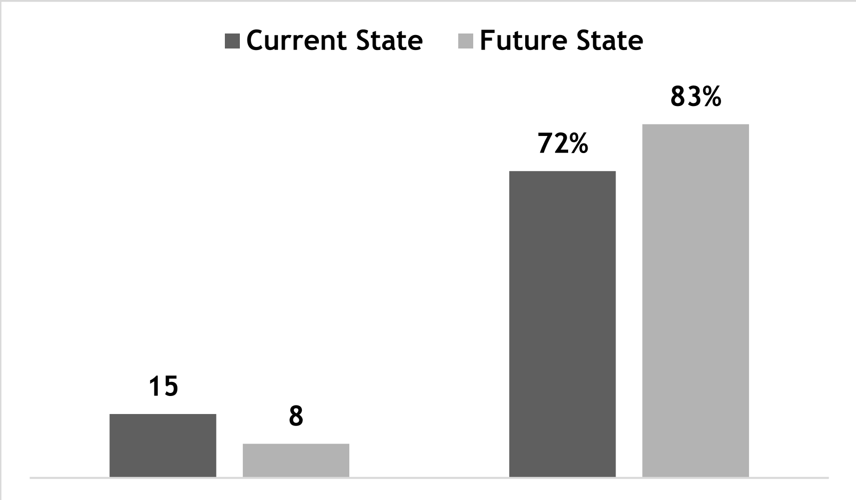

Figure 3: Current state versus future state

The estimated 11% improvement to the production ratio could be achieved by eliminating non-value adding time in procurement lead time and waiting time between the maturation and filtration processes adding up to an estimated 7 days. It is believed that the recommended improvements to the bottling line will further increase the production ratio.

6 CONCLUSION

This section highlights the project's key findings and presents a conclusion to the work carried out by the researcher. It proceeds to present avenues for future studies to be done.

6.1 Project findings

The main objective of this project is to identify areas of improvement on the CBC production line and subsequently recommend improvements to management, to eliminate process wastes on the production at CBC.

To identify CBC's value stream by separating value-adding from non-value adding processes, a current state value stream map was developed using the information and data collected through interviews and a time-motion study. This allowed for areas of concern to be identified. Additionally, a Lean Assessment Tool found in literature was applied to develop solutions to recommend to management.

A future state value stream map was developed that incorporated the recommended changes to be made. A summary of the proposed solutions to each issue identified can be seen in the table below.

Table 6: Summary of improvement recommendations

Area of concern	Proposed solution
Lack of accurate production scheduling and demand forecasting	Introduce MRP software to generate accurate demand forecasts and production schedules using historical data and market trend data.
Type of waste	**Proposed solution**
Over-production of finished goods	Use MRP software to determine customer demand accurately and subsequently determine the correct level of production.
Over-processing: Repeated setting up and cleaning of filtration system	Use MRP software to determine an optimally sequenced production scheduling to group together the filtration process of similar beer products.
Defects: Defective finished goods	Conduct worker training for floor staff to improve their all-around ability. Additionally, introduce colour-coded Kanban cards and 5S for fail-safe selection of packaging materials.
Motion: Manual sticker placing on boxes	Automate box labeller on the bottling line to replace the manual process.
Motion: Excess material changeovers	Use MRP software to generate optimised production schedules that sequence the production of similar orders to reduce material changeovers.
Motion: Manual transfer of stock-related information	Use signal Kanban cards to inform the office staff of resources that are diminishing.

6.2 Opportunities for future work

The following opportunities have been identified for future researchers to elaborate on the work completed by the student. Future research can target specific areas of improvement that the student identified or take a holistic approach.

- Test the recommendations mentioned above by implementing them on the CBC production line.
- Conduct a cost estimation for the implementation of the recommendations to develop a budget.
- Compare various MRP software packages to establish the one best suited for CBC.
- Apply the analysis framework followed in this project to similar or different industries to achieve similar research objectives.

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STATUS OF SUPPLY CHAIN TECHNOLOGY ADOPTION IN THE SMALL AND THE MEDIUM ENTERPRISES IN SOUTH AFRICA: A REVIEW

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ABSTRACT

Business success is dependent upon the strength of its supply chain management strategies. Supply chain technology (SCT) adoption remains key in the success of supply chain management. Some Small and Medium Enterprises (SME's) fail due to challenges such as limited technology access, low productivity, and poor managerial capabilities. The COVID-19 pandemic has further destabilized operations, affecting productivity globally in various sectors. While some SMEs are adopting technology to reinforce their competitive edge others are resisting technology adoption. This study reviewed SCT adoption within the South African SMEs to ascertain the progress made thus far. The study used a systematic literature review method to synthesize various peer-reviewed articles between 2010 and 2020 regarding South African SMEs. Reviewed literature indicated that some SMEs that embraced technology to improve their supply chain activities achieve improved quality services, reduced costs, and improved efficiency while other SMEs rejected technology adoption because of compatibility and perceived relative advantage. The limitations of the study lie in it's inability to identify the exact number of SMEs that adopted technology in the reviewed period.

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1 INTRODUCTION

The success of any business is dependent upon the strength of its supply chain (SC). Supply Chains are a critical part of world trade [1]. When a supply chain is managed efficiently, this ensures that there is the delivery of the right product in the right quantity at right time at the right price [2]. In South Africa, SMEs are classified as small or medium enterprises with varying sets of thresholds for each sector. SMEs are estimated to account for 90% of South Africa's business establishments contributing 52–57% of the country's gross domestic product and 61% of employment [3]. South African SMEs are diversified and operate in different industries, including retailing, wholesaling, to

urism, mining, farming, manufacturing, construction, and service and they face challenges that affect their growth and survival [4]. Some Small and Medium Enterprises (SME's) fail due to challenges such as limited technology access, low productivity, and poor managerial capabilities. According to [5], enterprises are reluctant to share information with their supply chain partners due to the unequal distribution of risks, costs, and benefits among such partners. The COVID-19 pandemic has further destabilized operations, affecting productivity globally in various sectors. While some SMEs are adopting technology to reinforce their competitive edge others are resisting technology due to the fear of the unknown. The emergence of electronic commerce (e-commerce), has notably been a remarkable value-add to all businesses that choose to adopt Information Technology [6]. A study was done by Mathu [6], to investigate how supplier-customer information sharing enhanced supply chain collaboration and integration in South African SMEs concluded that IT adoption speeds internal alignment of enterprises and cooperation with external partners. It was therefore the aim of the study to review SCT adoption within the South African SMEs to ascertain the progress made thus far. In the sections that follow, the paper reviews literature,explains the methodology that was used, discusses the results that were obtained and finally concudes the study.

2 LITERATURE REVIEW

The sharing of information among supply chain networks allows the supply chain drivers to work together with the goal of integrated and coordinated supply chains for effective supply chain management [7]. In his supply chain definition, Van der Vorst [8] takes a process view, where he looked at a supply chain as a sequence of decision making and execution processes and material, information, and money flow that aim to meet final customer requirements and take place within and between different supply chain stages. In his study, Janvier [9] consented that the role of a supply chain is to add value to a product by transporting it from one location to another, throughout the good can be changed through processing. Supply chain performance can therefore be linked to the capability of a business to reduce their operational costs through the timely delivery of a product or service in the correct quality and quantity [10]. Thus, Higher supply Chain Performance is vital in improving a firm’s market share [11]. In his attempt to emphasize the importance of supply chain management adoption in SMEs, [12] states that SMEs are lagging in appreciating how integrated supply chains drive remarkable changes in business processes resulting in improved quality services, reduced costs, and efficiency. According to [13], the concept of supply chain management started to emerge in the mid-1960s, and the first publication took place in 1982.

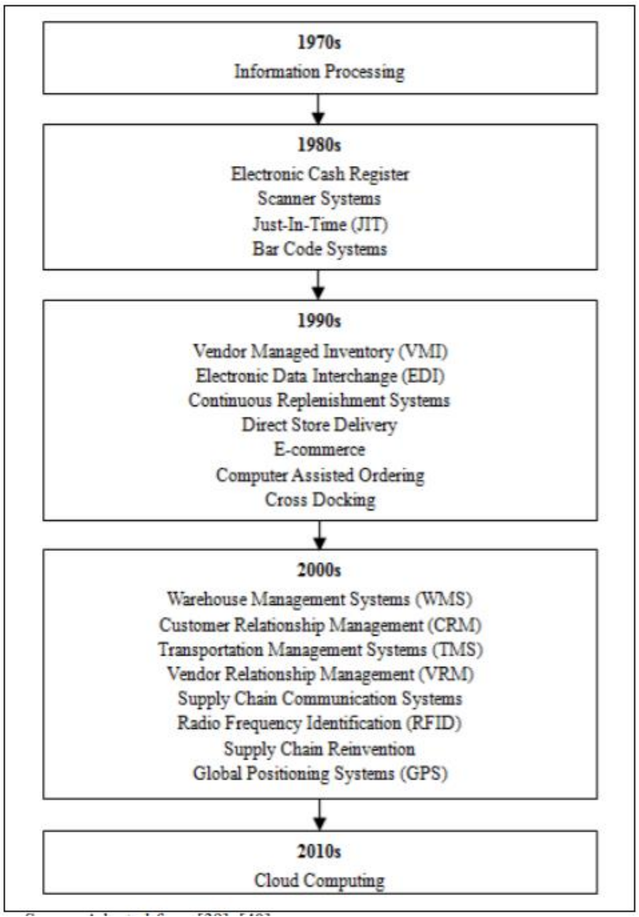

Figure 1:Supply Chain Technology Adoption Evolution [13]

Figure 1 adopted from [13] illustrates the evolution of supply chain technology adoption from the 1970s until 2010s. In the 1970s focus was maily on information processing then in the 1980s technologies such as electronic cash registers,scanner systems, and barcode systems were then introduced. The 1990s introduces wendor managed inventory, electronic data exchange e-commerce,computer aided ordering and cross docking. In the 2000s supply chains evolved with warehouse management systems, customer relationship management, supply chain communication systems and supply chain reinvention. The 2010s saw an increase in cloud computing in supply chain management.

3 METHODOLOGY

A systematic literature review was conducted to determine supply chain technology adoption within the South African SMEs to ascertain the progress made thus far. According to [14], systematic reviews involve a comprehensive and systematic search to locate all relevant published and unpublished work that addresses one or more research questions. In this study, the systematic literature review was used by defining search keywords to synthesize various peer-reviewed articles about technology adoption in South Africa between 2010 and 2020 using three databases. The authors focused on the past ten years as clear growth patterns were expected to be noted during this period. Table 1 indicates the filters used for excluding and including literature that was used when conducting the systematic literature review.

Table 1: Literature Search Filters

Year	2010-2020
Language	English
Keywords	Supply chain technology adoption, information communication technology, Small and medium-sized enterprises, productivity, competitive advantage
Databases used	Google Scholar, Scopus, IEEE Xplore

4 RESULTS

Reviewed Literature indicated that there are various reasons for SME adoption and non-adoption of technology in the South African context. Author [15] emphasized that though SMEs are engines of GPD growth, due to multiple reasons they tend to be slow in the adoption of digitalization and technology. Author [15] further argued that SMEs that embrace ICT grow multiple times faster than their sluggard competitors. According to [16], the adoption of technology helped SMEs improve organizational efficiency and it assisted in increasing the competitiveness of organizations. Madzimure [17] conducted a study where the relationship between e-procurement, supplier integration, and supply chain performance in retail SMEs in South Africa was investigated. The study used a quantitative research approach in which a sample of 283 SMEs in Gauteng Province, South Africa, were surveyed using a structured questionnaire [17]. The study found that supplier integration exerts a positive and significant linear relationship with both the tangible and intangible dimensions of supply chain performance. According to [18], the adoption of new technologies can contribute to both efficiency and effectiveness and it can serve as a key source of long-term competitive advantage in entrepreneurial ventures. Using the technology-organization-environment (TOE) model Gono [19] investigated the adoption and impact of information and communications technology (ICT) by small and medium-sized enterprises in South Africa as illustrated in figure1 with a focus on ICT adoption based on three main contexts namely technological, organizational and environmental.

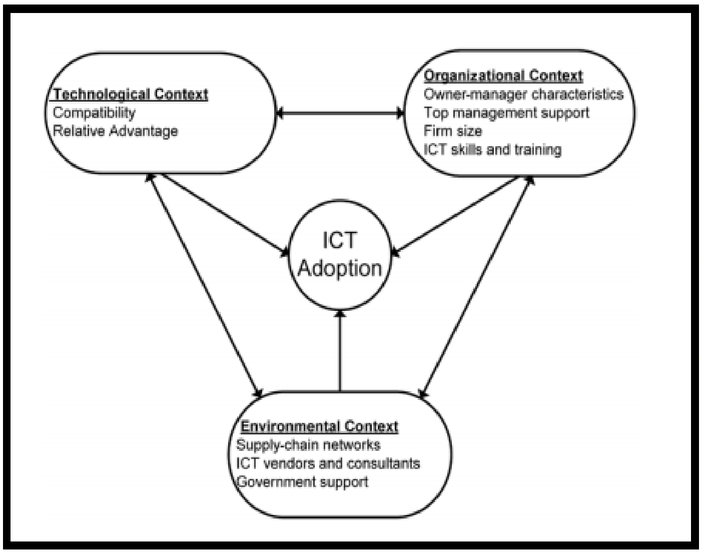

Figure 2: A model of ICT adoption by South African SMEs [19]

The study by [19] was undertaken through the aid of a questionnaire survey that included 130 SMEs operating in the Johannesburg manufacturing and logistics industries to understand the adoption and impact of ICT in SMEs. The study found that the technology context has a high impact on SMEs' adoption of ICT while compatibility and relative advantage also had a significant role in determining ICT adoption and impact. In his conclusion, Gono [19] states that supply chain networks have emerged as both a driver and an effect of ICT use in the South African context. Furthermore, the study found that supply chain capability can serve as a catalyst in transforming the competitive nature of firms, but firms can also be disadvantaged if they become too dependent on larger counterparts for survival and steady growth as firms with poor ICT capacity are often reliant on external assistance. In a similar study, Bvuma [20] aimed to gain a deeper understanding of the factors affecting ICT adoption by township SMMEs in South Africa by providing insight into various SMME characteristics and their varying levels of ICT adoption and perceptions. Data was collected through the adoption of a qualitative exploratory research method using in-depth interviews and observations of a sample of 21 SMME owners operating in Soweto. The results of the study state that township SMMEs are not adopting ICTs and the current ICTs adopted are not fully deployed [20]. In conclusion, Bvuma [20] deduced that township SMMEs require unique interventions when encouraging them to fully adopt ICTs as they are more likely to adopt technology if needs such as ICT awareness and ICT training are addressed. Using 407 SMEs operating in Gauteng, the study conducted by [21] aimed to analyze the connection between Supply Chain Management strategies, supply chain agility, and supply chain performance among SMEs in South Africa. To analyze collected data, the study employed exploratory factor analysis, Pearson correlations, and regression analysis. The study found that four supply chain strategies namely supplier collaboration, total quality management, technology adoption, and supply chain integration correlated with supply chain agility while technology adoption emerged as the strongest predictor of supply chain agility. Thus, the supply chain agility correlated with and predicted supply chain performance [21]. The study concluded that technology adoption, therefore, requires primary attention from SMEs for them to be agile and in turn improve their supply chain performance. In his study Pillay [22] aimed to identify the barriers to ICT adoption and use amongst SMEs in the South African manufacturing sector. Through the use of an online questionnaire, the study collected data from 81 SMEs in the manufacturing sector in Gauteng. The study examined three barriers that were considered to be of significant importance to SMEs ' ICT adoption. They examined barriers that were lack of hardware, immediate return on investment, and the lack of infrastructure [22], where it was then concluded that if SMEs can overcome the identified barriers, they can easily then adopt technology into their supply chains. Patterson [23] conducted a study that analyzed the factors involved in SMEs adopting new supply chain management technologies and further developed a model of the key factors influencing the adoption of supply chain technology. Figure 2 illustrates the organizational and environmental variables hypothesized in the study and the nature of their expected relationship with supply chain technology adoption. The study concluded that the integration of supply chain activities and the technologies to accomplish it have become competitive necessities in most industries [23].

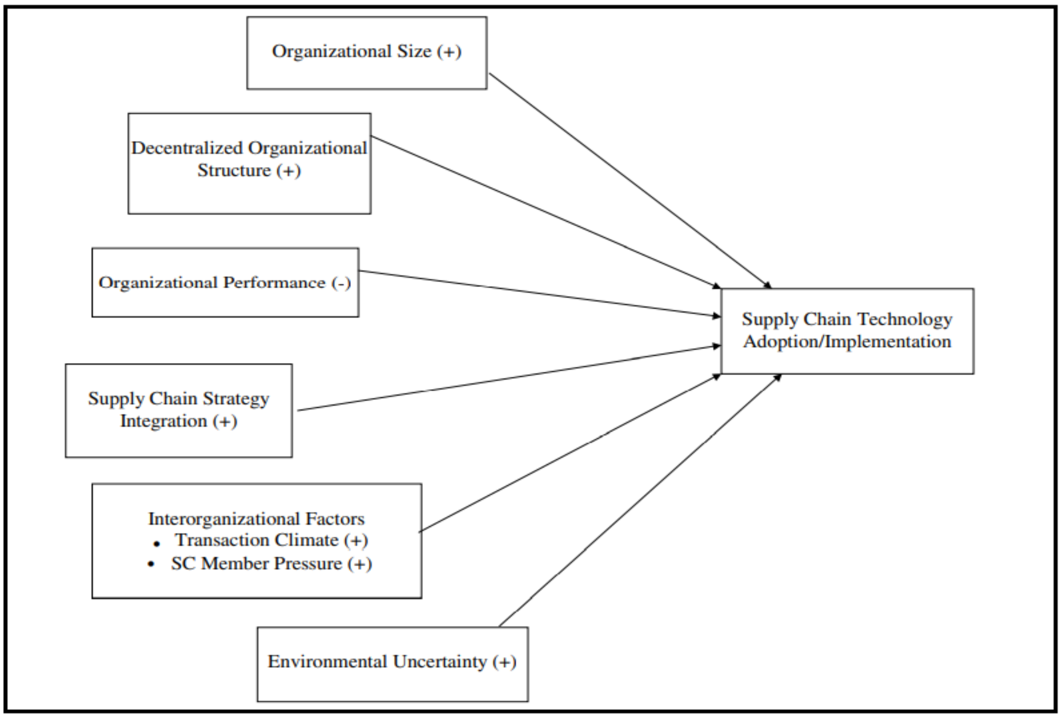

Figure 3: Antecedents of supply chain technology adoption [23]

Some of the reasons for technology non-adoption that were identified through reviewed literature include SMEs compatibility and perceived relative advantage, lack of ICT awareness and need for training, Lack of funds for required hardware, concerns related to an immediate return on investment, and the lack of required infrastructure.

Table 2 illustrates some of the literature that was reviewed for the period 2010-2020. The table focuses on the aim of the study that was reviewed as well as the findings that were obtained through the specified study.

Table 2: Highlights of literature found for the period 2010-2020

Author	Year	Aim of study	Findings of study	Total relevant studies found
[24]	2010	To examine the driving forces, challenges, benefits, barriers, and strategies to decrease barriers to information and communication technologies (ICTs) adoption and assimilation by small- and medium-sized enterprises (SMEs) in this era of globalization.	ICTs adoption and assimilation in SMEs is critical to enhancing their competitiveness. In addition, ICTs usage in SMEs will enhance accessibility into the international markets.	[3],[24],[25]

Author	Year	Aim of study	Findings of study	Total relevant studies found
[26]	2011	To investigate how Information and Communication Technology (ICT) has been used to add value to Small and Medium Enterprises (SMEs) in South Africa, particularly in the retail, production, and service provision sectors	It was found that ICT does indeed add value to SMEs, the use of ICT differs between different sectors, and South African SMEs encounter several critical barriers in the process of adopting ICT.	[1],[9], [26], [27]
[28]	2012	The study analyzed, in-depth, the literature on determinant factors that stimulate the adoption and use of ICT and the impact on organizations.	There are a lot of best practices that show how SMEs, which have heavily invested in ICT, increase the turnover and market share, hence becoming successful companies.	[12],[28]
[29]	2013	The study investigated the influence of IT on SMEs' performance and the mediating role of strategic purchasing and logistics integration.	IT has a stronger impact on logistics integration via strategic purchasing. Thus, IT alone, when not utilized in conjunction with other logistics activities such as strategic purchasing in the SME sector, will not yield an optimum impact on logistics integration and business performance.	[4][29][4], [30]
[31]	2014	Investigates the awareness of cloud computing within SMEs in South Africa.	The findings reveal a lacking level of cloud computing awareness, thus limited knowledge on cloud computing benefits and services	[7],[10][31], [33][31], [33],[32]
[34]	2015	The objectives of this study were to determine the current level of e-commerce adoption and factors that motivate the adoption by Small and Medium Enterprises (SMEs) in Pretoria East.	The results show that only three independent factors namely relative advantage, competitive pressure, and IT knowledge were statistically significant. Relative advantage emerged as the most important factor influencing the adoption of e-commerce among SMEs in terms of relative importance.	[34][35],[36],[37],[38]

Author	Year	Aim of study	Findings of study	Total relevant studies found
[39]	2016	The study aimed to explore the challenges faced by SMEs in adopting the Cloud Enterprise Resource Planning (ERP) system.	The study found eight (8) emerged themes that are reluctance to adopt cloud ERP among SMEs, this is attributed to knowledge, data security, vendor trust, technology trust, system availability, and cloud ERP system functional fit.	[5][19],[22], [39], [40],[41]
[42]	2017	The objective of the study is to identify challenges experienced by SMEs when implementing ERP systems and to suggest requirements for achieving successful implementations in SMEs in Southern Africa.	The study suggested that a successful ERP implementation requires sufficient and appropriate training, reliable internet connection, involvement of end-users, change management, as well as sufficient demonstration of the prospective ERP system.	[11], [42][43],[44]
[45]	2018	This study aimed to investigate the significant factors hindering the adoption of software as a service among South African SMEs	The study findings indicate that some SMEs have not used Software as a Service because they have never heard of it but may consider SaaS solutions if it reduces the organization's IT expenditure.	[45], [46],[47]
[48]	2019	The purpose of this study was to investigate the impact of moderating factors on the evaluation of new and emerging digital technologies (ICTs) compared with existing digital technologies in current use among Small and Medium Enterprises (SMEs).	The study concludes that for South African SME owners, no matter their age, experience with the use of existing ICTs, and working experience, these characteristics do not differentiate the individual perceptions towards the evaluation of existing ICTs before adopting emerging ICTs.	[6][14], [48], [49],[50],[51], [52],[53]
[54]	2020	This study aimed to investigate the determinants that influence the intention to adopt ICT by SMEs in developing countries using Pietermaritzburg in South Africa as an example to understand this phenomenon	Based on the findings of the study, it is concluded that SMEs need to pay particular attention to ICTs that are relevant to them, including the characteristics and resources of the organization to successfully adopt these technologies	[17], [18], [20], [54][55], [56], [57]

Table 2 illustrates the reviewed literature that represents different phases that SMEs have been faced with from 2010-2020, wherein in 2010-2013 most literature was aimed at highlighting the importance of ICT adoption for SMEs. During 2014-2016 the focus shifted to highlighting why SMEs are failing to adopt ICT. While 2017-2020 saw more literature focusing on the various types of technologies that were emerging from which SMEs would benefit if adopted. According to a report by [58], the decentralization of technological services has enabled SMEs to access new markets, thus minimizing business costs, and maximizing efficiency. In its recommendations, the report emphasized that SMEs should better utilize technology that is easily accessible to them such as their smartphones to take advantage of web-based services that can help to grow their business. Education in the use, benefits, and cost-effectiveness of technology, such as e-commerce and cloud services, needs to be offered to SMEs to proactively encourage uptake and there is a drastic need for affordable and quality internet access in the country. Figure 3 illustrates a model that was developed by [18] that can assist SMEs in overcoming barriers to technology adoption. It is therefore proposed as a solution to combat SME issues related to technology non-adoption in South Africa. The model is designed from a poverty perspective where poverty conditions are the main barriers to technology adoption. In some instances, technology non-adoption from SMEs leading to technology and digital illiteracy is due to poverty conditions. The model identifies three external enablers namely training, access, and practice as having the ability to indirectly increase SMEs' technology and digital literacy [18]. The enablers will then encourage a need for technology and digital literacy development which will then lead to transformation within SMEs that will lead to technology adoption through the aid of funding or incubators in some instances. In the conclusion, the study [18] further states that although technology and digital literacy are the starting points leading to technology adoption, organizations possess the absorptive capacity to incorporate, assimilate, and exploit new technologies.

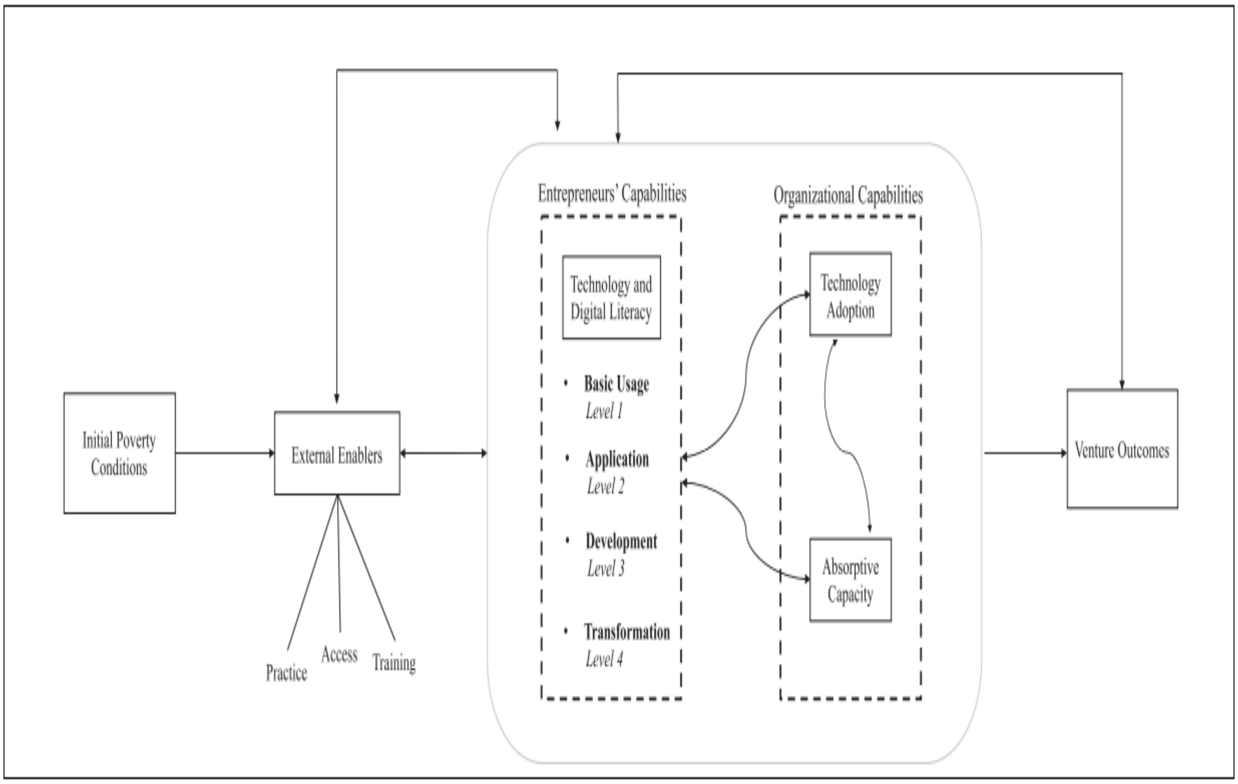

Figure 4: Model of poverty conditions and technology adoption [18]

5 CONCLUSION

Supply chain technology (SCT) adoption remains key in the success of supply chain management of any business. Some Small and Medium Enterprises (SME's) fail due to challenges such as limited technology access, low productivity, and poor managerial capabilities. In his study [12] emphasizes the importance of supply chain management adoption in SMEs, stating that SMEs are lagging in appreciating how integrated supply chains drive remarkable changes in business processes resulting in improved quality services, reduced costs, and efficiency. It was therefore the aim of this study to review SCT adoption within the South African SMEs to ascertain the progress made thus far. Literature from the past 10 years (2010-2020), was reviewed and it indicated that there are various reasons for SME adoption and non-adoption of technology in the South African context. Reviewed literature also indicated that SMEs that embraced technology to improve their supply chain activities, yield remarkable productivity, improved quality services, reduced costs, and efficiency [12]. The period 2010-2020 illustrated the various phases that SMEs have gone through in terms of technology introduction and adoption. The study found that there was a steady increase in terms of literature that analyzed SME technology adoption which sees an increase from the year 2014. The significance of this study lies in its attempt to review literature that analyzed the state of SMEs in terms of technology adoption in the past 10 years, highlighting the benefits that can be reaped by SMEs if they adopt the technology. The study further analyzed a model that was proposed by [18] and deemed it as a possible solution for SMEs that are struggling to adopt technology for various reasons. The limitations to the study lie in its inability to identify the exact number of SMEs in South Africa that adopted supply chain technology during 2010-2020 however future work is suggested to enable the analysis of technology adoption trends in the stated period.

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TRENDS IN ENVIRONMENTAL SUSTAINABILITY OF ADDITIVE MANUFACTURING

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ABSTRACT

Additive manufacturing has been commercialized, and research to improve the process is ongoing. Aside from economic sustainability, additive manufacturing must demonstrate environmental friendliness. The review answered the research question of when how much literature has been published on additive manufacturing environmental sustainability. The document highlights the trends in environmental sustainability publications with respect to additive manufacturing. The systematic review was focused on metal additive manufacturing, though other additive manufacturing methods were reviewed for comparison and to get a general overview of the extent which additive manufacturing has gone in sustainability studies. So far much of the research covers energy consumption and material usage of additive manufacturing. The results will be used for future researchers who want to know the extent to which environmental sustainability has been conducted. There is a gap in the environmental impact studies in additive manufacturing which future researchers can fill by carrying out more studies on environmental impact.

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1 INTRODUCTION

Many studies on the environmental sustainability of metal Additive Manufacturing (AM) are comparison studies between conventional and additive manufacturing [1]. The usual difference in conventional manufacturing and additive manufacturing is the pre-manufacturing and manufacturing stages [2]. Many of the studies have shown that additive manufacturing has improved material usage compared to conventional manufacturing [2] [3] [4]. It is difficult to calculate energy usage of additive manufacturing because there are other processes that feed into the energy consumption of additive manufacturing within its value chain. The more energy a process uses, the more resources are required to create the energy needed to sustain the process. Much of the energy is extracted from organic resources which are difficult to replace and thus bring permanent damage to the environment [1]. These processes need to be included to get a holistic overview of energy consumption of AM which many studies do not cover. The processes to be included are the material extraction process and material refining process. Material usage stage can be used which may include the benefits additive manufacturing brings through weight reduction.

The energy consumption per part of additive manufacturing may be difficult to compare as the batches in AM are different mix compared to conventional manufacturing. Additive manufacturing has the advantage of less tooling for complex parts and can be advantageous for customised parts because of the small batch requirements [5]. Less tooling in manufacturing entails less energy needed to make a part.

The majority of the studies on sustainability are based on energy consumption of which a number are comparative studies between AM and conventional manufacturing [6] [7] [8] [9]. Metal additive manufacturing has the vast majority of the studies in energy comparison [5] [10] [11] [12] [13]. The studies on material usage and recycling have also been encode-operated into additive manufacturing but are a few [14] [15] [16]. Stereo lithography, fused deposition modelling and construction 3D printing take up the majority of pollution and social impact studies as the materials can disintegrate and change chemical structure with time. Few studies highlighted the social and health impacts of additive manufacturing and that’s an area that needs to be taken into consideration [17] [18].

2 METHODOLOGY

A qualitative approach deductive approach was used to conduct the research. The main subject of the research is environmental sustainability with much focus on additive manufacturing. Additive manufacturing is fairly new and the environmental impact needs to be known. Finding out how much research has been conducted in environmental sustainability in additive manufacturing important and this is where the research question can be deducted.

The research question to be answered is:

To what extent have researchers published on environmental sustainability of additive manufacturing?

2.1 Purpose of study

The purpose of the study includes the following:-

a. To find out the current trends in additive manufacturing environmental sustainability.
b. To find out if there are studies on environmental sustainability in additive manufacturing and its related processes in the value stream.
c. To identify the gaps in environmental impact assessment for additive manufacturing.

To answer the research question a systematic literature review was conducted. The research is descriptive and has a few elements of quantitative so a mixed method of research was used [19]. A systematic review is a review of a formulated research question that uses systematic and repeatable methods to identify, choose and critically appraise all relevant research. In a systematic review data is collected and analysed from the studies that are included in the review [20]. A systematic reviews aims to find research articles related to the research question and critically analyses the data. The steps taken to conduct the research were:

1. Identify the research topic
2. Identify the research question
3. Identify the search terms to be used
4. Identify inclusion and exclusion criteria
5. Identifying relevant work within the studies
6. Assessing the quality of studies
7. Extracted the relevant data from included studies
8. Present results and assess the quality of evidence

The data base used for the systematic review is Scopus. The reason for using Scopus is that Scopus contains multiple scientific articles. The second stage is then to find out the search terms that are related to environmental impact. A search was done for different topics on environmental sustainability and impact with the aim to cover all aspects of the environment with respect to additive manufacturing. In order to ensure the results were up to date a filter was used to limit the result from 2016 to 2020. The journals were then reviewed and grouped according to the manufacturing method and topics. This was done to make it easy for future researchers to know the extent which each additive manufacturing receives attention.

3 SELECTION OF DATA

After conducting an inititial search it was found that most of the data was not relevant. The researcher were only looking for data only related to environmental sustainability of additive manifactruing. A qualitative approach was used as the research was descriptive and partially quantitative as it sought to find out the number of publications for each type of additive manufacturing. The ininial search sought to find the topics related to environmental sustainability and the search terms were "environmental impact assessment" OR "environmental conscious manufacturing" OR "life cycle assessment" OR "life cycle analysis" OR "cleaner production" within the abstracts, titles and keywords as shown in
Table 1. The secondary search sought to find the publications related to additive manufacturing with additive manufacturing as the key search term. The asbratcts and title were anlysed and articles that contained additive manufacturing related terms were fished out. The terms that were the researchers were looking for were additive manufacturing, selective laser menlting, stereolithograghy, selective laser sintering, Fused deposition, inkjet additive manufacturing, and 3D printing. This help find articles related to additive manfactruing. Within the articles related to additive manufaftriuing the researcher sought to find articles that were related to environmental sustainability. The articles that included economic and financial sustainability were excluded. The terms that the researcher were looking for were cleaner production, environmental conscious manufacturing ,lifecycle assessment environmental impact assessment and life cycle analysis. For an article to be relevant it should contain and additive manufactriing technique and an environmental sustainability topic. Within the research it was found that some of the articles included energy consumption of additive manufacturing. The articles that included energy consumption were counted as relevant because energy consumption is relevant for environmental sustainability of additive manufacturing. The the articles were then grouped according to the various additive manufacturing techniques. Within the articles the number of articles covering each aspect of environmental sustainability were counted to find out the extent of puplications of each environmental aspect and topic highlighted in Table 2 and Table 3. Table 4 up to

Table 11 highlight the studies for environmental sustainability and impact for different additive manufacturing techniques.

4 RESULTS OF THE SCOPUS SEARCH

Table 1 shows the results from the search done on Scopus to obtain the trends environmental impact studies in additive manufacturing. The inclusion and exclusion criteria are highlighted in

Table 1. The main search terms on for the research was environmental impact, environmental conscious manufacturing, life cycle assessment and cleaner production. The search was limited to articles related to additive manufacturing.

Table 1: Search terms and strategies

Search term	Secondary Search term	Filters Used	Results for primary search	Result after secondary Search	Relevant Articles
"environmental impact assessment" OR "environmental conscious manufacturing" OR "life cycle assessment" OR "life cycle analysis" OR "cleaner production"	Additive Manufacturing	2016-2020	26911	588	95

5 TRENDS IN SUSTAINABILITY OF ADDITIVE MANUFACTURING

The articles from the Scopus search were evaluated to find out which sustainability method was used with the aim to determine how additive manufacturing is progressing in terms of sustainability for the environment. The papers were also further assessed to find out the aspects of the environment which the researchers focused on. Table 2 shows the number of articles found for each aspect of environmental sustainability aspects. Only the articles that clearly covered the environmental sustainability aspects were counted. The articles which lacked clarity in the aspects on sustainability were not included in Table 2.

Table 2: Aspects on Sustainability covered in Additive Manufacturing

Environmental Impact assessment	Cleaner production	Life cycle Assessment
12	8	42

Life cycle assessment is most common method in assessing environmental sustainability in additive manufacturing. Lifecycle assessment looks at the whole value chain and can evaluate how each process can affect the environment [21]. Though lifecycle assessment evaluates at every stage in the value chain, very few studies evaluate indirect environmental effects which include, transportation, logistics, and effects of decentralising manufacturing [22] [23] [24] . Many of the studies focus on energy consumption of additive manufacturing while a good number focus on material usage. Some studies overlap their focus and may fall under multiple topics. The few that focus on pollution are in construction and fused deposition. The studies that focus on cleaner production are also focused on energy consumption carbon emission and pollution.

Cleaner production focuses on preventative measures towards reducing environmental impacts of products by reducing the damage to the environment. Cleaner production is company specific and aims at improving production while preserving the environment. Environmental impact assessment occurs before a company embarks on a new activity. It aids in determining the level of impact an activity has on the environment. It is a support tool to aid in assessing the potential impacts of an activity. The aim is to determine the likely consequences and effects and of a decision on the environment. The definition and implication of each tool varies from territory to territory. It is therefore important for additive manufacturing organisations to know how to use each of the tools. From previous literature reviews the extent of knowledge of sustainability tool in additive manufacturing needs to be improved in order to get it accepted in industry as a sustainable manufacturing method [25]. Confusing cleaner production and lifecycle assessment is common and future researchers need to take note of the differences. Determining which tool to use depends on the objectives of a firm as well. If the aim is to improve energy savings of the process cleaner production is recommended. If the researcher aims to look into how the process affects the environment during its lifetime, lifecycle assessment is recommended [25]. Table 3 shows the areas covered by research articles in relation to environmental impact.

Table 3: Areas Covered by additive manufactruing on sustainability

Energy Consumption	Material usage	Social Impact	General	Pollution
30	21	6	16	7

Of the search results, on environmental sustainability of additive manufacturing only 41 were related to selective laser melting. Selective laser melting is layer by layer additive manufacturing technique used for manufacturing metal parts. Table 4 up to

Table 11 show the publications on sustainability each table representing an additive manufacturing technique.

Table 4: Article on Journals pubished on Selective Laser Melting with regards to environmental impact

Title of Article	Year	Author
Environmental assessment of the near-net-shape electrochemical metallisation process and the Kroll-electron beam melting process for titanium manufacture	2020	Dolganov, A., et al
Environmental analysis of selective laser melting in the manufacturing of aeronautical turbine blades	2020	Torres-Carrillo, S., et al
Study of the environmental implications of using metal powder in additive manufacturing and its handling	2020	Jon Inaki Arrizubieta, et al
Environmental sustainability evaluation of additive manufacturing using the NIST test artefact	2020	Kwon, J.Y., et al
Title of Article	**Year**	**Author**

Energy modelling and eco impact evaluation in direct metal laser sintering hybrid milling	2020	Ahmad, N., Enemuoh, E.U.
Comparative Analysis of Ecodesign in the Design and Manufacturing Methods for Mechanical Parts Made of Nylon PA6	2020	José M. Paricio-Sánchez, et al
A deep look at metal additive manufacturing recycling and use tools for sustainability performance	2019	Ana E. Oros Daraban, et al
Understanding the sustainability potential of part consolidation design supported by additive manufacturing	2019	Yang, S., et al
Environmental assessment of additive manufacturing in the automotive industry	2019	Böckin, D., et al
Energy-based life-cycle assessment (Em-LCA) for sustainability assessment: a case study of laser additive manufacturing versus CNC machining	2019	Jiang, Q., et al
Energy consumption consideration of 3D printing	2019	Annibaldi, V., et al
Repairing Automotive Dies with Directed Energy Deposition: Industrial Application and Life Cycle Analysis	2019	Jennifer Bennett, et al
Comparative study for environmental performances of traditional manufacturing and directed energy deposition processes	2017	Zhichao Liu, et al
A life cycle assessment-based approach for evaluating the influence of total build height and batch size on the environmental performance of electron beam melting	2018	Le, V.T., and Paris, H.
An exploratory investigation of Additively Manufactured Product life cycle sustainability assessment	2018	Harstvedt, J.D., et al
Characterizing the influence of resource-energy-energy factors on the environmental performance of additive manufacturing systems	2018	Nagarajan, H.P.N. and Haapala, K.R.
Energy savings through additive manufacturing: an analysis of selective laser sintering for automotive and aircraft components	2018	Hettesheimer Tim; et al
Cost- and energy-efficient manufacture of gears by laser beam melting	2018	Tobias Kamps, et al

Title of Article	Year	Author
Environmental modelling of aluminium based components manufacturing routes: Additive manufacturing versus machining versus forming	2018	Ingarao, G., et al
Energy Consumption in Additive Manufacturing of Metal Parts	2018	Liu, Z.Y., et al
Impact of Total Build Height and Batch Size on Environmental Performance of Electron Beam Melting	2018	Le, V.T., and Paris, H.
The Role of re-design for Additive Manufacturing on the Process Environmental Performance	2018	Priarone, P.C., et al
Integrating additive manufacturing and repair strategies of aero-engine components in the computational multidisciplinary engineering design process	2018	Al Handawi, Khalil; et al
Environmental Impacts of Selective Laser Melting: Do Printer, Powder, Or Power Dominate?	2017	Faludi, J., et al
Toward a Sustainable Impeller Production: Environmental Impact Comparison of Different Impeller Manufacturing Methods	2017	Peng, S., et al
Life Cycle Assessment of 3D Printed Products in a Distributed Manufacturing System	2017	Cerdas, F., et al
Evaluating Eco-Efficiency of 3D Printing in the Aeronautic Industry	2017	Mami, F., et al
Environmental and Economic Implications of Distributed Additive Manufacturing: The Case of Injection Mold Tooling	2017	Huang, R., et al
Comparative Energy, Resource and Recycling Lifecycle Analysis of the Industrial Repair Process of Gas Turbine Burners Using Conventional Machining and Additive Manufacturing	2017	Frank Walachowicz et al
Influence of Material-Related Aspects of Additive and Subtractive Ti-6Al-4V Manufacturing on Energy Demand and Carbon Dioxide Emissions	2017	Priarone, P.C., et al
Environmental impact assessment of an innovative strategy based on an additive and subtractive manufacturing combination	2017	Le, V.T., et al
Environmental Sustainability of Laser Metal Deposition: The Role of Feedstock Powder and Feedstock Utilization Factor	2017	Ma, K., et al

Title of Article	Year	Author
Comparative Life Cycle Assessment of Conventional and Additive Manufacturing in Mold Core Making for CFRP Production	2017	Kafara, M., et al
Preliminary Investigation on Life Cycle Inventory of Powder Bed Fusion of Stainless Steel	2017	Nyamekye, P., et al
Assessment of additive and conventional manufacturing: Case studies from the AEC industry	2017	Mrazovic, N., et al
Comparative environmental impacts of additive and subtractive manufacturing technologies	2016	Paris, H., et al
Comparison of conventional injection mould Inserts to Additively Manufactured inserts using life cycle assessment	2016	Hofstätter, Thomas; et al
Challenges in assessing the sustainability of wire + arc additive manufacturing for large structures	2016	Bekkera, A et al
Quantifying the overall impact of additive manufacturing on energy demand: The case of selective laser-sintering processes for automotive and aircraft components	2016	Hettesheimer, Tim; et al

Table 5: Fused deposition

Title of Article	Year	Author
Sustainability in extrusion-based additive manufacturing technologies	2016	Freitas, D., et al
Sustainable impact evaluation of support structures in the production of extrusion-based parts	2016	Almeida, H.A., and Correia, M.S.
Sustainability and environmental impact of fused deposition modeling (FDM) technologies	2020	Suárez, L., and Domínguez, M.
Environmental and economic analysis of FDM, SLS and MJF additive manufacturing technologies	2019	Tagliaferri, V., et al, Venettacci, S.
Mechanical recyclability of polypropylene composites produced by material extrusion-based additive manufacturing	2019	Spoerk, M., et al
Uncertainty and Variability of Energy and Material Use by Fused Deposition Modelling Printers in Makerspaces	2018	Ruoyu Song, et al
Environmental sustainability evaluation of additive manufacturing using the NIST test artefact	2020	JuYoun Kwon, et al

Table 6: Stereolithograghy

Title of Article	Year	Author
Power consumption estimation for mask image projection stereolithography additive manufacturing using machine learning based approach	2020	Yang, Y., et al
Life cycle impact assessment of desktop stereolithography	2020	Mele, M., et al
Environmental performance of 3D-Printing polymerisable ionic liquids	2018	Maciel, Vinícius Gonçalves et al
A life-cycle assessment framework for stereolithography	2019	Mele, M., et al

Table 7: Selective Laser Sintering

Title of Article	Year	Author
Green Fab lab applications of large-area waste polymer-based additive manufacturing	2019	Dennis Byard, et al
Manufacturing and recycling of 3D printed continuous carbon fibre reinforced PLA composites	2017	Tian, X., et al
Powder life cycle analyses for a new polypropylene laser sintering material	2016	A. Wegner and T. Ünlü
Environmental sustainability evaluation of additive manufacturing using the NIST test artefact	2020	Jungmok M. et al
Environmental sustainability of orthopaedic devices produced with powder bed fusion	2020	Cappucci, G.M., et al

Table 8: Inkjet

Title of Article	Year	Author
A framework to reduce product environmental impact through design optimization for additive manufacturing	2016	Tang, Y., et al
Using life cycle assessment to determine if high utilization is the dominant force for sustainable polymer additive manufacturing	2020	Shi, Y. and Faludi, J.
Internal fibre structure of a high-performing, additively manufactured injection melding insert	2018	Sina Baier, et al
Environmental sustainability evaluation of additive manufacturing using the NIST test artefact	2020	JuYoun Kwon, Et al

Table 9: General publications on Sustainability

Title of Article	Year	Author
A social life cycle assessment framework for additive manufacturing products	2020	Naghshineh, B. et al
Sustainability-driven multi-objective evolutionary orienting in additive manufacturing	2020	Mele, M. et al
Impact of industry 4.0 on environmental sustainability	2020	Judit Oláh, et al
An eco-design for additive manufacturing framework based on energy performance assessment	2020	Yi, L. et al
Framework for life cycle sustainability assessment of additive manufacturing	2020	Genésio Ribeiro,et al
Corrigendum to “Novel materials can radically improve whole-system environmental impacts of additive manufacturing”	2020	Faludi, J., et al
Life cycle assessment framework for sustainable development in manufacturing environment	2020	Kaswan, M.S., et al
Case study of different additive manufacturing (AM) processes from environmental impact assessment	2019	Kwon, J., Kim, N., Ma, J.
Comments about the human health risks related to additive manufacturing	2018	Vincenzo Lunetto, et al
Strategically Aligning Additive Manufacturing Supply Chains for Sustainability and Effectiveness	2019	Carsten Feldmann, et al
Micro timber: The development of a 3D printed composite panel made from waste wood and recycled plastics	2019	Sandra Karina, et al
Transformation of E-Waste Plastics into Sustainable Filaments for 3D Printing	2018	Gaikwad, V., et al
Investigation of energy requirements and environmental performance for additive manufacturing processes	2018	Liu, Z. et al
Close-looped recycling of polylactic acid used in 3D printing: An experimental investigation and life cycle assessment	2018	Zhao, P. et al
Additive manufacturing from a strategic sustainability perspective	2018	Villamil, C., et al
TEAM: A tool for eco additive manufacturing to optimize environmental impact in early design stages	2018	Laverne Floriane, et al

Title of Article	Year	Author
Addressing Hazardous Implications of Additive Manufacturing: Complementing Life Cycle Assessment with a Framework for Evaluating Direct Human Health and Environmental Impacts	2017	Bours, J. et al
Environmental Dimensions of Additive Manufacturing: Mapping Application Domains and Their Environmental Implications	2017	Kellens, K. et al
Recycling and remanufacturing of 3D printed continuous carbon fibre reinforced PLA composites	2016	Xiaoyong T. et al
Additive manufacturing-a sustainable manufacturing route	2017	Domnita F. et al
Energy and emissions saving potential of additive manufacturing: the case of lightweight aircraft components	2016	Huang, R., et al
Environmental impact assessment studies in additive manufacturing	2016	Kerbrat, O. et al
Sustainable design for additive manufacturing through functionality integration and part consolidation	2016	Tang, Y. et al

Table 10: Literature Reviews on Sustainability

Title of Article	Year	Author
Sustainable design in 3D printing: State of the art	2020	Luis A.S.G et al
How has LCA been applied to 3D printing? A systematic literature review and recommendations for future studies	2020	Saade, M.R.M., et al
Current options in the life cycle assessment of additive manufacturing products	2020	Výtisk, J. et al
State of art review on sustainable additive manufacturing	2019	Agrawal, R. et al
A parametric life cycle modeling framework for identifying research development priorities of emerging technologies: A case study of additive manufacturing	2019	Yao, Y. and Huang, R.
Environmental performance of additive manufacturing process – an overview	2018	Garcia, F.L. et al

Table 11: Additive manufacturing in Construction Publications on Sustainability

Title of Article	Year	Author
Environmental assessment of large-scale 3D printing in construction: A comparative study between cob and concrete	2020	Alhumayani, H. et al
Environmental Effects of Accelerated Pavement Repair Using 3D Printing: Life Cycle Assessment Approach	2020	Yeon, J. et al
In situ Resource Utilization and Reconfiguration of Soils Into Construction Materials for the Additive Manufacturing of Buildings	2020	Bajpayee, A., et al
Life cycle assessment of 3D printing geo-polymer concrete: An ex-ante study	2020	Yao, Y., et al
Environmental Impacts of 6-Axes Robotic Arm for 3D Concrete Printing	2020	Kuzmenko, K., et al
Rheology and buildability of sustainable cement-based composites containing micro-crystalline cellulose for 3D-printing	2019	Long, W.J. et al
Guiding building professionals in selecting additive manufacturing technologies to produce building components	2018	Mrazović, N. et al

6 STATISTICS

The statistical data for the research found that there is an increase in publications of articles on environmental sustainability of additive manufacturing.

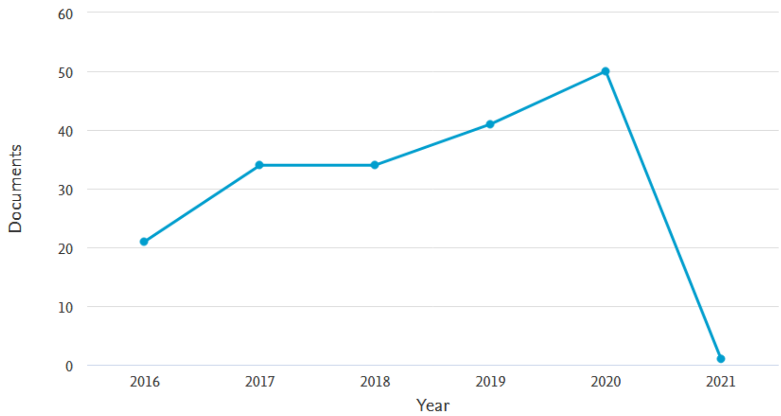

Figure 1: Sustainability by year from 2016 to 2021

Figure 1 shows the publications of sustainability for additive manufacturing. The numbers of publications have been increasing from 2016 to 2020 showing researchers are now focusing more on the environmental sustainability of additive manufacturing.

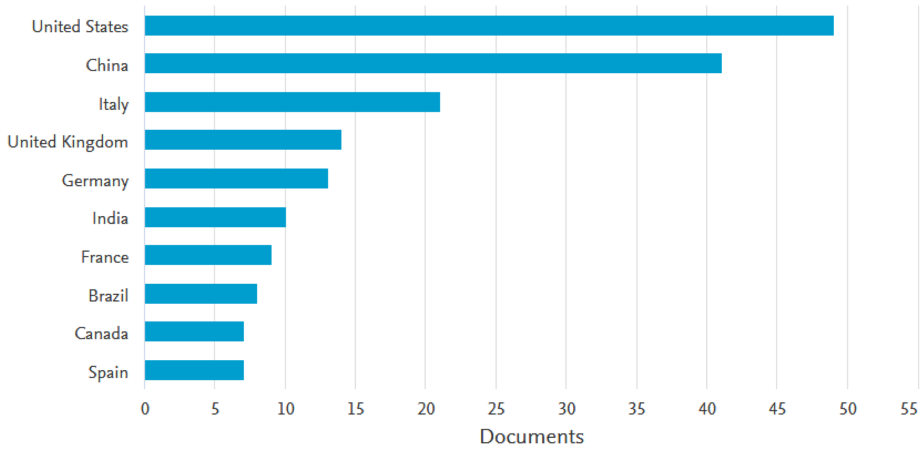

Figure 2: Documents on Sustainability by Country

Figure 2 show that United States of America has the most publications on environmental sustainability followed by China and Italy.

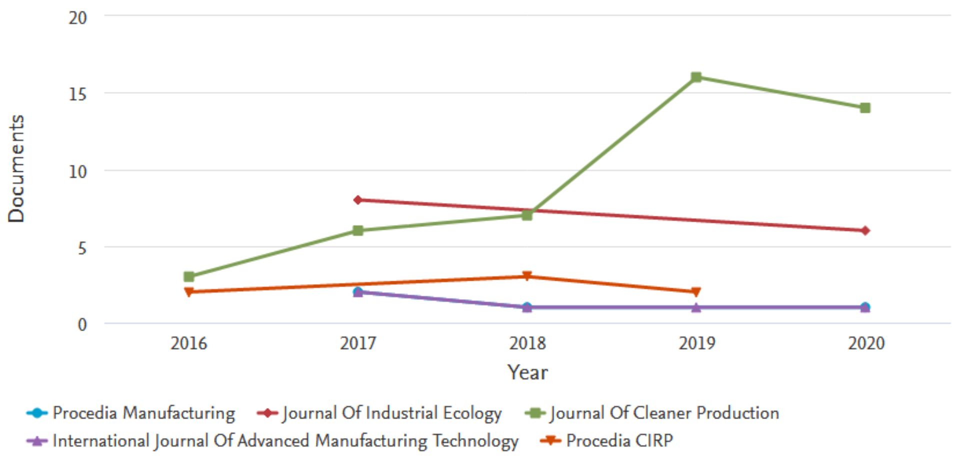

Figure 3: Documents by Year and Journals

From Figure 3 the Journal of Cleaner production has the most publications for additive manufacturing environment related topics. From 2016 to 2020 they are the only journal which shows increase in environment impact for additive manufacturing.

Table 12: Countries by Publications

Country	Documents
United States	49
China	41
Italy	21

United States and China are leading publishers for environmental awareness related topics for additive manufacturing. United states and China are leading economies in the world and thus it makes sesnces that they have more publications on environmental sustainability of additive manufacturing.

7 DISCUSSION

Additive manufacturing has a wide value chain that starts from extraction to recycling of the material to be printed. Much of the publications on environmental sustainability are primarily in selective laser sintering. It was also found that many of the studies involve energy consumption comparisons between convectional manufacturing and additive manufacturing [20] [1] [13] [26] [10] [27] [7]. Another area that is covered is material usage with most products having an environmental impact in the disposal phase [14] [16].

One process that improves recycling and environmental sustainability is spheroidisation. The systematic review did not retrieve articles on the impacts spheroidisation would have on additive manufacturing value chain and on the environment. The potential environmental impacts of spheroidisation and recycling are assumed to be positive, but solid research needs to be done to assess the environmental impact. At the moment little concrete research is available which proves that spheroidisation is environmentally friendly and can impact positively to the environment. Much of the research addresses the energy consumption of additive manufacturing [10] [1] [20] [13] [26]. The research available focuses more on improving the additive manufacturing processes and making the processes more efficient [28].

It is also worth noting that in metal additive manufacturing, the environmental impact is usually compared to conventional manufacturing methods. There is also need to take into account the impacts of the processes that go into the creation of the powders when doing the comparisons. The processes include the extraction of the powder material to the atomisation processes. Other aspects that affect the value chain of additive manufacturing need to be included in order to do a complete evaluation of its impact on the environment. Researchers have also concluded that the energy consumption of additive manufacturing is less for smaller batches than conventional manufacturing [29] [30]. Focus can also be directed towards material use and carbon footprint of AM to prove its environmental sustainability. The land use is another aspect of the environmental impact that can be assessed [31]. The activities in manufacturing that contribute to environmental impact are metal extraction, powder making and processing, printing, assembly and warehousing. Activities that contribute to additive manufacturing are further discussed in 7.1.1, 7.1.2, 7.1.3, 7.1.4, 7.1.5 and 7.1.6 with their environmental impacts elaborated.

7.1.1 Material Extraction

These activities will include the mining and processing of the material which is an energy demanding process [32].The common material for metal additive manufacturing is titanium, aluminium and stainless steel. Titanium is the most expensive of the metals because of its multiple stages that are required to extract it [33].

7.1.2 Powder Production and processing

After material extraction the material needs to be converted to powder. Atomisation of the metal is the next process and can be done through water, gas or plasma atomisation. Metal is molten and then broken down by high speed fluids forming metal powder. In plasma atomisation the particles are usually spherical. In cases where the particles are not spherical the powder is spheroidised through plasma spheroidisation. Plasma spheroidisation can remove impurities: oxygen and nitrogen which can compromise the metal properties [34]. Spheroidisation can be used to recondition used powder and bring it back to its original properties. Spheroidisation at this stage will help avoid re-melting the metal and thus save energy. Spheroidisation will also prevent unnecessary disposal of unused powder which in turn helps the environment by reducing the need to mine more metals.

7.1.3 Processing

Selective laser melting is the most studied metal additive manufacturing method and this is the process in which much of the sustainability studies are based [4]. For metals, the parts are printed one layer at a time. Each layer is melted and a powder is layer on the previous layer for the next sintering phase. The energy required depends on the metal involved and the melting point of the metal. Precious metals are more difficult to print that other metal because of their reflectivity [35]. The most common application is aerospace automotive and medical with the majority of the studies being comparative studies in the energy consumption of the processes.

Many of the studies show that additive manufacturing is best suited for custom parts as there is no difference in tool change over whether the part is complex or not [9]. Conventional manufacturing in particular machining has multiple tool change over which can add to transportation and logistical activities. Transportation of material can add to overall energy consumption of the process. Additive manufacturing produces less scrap than conventional manufacturing. Machining can produce 90%scrap from a billet which may need to be taken back for reprocessing [36]. The scrap from the conventional manufacturing will need to be transported to form more billets adding to emissions due to shipping. In many cases the scrap may be discarded as it may be difficult to process because of the by-products from subtractive manufacturing. This will entail additional metal that needs to be extracted from the ground. With additive manufacturing the unused metal powder can be reused multiple times and with spheroidising and reconditioning the number of times a powder can be reused can be increased and thus reducing the extraction of metal from the ground[37]. This can then improve the environmental sustainability of the additive manufacturing process chain. The powder that can be used multiple times and cannot be reused for additive manufacturing can be taken back for spheroidising [38]. The powder can, therefore, go through multiple cycles with minimum loss, but there are, however, very few studies that highlight the environmental viability of the spheroidisation process [39].Additive manufacturing takes up little space and thus can be great for countries with limited space [40].

7.1.4 Assembly

Additive manufacturing can allow designers to produce fewer parts for a particular function than in conventional manufacturing without losing functionality. This means that less material is used for a part and also less energy is required for assembly. Less parts also entails less logistical costs and activities [41].

7.1.5 Ware housing and storage

Owing to the capacity to make functional parts with less material and parts little warehouse and storage space is required. Not many studies highlight the importance of warehousing and storage for sustainability. Space is limited in some territories and thus the fact that additive manufacturing can save space in many of its processes in the value chain must be highlighted [42].

7.1.6 End User

Lighter parts are a possibility because of additive manufacturing. This ability is important in the aerospace industry as a reduction of 50 grams can have a significant positive effect on the carbon foot print. A lighter aeroplane requires less fuel and additive manufacturing has the potential to give freedom of design [43]. Bugatti Veyron manufactured its spoilers using additive manufacturing which was difficult to fabricate using conventional methods. The spoiler allows the car to move more efficiently due to the aerodynamic properties of the spoiler [35].

7.2 Disruption to the supply chain

Additive manufacturing can produce on demand thus cutting down on inventory. Local manufacturers can make their own spare parts without having to source from international suppliers. With Additive manufacturing technologies are improving and soon will be there will be a wide range of geometries that local manufacturers can make [44]. This can reduce inventory and transportation thus reducing carbon foot print due to emissions from vehicles. The advantage of having the ability to make assembled parts with fewer components also lowers logistical problems and thus indirectly impacting the environment indirectly. Reducing transportation in manufacturing is vitals as it accounts to much of the emissions [45].

7.3 Emissions

Much of the studies on environmental impact are based on carbon emissions, but do rarely do they consider deposition of hazardous substances due to conventional manufacturing. Machining needs a coolant for efficient cutting. The cutting fluid contains oils, biocides and corrosion inhibitors. Other machining processes can use gasses and gels as coolants which can be hazardous to the environment. Many of the substances can cause irritation on human skin and if inhaled can cause respiratory problems [46]. With injection moulding catalytic debinding process also uses hazardous substance. With metal additive manufacturing coolants are not needed and there is limited human exposure to the 3D printer. The other problem comes when the oils are disposed of. If they are disposed of recklessly the effects on the environment are serious and can cause pollution [35]. Deposition standards of hazardous material from conventional manufacturing vary worldwide. As mentioned earlier, additive manufacturing gives room for freedom of design and lighter parts can be made which is desirable in aerospace and automotive industry. This can greatly reduce the carbon emissions as lighter parts means less fuel consumption. Better aerodynamics parts can be made due to the freedom of design.

7.3.1 Additive Manufacturing and the supply chain

The environmental effects of additive manufacturing occur in various stages. Each stage has an associated material usage and wastage, energy consumption and carbon footprint. Studies are evolving to all stages in the value chain instead of just comparing 3D printing process with other manufacturing processes without factoring in processes that lead to the 3D printing. The material required for additive manufacturing maybe different from the material used in conventional processes and thus may have different effect on the environment [42].

7.4 Life Cycle of Spheroidisation

Energy consumption of additive manufacturing is the dominant research topic in sustainability and other aspects also need to be looked into [47]. Efforts have been made to reduce the resources that additive manufacturing requires through spheroidisation [47].Additive manufacturing needs to be adopted and accepted by industry and thus there is need to do thorough research on sustainability [44]. One way of making additive manufacturing more sustainable is recycling printing material through spheroidisation. The impacts of spheroidisation include less material usage and less land pollution. Studies have covered the environmental impact aspect of additive manufacturing, but there is still a lot to be done for spheroidisation. Spheroidisation is part of the value chain in additive manufacturing and its positive environmental impacts need to be known [44].

There are other aspects of the environment that need to be covered which includes water air, land and health. Though many studies have been done on environmental impact and life cycle assessment there is need to do more on specific aspects [44]. This can give a holistic view of the environmental impact of Additive Manufacturing. Several studies on spheroidisation are on-going and the process is rapidly improving. Studies need to be carried out on the sustainability of the process at and how it affects the value chain in additive manufacturing. South African Nuclear Energy Corporation in South Africa has a spheroidising plant which has been adopted to spheroidise

Ti6Al4V [48]. Each material has different environmental effect throughout its lifecycle and studies need to put more focus on aspects of the value chain of various materials.

8 CONCLUSION

Environmental impact of additive manufacturing is still an area of research that needs to be explored and many researchers are starting to focus on the area. For additive manufacturing to be successfully adopted in industry it must prove to be sustainable. Efforts to make additive manufacturing more sustainable are still being made and one of the ways is through reconditioning of metal powder by spheroidisation. More research needs to be done on the spheroidisation of metals for additive materials as it can impact on energy savings and reduce material waste in additive manufacturing. So far much of the research covers energy consumption and material usage of additive manufacturing. It was also noted that comparative studies between additive manufacturing and conventional manufacturing are also common within research.

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THE JOURNEY OF OPTIMIZING EQUIPMENT DATA TOWARDS INDUSTRY 4.0

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ABSTRACT

The paper uses case study approach in using predictive maintenance as the one of the steps that every industry needs to consider. This causes changes in technological and cultural features. Among technological features belong to maintenance management. The approach towards equipment maintenance has changed throughout the revolutions to predictive maintenance. Instead of fixing equipment, companies can predict downtime before it fails and minimize the risks and costs. This paper shows changes in maintenance management strategies in the context of the journey in industry revolutions. The literature review of this paper summarizes the characteristics of each industrial revolutions and maintenance management approach together with paradigm shifts that accomplished them. The first industrial revolution with breakdown maintenance, the second industrial revolution with preventive maintenance, the third industrial revolution with proactive maintenance, and the upcoming fourth industrial revolution with predictive maintenance.

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1 INTRODUCTION

Any manufacturing company that follows the industrial revolution has changed technologically and in its characteristics. The technological features belong to maintenance management. These features include incorporating a sensor into the equipment to monitor data. The use of this data can prevent equipment failures from reaching a particular operation. This data can refine the predictive maintenance program by providing an early warning to predict failures with real-time data [1]. Predictive maintenance data can optimize equipment performance. The approach to equipment maintenance has changed over the years of the revolution. These approaches have changed from reactive maintenance to continuous predictive maintenance. It's no longer about fixing equipment [2]. It's about using data gathered from the equipment via its sensors. This requires reading the values from the sensors on the devices.

The manufacturing industries currently witness the fourth industrial revolution known as industry 4.0, connected, providing rise to cyber-physical production to monitor data [3]. As a result, traditional manufacturing processes are undergoing an enormous transformation, changing how companies approach manufacturing. Companies seek to predict the data to minimize the risks and costs associated with it. Using maintenance data of equipment is vital for the total productive effort. The downtime of equipment can be expensive to produce [4]. However, it can lead to the production of a high-quality product. In turn, these high-quality products provide benefits leading to producing many products. This approach is in line with the need to remain competitive and meet product production targets. It could be a competitive area, whose improvement may increase profit and bring many benefits.

In the mid-1990s, preventive maintenance was credited with a significant production interruption by catching equipment challenges before failure [5]. However, manufacturing management within production felt there was room for improvement. There was a call operation afterwards. Later in the 1990s decision was made to modify the equipment structure to improve its information [6]. Bagadia [7] implies all maintenance measures that help save and predict equipment conditions. It goes alongside the advancement of industry the improvement of maintenance.

The growth of data in the manufacturing industry competition has changed the way it operates. These have affected maintenance and change its role even more crucial for business success. However, some manufacturing industry has already undertaken independent initiatives to promote data science to focus on industry 4.0 [8]. It revolutionized the industry for the future; this version provides a roadmap for development.

2 OBJECTIVES

Equipment maintenance is important when using historical data to predict and avoid future equipment condition failure. To achieve the objective of this paper, the following steps should be followed:

- To demonstrate the journey of equipment maintenance throughout the revolutions from reactive to predictive.

- Explore and outline the steps to change the future for automation of equipment data.

- Take one step at a time and a shorter one.

This paper will begin with an overall maintenance management analysis to illustrate how to formulate a maintenance strategy and continue focusing on predictive maintenance.

3 INDUSTRIAL REVOLUTION 4.0 AND MAINTENANCE

It is now 46 years since the last industrial revolution and many new technologies have entered the manufacturing environment. A new initiative in research and practice is working to define the parameters of the next revolution [9]. It is important that these parameters also define maintenance planning and asset management for the plants of the future.

The first three industrial revolutions happened first and were named after them. With Industry 4.0, this will be the case. The revolution is still in progress [10]. The changes are happening faster because of the interconnectedness of the world. The ideal manufacturing company of the future is maintenance free, and every piece of equipment should be available 100 percent of the time. Industry 4.0 is changing the way manufacturing companies do business, creating a new world where assets are digitized through automation. Often, laziness prevents companies from taking the first step. Once one step is taken towards the company's goal, the second step would quickly follow. But take the first one. This reminds the words of Lao Tzu: "Not only does a long journey begin with a step, but also a shorter one". To predict data, devices need to produce data by using sensors for optimization. For this reason, the step from device sensor data acquisition to data prediction must become smaller in the future. After an initial review of the relevant literature by the researcher, there was no study that took a step towards data prediction in devices on this topic.

Over time, there have been three notable industrial revolutions [11]. The process of shifting from manual labor to the use of steam-powered machines has given rise to industries during this period [12]. The second industrial revolution begins with better ways of manufacturing means of production. The third industrial revolution began as technology became more prominent in industry. This led to automated production lines and processing industries that are mainly controlled by digital technology [13]. However, in 2010, the vision for the next industrial revolution was presented and called Industry revolution 4.0. This is very fitting given the great advances in recent technologies and their potential to improve manufacturing facilities. Without a crystal ball to predict what it means to revolutionize industry for the future, this is nonetheless a version that provides a roadmap for development. The result has been the industry revolution 4.0, which is evolving into a smart industry that can eventually be accessed and controlled via the internet. This applies to reading sensor readings from a single device and communicating with data stores.

The new Industrial Revolution 4.0 has been driven by technological advances in sensing and wireless data transmission, which has been adopted by those developing strategies within the enterprise to provide an unprecedented level of equipment data [14]. Properly analyzed, equipment failures are detected with greater accuracy, reducing unplanned machine downtime within a system. Industrial Revolution 4.0 maintenance supports the digital version of everything we as humans have done over the years to ensure our assets deliver value to the business. This includes a holistic view of the data sources, the ways they can be connected, the ways they can be captured, the ways they can be analyzed, and the recommended actions to ensure the function (reliability) and value of the assets with digital support. At the same time, too much maintenance means additional costs, resources, and lost production. The goal of the last few years has been to introduce a maintenance strategy that can calculate maintenance requirements before a failure occurs.

4 METHODOLOGY

This paper is a single, in-depth case study of a company operating in the equipment industry in Alberton. The paper uses data collection, which is collected from the equipment's data. It has helped the researcher to use it to predict the equipment maintenance due easily. This paper aims to study the same company because it enables one to step forward in-depth research on certain phenomena in a real-life context. The company has adopted the most advanced Internet of Things (IoT) technology and sophisticated sensor data on equipment [15]. It can build machine learning into a new commercialized service-oriented offering, embedding a new business model's predictive maintenance strategy. This case is an exciting illustration of the step forward's importance in optimizing technology and predictive maintenance in equipment.

4.1 Case description

This section describes the case study in greater detail, based on direct observation. Data reveals the company's strategy and implications for IoT and predictive strategy offerings. This paper describes the company and case background, then the general step to equipment data automating in theory and its value to create through its use of IoT technology on the equipment to predict. The maintenance data used to support the results of this paper have not been made available because sharing the data might compromise data privacy. Moreover, the authors were not allowed to share all data due to security concerns.

4.2 Case background

This company is one of the leading companies based in Alberton that provides solutions for installing, maintaining, and modernization equipment. It has a strong presence in Alberton. In addition to manufacturing equipment in Alberton, the company is aggressively expanding its service business by providing a predictive maintenance strategy, major retrofits of an installation's useful life. The company installs many of its equipment nationwide, providing a platform for attracting customers to its service offers. Therefore, the company has an incentive to aggressively seek opportunities to expand its service offering for higher revenue from external and internal to improve service productivity and lower the cost.

4.3 Outlook of present-day

The new technology can be disruptive; upending the status quo is always challenging for the manufacturing company and its workers. For manufacturing, the smart factory's future aim has quickly become a reality, and even those who are hesitant to embrace these advancements find it hard to ignore. As the world advances steadily toward industry revolution 4.0, manufacturing companies should prepare to redefine how they approach equipment.

Companies are amid a significant shift that is redefining how the industry operates. The amount of data collected from digital sensors is growing exponentially, enabling more robust business insight. Today, the information is already helping manufacturers increase optimization, but the IoT concept also applies to automated equipment.

Today, automating is a solution, which optimizes equipment data and IoT. By connecting hardware and software solutions, manufacturers can maintain comprehensive control and visibility into their entire operation [16]. Production managers are optimizing the equipment data collected by their industry revolution 4.0 solutions within the equipment industry. The approach helps to predict to improve their existing processes. By recognizing a consistent challenge via data, the manager can more comprehensively understand the global or local issue than visually assessing challenge processes.

4.4 Steps to optimize equipment data

There is a process to adopt new technology in equipment. In a manufacturing company that manages equipment every day, maintenance is crucial for efficiency, safety, and bottom line. By implementing predictive maintenance, strategies can optimize equipment to save costs [2]. This optimal asset prediction and further improves efficiency and quality. It goes one step further with a smart predictive strategy.

The smart predictive strategy is a modern approach technique that optimizes multiple technologies [17]. It goes beyond traditional proactive strategy into five key steps to reach a smart predictive strategy. Following these steps, the company can realize the predictive strategy's operational and financial benefits. Although this technology can transform equipment programs, the best-in-class optimization initiative is not generally built in a single day. This paper enables a smart predictive strategy by following the steps outlined below.

4.4.1 Five predictive maintenance strategy steps

Step 1: Start small with a pilot

A pilot generally takes about three to four weeks on one or two critical assets. This initial effort includes sensor implementation and data streaming connections to perform visualization. Installing new technology in a new environment requires change, which comes with a learning curve as workers work to understand how to make the company more productive and their jobs more efficiently. In the fourth industrial revolution, technology and data sharing came as a packaged deal [18]. Decision-makers can track and analyze data to ensure that technologies are performing the tasks as intended. In the adoption processes, management focuses on ensuring that the workers believe in the technology.

Step 2: Equipment health monitoring

Adoption is often the most challenging step that companies must ensure workers use the new solution to its full potential. It takes time to collect performance data, and patience will be key. This information and equipment failure data generate better predictions for equipment.

Step 3: Optimize failure data thresholds

Once these data can be reliably connected wireless or remotely and equipment has provided enough failure data, the failure thresholds can be optimized [19]. Although it takes time for many companies to reach this step, organizations can identify where technology can perform well and have room for improvement. By assessing quantified data, management can understand where variance is coming from and adjust processes accordingly. This leads to optimization to meaningful improvement to the bottom line. The process of optimization is a crucial step to truly in the journey toward industry 4.0.

Step 4: Leverage data science

Data science can create predictive models with machine learning technology to update algorithms, increasing predictive capabilities with each failure until unplanned downtime can be avoided.

Step 5: Reaching a smart predictive maintenance strategy

For those steps with long-term vision or goal, achieving these steps 1-4 can lead to smart predictive maintenance, helping the business maintain a competitive edge.

5 METHOD

This section is organized according to the roadmap of equipment predictive maintenance from Figure 1. Section 3.1 examines the process optimization of equipment lifecycle to increase data collected uptime for prediction. Section 3.2 explores the maintenance of equipment journey design concept within the maintenance lifecycle structure, describing each revolution from the beginning to now. The author's intention uses the maintenance strategies to sustain the revolution to the present day. Finally, layout the step that needs to be taken to move toward industry 4.0 to predict equipment data.

5.1 Optimization process

Optimization parameters using sensors on the equipment performance [20]. However, it needs to adjust the process to optimize a specified set of parameters. These parameters include the mean time to repair and between failure divide by the number of maintenances. Optimizing equipment enhances the effectiveness of equipment to ultimately improve productivity [21]. Hence, this justifies the exploration the use of predictive strategy as a means of optimizing equipment. Process optimization aims to optimize equipment to avoid unnecessary costs and maximize output while achieving the process objective. When proper regular maintenance is applied to a piece of equipment, it maximizes its production output and increases its useful life. It improves utilization resources of operational process output and increases equipment life and performance. Optimization encompasses designing sensors on the equipment. Managing equipment led to improve process output.

5.2 Maintenance strategies

A maintenance strategy is an effort that requires repairing equipment before it is damaged or replaced [22]. Although there is no consensus on the definition of maintenance strategy, an effective maintenance strategy is about optimizing the uptime and performance of assets. Selecting an effective maintenance strategy requires better knowledge of maintenance management principles and practices for specific equipment performance. The maintenance strategy can significantly impact the organization's bottom line, but many maintenance teams or managers overlook appropriate strategies altogether [23]. With the operating of equipment, maintenance ensures that machinery produces high-quality products for the customers at the correct time. It is important to develop strategies that properly maintain the equipment pieces to ensure that they remain operating. Figure 1 presents the strategies continuum, covering four basic maintenance management approaches: reactive, preventive, proactive, and predictive.

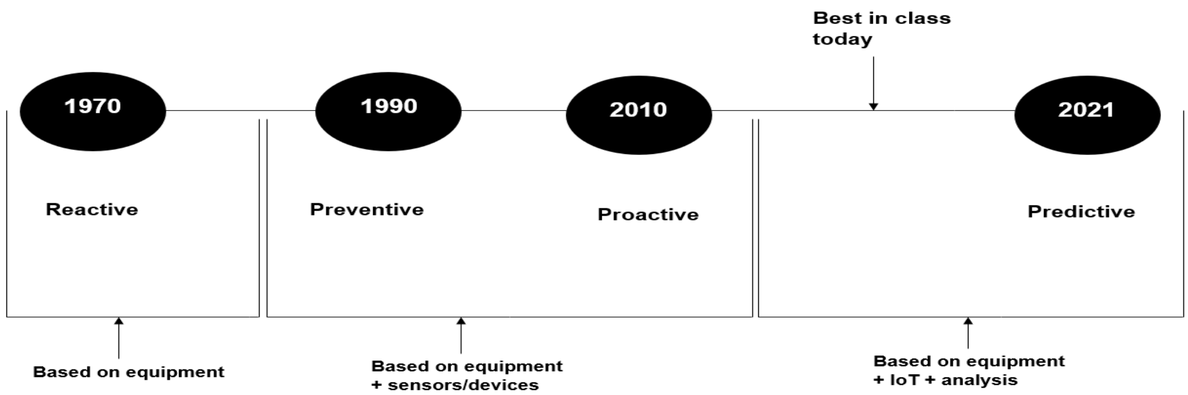

Figure 1: The modern predictive maintenance journey adapted source from Deloitte analysis Ren [24]

5.2.1 Reactive Maintenance

Zaim *et al.* [25] define it as a choice between reactive maintenance and proactive maintenance. This maintenance strategy helps extend the useful equipment life and improve its reliability and availability [26]. Gallimore & Penlesky [27] consider this a combination of reactive maintenance, regular scheduled preventive and proactive maintenance, inspection, equipment backup, and equipment upgrade. The first industrial revolution was the main cause of the massive increase in labour productivity in manufacturing through the introduction of machines. This led to the industrialization of manufactures [28]. During this period, most maintenance form characteristic was the breakdown maintenance known as "corrective maintenance". The aim of it was to put the broken or damaged equipment back to the normal operational condition.

"Do not fix something if it is not broken" was used to be a traditional reactive maintenance strategy many years ago. Some companies widely use the reactive maintenance approach to save costs, according to Xing & Marwala [29]. Reactive maintenance plans, by their very nature, do not encourage these maintenance activities. The resulting equipment may not operate optimally and tends to have a shorter life. However, it is the way to determine which equipment falls into this category. This strategy is used once when the machine has completely failed. Filling out reports, ordering, or locating replacement parts required maintenance expertise. These processes often resulted in unnecessary delays, downtime, and overtime costs.

Consequently, lead times and delivery schedules get compromised. Some manufacturers argue that reactive maintenance strategies are less expensive. This argument brings in the costs of downtime. Fogg [30] argue that maintenance resources' reactive maintenance procedures contribute to a vast and rapid increase in understanding. Similarly, the reactive maintenance approach leads manufacturing organizations treating the symptom rather than the problem itself, such as repeatedly addressing equipment failure issues rather than their root cause [31].

In the 1960s and 1980s, manufacturing companies' maintenance have been seen as only a background operation [32]. It was considered as minor importance and valuable when a breakdown occurred. The prediction and preventing notions then did not exist. The maintenance technicians worked on greasing or monitoring, and strategies deployed only based on corrective operations and repairs.

The world of industrial and implications was different from the one operating now. Manufacturing industries activities grew to support the new production capacities. The industries are grouped based on the primary support of the technological revolution. This means that organizations can create value utilizing the production that characterized the industrial revolution. It stands on the brink of a reactive technological revolution that is fundamental to an organization. Reactive maintenance used to be the predominant strategy for many years, and industry was burgeoning on the production lines. Equipment failure could disrupt the production lines but was not leading to considerable losses. It is because the equipment was not integrated into a more general system. Then companies understood how critical the maintenance service is to the manufacturing.

Manufacturing companies gradually invested a considerable amount in their fixed assets and became conscious of safety. To protect the workers, they were interested in maintenance from the beginning to give it more importance [33]. The equipment was developed by combining new advanced technologies and software. Therefore, there were many accident risks and companies wanted to counter them. Therefore, the reactive maintenance strategy became more important in manufacturing. Accident risks were reduced, equipment functionality was critical, and breakdowns were avoided. It is amazing that companies want to develop maintenance for human reasons and not for purely economic reasons.

5.2.2 Preventive maintenance

The second industrial revolution, which began in the 1980s, increased the risks associated with high-powered equipment. Equipment maintenance began to build the manufacturing industry [34]. A more competitive market developed, forcing manufacturers to increase production. At the height of the second industrial revolution, manufacturing outgrew itself. Breakdowns caused higher costs and thus the first attempts at preventive maintenance. This attention was necessary, but there was not enough time for manufacturers to avoid delays or potential breakdowns. This led to an increase in downtime and the cost of repairing equipment. The maintenance industry underwent significant changes to transform into an effective manufacturing sector, which led to training in the 1980s [35]. In fact, it became necessary for knowledgeable individuals trained to handle maintenance issues to evolve into a safer environment. The function of maintenance includes checking, servicing, replacing, or repairing the necessary equipment. They have been described as cost-effective practices to keep equipment operational either before or after failure. The main goal of preventive maintenance was to move from one scheduled maintenance to the next scheduled maintenance without failures. Along with artificial intelligence and sensor technology, these practices became the standard for manufacturers, pushing the old reactive practices off the scene. This increase in production demanded better maintenance practices, which led to manufacturing industry standards evolving to develop predictive maintenance.

New technologies allowed for a more comprehensive understanding of the condition of equipment and became an important factor. Safety and environmental concerns became paramount, resulting in just-in-time maintenance and maintenance focused on reliability. These new technologies and inventions are still used today. Science outdated to connect to technology has been applied to the manufacturing industry. This has created new materials to replace the old methods.

Preventive maintenance can be referred to as an action based on a specific schedule that detects, avoids, or mitigates the deterioration of a component to maintain or extend its life by optimizing it appropriately [34]. In practice, any repair or replacement is carried out as soon as they are detected. This can prevent potential damage to the equipment [36]. However, this strategy is more expensive than reactive maintenance. Although it can be cost effective when practiced on low volume equipment. Wireman [37] argues that preventive maintenance also increases the cost of maintenance personnel. Cloete [38] further discusses that proper maintenance is aimed at preventing the failure of a plant. Loosemore & Hsin [39] argue that understanding the relationship between planned preventive maintenance and a building and core business objectives. For many manufacturing companies, maintenance has saved much more by starting the right preventive maintenance program. It has gained several advantages over purely reactive maintenance [40].

There are major types of preventive maintenance depending on the condition of the equipment. In time-based maintenance, a trigger is waited for before taking preventive action and improving the performance of the equipment. The trigger is based on the number of items and lead times. Usage-based maintenance uses triggers based on actual usage of each piece of equipment. By tracking usage with the Equipment Monitor and the hours of operation for each piece of equipment, maintenance managers can set up planned preventive maintenance based on predetermined parameters.

Gross [41] argues that without sufficient maintenance planning and long-term. Shell argues that proper selection of lubricants and fuels can play an important role in reducing maintenance costs and downtime. This can help avoid the consequences of component or system failure. However, a wise preventive maintenance strategy can reduce premature equipment failure, ensure worker safety, and save millions of dollars in costs. Maintenance encompasses the principles and practices used to repair damage or replace components that have potential or actual performance degradation or damage. The approach to selecting the optimal maintenance strategy is a critical step in achieving a cost-effective and operationally effective system. Previous maintenance optimization efforts have focused only on minimizing cost and maximizing production or availability. Fogg [30] argues that the first step is to gain the capability needed to take this major revolutionary step. Therefore, preventive maintenance is best because it can not only help reduce unplanned downtime but also reduce costs. Therefore, preventive maintenance is essential to maintain reliability.

5.2.3 Proactive maintenance

In 2010, the industrial revolution 4.0 introduced wireless sensors on devices to connect input factors to monitor data and observe status. The sensors enable the user to monitor the performance of the equipment to avoid unnecessary downtime. An integrated data system is used to analyze and visualize the performance of the devices. Even though this method is useful, it requires more time and investment. Organizations that are armed with data can analyze it and take action to optimize device performance while reducing costs. This approach combines reactive and preventive maintenance with sensors and increases overall economic efficiency [42]. It aims to identify and correct the problems that can lead to failures, such as improper equipment lubrication, misalignment, contamination, and other suboptimal conditions. Al-Turki *et al*. [43] argue that the goal of maintenance should include developing product performance through proactive maintenance. Proactive maintenance is more cost effective than the rest. However, a proactive maintenance strategy extends equipment life and improves its performance. It reduces maintenance and operational costs by addressing hidden operational inefficiencies. Therefore, a proactive approach is the only way to effectively protect equipment.

The impact of device reliability on their performance has driven organizations to adopt a proactive maintenance philosophy. Proactive maintenance is a strategy that addresses the root cause of equipment condition [44]. It leads to longer equipment life, less planned and unplanned downtime, less spare parts inventory and is more cost effective. Thus, it is undoubtedly proven that proactive maintenance adds value to the manufacturing industry. Although the cost savings are achieved by avoiding downtime and increasing equipment reliability and availability. The strategy of proactive maintenance is to reduce equipment failure. The equipment can remain in operation for a longer period. However, the major challenge is that it requires a lot of time, a huge paradigm shift, and organizational changes, unlike previous maintenance approaches. This maintenance strategy uses real-time monitoring to understand the condition of a plant.

Proactive maintenance focuses on finding and eliminating the root causes of asset failure rather than the failure symptoms. Therefore, this strategy is considered the best maintenance approach for any asset. However, many companies do not realize that proactive maintenance can be more effective. Maintenance activities are viewed as emergencies. This is the first sign that a plant can no longer be maintained efficiently. This also prevents sudden equipment failure.

Modern technologies, tools, and software such as equipment monitoring systems enable more efficient and effective proactive strategies. This helps companies access operational data about their equipment. They can be more accurately tracked and optimized to balance costs and risks. This can help limit some of the significant costs that can come from implementing a plan. Preventing problems is essential to maintaining equipment reliability. Rather than triggering corrective and preventive actions, proactive maintenance software can monitor condition-related challenges and identify opportunities for improvement using intelligent systems, leading to continuous improvement and cost reduction. Although the maintenance approach has its pitfalls, the proactive approach complements it. Therefore, it is considered the best among the other maintenance approaches. Therefore, adopting a proactive maintenance approach to maintenance work and technology can lead to significant savings.

5.2.3.1. Condition-based maintenance

The condition-based maintenance strategy involves monitoring assets and providing technical and observational data. However, instead of just collecting data from various sources, data on the condition of assets is continuously collected using sensors and portable diagnostic devices. This strategy ensures that each asset is available when it is needed and avoids performing maintenance too early or too late. Collecting condition information as a monitoring technique to determine the optimal time to perform maintenance to mitigate conditions that lead to failures.

In general, condition-based maintenance can be considered as a method to reduce the uncertainty in performing maintenance tasks, according to the requirements arising from the condition of the equipment [45]. Thus, condition-based maintenance allows problems to be detected and solved in advance before equipment damage occurs. In condition-based maintenance, the life of the equipment is monitored based on its operating condition, which is measured by monitoring parameters such as vibration, temperature, scrap, contamination, and noise level [46]. According to Jardine *et al.* [47], a condition-based maintenance program recommends actions based on the information from condition monitoring.

The core aspect of condition-based maintenance is condition monitoring, which can be performed using different approaches and at different technology levels [11]. The condition monitoring process also includes evaluations based on monitoring to measure or assess the condition of the equipment [48]. According to Walker [49], the implementation of a condition-based maintenance strategy involves the use of condition monitoring technologies. Although there are many conditions monitoring tools available, they are rarely used. Condition-based maintenance helps to establish an early warning system and teaches the integration of technology, data collection, and change management into maintenance practices.

In the early 2010s, the Industrial Revolution 4.0 gained momentum to take a step towards plant automation [50]. Unlocking the true potential of the Industrial Revolution 4.0 is not just happening once in maintenance. Adopting a new kind of better maintenance is a journey paved with improvements. Practical changes to maintenance strategy take time; they empower the team and unlock the potential of Industry 4.0. The practical approach to optimizing assets is to use collected data to predict future events. Therefore, this approach helps with maintenance by connecting wireless IoT sensors to a plant monitor. The idea of IoT is so comprehensive that it is called industrial revolution 4.0.

Today, technicians or operators can see equipment failures in real time as the failure occurs. The IoT can improve maintenance management processes through automation and analytics based on real-time data. Failure data from multiple sources can be collected, aggregated, and analyzed in real time to verify conditions when equipment fails. Managers who are knowledgeable can not only optimize equipment, but also realize the potential of Industry 4.0 reliability. Moving to a predictive maintenance strategy is now the highest form of maintenance. This is a strategy to prevent equipment failures by analyzing data to identify patterns and predict risks before they occur [51]. The fundamental components of predictive maintenance in Industry 4.0 are Big Data, sensors, and the Internet of Things. Smart sensors are the driving forces of Industry 4.0 and IoT in factories and workplaces. Once implemented at scale, the combination of sophisticated sensors and increased computing power will enable new ways of analyzing data and actionable insights to improve many areas of operations. The result will be accountable and flexible production processes that ensure and improve performance across multiple industries.

The impact of sensors on business performance, both today and in the years to come, will be primarily in cost savings through the implementation of sensor technologies and in increased production flexibility by optimizing the use of just-in-time processes. The early use of smart sensor technology focused on improving the manufacturing process of existing equipment [52]. But the real revolution associated with Industry 4.0 is not simply in cost savings through the optimization of production processes, but in new business models [53]. Such new devices will be developed first by customization and then by combining smart sensor data and data analytics to enable companies to offer a combination of high precision, high reliability, and high volume. In addition, the data collected by sensors will help create new services associated with the use of specific devices. The industrial revolution 4.0 means that sensors can self-test, monitor and improve their performance, reducing the amount of failure data [54]. Optimal industrial processes will increasingly include sensors that warn of damage before failure occurs.

6 DATA COLLECTION

The predictive maintenance data of the equipment was collected on the data source of sensors. The installed sensors have collected the information in real-time on the equipment's performance and “health”. The sensors' data that were needed to measure and collect depended on the technique intended to monitor the equipment. The data of the sensor-based equipment in operation were important as a source of valuable dataset samples. The dataset was used to predict the maintenance for future failure occurrences. This dataset is imported from the company’s data warehouse, where sensors send the data.

7 DATA ANALYSIS

The data analysis involves breaking the underlying data into smaller parts to understand better the phenomenon represented by these data. In addition to examining methodological sources to determine appropriate ways to analyze the data. The quantitative approach was useful in dealing with the maintenance data from the equipment during the analyses. The IoT allows sensors to send all the information to a central system to analyze. The paper has used data mining as the technique that is capable of predictive maintenance. Data mining is the practice of using dataset to generate new information. This technique is the process of extracting data sets involving methods of statistics. Based on the company’s collected equipment and maintenance logs data history. The maintenance history contained information on what repairs were made, what parts were replaced.

In this paper, 100-line maintenance data in twelve months from equipment company A were used. The dataset consists of nine input variables and an output variable (failure count). The input variables or factors are operational before failures occur. The input variables/factors are operational and environmental parameters that could influence failure occurrence and the length of operation before failures occur. Input variables include material hours, the number of equipment removals, and the number of faults with planned/unplanned removals. These data were analyzed and represented in a format suitable for modelling, and variables were characterized with the corresponding domain classification, shown in Table 1. The output variable is the number of equipment failures. A sample of the dataset is provided in Table 2.

Table 1: Input variables and an output variable of maintenance data

Parameter	Description
Equipment hours (EH)	The total duration of material for equipment on different aircraft in a selected time
RM	The number of removals of the equipment in the last 12 months
PR	The number of planned removals of the equipment in the last 12 months
UR	The number of unplanned removals of the equipment in the last 12 months
OR	The number of other removals of the equipment in the last 12 months
FR	The number of faults with removals of the equipment in the last 12 months
FPR	The number of faults with planned removals of the equipment in the last 24 months
FUR	The number of faults with unplanned removals of the equipment in the last 12 months
SR	The number of safe removals of the equipment in the last 12 months
NF (output)	The number of equipment failures in the last 12 months

Table 2: Equipment maintenance data

FH	RM	PR	UR	OR	FR	FPR	FUR	SR	NF
222.3	4	0	7	0	8	0	8	1	6
352.9	8	1	5	1	3	0	3	3	3
339.2	9	0	9	0	7	0	5	2	6
245.4	7	0	8	0	7	1	6	1	8
456.4	12	0	12	0	9	0	12	2	10

8 RESULTS

Predictive maintenance does not demand anything except informal mathematical computations to know when equipment needs repairing or replacement; this allows maintenance performance in a timely and effective manner. Facility managers gain more time to focus on necessary tasks instead of performing guesswork.

A program is developed to gather data for analysis through data mining algorithms. Selected equipment's maintenance and operational data were identified. Nine input variables and an output variable were determined. According to using pure 100 rows, nine inputs, and an output (100 × 10) data, LR models were trained and tested. The parameters of the predictors used in the study.

The prediction results for the raw dataset composed of 100 records and 9 attributes are presented in Table 2. In contrast, the LR algorithm provided the best results based on the MAE and RMSE performance criteria.

Figure 2 provide the linear correlation between the predicted and target results for the test data of LR. The results indicated that the regression line in the test and the predicted data of LR provide y1 = 0.9976x + 0.0155.

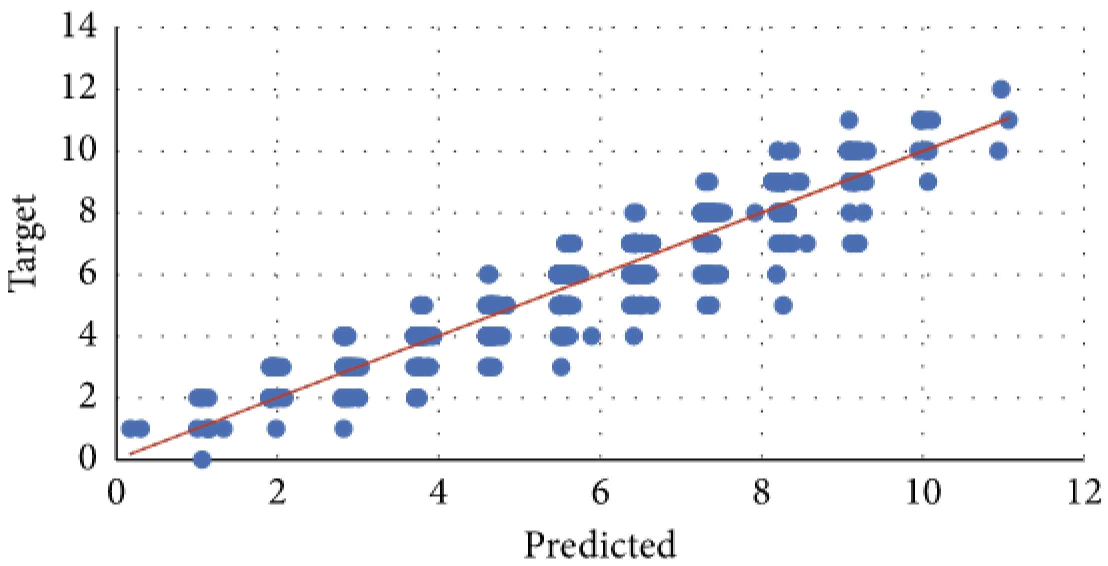

Figure 2: Correlation between predicted and target values of the dataset for LR

9 CONCLUSION

The use of maintenance data is important for reliability and maintenance costs analysis. The reason is that predictive maintenance can be planned based on estimates. The main target of predictive maintenance is to predict equipment failures and plan strategies for spare parts of system components to analyze the reliability and maintainability of a complex repairable system. In this paper, a data preparation model was applied to the maintenance dataset of a material handling system. The proposed data preparation method was put into practice using model LR. The results show that the LR model has better performance in predicting the failure counts. The results indicate that the proposed data preparation model significantly improves the accurate prediction of failure counts. This paper could function as a guide for using data preparation methods in data mining algorithms.

Predictive maintenance is important because it guarantees that it can do the maintenance too early and waste money on work that is not needed or predict if it is too late to do anything because of excessive deterioration that has already happened. With the usage of predictive maintenance, manufacturing operators are beginning to understand the importance of using predictive maintenance to monitor equipment; thus, industry revolution 4.0 relies on it. Predictive maintenance is key to save future resources. This paper has shown the industrial revolutions of each maintenance strategy, and it has demonstrated that with the data collected from sensors, it is important to use it for future prediction failure of equipment.

Regardless of where the company is on the maintenance journey, a smart predictive maintenance strategy accelerates digital transformation. As the world moves toward Industry 4.0, it is important to follow these steps to optimize the manufacturing environment. It is preparing to see an automated device working side-by-side with workers and production managers, staying up to date with reports and dashboards that monitor equipment failures and manage operations.

Industry 4.0 is taking shape, but already manufacturing innovators are working on this new industrial revolution. It seems that taking the first step is the most cost-effective path to Industry 4.0. Companies that have implemented automation in their manufacturing environment are ahead of the curve. Some companies have recognized the need to optimize equipment data for maintenance, data-driven predictions, and networked systems. This new connected approach to automation opens a promising future and leads manufacturing companies to the next generation of smart factories. Once the first step towards the company's goal is taken, the second step follows.

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DEMYSTIFYING THE FACTORS THAT IMPACT INTEGRATION OF MANAGEMENT SYSTEMS: A TOP MANAGEMENT SOUTH AFRICAN PERSPECTIVE

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ABSTRACT

The integration of management systems is amid a jungle of theories and has many theorists. Therefore, suffers under-theorising which could be inherently stemmed from its diversely proposed definitions. To be situated in an embryonic pre-paradigmatic phase, getting to a more unanimous definition in this realm is the first step in laying a solid foundation for integration theorising. The aim of this paper is to provide top management perspectives on the factors that impact the integration of management systems. Fourteen face to face semi structured interviews with senior management were used to obtain adequate information. A thematic analysis approach was followed to identify the factors of integration. The results of the study indicate that there eight prominent factors that impact integration. These factors will assist management to integrate management systems with more confidence and thereby improve organisational efficiency.

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1 INTRODUCTION

Most integration theories have been advanced within the background of first world academia [1], and although their pedigree differs, and subsequently their ontological and epistemological foundations, they share quite a lot of common ground [1]. In other words, many theorists make broader claims such as 'explaining integration', when what they really do is a much more limited to organisations, for instance explaining results of intergovernmental conferences, criticising a particular conceptualisation of integration, or seeking to understand the historical development of a particular aspect of integration. This problem, as well as the criticism of it, is not new. In recent years the number of management systems (MSs) and standards have increased tremendously, however the factors that impact integration, is not well researched in Africa, more especially South Africa. The purpose of these MSs is to facilitate organisations to systematically address various stakeholder requirements. International Organisation for Standardisation (ISO) has developed Quality standards for some of the MSs, including quality, environment, customer satisfaction, and auditing, among others. Research has shown that maximum benefits from (standardised) MSs are obtained when they are integrated into one holistic MS [2].

Furthermore, an organisation's management is responsible to stakeholders and is responsible for all activities and actions that are realised in an organisation [3]. According to stakeholder theory, organisations must take into account the interests and expectations of their various stakeholders, defined as ''any identifiable group or individual who can affect the achievement of an organisation's objectives, or who is affected by the achievement of an organisation's objectives'' [4]. Moreover, complexity is concerned with pattern formation. The research of complexity is bounded by the capacity of self-sustaining systems to interact and adapt autonomously within the self-defining boundaries that sustain the agent intra-actions and inter-actions [5]. According to these theories, organisations are complex systems and management is not only accountable to their shareholders, they must also take into account the needs of various groups or individuals who have a direct or indirect relationships and stakes in their activities: employees, customers, government agencies, NGOs, suppliers, and the media. As the number of management systems versus standardised management systems increases, their integration becomes a necessity [6].

1.1 Background to the study

A management system is a chain of interconnected components, processes or actions that produce strategic results. These systems can be put together to work in harmony forming new systems. However, many organisations are not realising the benefits of integrating management systems. For example, ISO 9001, ISO 14001 and OHSAS are said to be integrated into SHEQ system but in effect, it is 3 systems working in parallel. This means that they are combined to a certain extent but not totally integrated. In other words, there is the intention of integration but the result is not integration. With the increase of the use of ISO systems, an increase of 3% per year [7], and the need for organisations to reduce operating expenses it is important to integrate more systems effectively and efficiently to improve organisational efficiency.

1.2 Research problem

Although integration is not a relatively new concept, most work in the field have been limited to processes and models. Most studies have been undertaken in Europe and in first world countries [8], however research on integration that has been conducted on the African continent is scant and more especially in South Africa. The phenomenon that will be investigated in this study involves testing the perceptions of senior management on the factors that influence management system integration. Consequently, there are insufficient evidence as to what are the factors that impact integration of management systems. European literature focused on challenges, benefits and degree of integration, however the (soft) factors have not been explored exhaustively. This paper will focus on research methodology to investigate the relationship and validity of the factors of integration. Hence the formulated problem statement for this study is; *to identify the factors that impact the integration of management systems.*

2 RELATED LITERTATURE

Eminent scholars such as Anderson [9]; Blau [10] have contributed significantly to the development of information theory and social theory respectively. Reflecting on the development, achievements and problems of approaches (ontological and epistemological form) to integration, the presentation of complexity and systems theory will allow for comparing and relating individual approaches to each other. The rise of complexity in the social sciences can be viewed as linked to concerns over globalisation, particularly bipolar stability in the wake of the end of the Cold War [11]. Complexity copes with the difficulty of incorporating structure and transformation, stability and change, and the interactions of multiple actors operating at a variety of systemic levels, through the concepts of emergence and a complex adaptive system. In general systems theory, a system is commonly seen as "no more than the sum of its parts" [11] and the patterns of interactions and relationships among them. This paper will use the theories of complexity and systems to show the link to the factors that are required for the integration of management systems.

2.1 Defining integration

Many organisations implement a management system but do not have a structured manner or framework to do so. The new world of integration as a set of interrelated processes that share human resources, information, materials, infrastructure, financial resources [12]. In addition, integration is a seamless process of incorporating different levels of an organisation that share common strategic goals. Also, integration is about the interconnectedness in a cohesive manner to ensure the efficacy of all stakeholders [12]. Integration of management systems is organised in order to meet goals related to satisfying different stakeholders.

2.2 Identified theory aligning to integration

In recent years, systems thinking approaches and the application of complexity theory to evaluation seemed to have gained momentum, if judged by the publication of books and journal articles. These approaches are appealing because they are non-partisan and offer an unbiased approach to the study.

2.2.1 A review of complexity theory

With the lens of complexity, we are able to see whole systems as irreducible examples of knowledge in action, thus establishing a clear link between behaving and thinking, or between "data of sense and data of consciousness" [13]. Complexity theory contains several different approaches, substantive foci, and theoretical priorities [14]. Furthermore, complexity theory introduces an orientation that allows consideration of social systems in terms of both the information and communication exchanges that make social systems distinct from their biological foundations [14]. Complexity focuses on emergent behaviours that result from interactions within and among self-organising and adaptive systems [15]. The goal of the complexity sciences is to comprehend and explain general laws of pattern formation which signify transitions within autonomous, open systems [15]. Complexity copes with the difficulty of incorporating structure and transformation, stability and change, and the interactions of multiple actors operating at a variety of systemic levels, through the concepts of emergence and a complex adaptive system.

As an example, in the research by Walton [16], 41 key informant interviews were conducted on expert views on applying complexity theory and evaluation. Participants described complexity in two broad ways:

- complexity of interventions; and
- Complexity of social systems within which interventions are delivered.

These categories are not mutually exclusive, with some participants noting that these two types of complexity interacted. Participants who focused on complexity of interventions were often evaluation practitioners, and they focused on application of systems methods to evaluation. Those participants who focused on the complexity of social systems were likely to be engaged with complexity and systems approaches wider than the evaluation field and in policy, politics, and health and social service fields.

2.2.2 Decision theory related to management

According to Roberts and Handline [17], decision theory itself provides a discrete approach to each decision, although it recognises the implications that a prior decision has for a present one. It recognises, also, that a sequence of decisions may be necessary to solve a problem. In other words, that more than one decision may be required to solve a particular problem. Nonetheless, decision theory does not indicate how precedence is to be established for either discrete decisions or a related series. Therefore, a theory of decision-making needs to be complemented by the development of a direct approach to the setting of decision-making priorities and schedules. Theories of organisation and management deal with the recognition of decision situations, but offer little help to an executive in scheduling decisions. However, using intuition, logic, and mathematics, the executive can approximate the gain potential of each decision situation. He or she can then use these approximations to establish priorities for decision-making. This decision-making schedule will increase the executive's effectiveness and maximise benefits to his or her organisation.

In Figure 1 the author indicates that to manage is to make decisions and allocate resources, including human resources. In the dynamic and the fast-changing business environment of the 21st century, organisations need managers who are also strong leaders and vice versa.

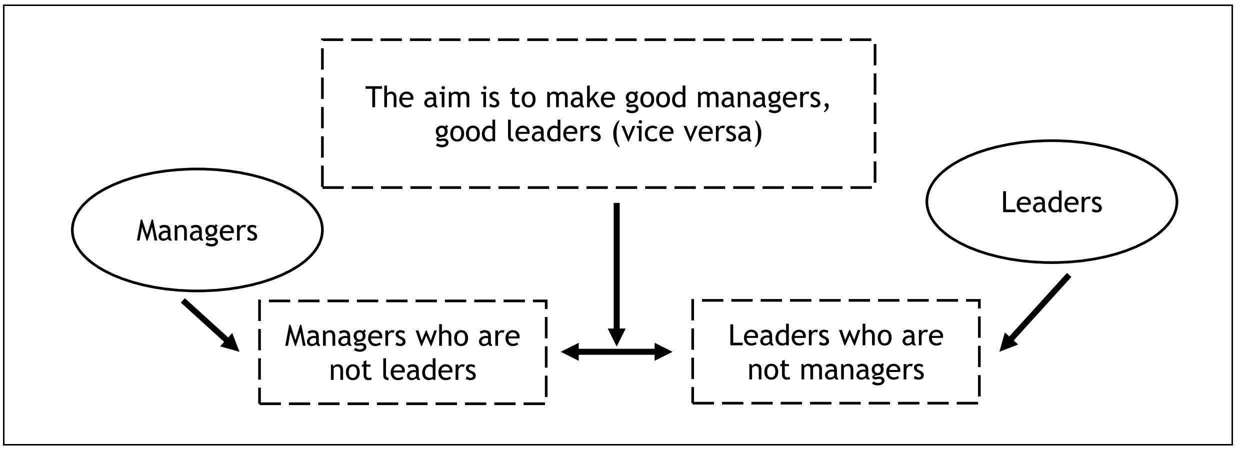


Figure 1: Integration of leadership and management

Source: Du Toit et al. [18]

Managing therefore means analysing, and often calculating, based on facts from organisational reports. In fact, the task of management is to formulate strategies based on the resources and capabilities of the firm and match them with identifiable opportunities in the external environment by selective market entry.

2.2.3 Leadership

The concept of leadership is complex. A review of the literature highlights the large body of research on leadership and the multitude of definitions of the concept itself [19]. The behavioural approach to leadership was conducted by two namely:

- Researchers at the University of Iowa have identified the following leadership styles – autocratic; democratic (the style of leaders which involves employees in decision-making, delegates authority, encourages participation in deciding work methods and goals, who gives feedback) was the most effective style; laissez faire, whereby leaders left all the decisions to their employees and do not follow up, was ineffective in every performance criterion when compared to the other two styles.

- Meanwhile, researchers at Ohio State University identified two leadership styles, namely initiating (this is the way a leader defines and structures his or her role and the roles of employees) and consideration (this is the extent to which a leader has the job relationship characterised by mutual trust, respect for employees' ideas and regard for their feelings). The research conducted by University of Iowa and University of Ohio is in line with the behavioural approach to leadership, in that successful leaders behave differently from unsuccessful leaders. Every action, every decision, every reaction, every plan should be filtered through your philosophy. Your philosophy becomes your compass. It keeps you on track. It becomes your true north [20].

Therefore, the leaders of an organisation should have insight into their employees' experiences and the environment in which they work to ensure that there is alignment between the required organisational climate and organisational objectives.

The African approach builds on participation, duty and spiritual authority. It requires transparency, accountability and legitimacy. Leaders are role models who demonstrate personal commitment to the values and goals their organisations have set [21]. They have the ability to create a compelling vision and achieve the enthusiasm and personal commitment of groups. The concept of Ubuntu in African leadership is pivotal because it emphasises the collective brotherhood of humankind. One criticism of African leadership is that there is still insufficient empirical research to support it. However, the fact remains that this leadership approach has significant relevance for African countries, including South Africa [12].

2.2.4 Management

There are four types of management. He distinguished the first three based on their behaviour towards time and change [22].

- Reactive management: The reactive approach to a problem is to identify the cause and try to remove, suppress or solve it. After the problem is solved, the system returns to the state it was before the problem arose.
- Inactive management: Inactive managers are satisfied with the way things are. They don't want a change, and therefore will only repair the damage. Therefore, they believe that if things are not broken, leave them alone.
- Proactive or pre-active management: Proactive managers think change is an opportunity to be exploited so they welcome the opportunity. They always think the future could be better than today, even if the present is good. Proactive managers attempt to predict and prepare for the future, and therefore establish visions and objectives.
- Interactive management: This consists of bringing the problems under control considering that the results are due to the consequences of the activities of the organisation. Interactive management must be continuous and can begin with any of these six phases: analysis of the situation, ends planning (visions, objectives and goals), means planning (policies, programmes and projects), resource planning, implementation and control.

Interactive planning is therefore a kind of proactive planning in which you work from the ends to the means. The scientific and the multilevel synergetic approaches to management are examples of proactive and interactive management [15].

2.2.5 Employee performance as an enabler to integration

The concept of work design considers how an organisation enables employees to achieve higher levels of performance. High performance work is characterised by flexibility, innovation, knowledge and skill sharing, alignment of work with organisational objectives, customer focus, and rapid response to dynamic business needs [23]. Within this framework, work design is closely linked with empowerment and strategic planning. Fair compensation, career progression, and practices that enhance employee well-being and satisfaction are other related concepts. As an example, through augmenting worker job satisfaction, an increase in productivity may be obtained, which can imply greater efficiency in the organisation [24]. According to Maryska and Sladek [3], measuring results and performances have a long tradition. Rapid development in this area is visible especially in the last ten years. However, Burita and Zeman [25] argue that errors in business processes result in poor data accuracy. Achieving business excellence is viable in two ways: by implementing concepts of total quality management (TQM) and through integration [12].

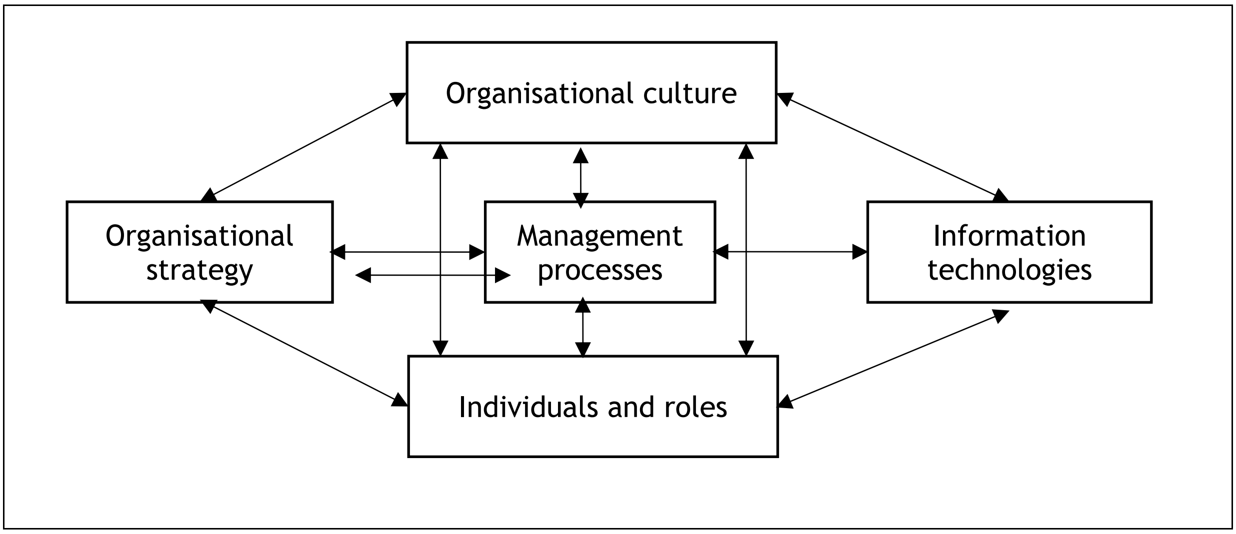


Figure 2: Morton's model of organisational efficiency

Source: Morton [27]

According to Figure 2, all components mentioned in the model are important, but information technologies and individuals are the most important ones [27] Individuals, and human resources in general, are the essence of the organisation and the crucial factor that influences other components in the model.

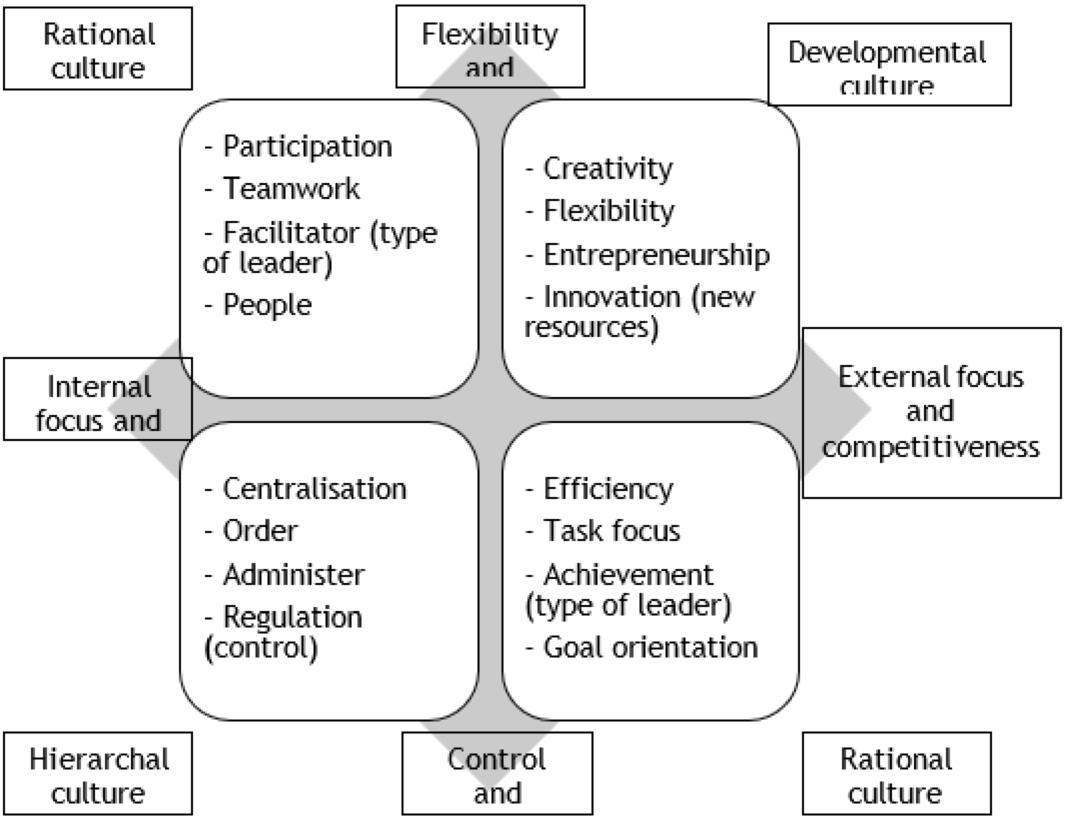
The dimension of increasing performance in an organisation is one of the most highlighted integration benefits [28]. Anderson [29] confirms that performance equals motivation multiplied by ability. The fact an organisation needs to work together as demonstrated by [29] talks to [8] description of organisational performance. Furthermore, in Denmark 90% of organisations with at least two management systems have integrated their management systems [30]. In a survey of IMS experiences in Danish organisations found that 91% of the organisations with three or more certified management systems have implemented an IMS and 90% of the organisations who participated in the survey have integrated their management systems and have achieved time and cost reductions as a result [6].

2.2.6 Organisational culture as an integrating factor

The cultural environment consists of all the institutions and forces that have an effect on the basic values, perceptions, preferences, and behaviours of the members of a society [31]. Workplace culture refers to the values, beliefs, norms, customs, and practices of an organisation [31].

Organisational culture is the underlying values, beliefs and principles that are the foundation of organisations' management systems [21].

Figure 3: The competing values framework (CVF) of organisational culture



Source: McDermott and Stock [32]

The competing values framework (CVF) has been diagrammatically presented in Figure 3. CVF assumes that all four quadrants are ideal for organisations [32]. Organisations rarely follow only one culture type.

Therefore, while utilising CVF for assessing the organisation's culture, it is essential to determine the associations between culture types and different facets of the construct. Factors such as the use of information for improvement, allocating authority equal to responsibility, attitudes regarding job security, approaches and incentives for teamwork and collaboration, opportunities for learning and involvement, fostering a climate of fairness, and providing compensation based on equality are some of the many organisational factors which shape workplace culture [33].

3 EXPERIMENTAL METHOD

The qualitative researcher studies things in their natural setting, attempting to make sense of or understand phenomena in terms of the meanings people bring to them [34]. Figure 4 show the process of the qualitative study.

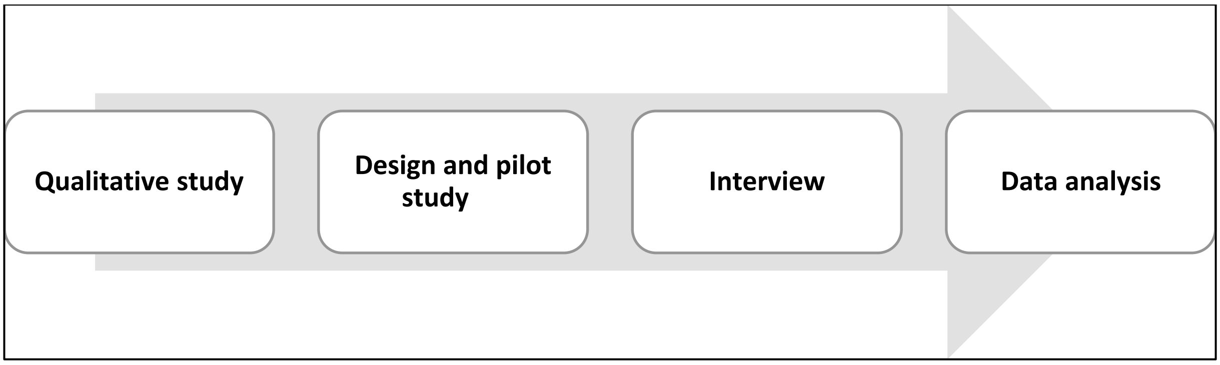


Figure 4: summary of qualitative study

Source: authors

The qualitative approach is a set of interpretive, material practices that make the world perceptible [34]. Using this approach has enabled the researcher to collect and to dig deep into the factors for example (leadership, management, organisational culture and employee performance) in order to attain a complete understanding of integration in organisations.

Considering that ICT organisations develop, implement and manage management system integration for organisations, the research utilised the four of the major ICT companies based in South Africa with a global presence as input to the research.

3.1 Design and pilot study

A concept interview guide was designed and then it was validated through two professors, one of which is an NRF rated professor specialising in business research and a full professor specialising in quality management, at the University of South Africa. The initial interview was considered to be the pilot of the study and small changes were made to the interview guide.

The purpose of the exploratory phase was twofold.

- To gain some deeper understandings about the IMS in organisations against the backdrop of IMS literature. The insights generated from the qualitative phase informed the quantitative phase to develop the research instrument, i.e. questionnaire for the second phase; and
- To negotiate access for the quantitative phase of the research.

The participants were purposefully sampled and access to them was through diarised meetings.

The decision to use these four major ICT companies was after applying the following criteria:

- the organisation had to be based in South Africa and be a listed organisation either in South Africa or internationally.
- the total gross revenue had to exceed one billion rand annually.
- the organisation had to have a global footprint, meaning organisations had to have a presence in at least more than three continents.

3.2 Interviews

The fourteen semi-structured face-to-face interviews lasted between 35 and 60 minutes each. The checklist below was used as guide. The interviewer used broad questions to ease into the interview to ensure the participant was feeling relaxed.

- Appearance at the interview by the interviewer.
- Information of the interview

- Opening of the interview (all covered in less than 5 minutes)
  The request to record the interview was stated and was granted. A Samsung Galaxy and a Dell computer were used simultaneously as backup.
- Closing the interview
- The participant was thanked for his or her time for contributing to the research.

Table 1 indicates the demographic information of participants and interview context.

Table 1: Demographic information of participants and interview context

Source: authors

Participant No	Designation	Experience	Qualification	Age Group	Gender
1	Chief Executive Officer	Integration	Masters	50-55	F
2	IT Executive	Management systems	Degree	55-60	M
3	Chief Information Officer	Management systems	Masters	40-45	M
4	Chief Information Officer	Management systems	Degree	40-45	M
5	Chief Information Officer	Management systems	Masters	35-40	M
6	Chief Information Officer	Management systems	Degree	50-55	M
7	Chief Information Officer	Management systems	Degree	55-60	M
8	Senior Manager	Management systems	Honours	40-45	M
9	Senior manager	Management systems	Degree	55-60	M
10	Senior Manager	Management systems	Honours	35-40	M
11	Senior manager	Integration	Degree	55-60	M
12	Chief Information Officer	Integration	Honours	40-45	M
13	Chief Information Officer	Integration	Degree	55-60	M
14	Quality Executive	Integration	Honours	35-40	M

3.4 Data analysis

The research intended to measure the intangible, i.e. views and opinions of the cases which are regarded as abstract in nature [34]. The research approach intended to tap into the minds of individuals of top management. The interview data was analysed using a thematic analysis [35]. According to Braun and Clark [36], a thematic analysis can be defined as a qualitative method for identifying, analysing, and interpreting themes of patterns or themes within a particular dataset for qualitative research findings. It aids the organisation of data acquired and the detailed description of data.

Table 2: Thematic analysis criteria

Step	Criteria
1	Researcher should familiarise oneself with the data acquired from each participant
2	Initial code generation
3	Searching of themes
4	Themes reviewed
5	Themes defined
6	Produce a scholarly report

The thematic analysis revealed the following in relation to the research conducted. The following six themes were identified.

Theme 1: Leadership influence on integration

Most participants, as leadership into their organisation, indicated that people must buy into the integration of management systems (transactional leadership). This means that participants agreed that when you embark on integration that employees be consulted, using a design thinking philosophy, and not having to know all the answers but sitting, engaging, understanding the integration process. When leadership shows that they are committed to making the change, that they are committed to listening to the people, that is half the battle won already. With the exception of 2 out of the 14 participants indicated that leadership did not engage with their employees when integration was going to be undertaken in their organisation.

Theme 2: Management as a planner for integration

Participants agreed that the integration of management systems was enabled by management and executives to have certain analytics, productive analytics for their organisation so that will include the engine of the organisation's reporting. Also a scorecard capability and analytics for employee to forecast for the future business as well as understanding the past engagements will ensure that integration of management systems will be implemented in a cohesive manner.

Theme 3: Organisational culture

Participants indicated that from a management systems perspective, what's important to know in your organisation, and that culture is actually identifying clearly and very simply what those clear goals are for the global organisation, those then it can cascade into all vertical of businesses as well as our horizontal businesses.

Theme 4: Employee performance

Participants indicated that the traditional performance management process was not as effective as recognising that every employee is on their own journey. Participants revealed that recognising every person has their own journey within an organisation, and organisations must see to it to identify on an individual basis a microcosm of a performance management culture that is very individual-based. Every person feels loved and welcome and identify where there are errors for development and what their strengths are. This must be taken into consideration when integrating management systems.

Theme 5: Standardisation for organisational efficiency

Participants revealed that to standardise a lot of the systems to ensure integration is important and ongoing. Also, the core of getting to an integrated way or management systems to ensure it is a repeatable way of doing things across the system must be measured, as well. It was revealed by 10 or the 14 organisations that they were in the process of standardisation whilst the other 4 was just embarking on the process of standardisation.

Theme 6: Innovation for improving integration

Most participants indicated that their organisation did not have formal platforms for integrating management systems. Participants also revealed that there existed silos in organisations which inhibited innovation processes. In 2 of the government participants, indicated that innovation was not an integral part of their make-up and should be developed to ensure that innovative thinking was encouraged.

Table 3: Categories of themes and participant responses

Source: Authors

Category of Theme	Code	Participant response
Leadership	**T1**	*" [Y]ou've got your leadership profiles and your sponsorship profiles and your stakeholder management and all of those elements of a framework very nicely planned out because without those, you're obviously going to struggle to do it (IMS)....." (Participant 1)* *" So, for leadership it's integrated, it's not silos. Ja, sometimes for management it's, you feel the silos and management informs that leadership. It is a management style, looking after staff and deals with things that impact the quality of the business, as seen by the customers" (Participant 2)*
Management	**T2**	*"[S]o senior management would basically interact with the likes of your architects and stuff like that and try to understand you know how we're going to fit everything together " (Participant 5)* *" The system [IMS] that will enable management and executives to have certain analytics, productive analytics about your organisation so that will include the engine of your reporting " (Participant 7)*
Standardisation	**T3**	*"..... A standardised system, I suppose comes from the definition of the word standard. So, it is a system that is defined by predefined standards that can be kind of either local or international." (Participant 2)* *".... Standardised is the standard payroll that comes from where the software is developed ..." (Participant 8)*
Organisational culture	**T4**	*"... from a management systems perspective, what's important to know in our organisation, we have a culture we call high performance delivery ...." (Participant 1)* *"....... The ownership of organisational culture is at the senior management to take the management thereof..." (Participant 2)*
Innovation	**T5**	*" There's many different siloed-thinking people who work separately and there's a lot of this, not built here mentality - I'm very different. Well you're not different " (Participant 2)* *" I mean innovation ...You know, a system can be anything right, it's, so, for me it is, it should be things working together to give me the information that I require." (Participant 6).*
Employee performance	**T6**	*"...[I]t's actually scrapped its traditional performance management system. So your traditional performance management system is linked to or the strong correlation to remuneration. We've actually completely scrapped that and replaced it with what we call a performance management system..." (participant 12)*

The categories of themes identified for the qualitative phase of this study and participant responses for each category is presented in Table 3.

4. DISCUSSION OF FINDINGS

The interviews proved to be extremely beneficial to the research, but more specifically to instilling confidence in the research instrument (part 2 of this research). The interviews yielded the following common aspects:

Theme 1: Leadership

All participants claimed to use a combination of leadership styles which were not limited to participative, supportive and directive leadership. It was deduced that organisations wanted to empower their management so that they could be more effective in their leadership styles. This would lead to improving the efficiency in implementing an IMS in their organisations.

Theme 2: Management

Management indicated that leadership was not consistent in decision-making, lacking trust, and policy implementation was either not enforced or non-existent. Management is the interface between leadership and operations and must ensure that an effective organisational culture is enabled through sound motivation techniques, such key performance indicators. An IMS cannot function without management enabling processes. This will drive employees to improve efficiency and obtain the desired performance in an organisation.

Theme 3: Standards

All organisations had at least a national standard. However, standards were perceived to be an important factor to satisfy stakeholders' needs especially in the FMCG sector. Government did not implement standards and deemed it as a non-critical requirement. In this research, the development of standards was seen as a strong dependent factor. Standardising organisational processes was seen as an instigator to improved efficiency levels in terms of integration. An integration of management systems will improve efficiency when standards are in place.

Theme 4: Employee performance

Employee performance was seen as important for organisational efficiency. However, the silo effect was evident in most organisations and integration of management systems will be a problem when this process is undertaken. The employee performance factor is critical for organisational success. Employee performance must be driven through formalised processes to ensure the organisation achieves its objectives.

Theme 5: Organisational culture

Organisations seem to differ in terms of especially a high-performance culture. It seems that the goals of the organisation and employees' goals should be aligned to be a cohesive unit, although this was not evident from most of the interviews. Theoretically, organisational culture should be driven by top management; however, this was not consistent across the management of organisations who were interviewed. The opinion of the participants indicated that they believed that organisations should ensure that norms, beliefs and values are entrenched through management. This is also evident in the literature. Organisational culture is part of the leadership responsibility and distilled through the organisation.

Theme 6: Innovation

Innovation seemed to be conflicting. Leadership indicated that employees should be innovative in their work situations and improve the efficiency of the organisation. However, innovation platforms were still a problem and needed to be developed at all three levels of the organisation (strategic, business and operational). Management has an important role to play in ensuring that innovation platforms are enabled and sustained in organisations. With innovation platforms in place, an IMS will ensure organisational efficiency.

5 MANAGERIAL IMPLICATIONS

Building and maintaining quality relationships between employees and managers would improve the organisational climate. Top management support has been highlighted as an important contingency factor in supporting various management practices. Therefore, organisations' leaders and management should have insight into their employees' experiences and the environment in which they work to ensure that there is alignment between the required organisational climate and organisational objectives.

6 CONCLUSION

The study undertook to demystify the factors that impact integration of management systems. The discussion of the findings revealed six (leadership, management, standardisation, organisational culture and employee performance) as important themes that South African organisations should consider when integrating management systems. These themes are critical in demystifying integration of management systems.

Outlining the topic was the initial step in the literature review process followed by searching for relevant academic articles, which in the current research was conducted through the relevant database after specifying the key words and terms that would be used. In addition the next step in the literature review was to assess the quality of the articles based on academic peer reviewed articles and then to provide the plan through a process of thematic analysis. An extensive review of the literature based on the following theories complexity theory and systems theory. Moreover, the identification of the useful and related studies was extracted by summarising all studies related to the topic. Finally, the process of synthesis of the literature focused on capturing the dominant ideas related to the integration as it existed at the time of this study.

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DESIGNING A DECISION SUPPORT SYSTEM FOR WORKFORCE PLANNING IN A SOUTH AFRICAN TERTIARY INSTITUTION

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ABSTRACT

Higher Education management is facing increasing pressures to improve their management styles worldwide. Recent developments have seen staff evaluations shifting towards a result-driven workload beyond performance. Consequently, management needs to develop effective strategies to capture, store and process workload information to make informed workforce decisions. This study aims to enable an engineering faculty in a South African tertiary institution to improve its workforce planning using a decision support system (DSS). The DSS was designed using a hybrid Agile V-model methodology with iterative system development processes. Management verified the system with an online semi-structured survey. The DSS can integrate data to present informative analyses on the workforce to enable the effective management thereof. These capabilities of the system are crucial for any organisation to improve its current workforce planning and combat adversities with informed decision making. Furthermore, it serves as a blueprint for workforce planning in the COVID-19 and post-COVID-19 era.

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1 INTRODUCTION

1.1 Industry contextualisation

Higher Education (HE) institutions are constrained in meeting the rising demand of student enrolments [1]. The increased enrolment levels place additional pressures on HE executives to improve their management styles. Simultaneously, staff evaluations are shifting from performance to outcome-driven assessments [2, 3]. This ultimately forces management to embrace adapted workforce planning techniques.

Moreover, the COVID-19 pandemic redefines existing and future working environments, which result in many standard assessment practices being re-evaluated and revised, especially in HE institutions [4, 5]. More interestingly, COVID-19 creates long-term effects on institutions and will require forward-thinking to standardise and reshape a new normal [6]. Ultimately, this global pandemic is forcing institutions to consider workforce planning as a sound means to re-engineer, re-design and re-envisage [7].

Workforce planning can be summarised to establish a robust and skilled workforce dedicated to the correct jobs at a specified time [8]. However, it entails various aspects that can be used to further define it. By classing these as aspects, it aids in identifying more specific parts to address when configuring workforce planning. **Error! Reference source not found.** provides a merged definition of these aspects.

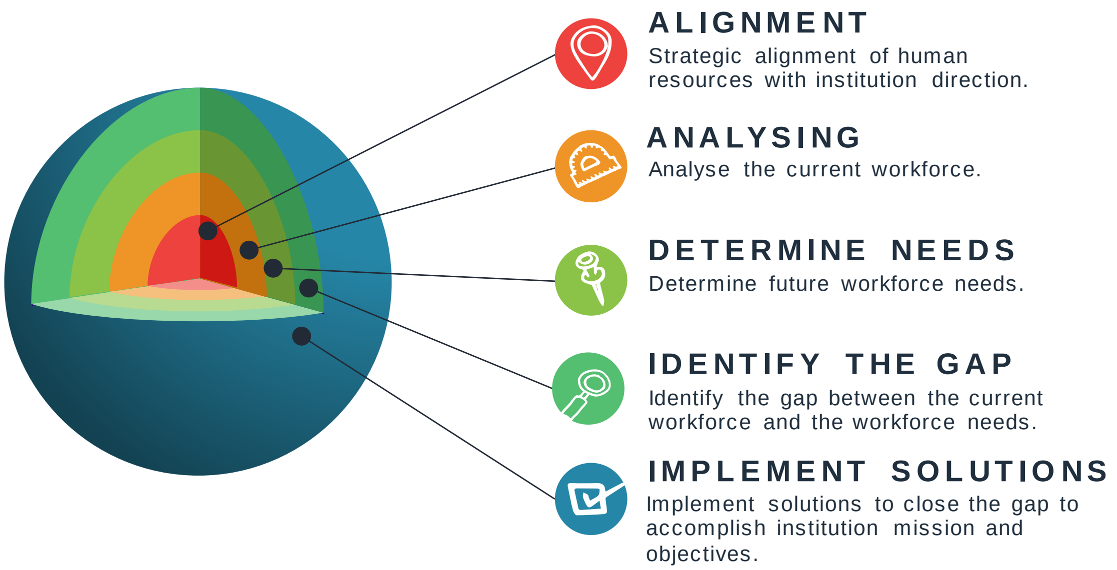

Figure 1: Core Aspects of Workforce Planning adapted from Helton and Soubik [9]

Each of these aspects, encapsulated in **Error! Reference source not found.**, plays an integral part in the successful implementation of workforce planning [9]. Workforce planning has many advantages that will be beneficial to the decision making in any institution. According to Martin [10], workforce planning produces critical information on the hiring, productivity of the workforce and deterioration rate of the institution. Not only does it help determine a headcount, but it also provides flexible employee solutions that will be valuable to the future of the institution [11]. These benefits will assist management to identify risks with contingency methods to produce industry intelligence, namely the strategic use of information for decision support. [12].

HE management should conduct workforce planning to protect their staff from becoming overworked since it can influence faculty morale and overall research and teaching effectiveness [13]. However, the road to workforce planning in most HE institutions is still complex since there is no way to determine true utilisation [14]. Kenny [15], revealed that the work allocation of time-based models creates difficulties since a specific time allocation cannot be determined over such a widespread multi-disciplinary institution. The study found that the time individual academics take to complete a research publication or prepare for a lecture will vary due to their capabilities and experience. A similar argument can be made with other work responsibilities. This further supports that the need for some agreement between the workforce and management requires a careful balance of various tasks.

1.2 Case study investigation

This study focuses on the academic staff of an Engineering Faculty housed within a HE institution in South Africa, who is not exempt from the aforementioned challenges experienced worldwide. The Engineering Faculty has an executive dean who manages academic and support staff. The academic staff is divided into four main entities, namely (1) industrial, (2) mechanical and nuclear, (3) chemical and minerals and (4) electrical, electronic and computer engineering. Within these entities, the workforce is divided according to job level categories representing specific job levels ranging from Professor (A5) to Junior lecturer (A9), as encapsulated in Figure 2. This Faculty needs to take the necessary strategic steps to conduct workforce planning since each of these categories dictates a specific job description with set responsibilities. These responsibilities are subject to the number of undergraduate courses, post-graduate students and research publications written by the academic. The support staff note those numbers of outcomes with other relative information.

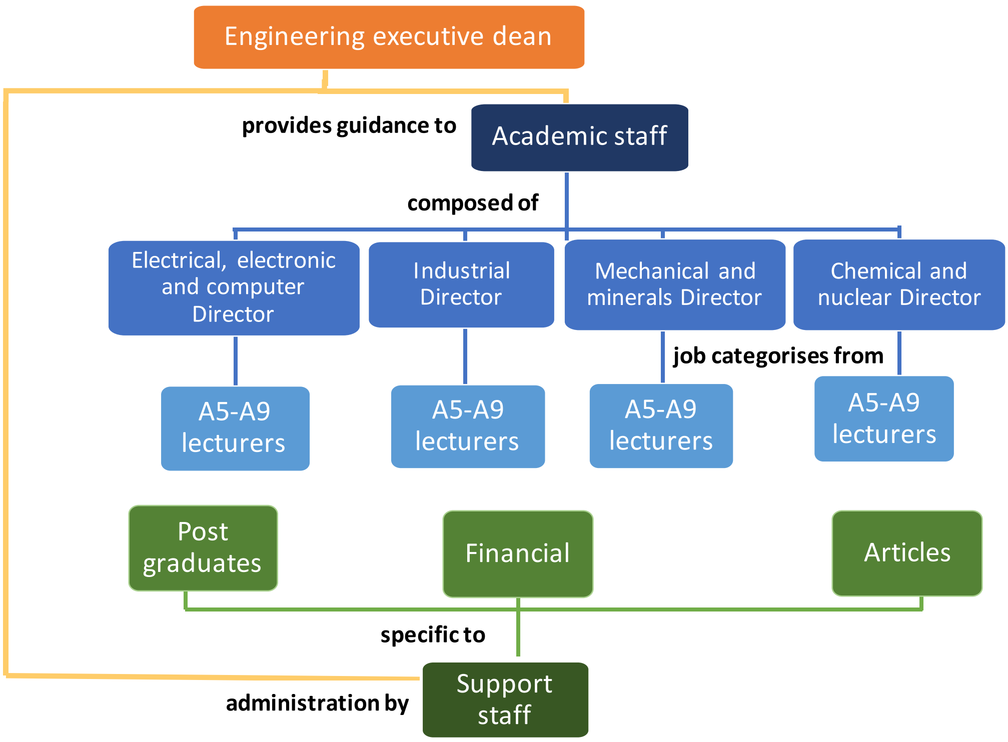

Figure 2: Categories and Responsibilities of Engineering Faculty

The various Faculty entities (academic and support staff) interact with each other continuously. Due to the diverse representation of this workforce across different engineering disciplines with various roles (Figure 2); the need for coherent and standardised workforce planning becomes a necessity.

The current task agreement (TA) system is not able to consolidate information between the Faculty entities. Therefore, no summative information can provide information on the workforce to conduct workforce planning. Moreover, COVID-19 forced this institution to work in a semi-decentralised working environment. COVID-19 prompted institutions to either adopt a semi-centralised or decentralised working environment or variations thereof [16]. Semi-centralised strategies entail working in rotating shifts or purchasing additional property to divide the functional workforce into independent regions. Decentralised strategies entail a workforce that is completely divided with work from home initiatives. Due to the changes in asset management practices, not only this institution but others as well need to consider alternative measures to manage people across different locations. Considering, the need for informed decision making still exists, irrespective of the environment or institution [16].

1.3 Research problem and aim

Whilst considering the immense benefits workforce planning has, this Faculty has no effective way to conduct it. The diverse representation of the Faculty contributes to the necessity for informed decision making. However, their current TA system fails to provide them with summative information regarding their workforce. Moreover, COVID-19 is adapting their asset management practices which is creating added pressures on management to conduct effective workforce planning. However, to conduct workforce planning the Faculty needs a system that can provide the necessary information on their workforce to aid them in decision making.

Against this background, it is clear that there are no effective means to capture, store and process the information on the varying Faculty workload. This study serves to enable the engineering faculty management to improve their workforce planning by means of a system that can offer decision support.

The composition of this research paper is outlined whist considering the components of the hybrid Agile V-model methodology, further explained in Chapter 2. The user requirements are identified Chapter 3, by investigating the shortcomings of the current system with root cause analysis techniques (Fishbone, BPMN, Five Why). The findings of these root causes are translated into system requirements and specifications. Chapter 4 is divided into three sub-chapters. Chapter 4.1 showcases the detailed design with the system selection process. In Chapter 4.2, the iterative system software coding takes place and the functionality of the DSS is explained. Chapter 4.3 addresses the system testing and results to extract valuable conclusions and future recommendations that are mapped out in Chapter 5.

2 RESEARCH METHODOLOGY

A hybrid Agile V-model methodology was followed in this study, combining all the respective traits such as flexibility of user changes throughout the process, proactive error tracking and no user training needed before implementation [17-20].

The V-model is a branched Waterfall method, however, the V-model is rigid and not very flexible to changes because system coding is only conducted once in the implementation phase [17]. A system design case study used the V-model since its cross-domain design considers overall system requirements [21]. However, the study found that one iteration of the V-model could not deliver a complex system and created multiple V-model cycles in reparation. This further supports that one cycle of the V-model will not allow successful designing of complex systems and that at least one iteration of system coding should be considered.

An Agile methodology ensures short iterations of software programming versions [18]. It requires direct contact between the user and the design, ensuring that there are no communication barriers or most commonly known as silos in systems engineering [18]. A mobile software development case study used an Agile methodology successfully [20]. However, the study concluded the methodology does not focus on the unique requirements and constraints for mobile software development and recommended that future work should combine this method with another. For this reason, an Agile V-model methodology was selected, since this study will develop a complex software system with various user roles and responsibilities.

Figure 3 explains the representation of this Agile V-model methodology. The first phases transform the user needs into a detailed design and after the system coding, the system is finally tested with the integration phases.

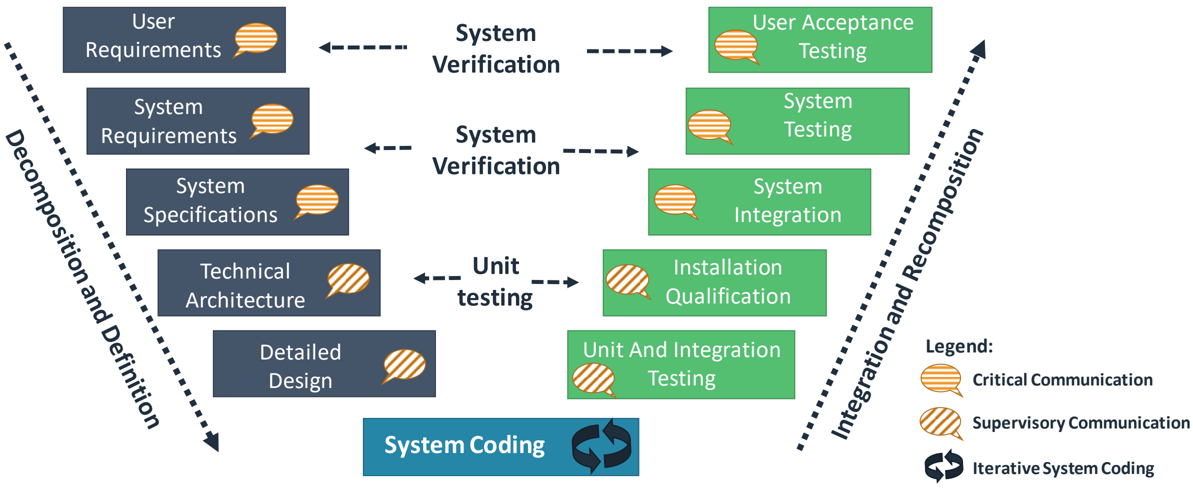

Figure 3: Agile V-model Methodology

As demonstrated in Figure 3, there is continuous communication between the designer and client in all the stages at two specific levels. Critical communication refers to close and high-level communication, where supervisory communication refers to small confirmations between the client and designer.

3 ROOT CAUSE ANALYSIS

The challenges of the Case study introduce necessary concepts that a system should include to aid in workforce planning. Therefore, the current TA process in the Case study needs to be investigated to recognise the increased challenges and translate them into the system requirements.

Within this Faculty, decision making is currently fulfilled using task agreements (TA). TA enables institutions to strategically position themselves whilst identifying core improvement activities within the institution [22]. These Excel-based TA are distributed to the workforce via a virtual platform. After the TA is received by the users, they indicate the tasks that they aim to complete in the coming year and send it back to management. Management consolidate these TA documents to gain summative information on the work balance of their staff.

The current system is illustrated with a Business Process Model and Notation (BPMN) which is further analysed using a Fishbone diagram to highlight the major system challenges. A Five Whys Analysis examines these root causes further to reveal the core aspects contributing to the current TA process insufficiency.

BPMN is serves as a means to explain a current process and identify any constraints [23]. Figure 4 describes the current TA process with a BPMN. There are three leading role players in the current system — the user, administrator and system. The BPMN is divided into four stages concerning composition, completion, submission and consolidation of the TA process.

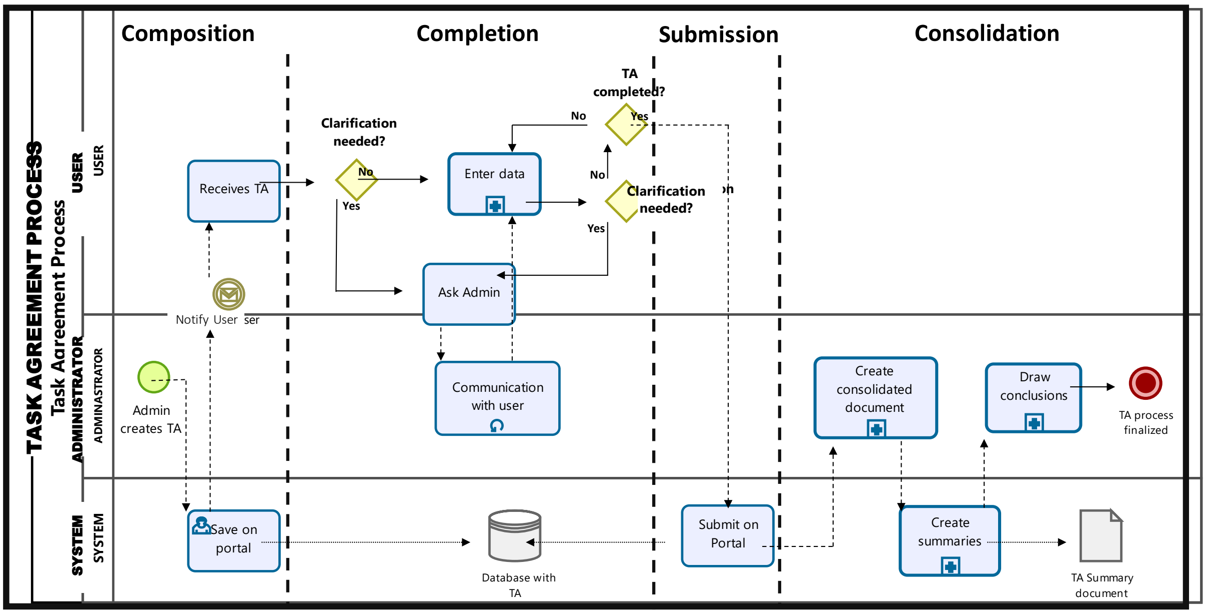

Figure 4: Current TA Process BPMN

It is important to observe (Figure 4) that many tasks depend on the administrator. With the current process, the administrator has to assist users, consolidate all TA, and draw conclusions. This process may appear as only three responsibilities; however, the administrator has many other Faculty related responsibilities which consume valuable time. These challenges need to be streamlined to ensure increased process effectiveness. They will be addressed in the system requirements with the major improvement to shift most responsibilities from the administrator to the system. These challenges are further studied to determine the root causes by means of a Fishbone diagram.

The Fishbone diagram is an effective tool to visualise potential causes of the problem whilst sorting them into specific categories [24]. The client and the designer worked together to complete the Fishbone diagram. After completion, both discussed possible core aspects that were directly linked to other root causes. Figure 5 illustrates the Fishbone diagram of the current TA process to identify problems as to why the system is not functioning at its desired level of effectiveness.

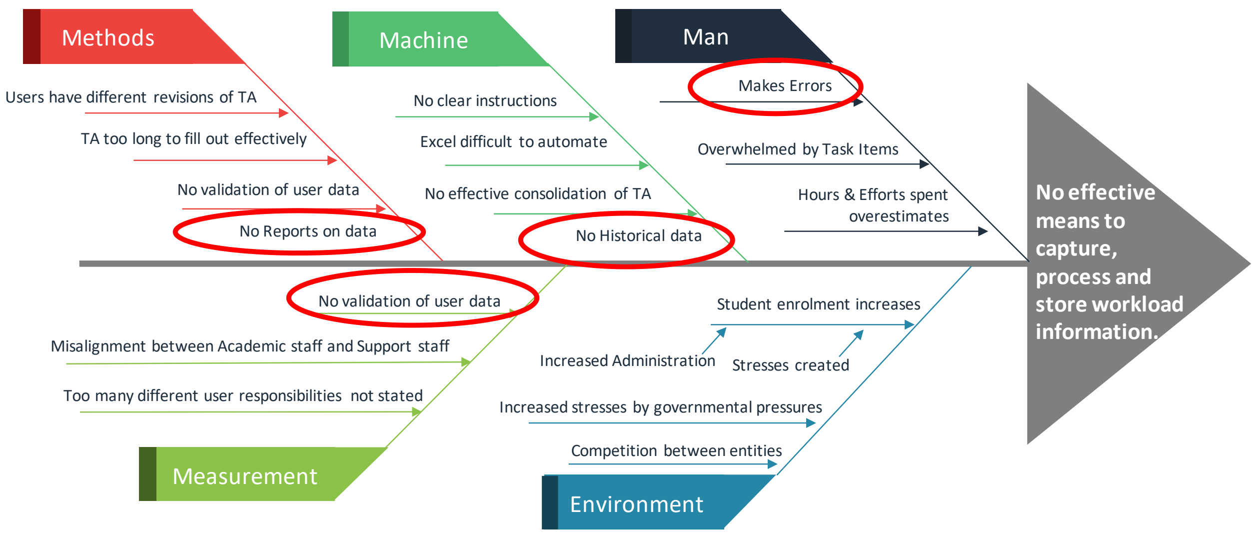

Figure 5: Fishbone Diagram Current State Analysis

From Figure 5, the consolidation of the TA and misalignment between academic and support staff were noted as an important cause of concern. Moreover, the validation of user data (processing functions), user errors (capture functions) and no reports or historical data (storage functions) are major concern areas that need further investigation.

The Five Whys Analysis reveals correlations between the BPMN and Fishbone previously discussed. The leading causes from the Fishbone diagram were traced back to the three main initial problems orientated around the capturing, processing and storage of information. Each cause is further analysed to determine root causes. In order to categorise the final outcomes in Figure 6, a numbering system was used: (1) Administrator responsibilities, (2,3) Cloud and Excel-based TA and (4) Primary key identification.

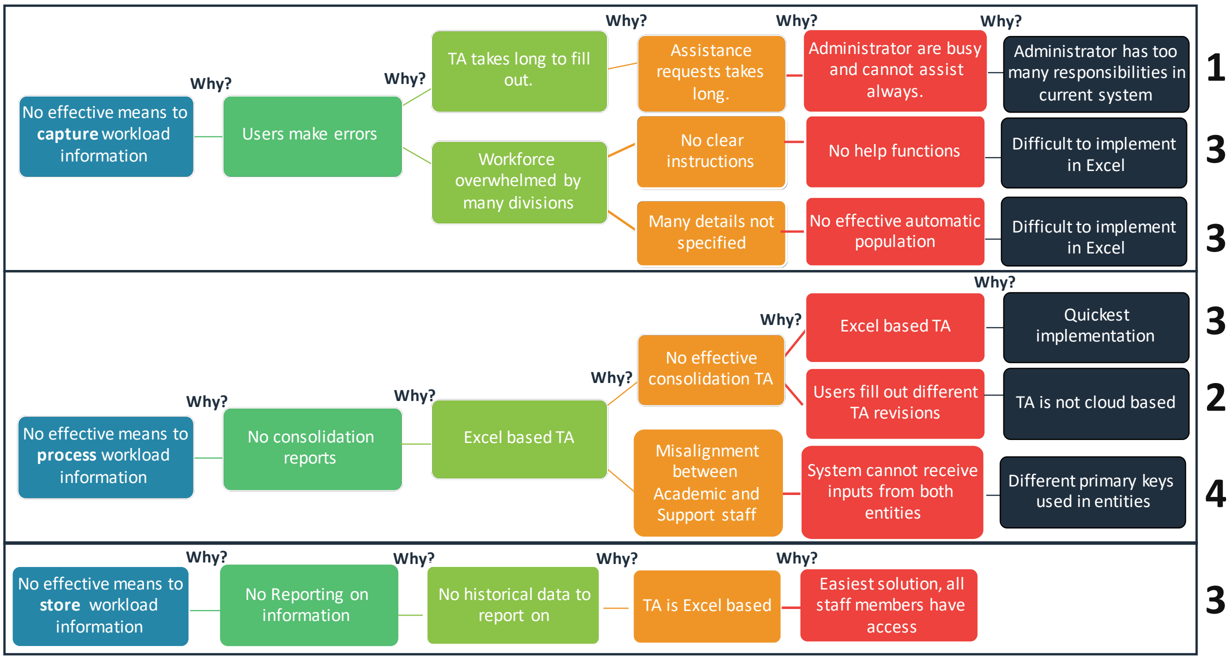

Figure 6: Five Whys Analysis

The common outcomes in Figure 6 have specific implications, namely:

1. The dean (Administrator) should have fewer responsibilities.
2. Irregular revisions of the TA between users should be addressed by deploying it on a cloud-based system to ensure coherence.
3. The current TA is Excel-based, and this is a direct cause for many other problems.
4. The current system does not contain any primary keys (personal information from the workforce staff ID) that can be used to store and query data with the system.

The root cause analysis investigated the inefficiencies within the system that need to be addressed. However, to make this necessary stride, the length (interdependence) and direction (strategy) need to be determined. In order to achieve this, the system design requirements must be investigated.

System and client requirements are critical to state before determining conceptual system designs [25]. In this study, system requirements stem from the root cause analysis performed in parallel with the client and designer. It enables the developer to ensure the system solves the specific problem. These system requirements are divided into four categories: system-specific, user, management and output requirements. **Error! Reference source not found.** outlines the divisions in context to this study.

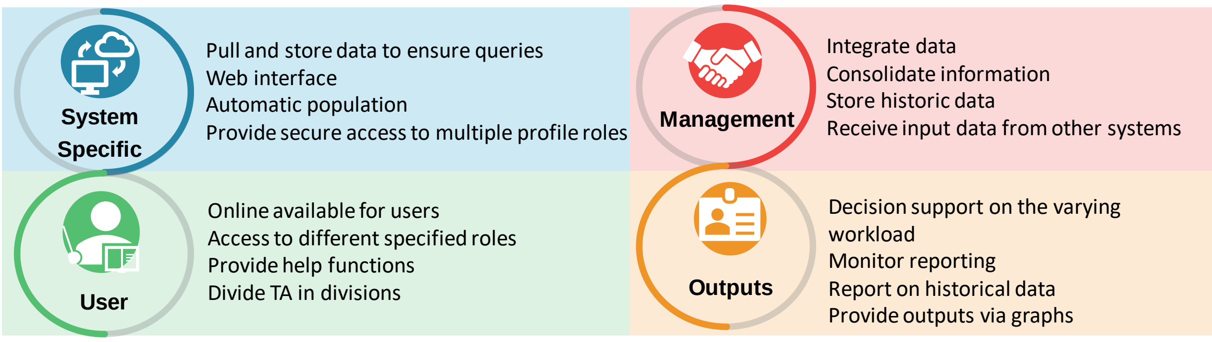

Figure 7: System Requirements

Systems that will provide management with supportive information are the ideal systems that can significantly contribute to addressing the workforce planning needs of an institution.

4 FINDINGS AND RESULTS

As discussed in Chapter 2, the Agile V-model methodology was deemed most appropriate. The left side entails the definition and decomposition of user requirements in order to facilitate system coding.

The right side integrates and recomposes the system to ensure that the final design passes the user acceptance testing.

For the final design, a design selection process was followed, as discussed in Chapter 4.1. Furthermore, the system architecture and coding are introduced in Chapter 4.2. As for the system integration and testing via verification and validation, these are discussed in Chapter 4.3.

4.1 Design selection process

Three conceptual designs were identified from the system requirements (1) Management Information System, (2) Performance Management System, and (3) Decision Support System. Each of these systems was evaluated with a decision matrix where the comparisons directly stemmed from the system requirements [26]. The designer and the stakeholder scored each conceptual design against a criterion of achievement specific to the system requirements. The decision matrix results suggested that the MIS and DSS were the best suited conceptual designs.

To support these findings and ultimately, select a final design the conceptual designs were evaluated with an Analytical Hierarchy Process (AHP). An AHP aids in decision making by assessing overall motivation, rationale and importance weighing to determine a final result [27]. The AHP results concluded that the DSS will be the best suited conceptual design. Considering that the decision matrix and AHP both support the DSS, it was deemed the most appropriate concept design.

4.2 DSS Software Design

The DSS was coded in Hypertext Mark-up Language (HTML), PHP and JavaScript; an embedded web scripting language. The system comprising creating a database with various linked tables connected to a web interface. **Error! Reference source not found.** explains the architecture of the system.

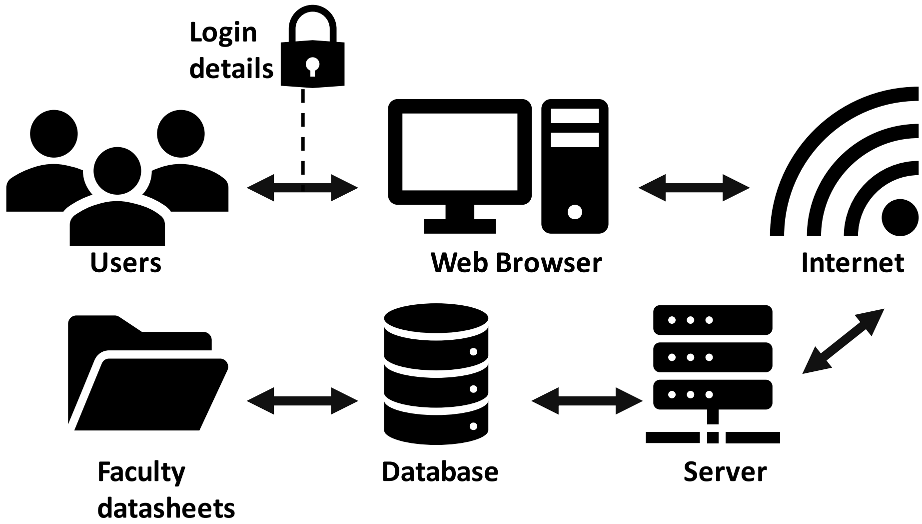

Figure 8: System Architecture

The system is accessible via a web browser with an internet connection (**Error! Reference source not found.**). However, each user had their login details (username, password) with a security question and answer. These added security measures ensured data security and encryption. Administrators could upload all faculty datasheets to a centralised database linked to a server. This database stored all the information regarding the workforce.

Given the root cause analysis and system requirements, the DSS must be able to store, capture and process data on the Faculty workforce. These three aspects will enable decision support for the Faculty and are further examined in **Error! Reference source not found.** to address system functions.

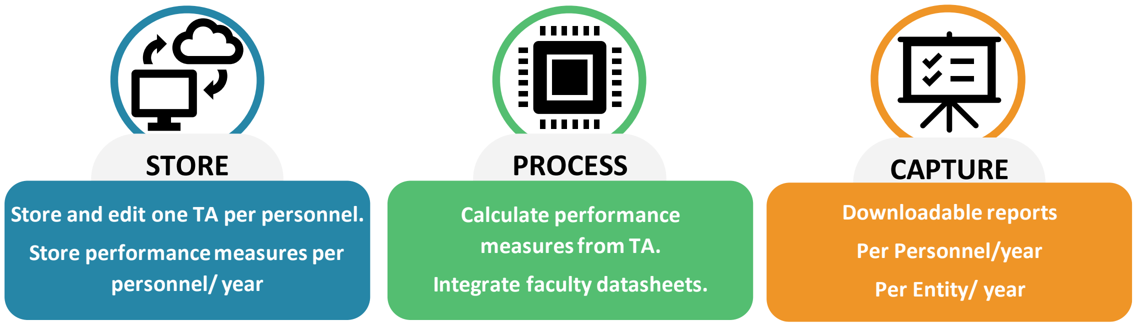

Figure 9: Store, Process, Capture capabilities

Each aspect explained in **Error! Reference source not found.** addresses critical system requirements. To store data, the system needs to create new, edit and recall TA and performance measures per personnel and time period. The system needs to process data by calculating performance measures from the TA listings and integrate various faculty datasheets with the specific personnel ID (data relating to the subjects given, publications completed, etc.). To capture data, the system should communicate all the aspects mentioned above in comprehensive summative reports according to entity or personnel over prescribed periods.

By considering the aforementioned system requirements, the specific user roles need to be addressed per system requirement. The DSS has three key roles - dean, entity directors and administrators, each with its user interface. **Error! Reference source not found.** encompasses the system requirements with an explanation of the tasks each user role has. The specific roles are shown by dedicated columns per user.

Table 1: System Requirements per Role

	System requirements	Explanation of user tasks	Executive Dean	Entity Director	Admin
1	Improve the security of the system and ensure multiple user profile log-ins.	Users can change their password and provide a security question to enhance the security of the system.	X	X	X
2	Enable workforce information TA to be stored.	Create or edit any TA. The user should enter the personnel ID and proceed to the TA page.		X	
3	Ensure individual historical data can be requested. Capture workforce reports.	Download any personnel Performance agreement report. The user should enter the personnel ID with a specified year that needs to be queried.		X	X
4	Ensure historical data can be requested from the entire entity.	Download any summary of all the previous year's Performance Agreement reports of specific personnel or an entire entity per time period to report on personnel and entity progress.	X		
5	Improve system usability and adaptability.	All subjects and TA items have automated populated data (amount of students, credits and task weights). The specified weight allocated can be updated.	X	X	
6	Integrate faculty datasheets with the system.	Update the faculty lists with a link to a template Excel form to populate and upload which ensures data integrity.	X	X	X

During each phase of the Agile V-model methodology, there was continuous communication with the client. Two iterations of system coding ensured that all client requirement changes could be addressed and incorporated into the ultimate design. The first iteration of system coding relied on designing a prototype system whilst completing the system architecture. The second coding iteration supported additional system requirements and a more detailed design. The two iterations enabled the system to have a higher quality with more functionality for the end-user.

4.3 System demonstration and survey testing

After designing the system, it was tested with a semi-structured survey. The testing involved a future user of each user role to validate and verify the functionality of the system.

A structured demonstration was presented live to the dean, entity directors and administrators of the Case study Faculty in an online environment. The participants were chosen since they will be potential system users because of their role within the Faculty. Afterwards, the system encompassed verification and validation with an electronic semi-structured survey poll using virtual conference software.

The semi-structured survey was comprised of ten survey statements that were configured with a 5-point Likert scale (Strongly Disagree – Strongly Agree). Each statement verified adherence to the system requirements and validated the problem statement and aim. The data was treated as interval level since the difference between each scale is evenly spaced [28]. It is important to describe Likert scale data with a mean, standard deviation and standard error calculations [28, 29]. The mean and standard deviation are calculated for each statement in

Table 2, segmented by the verification and validation statements. The mean and standard deviation totals are also calculated for the entire sample.

Table 2: Semi-structured Survey Results per Statement

Type	Survey statement	Mean score	Standard deviation score
Verification	The user interface is logical and easy to understand.	4,33	0,50
	The system automatically populates fields and lessens errors probabilities.	4,44	0,53
	The system provides proactive error handling.	4,11	0,60
	The system aligns faculty information lists with the system.	4,33	0,71
	The system provides performance measures to enhance strategic planning.	4.0	0,50
Validation	The system stores data on the workforce.	4,33	0,50
	The system uses the data and process it to generate information.	4,22	0,44
	The system captures this information to aid with decision support.	4,55	0,52
	The system store process and capture data on the workload.	4,55	0,52
	The system provides the ability to make informed decisions on the engineering staff per entity.	4,33	0,5
Sample Totals:		**4,32**	**0,536**

The mean of each statement was averaged to display the entire sample mean as 4,32. This showed most respondents either agreed (4) or strongly agreed (5) with the statements. Standard The total sample standard deviation described the distribution of the entire sample as 0,536. This indicated the results had a high relatability to the mean scores, and the respondents reached consensus [30]. The low variability shows the data are closely spread against the mean; indicating that participants scored similarly [31].

To conclude that the sample provides an accurate representation of the entire population, the standard error needed to be calculated from the average of the sample means [32]. The standard error is the standard deviation of the statement means calculated as 0,177. The low standard error value suggests that the individual sample mean is relatively close to the true population mean [33]. The margin of error at 95% confidence is 1,98 resulting in a true mean of 3,97 and 4,87. This further supports the high level of consensus that has been reached in this study.

Now that this research has shown a path towards workforce planning, we can look back at the steps the DSS has allowed the Faculty to make towards improving their workforce planning.

5 CONCLUSIONS AND RECOMMENDATIONS

This DSS provides critical information that enables the Faculty to conduct workforce planning. The Case study confirmed that the DSS is fully functional and can be implemented. Implementing a DSS to aid in workforce planning will not only allow the Faculty to make better decisions but will also enhance the teaching and learning for students, research outputs for the researcher and encourage community engagement.

However, this DSS can also provide strides in other directions with workforce planning as an end destination for not only this Faculty, but other HE institutions as well. It can be altered for any institution, since it relies on database models that speak to workforce planning as a universal concern. However, the DSS will only truly be a success with data integrity [34]. Future studies can evaluate measures to ensure data integrity by implementing the DSS. A valuable contribution to research could seek inspiration from this study and incorporate specific work environment needs regarding workplace planning. This can be used to implement similar strategies in other work environments, albeit a new case study or large-scale comparative analysis. Other research initiatives could implement the DSS to study workload distribution further and determine the long-term effects of an under or over utilised workforce. This could lead to extremely insightful discussions amidst COVID-19 since studies show that productivity decreases in work-from-home environments [35, 36].

It will also be of research interest to implement the DSS in different HE institutions to compare the outcomes of residential and distance education types of institutions. Such a comparative study can appeal to an array of discipline-specific practitioners and academic scholars. Beyond this recommendation, the adoption of the DSS for workforce planning can also be incorporated in the work environment of other industries.

COVID-19 demanded institutions to change their asset management methods, which is forcing management to consider alternative measures to oversee their workforce across different locations. Productivity becomes even more complex to measure in decentralised environments; further necessitates the need for workforce planning. Moreover, the Information Age is emphasising the value of knowledge management and the significant contribution it makes to gain a competitive advantage [37]. This DSS is pivotal for sustaining productivity in the future since the need for informed decisions will always exist.

Institutions that implement this DSS will ensure that their workforce and management are informed and integrated. This can result in overall business improvement and customer satisfaction, ultimately increased revenues. Moreover, the DSS can apply to any organisation, private or publication institution or industry. This research will advise any entity on their first step towards improved workforce planning and informed decision making during the COVID and post-COVID era.

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A FRAMEWORK FOR MEASURING KNOWLEDGE TRANSFER SUCCESS IN PROJECTS

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ABSTRACT

Knowledge transfer success is regarded as one of the tools that enable project-based organizations to gain a competitive edge. There is however a gap in the literature regarding the measurement of knowledge transfer success and the indicators can be used to ascertain it. The objective of this study is to develop a measurement framework that can be used to indicate the success of knowledge transfer and how the use of that knowledge took place. Through a research study using the Delphi Technique, it was determined that the knowledge transfer success indicators that can be used to measure transfer success can be categorised under knowledge application, knowledge value, knowledge evaluation, and the nett impact due to the received knowledge.

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1 INTRODUCTION

We have all heard the sayings, “One cannot manage what cannot be measured” and “What is measured is what gets done”. These statements also apply to knowledge transfer success. For an organization to ascertain that knowledge was transferred it must be measured. Measurement enables organizations to track the progress of knowledge management. This helps with decision making to improve, control and compare the efficiency of each mechanism used to affect the transfer of knowledge. Measurement is the only tool available to demonstrate the worthiness and the value-added to the knowledge of the recipient, without this evidence no one will ever know that knowledge was transferred from one party to another [1]. As a result, this study is undertaken to establish the knowledge transfer success measurement framework.

Projects have a predetermined end. Furthermore, teams assigned to execute complex tasks in project-based organizations are appointed temporarily and are expected to produce project deliverables under stringent conditions such as budget and pressing deadlines. Project teams are made of individuals with diverse skills and technical backgrounds. As a result, knowledge is created [2].

Organizations are faced with the knowledge paradox that projects are deemed as conduits and good sources for new knowledge creation, however, the created knowledge is subsequently misplaced and not transferred [3]. This can be attributed to the project time period and that the knowledge created is scattered among different project phases and sits with different stakeholders involved in the project. Upon project completion, all the project stakeholders’ part ways taking their knowledge with them as they only work together for a limited time. As a result, knowledge transfer is hindered [4]. The retention of project experiences allows for organizations to compare their various projects systematically so to record their most potent problem-solving technics, which can then help to improve subsequent projects by executing tasks more efficiently [5].

The knowledge in the form of experiences resides among the people involved in the project. These experiences might not form part of the project records and documentation. Under normal circumstances these experiences cannot be passed to the other people or the organization upon completion of the project, hence the knowledge remains with those that were part of the project [5]. Moreover, the current study intends to derive the measurement framework to be utilized to ascertain that the knowledge transfer was successful.

The success of project-based firms, more importantly, those within the engineering and construction industry are dependent on their potential to finish projects within the scheduled time, budget, and per the client’s requirements [6]. This ability has to be maintained from one project to another for the organization to remain competitive, otherwise, work will be taken elsewhere to the competitors that have displayed to be more knowledgeable. It is, therefore, crucial to take the lessons learned from the previous project and apply them to the next inline similar project to avoid making the same mistakes repeatedly [6]. As a result, an organization is enabled to enhance its operations and to stay competitive all the time. This stresses the importance of knowledge transfer because the survival of project-based firms is dependent on it [7]. However, how can one tell that knowledge transfer was a success?

Studies by Bellini, Aarseth & Hosseini [8], Chan, Pretorius & Oerlemans [9], Louw et al. [6], Lawson & Potter [10], Cummings & Teng [11], Pérez-Nordtvedt, Kedia, Datta & Rasheed [12] and Prinsloo, van Waveren & Chan [13] have looked into factors that influence the transfer of knowledge. However, a gap has been identified in the literature: there is no measurement framework in place to indicate the success of knowledge transfer both from the sender and the recipient perspectives. Hence, a need for the current study to establish the measurement framework together with the knowledge transfer success indicators.

2 RESEARCH OBJECTIVES AND QUESTIONS

Knowledge is deemed to be a soft factor and is related to knowledge management activities of which their success is hard to measure and to evaluate [4]. Van Waveren, Oerlemans & Pretorius [15] stipulated that it's difficult to tell what impact a particular piece of knowledge has on an individual's knowledge base, hence there is no measurement framework in place to effectively track the impact the transferred knowledge has on the receiving party. As a result, there is a need for the measurement framework and indicators that can be used to ascertain whether the knowledge transfer was a success.

The objective of this study is, therefore, to measure the success of knowledge transfer, to develop a measurement framework that can be used to indicate the success of knowledge transfer and how the use of the received knowledge took place.

Given the objectives, the research question is defined as:

> How can one measure whether the knowledge transfer in projects was successful?

3 LITERATURE REVIEW

Knowledge transfer success is described as the ability to which the knowledge transfer process yield positive outcomes and other significant performance effects. Thus, making knowledge available cannot be termed a knowledge transfer success indicator, knowledge needs to be comprehended and utilized by the recipient for it to be termed to have been successful [16]. The knowledge needs to impart changes in the recipient's behaviour. The amount of transferrable knowledge can be determined by tracking changes in both the knowledge and the performance of the recipient [16]. This study aims to expand on this effect by devising the indicators to measure the success of knowledge transfer. Four knowledge success categories were established from the literature. The categories consist of the positive outcomes of the knowledge transfer and will be utilized to represent the successful transfer of knowledge. The categories are knowledge evaluation, knowledge value, knowledge application and nett impact.

3.1 Knowledge Evaluation

The ability of the knowledge recipient to assess, test and verify the knowledge is closely linked to the successful transfer of the knowledge [17]. Reason being, one cannot assess the knowledge without fully comprehending it. Moreover, comprehending the knowledge indicate that knowledge has been successfully received [17]. The expected use is one of the constituents of knowledge evaluation which is proposed as one of the knowledge transfer success indicators. The expected use refers to the information received from previous projects that has been considered, verified and rejected as deemed to be not fit for the application. This phenomenon depicts that not all the transferred knowledge adds value and that it is not the sender's knowledge replication on the receiver that matters but rather the benefits that are realized due to the received knowledge [15]. The receiver would need to evaluate the received knowledge before arriving to the decision to either accept, reject or improve it. Hence, this factor is considered as the knowledge transfer success measurement indicator that will be tested as part of this study [15].

Another key constituent under knowledge evaluation is the probability of knowledge transfer success. According to Al-salti et al. [17], knowledge success can be measured by counting the number of knowledge transfers sessions conducted in a period of time. Thus, the knowledge source can count the number of knowledge transfer encounters and from that derive the likelihood of the transfer success depending on the number of engagements held. This indicator will be evaluated to check if it qualifies to be classified as one of the knowledge transfer measurement framework indicators.

The third factor that falls under knowledge evaluation is knowledge quality. Knowledge quality refers to ensuring that the fit-for-purpose knowledge with adequate context is grasped during the transfer and is availed at the most appropriate time for the fit-for-purpose users, the flow of the timely information to the appropriate individual at the right time. This is so they can apply the knowledge to add value to an organization, be it through an increase in revenue or saving in either time or costs, thus realizing the benefits of transferred knowledge. As a result, knowledge quality will be used as an indicator in this study to verify its contribution towards measuring the success of knowledge transfer [15].

3.2 Knowledge Value

When one measures the success of knowledge transfer, one should consider the value added to the receiving party [9]. This refers to the usefulness of transferred knowledge. Furthermore, the perceived usefulness of knowledge is determined by a degree to which the recipient regard knowledge to be meaningful, accurate, innovative, and valid [16]. For knowledge to be regarded as meaningful, it should be sensible to the anticipated users. Accuracy of knowledge refers to how related the knowledge is to the activities, tasks and difficulties facing the recipient and to the procedures and processes through which work gets executed. Knowledge being valid means that it is proven to be applicable and action-based. Furthermore, when knowledge is deemed to be innovative it is when it leads to the creation and development of something fresh, which can be new products, services or processes [16].

Hence, in this study, if it can be established that the knowledge recipient deems the knowledge to be useful based on the value-added, the transfer of knowledge will be considered to have been successful. As a result, knowledge usefulness will be evaluated as an indicator ascertaining the successful transfer of knowledge.

The knowledge value is defined differently by different authors, however, Al-salti et al. [17] agree with Chan et al. [9] as they stipulate that the knowledge transfer success is directly linked to the potential to which the receiving party deems the transferred knowledge as comprehensive, satisfactory and useful. The value added by the knowledge will produce a satisfied recipient. Thus, the transferred knowledge being well understood, satisfactory and useful to the recipient will be evaluated. Moreover, knowledge transfer success can be gauged by improved organizational process performance [15]. For a recipient to have the capacity to re-create the knowledge of the source for his own operations it would simply mean that the knowledge was successfully received, as it would be difficult to discern the knowledge unless that knowledge, when received, was properly comprehended. This will equates to the successful reception of knowledge [11].

Another key indicator which falls under the knowledge value category is knowledge internalization. Internalization refers to the degree of ownership, satisfaction and commitment to the transferred knowledge. The recipient must be satisfied with the content, format, ease of use, accuracy, and timelessness of the received knowledge. Knowledge ownership is defined as the intensity of the receiving party's association with the knowledge. Knowledge ownership allows the receiving party to infuse more of their own thoughts and to customize knowledge. The number of interactions with the knowledge triggers the feeling of ownership. The more the knowledge recipient engages with the knowledge the more comfortable one will be around the knowledge, as a result, the recipient becomes creative with the knowledge. This will only occur if the transfer of knowledge is deemed to have been successful [11]. Commitment refers to the interaction, value, time, energy investment, attention, willingness to put an extra effort to work with and to develop competence in utilization of the knowledge [17]–[20]. As a result, knowledge ownership, commitment to knowledge and knowledge comfortability as described above are put to test to authenticate their impact as measures of knowledge transfer success.

3.3 Knowledge Application

Knowledge application refers to the utilization of the received knowledge by the recipient to carry innovative pursuits. When the knowledge receiver starts to independently use the garnered knowledge, the transfer can be declared to have been a success. Reason being, it is highly unlikely for an individual or an organization to put into practise the received knowledge unless it has been well-received [9]. More and above, Ryoo [21] stipulates that when the knowledge base of a recipient has been enhanced through the transfer of vital knowledge, the receiving party can assemble and accumulate the expertise that enables them to carry out tasks smoothly and efficiently. In the current study, the ability of the knowledge recipient to utilize the newly received knowledge to carry out his operations will be used as an indicator to measure the knowledge transfer successfulness.

Another key factor that contributes towards the successful application of knowledge is complementary knowledge. Complementary knowledge stands a better chance to succeed as most parties are willing to come together and learn through the combination of varying complementary skills and resources. Complementary knowledge stands a better chance of stimulating new ideas. As a result, successful reception of this knowledge leads to independent use, creation of new knowledge and utilization of the knowledge for a different purpose [22]. According to Schulze, Brojerdi & Von Krogh [23], knowledge is declared to have been successfully transferred the moment the recipient displays the ability to independently work with the knowledge. Such a sense of knowledge ownership shows that the recipient is capable of solving problems using the knowledge. Furthermore, it is an indication that the receiving party can pursue tasks with the help of the new knowledge without any hindrances. When the knowledge source provides follow-up assistance by supporting the knowledge application, providing supplemental knowledge, providing corrections and giving real-time feedback, the recipient is enabled to act on the knowledge. Thus, the transfer success is enhanced and as soon as the recipient acts on the knowledge in his own capacity the transfer is deemed to have been successful [23]. Therefore, the independent use of knowledge by the recipient is one of the factors that will be tested if they qualify to be indicators of knowledge transfer success measurement framework.

Lindner & Wald [4] agree with Knudsen [22] and they put it in simpler terms by saying that the knowledge transfer success in a form of knowledge application can be attributed to effective knowledge management by the recipient, simply because one cannot manage what cannot be measured. Knowledge management alludes to the storage, sharing, retrieval and regeneration of knowledge when required. This ability clearly shows that the knowledge requires to be received with success, organized, sorted, and stored in a purposeful and readily accessible form to be produced when needed. Knowledge management requires knowledge transfer to have been successful before it being effected, hence, this factor is crucial at depicting whether the transfer was a success or not. As soon as one exhibits the knowledge management attributes, it clearly indicates that the knowledge transfer was a success [4].

To further describe the knowledge application phenomenon as the knowledge transfer success indicator, the concepts of instrumental and strategic use are looped in. Instrumental use refers to the application of the received knowledge on the subsequent projects, change in practice, and behaviour triggering new and enhanced operations. Strategic use refers to the manipulation of knowledge to gain power, improve own understanding, use of knowledge as a persuasive instrument and ammunition [15]. Thus, all these indicators developed from the literature will be put to test to ascertain if they hold as the knowledge transfer success indicators during data collection.

3.4 Nett Impact

Nett impact refers to the effect the transferred knowledge will have on an individual's performance in a work environment. The impact can be perceived as an indication that the received knowledge has given the recipient a more sound understanding of the context, has intensified the decision-making skills, and has improved the decision maker's perception. The individual's impact has a remarkable effect on the whole organization's performance [24]. Knowledge transfer success can be linked to any positive impact on the recipient and increased effectiveness in decision making by boosting the ability and thinking capacity of the decision-maker. Furthermore, it's associated with reusing the garnered knowledge from past experiences to enhance current and future decision-making pursuits. Decision making can be evaluated, measured and judged. As a result, it can be easily seen if the organization is settling on similar choices over and over and if they are utilizing the previous experiences to improve on decision making, making better and quicker decisions. [24].

Another constituent of the nett impact brought about by the received knowledge is the rate at which the knowledge is transferred, it manifests how quick the receiving party gathers new insights and skills. As a result, capability cannot develop unless the transferred knowledge is considered to be comprehensible and useful. Capabilities can't bestow to competitive advantage except when they are constructed speedily and economical [12]. This stresses the importance of the transfer success being linked to the speed and budget associated with the knowledge transfer. For example, if the knowledge is transferred speedily and economical, however, not considered to be relevant or easily comprehensive by the recipient, the transfer will not yield the anticipated outcomes. Conversely, if the recipient takes charge over useful knowledge, however, steadily so or utilizes enormous resources, benefits associated with the early bird are most likely to be constrained and might lead to costs outweighing the envisaged benefits. As a result, for the transfer of knowledge to be declared to have been successful, the speed of transfer, budget, and usefulness of knowledge should be on par. Hence, the current study investigates the contribution of these factors towards the establishment of a knowledge transfer measurement framework [12].

To provide better clarity on the nett impact brought about the received knowledge phenomenon, the conceptual use concept is adopted. Conceptual use refers to the information that the receiver knows about and it has made a change in attitude, thinking behaviour, level of knowledge comprehension, and helps to lay the foundation for decision making. Furthermore, conceptual use refers to the knowledge that hasn't been put to practise but has imparted the changes in terms of thinking behaviour of the receiver [15]. Furthermore, the knowledge transfer success in the form of the nett impact according to Zulpo & Riege [25], attributes to the improved speed in execution of tasks on subsequent projects. Meaning, time taken to carry out activities is reduced thus, the recipient's productivity is increased and more projects can be completed in a short period. Hence, enhancing the organizational competency and thereby creating a competitive advantage.

4 CONCEPTUAL MODEL

From the literature, as presented in the previous section a conceptual model is derived. This model is depicted in Figure 1 below. The conceptual model shows the flow of knowledge from the sender to the receiver, through the use of knowledge transfer mechanisms and the impact brought about by the received knowledge on the receiver. The conceptual model depicts all the proposed knowledge transfer indicators, as derived from literature, which will be evaluated by the expert's opinions. These indicators can then be used to prove that the knowledge has been successfully transferred.

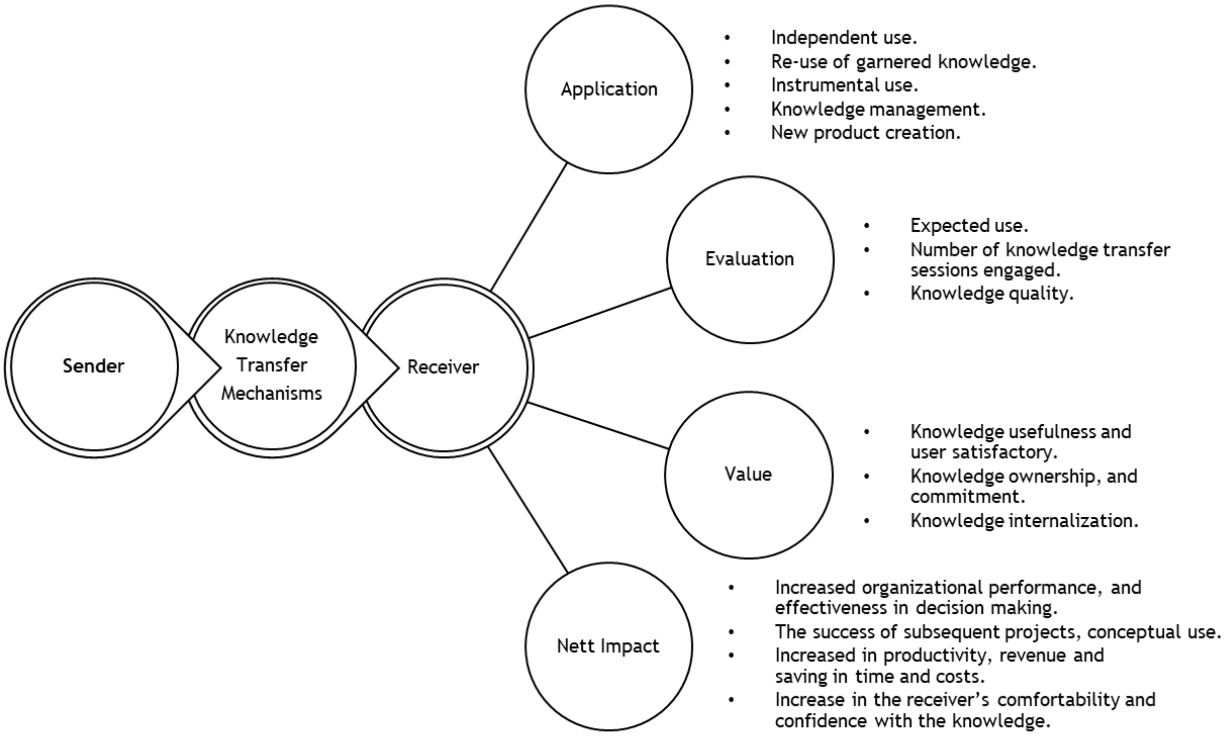

Figure 1: Research Conceptual Model

The knowledge transfer mechanism that supports the transfer of knowledge between the sender and receiver are known tools, methods and techniques that enable the flow of knowledge, such as brainstorming sessions, collaborations, documents, discussions, emails etc. [15] [26]. When the knowledge reaches the receiver, it brings about changes, any positive change effected signifies knowledge transfer success [7]. Thus, all the positive outputs manifested at the receiver as obtained from the literature are displayed around the receiver as shown in Figure 1 and detailed using the bulleted lists. These outputs are the factors that are proposed as knowledge transfer success indicators. Furthermore, the research aims to authenticate whether or not these factors can be adopted as knowledge transfer success measures.

5 RESEARCH DESIGN AND METHODOLOGY

Due to the exploratory nature of this current study, a qualitative research methodology was adopted. The research is bench-marked but not limited to the findings obtained from a theoretical review. The qualitative methodology used in this research helped to unearth trends in thoughts and opinions by using semi-structured interviews to collect data. A small, theory-guided sample size consisting of an independent group of experts were targeted to harness their viewpoints on the proposed knowledge transfer success indicators as presented in Figure 1. The aim was not to have all the expert group members to be gathered in one place or physically meet but rather to attain their judgements independently.

Each of the indicators identified in the literature was tested by the expert group members to assess their impact as knowledge transfer success measure through a Delphi study. The applicability of each of the parameters was determined based on how the respondent sees it fit to measure the knowledge transfer success [27].

When applying the Delphi Technique in the study, the author presented a topic guide to each respondent which briefly explained the background on each indicator presented in a conceptual model. The expert respondents had to decide to either accept or reject each predetermined indicators and each expert was awarded an opportunity to add any new indicators that were not derived from the literature. After each round of interviews, the author summarized all the responses obtained from the previous round from all experts and compiled these anonymised record together with the reasons in support of their judgements. The author then presented all the previous judgement's record to each expert and advised them to relook their earlier answers in comparison with the answers provided by the other members. This process was repeated two times after which consensus was reached. All the indicators that prevailed and received positive responses after two rounds from all the panel members were then deemed to be knowledge transfer success measures. Likewise, all the indicators that received negative responses were then omitted from the knowledge transfer success measurement framework.

To get rid of biasness and attain the most valuable results, the selection of the sample of experts followed a predetermined criterion namely to have accrued experience in projects as project managers, contractors or as consultants. The expert group members are knowledgeable concerning the information and perceptions underlying the topic of the current study. This approach required the use of open-ended questions which doesn't suggest any premeditated answers. An email was sent to each expert prior to the interview to invite them to the interview and inform them to feel free to express their ideas, opinions and affirming them that their anonymity was ensured. More and above the use of open questions, probes were utilized in data collection. The respondent's participation was voluntary.

The fundamental basis of the study is to derive the knowledge transfer success measurement criteria. The research informants, which are experts, informed the author based on their experience, what they understand from the indicators and which indicators presented in the conceptual model they view to precisely show that the knowledge has been successfully transferred from one party to another. They were also allowed an opportunity to add new indicators that were not derived from the literature. The indicators that received positive response were then classified as measures of knowledge transfer success.

The author set the requirement that the expert group members should be individuals that are knowledgeable about the topic. This required the members to have participated in the transfer of knowledge in one form or another and should be working or have worked in the projects environment. To meet this requirement, over 20 experts from different organizations were identified based on their working experiences in the field of projects and were requested to participate as research informants. 11 experts honoured the invitation. Refer to

Table 1 below for the expert group demographics. The experts working experiences ranges from a minimum of 13 years to 38 years of practice in the field of projects and are registered as professionals with various professional bodies in the field of the built environment in South Africa and abroad.

Table 1: Expert Group Demographics

Members	Role in the Organization	Industry Type	Working Experience
A	Chief Engineering Surveyor	Construction	17 years
B	Managing Director	Consulting in Structural Engineering and Project Management	13 years
C	Director	Consulting in Project Management	21 years
D	Senior Project Manager	Consulting in Project Management	34 years

E	Training Manager	Consulting in Project Management	29 years
F	Chief Engineer	National Government	26 years
G	Engineering Manager	Consulting in Project Management and Mechanical engineering	22 years
H	Senior Project Manager	Consulting in Project Management	38 years
I	CEO	Consulting in Project Management	26 years
J	Director	Consulting in Civil Engineering	30 years
K	Director	Consulting in Mechanical Engineering	21 years

6 KNOWLEDGE TRANSFER SUCCESS INDICATORS

After the two rounds of the Delphi technique, a consensus was reached. The first round constituted of diversified responses from the expert group. Each expert group member had selected indicators that they deemed best represented knowledge transfer success. What was noted was that all the experts selected more than one indicator that are presented in the research model. Furthermore, the experts chose different indicators and provided reasons for their respective choices. All the indicators derived from the literature were picked together with the new additions the expert developed. The new additions are as stipulated below:

- Internal and external knowledge dissemination, where the knowledge recipient becomes a knowledge sender. This means that the person whom the knowledge was transferred to becomes the knowledge sender. This indicator is to be added to the knowledge application category.
- Knowledge Institutionalization, refers to when the knowledge transfer becomes part and parcel of the organizational culture or project culture. When there is something learnt from a project it is documented and incorporated into the organizational processes and specifications for future projects to succeed so that the knowledge doesn't remain with individuals but is captured and becomes part of the organizational procedures, policies, workflows and culture, it remains embedded on the organizational processes and thus stays with an organization. This indicator is to be added under the knowledge value category.
- Experience and reputation, how the knowledge receiver is received on-site by other stakeholders, the more knowledgeable they become the more they will be treated with respect, and the client becomes more confident in working with the knowledge recipient. This applies to graduate trainees as they do site visits to gain practical experience in projects. This indicator is to be added under the knowledge value category.
- Type of questions asked, monitoring the type of questions the knowledge recipients ask. Questions give a clue on how much somebody knows when the knowledge is successfully transferred the questions become fewer, specific, more focused and intelligent. This indicator falls under the nett impact category.
- Shortened time is taken to execute tasks, this can be achieved through daily feedback on tasks given. The feedbacks show if the recipient understood the task, and what was expected of them. Feedbacks also indicate how long it took to complete the task. So, when the knowledge has been successfully received the time taken to complete tasks gets shorter, and productivity increases. This indicator belongs to the nett impact category.
- Lessons Learned and how much provision for such lessons learned is taken to the future implementation of similar work.

- Actual tests/exams, with pre-determined standard through formal questionnaires filled in by the receiver. This belongs to the knowledge evaluation category.
- The number of revisions needed to get it right. The more revisions to be carried out by the knowledge receiver upon receiving feedback signifies the lack in the knowledge transfer success. If one is given a task by the knowledge sender and after the review, they are told to make a lot of changes as the knowledge sender is not satisfied with the results it shows that the knowledge was not successfully transferred. This indicator falls under the nett impact category.

Going to the second round of the Delphi Technique, the author added the above stipulated new additions to the model together with their supporting statements which detailed the reasoning behind their selection from the first round. The expert group members were then urged to revisit their original answers in light of the new additions and the other predetermined indicators that they had not initially selected to represent the knowledge transfer success but that were selected and supported by the other panel members. The expert group members were also given an option of not revising their original responses if they still maintained the same sentiments. The author allowed the experts some time to reflect on their original responses and they then submitted their revised answers. At this stage it was found that all the expert group members had made changes to their original responses, no one held on their original views but they were all swayed by the explanations that accompanied the selection of each indicator. Hence, it was found that there was a correlation in all the responses after the second round. Thus, a consensus was reached.

Based on the findings that arose from the Delphi Technique, the conceptual model was updated to include the new indicators. The updated conceptual model can now be seen in Figure 2 and depicts the full range of knowledge transfer success indicators that can be used to measure knowledge transfer success. The new indicators which were not part of the conceptual model but were developed by the expert group are highlighted in bold.

The updated model as depicted in Figure 2 also answers the main research question namely: how to measure that the knowledge transfer was successful in projects.

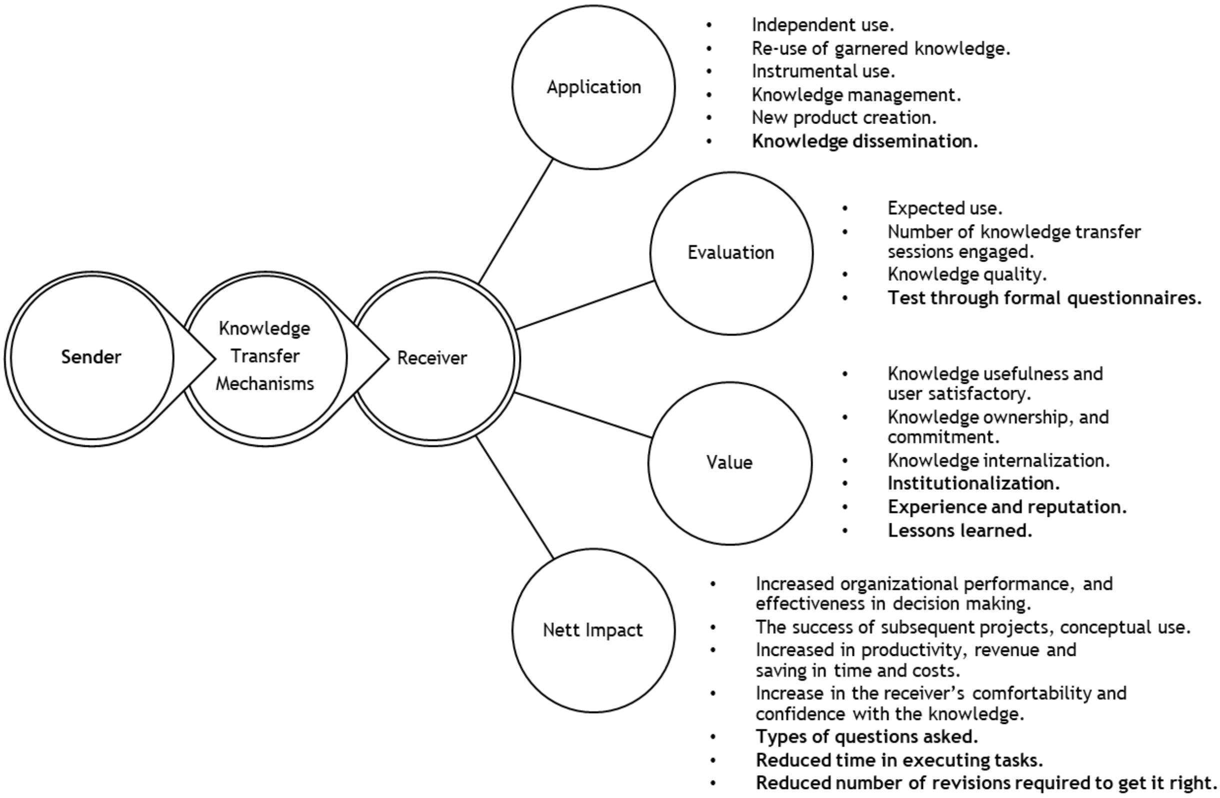

Figure 2: Knowledge Transfer Success Indicators

7 CONCLUSION AND RECOMMENDATIONS

The objective of the study was to develop a measurement framework and criteria that can be used to measure whether the transfer of knowledge in a project was successfull. Each of the measurement criteria can be viewed or evaluated for either a sender and/or receiver perspective to identify the overall success rate of the knowledge transfer. This study objective was fulfilled since the proposed knowledge transfer success measurement framework together with the success indicators were successfully developed. From the research, the knowledge transfer success indicators fall under the categories: knowledge application, knowledge evaluation, knowledge value and nett impact observed as a result of the knowledge received. For each of the categories subsequent evaluation criteria were developed.

As a recommendation for further study on the use of such a measurement framework an implementation example is proposed as depicted in Table 2 below and is discussed in more detail thereafter. It must be emphasized that the proposed knowledge transfer measurement framework is strongly dependent on the indicators stipulated in **Error! Reference source not found.** and Figure 2 above, and as a result, the framework skeleton must be populated with these indicators. Each organization will populate this framework based on what indicators are more important to them and which indicators apply to a particular project. Reason being, not all the indicators will be applicable at the same time and their level of desirability might vary according to the type of the project.

Table 2: Proposed Knowledge Transfer Success Measurement Framework

Indicators/Aspects	Weigh	Categories and Scores				Score
		Application	Evaluation	Value	Nett Impact	
Ability to Work Independently	15		N.A.	N.A.	N.A.	
Knowledge Dissemination	15		N.A.	N.A.	N.A.	
Quality of the Knowledge Gained	10	N.A.		N.A.	N.A.	
The usefulness of the Knowledge Gained	20	N.A.	N.A.		N.A.	
Ownership of the Knowledge Gained	15	N.A.	N.A.		N.A.	
Knowledge Institutionalization	10	N.A.	N.A.		N.A.	
Paradigm Shift/ Increased Effectiveness in Decision Making	15	N.A.	N.A.	N.A.		
Maximum Possible Score	**100**				**Total Score**	
Rating of the Success of the Knowledge Transfer based on the Total Score						
Total Score		**Rating of the Knowledge Transfer**				
0 to 30		Totally Unsuccessful				
30 to 50		Unsuccessful				
50 to 60		Partially Successful				
60 to 75		Successful				
75 to 90		Very Successful				
90 to 100		Extremely Successful				

Table 2 above presents the typical framework, each organization should customize their weightings according to what is more important to them, customize their score according to their priorities but the indicators and categories to be used must be the ones given in **Error! Reference source not found.** and Figure 2. Moreover, it must be noted to only pick the indicators applicable to the project at that time and weigh them as required by the project needs and specifications or by the organization. Indicators picked from the four different categories can be evenly distributed or one category can have more than the other categories. It depends on what is applicable at that time for a particular project. Reason being, projects are different and indicators are not all applicable to all the projects so they must be customized based on their desirability to the projects. One might find that nett impact indicators in one project contribute 70% of the total indicators applicable to the project, only to find that in the other project it only contributes 5% and other categories are more dominant.

The authors recommend for the project team, led by the project manager to meet prior to the project implementation to decide on the applicable indicators and their scores on a particular project. The authors propose that the process of selecting the indicators and their score be done through formal questionnaires but following the Delphi Technique methodology. Each member of the project team will select all the indicators he deems to be applicable together with their weightings, and a score will be allocated per weighting. Indicators are to be selected from Figure 2. As a result, the project manager will consolidate all the indicators from different members together with reasons behind their selection, this will be repeated up until consensus is reached amongst all the project members. The number of indicators agreed-on by the team will then determine the maximum possible score.

Another important point to note is that the organization can customize their indicator weightings anyhow they deem effective. The weightings don't have to accumulate to 100, it can be any number, however, each indicator's weightings should be distributed in such a way that when they are added they total to that particular predetermined number and a score will be allocated per indicator out of the total weighting of that indicator. Moreover, each organization can customize their total score ranges and anchors description or transfer success ratings anyhow they deem effective. For example, a total weighted score that falls between the ranges of 30 to 50 can be described as totally unsuccessful or extremely successful, all depending on what score was pre-set to represent the knowledge transfer success. The ranges and rating's description presented in Table 2 are what was derived by the authors to be sensible, sound, and realistic. All the decisions relating to the indicator selection, indicator weightings, and indicator scoring and success ranges is to be pre-determined by the project team through filling-in questionnaires but following the Delphi Technique methodology to reach agreements. As a result, the indicator's weightings and scoring will vary from one project to another and from one organization to another. The authors thus recommend further future studies to be done on the indicator's weightings and scoring method used to populate the framework.

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COMPARATIVE STUDY OF WATER FILTRATION METHODS IN SOUTH AFRICA

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ABSTRACT

Water is a basic need of life, impure water is associated with many health risks, implying the demand for water filtration is imperative. Water filtration involves the removal of contaminants from water in order to meet certain water standards both national and international. Water is mostly purified to produce drinking water. Other purposes of water purification include medical, agricultural and industrial application. Methods of purifying water are divided into large, medium and small scale. Water purification of large scale is when sources of water are rivers, streams, lakes etc. The medium scale purification is when water sources are wells, tanks, dams etc. Medium scale purification involves addition of the bleaching powder or chlorinated lime to water. Small scale purification is at domestic level, it includes boiling, chemical disinfection, filtration, and solar radiation. Different types of water filters are available, the use of each filter is depending on the water problem and water output requirement. These filters include mechanical filters, absorption filters, sequestration filters, ion exchange and reverse osmosis filters. There are limitations involved in these filtration systems, sometimes to improve the quality of water they are used in combination. This paper presents a comparative study of these filters on their economic benefit in terms of cost, ease of maintenance and replacement, etc, focusing on their suitability for use in South African water industry. From the review it is found that reverse osmosis is an ideal solution for high quality drinking water on all three scales, and the most cost-effective filtration method suitable for South Africa.

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1 INTRODUCTION

Filtration is the process of removing the solid particles from liquid or gas [1]. The filtration process in waste water treatment can be an intermediate or a final stage process. The purpose of this paper is doing a comparative study of water filtration methods in South Africa. Water that is intended for human consumption must be free from any hazard that may affect human health. There are contaminant parameters that must be met by the drinking water before considered to be safe, and these parameters were as set by WHO (World Health Organisation) [2] are used by many countries worldwide. Physical or chemical filtration method are usually used. Physical filtration is using filters to remove contaminant while, chemical filtration involves passing water through the active material [3]. Physical processes include filtration, sedimentation, or distillation. Biological processes include sand filters ration and use of active carbon while chemical processes involve flocculation, chlorination, and the use of ultraviolet light [4]. Proper filtration methods remove any Adour, bad taste, and any sediments. Water filtration is used in different industries such medical, pharmacological, chemical, and industrial application for clean and potable water. Natural bodies of water are seen as alternative for water purification in many communities for day to day use. These sources can be ground water, underground aquifers, creeks, streams, rivers, and lakes [5]. The standards of drinking water quality are set by Government or international standard. These standards specify the minimum and maximum acceptable concentration of contaminants [6-7].

2 IMPURITIES IN WATER

Colourless, odourless, and tasteless are properties that describe water. It is named as a “Universal solvent” because of its ability to dissolve many substances [7]. Impurities refers to negative substances that are in contact with water. Water can only be contaminated once it is in contact with negative substances. Some substances are good additions to drinking water, while other substances are undesirable. Suspended solids and dissolved solids encounter the water that is on the surface such as lakes, rivers, Dams e.g., Table 1 shows the list of common impurities that are found in water.

Table 1 Common constituents found in fresh water [8]

Constituent	Chemical formula	Difficulties caused	Means of treatment
Turbidity	Not shown as Units	Conveys unattractive appearance to water	Coagulation, settling, and filtration
Hardness	Magnesium Salts and Calcium (CaCO3)	Forms curds with soap, obstructs dyeing,	softening; demineralization; internal boiler water treatment; surface active agents
Alkalinity	bicarbonate(HCO3-), carbonate (CO32 ?-), and hydroxide(OH-), expressed as CaCO	Corrosion caused by condensate, CO2 in steam is produced by bicarbonate and carbonate	acid treatment; hydrogen zeolite softening; demineralization dealkalization by anion exchange

Constituent	Chemical formula	Difficulties caused	Means of treatment
Free Mineral Acid	H2SO4 , HCI. etc., expressed as CaCO3	corrosion	neutralization with alkalies
Carbon Dioxide	CO2	corrosion in water line	aeration, deaeration, neutralization with alkalies
pH		pH changes alkalinity or acidity in water	pH can be increased by alkalies and decreased by acids
Sulfate	SO42-	Added in solid state of water, when salfate is combined with calcium, calcium carbonate is formed.	demineralization, reverse osmosis, electrodialysis, evaporation
Chloride	Cl -	Increases the corrosive content of water.	demineralization, reverse osmosis, electrodialysis, evaporation
Nitrate	NO3-	useful for control of boiler metal embrittlement	demineralization, reverse osmosis, electrodialysis, evaporation
Flouride	F-	Good for dental care	adsorption with magnesium hydroxide, calcium phosphate, or bone black; alum coagulation
Sodium	Na+	causes corrosion in boilers under certain conditions	demineralization, reverse osmosis, electrodialysis, evaporation
Silica	SiO2	insoluble turbine blade deposits due to silica vaporization	hot and warm process removal by magnesium salts;

Constituent	Chemical formula	Difficulties caused	Means of treatment
Iron	Fe2+ (ferrous) Fe3+ (ferric)	discolors water on precipitation	aeration; coagulation and filtration; lime softening; contact filtration; surface active agents for iron retention
Manganees	Mn2+	Same as iron	Same as iron
Alluminium	Al3+	cause deposits in cooling systems and contribute to complex boiler scales	improved clarifier and filter operation
Oxygen	O2	corrosion of water lines, heat exchange equipment, boilers, return lines, etc	deaeration; sodium sulfite; corrosion inhibitors
Hydrogen Sulphide	H2S	cause of "rotten egg" odor; corrosion	aeration; chlorination; highly basic anion exchange
Ammonia	NH3	Complex soluble iron is cased by corrosion of copper and zinc alloy	cation exchange with hydrogen zeolite; chlorination; deaeration
Dissolved Solids	None	refers to the measure of undissolved matte	demineralization, reverse osmosis, electrodialysis, evaporation
Suspended Solids	None	refers to the sum of dissolved and suspended solids	subsidence; filtration, usually preceded by coagulation and settling
Total Solid	None	sum of dissolved and suspended solids, determined gravimetrically	Same as dissolved solids and suspended solids.

The change in colour of water depends on some soluble minerals contained by it. A pale yellow or green colour is produced by soluble iron salts, a blue colour shows the presence of Copper salts [9]. Dead or live microorganisms' changes taste and odour of water [10].

3 DRINKING WATER QUALITY IN SOUTH AFRICA

It is imperative for drinking water to meet certain requirements so it can be accepted for domestic use. As much we focus on the quality of drinking water, health aspect of water is very important. South African Bureau of Standards specification SANS 241 is used to assess the quality of drinking

[11]. It is very important that drinking water quality to meet the requirements for SANS 241 of 2000, There are two classes of drinking water that are described by SANS 241 [12].

1. Class 1 – drinking water consumption is accepted lifetime. This class of drinking water is recommended for compliance limit.
2. Class 2 – drinking water for consumption for a limited period. This class identifies water quality that poses health risk to consumers.

South Africa National Standard (SANS 241) drinking water specification ensures that there is no health risk over a lifetime of consumption. It has been found that non metro areas in South Africa are exposed to poor quality of drinking water. Poor water monitoring systems, lack of water systems research and development funding, lack of education about water quality are some of the reasons for failure of drinking water standards [13]. The South African water quality guidelines states that impurities found in domestic water such as cadmium, chromium (VI), lead, mercury and vanadium can cause lot of damage in human health. It is advisable not to use water containing these impurities even at lower concentration [14]. Corrosion, impaired product quality, are some of the results when industries use water that is of poor quality. Water and sanitation faculties in South Africa are subject to abuse, non-use, or breakdown such that 63% of Municipalities in South Africa cannot report if water quality requirements specification as per SANS 241 are met [15]. The DWS 2014 report states that 58% of wastewater treatment works of the country is at high risk while only 16% is at low risk [16]. It has been found that water quality from rural areas does not meet SANS 241 specification requirements [17].

South Africa have different sources of water, the quality of water needs to be assessed before the water is given for human consumption. Water for human consumption can be found in one of the following sources [18]:

- springs
- wells and boreholes
- rainwater
- surface water – rivers and dams
- bulk-supply pipelines, and
- a combination of the above

Water distributes from its sources to different communities, is facing multiple challenges.

The South African government is doing its best to ensure this water is treated before human consumption. There are many technologies that have been developed to ensure that water is well treated and meets the SANS 241 specification requirements.

4 FACTS ABOUT WATER FILTERS

The increase in human population and persistent drought in South Africa has increased demand of fresh water for human consumption. This, in turn, has increase pressure in wastewater treatment infrastructure [19]. When water passes through a damaged or rusted pipe it gets contaminated and it will not be safe to drink. Water filters help to remove contaminants and harmful bacteria from water. Filters have different quality, functions and designs. It is important to consider the following before buying a filter [20].

- Filter quality – there is wide range of filters with different brands, they remove different contaminants at different efficiency.
- Certification – it is very important in the design of filters
- The technology used – there are many filter technologies available.

It is important to select a filter that meet your requirements and that is accredited. On the filter label their certifications to look for such as [21]:

- National standards Institute (ANSI)-this standards verify contaminants, material, and structural integrity, verifies if drinking water meet the ANSI/NSF and EPA drinking water standard
- NSF International – this requires extensive testing of product, this programme ensures that the filter meets the design, material, and performance requirements of national standard.

Microorganisms are removed by many different filters. Each filter is designed and rated for certain size of microorganism. Micron is the standard rating size for filters. It is important to select a filter that will be able remove the contaminants or organism regardless of its size. Table 2 presents common microorganism and filter size [22].

Table 2 Common microorganism and filter size [22]

Organism	Examples	General size	Filter type	Particle size rating
Protozoa	Giardia, Cryptosporidium	5 microns or larger	Water filter	1.0-4.0 microns
Bacteria	Cholera, E. coli, Salmonella	0.2-0.5 microns	Microfilter	0.2-1.0 microns
Viruses	Hepatitis A, rotavirus, Norwalk virus	0.004 microns	Water purifier	to 0.004 microns

The two main types of filters are membrane filters and depth filters. Membrane filters are thin sheets that have different pore size, where particles that are blocked by these filters are normally bigger than the pore size [22]. The depth filters are made up of thick, porous material such as carbon and ceramic [22].

5 TYPES OF FILTRATION METHODS IN SOUTH AFRICA

Micro strainers are compared to water filters since for both can trap suspended solids. However micro strainers grains allow suspended particles to pass easily and that makes micro strainers less important. The two main methods of filtration currently used in South Africa are:

5.1 Sand Filtration

Sand filtration is a type of depth filtration and represents one of the steps in water purification process. It uses sand to accumulate debris from water running through it. There are three different types of sand filters named as rapid (gravity) sand filters, upward flow sand filters and slow sand filters [23]. Rapid sand filters and upward sand filters need flocculant chemicals to work effectively while the slow sand filter can work effectively without the use of chemicals [24]. Benefits of sand filters include [25,26]:

- Removal of contaminants
- Health maintenance of streams and rivers
- Improved cleanness of water

Sand filtration is the simple system, it is either graded sand or course monograde sand [27]. It is applied in different processes such as [27]:

- Wastewater treatment
- Cooling water preparation

- Drinking water production
- Swimming pool filtration
- Pre-treatment for membrane systems
- Surface water filtration
- Iron removal

Sand filters are classified into two different designs named as sand filters with underdrain and sand filters that are designed to infiltrate subsoil [28]. Sand filters with underdrain are designed such that the gravel layer and the perforated underdrain piping to have the infiltration and conveyance rate that is twice to the design flow from the sand bed [29,29].

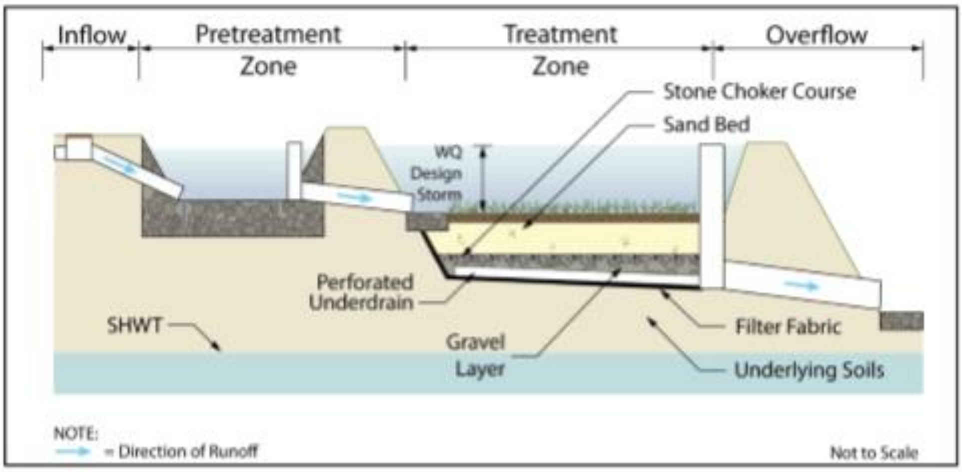

Figure 1: Sand Filter with Underdrain in a pre-treatment zone [28]

The underdrain piping, as shown in figure 1, needs to be connected to the downstream location such that it can be accessed easy for inspection and maintenance. Figure 2 shows the sand filter that is designed to infiltrate into the subsoil. As shown in Figure 2 this type of sand filter is designed such that the drain time depend to the permeability of the sand bed [28].

Regular maintenance is required for both types of filters to ensure effective sand filtration. For general maintenance of these sand filters each sand filter should have its maintenance plan. The structure needs to be inspected for any cracks, spalling or deterioration [30].

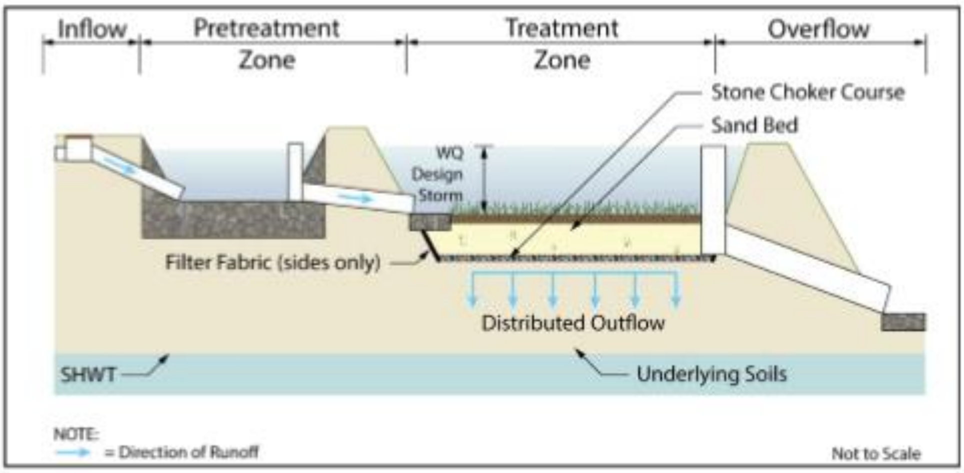

Figure 2: Sand Filter with Infiltration [28]

5.2 Reverse osmosis

Reverse Osmosis (RO) is an advance technology for the treatment of water for a wide range of applications such as semiconductors, food processing, biotechnology, pharmaceuticals, power generation, seawater desalting, and municipal drinking water [31]. The level of dissolved solids and suspended particles within the water is removed by Reverse Osmosis filters [32]. Reverse Osmosis uses a semi permeable membrane that allows only certain particles to pass through while retaining others. In this semi permeable membrane, the water particles pass through faster than the dissolved solids (salts). The permeation rate of the membrane is directly proportional to the applied pressure at which the highest recommended pressure rate is 7.0 MPa [33].90-95% of dissolved salts (ions), particles, colloids, organics, bacteria, and pyrogens from the feed water are removed by RO [34]. Figure 3 shows how osmosis work, where a less concentrated solution moves to high concentrated solution. For example, a solution with low concentration of salt and a solution with high concentration of salt, separated by semi-permeable membrane. Then the water with low concentration will move toward high concentrated solution [35].

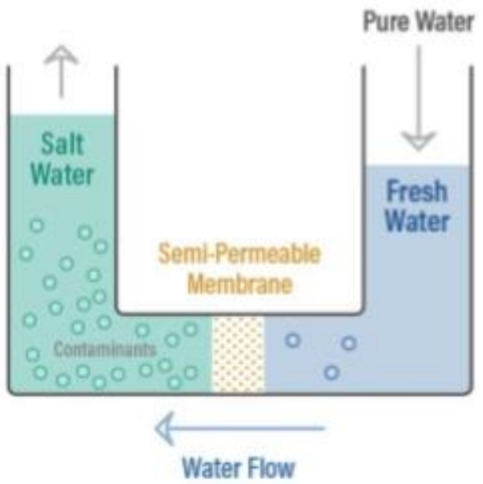

Figure 3: Sketch of how Osmosis work [35]

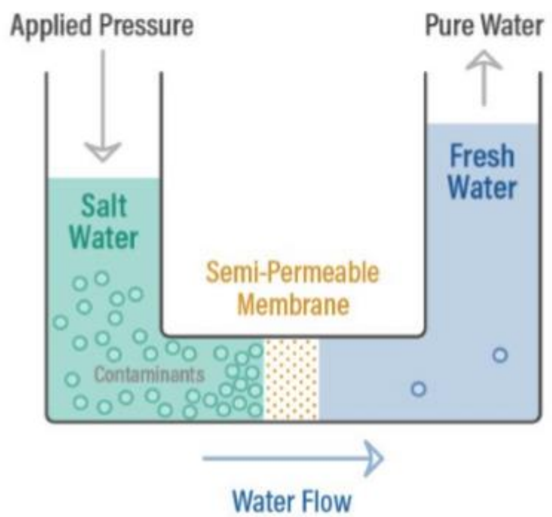

Figure 4: Reverse osmosis [35]

Many rural areas in South Africa get water from bore holes. Borehole water–suitable for human consumption because the nitrate-nitrogen level (>6 mg/l) and salinity (>lOOO mg/l TDS) levels are too high [36]. Reverse Osmosis ability to remove nitrate nitrogen from 42 mg/l to less than 1 mg/l (98% removal), makes RO to be effective for the denitrification of water in a rural area [37].

5.3 Ultrafiltration

If the fluid passes through a semi permeable membrane due to a driving pressure, ultrafiltration occurs. Ultra Filtration is a mechanical filter, it can remove solids of up to 0.025-micron, Ultrafiltration is a filter system, whereas reverse osmosis is a process where molecules are separated by applied pressure.A South African company known as Ikusasa Water in the Western Cape located in Somerset west is producing ultra-filtration membrane for high quality, potable (potable) water [38]. Ultrafiltration (UF) is a method that simultaneously do purification, concentrating and fractionating macromolecules or fine colloidal suspensions [39]. Some Ultra filtration applications are as follows [40].

- The production of ultrapure water
- Cheesemaking
- Whey and potato protein recovery
- Egg and animal blood processing
- Clarification of juice, wine, vinegar and gelatine solutions
- Downstream processing
- Membrane bioreactors
- Recovery of electrodeposition paints
- Treatment of oil and latex emulsions
- Applications in the pulp and paper industry
- Treatment of bleach plant effluents
- Deracination of washing liquors

UF Membrane is made up of two different designs of porous material such as tubular and flat sheet. Two major modules of Ultra filtration are hollow fibre (capillary) and spiral wound. And there are other modules such as rotary module, vibrating module, and Dean vortices [41].

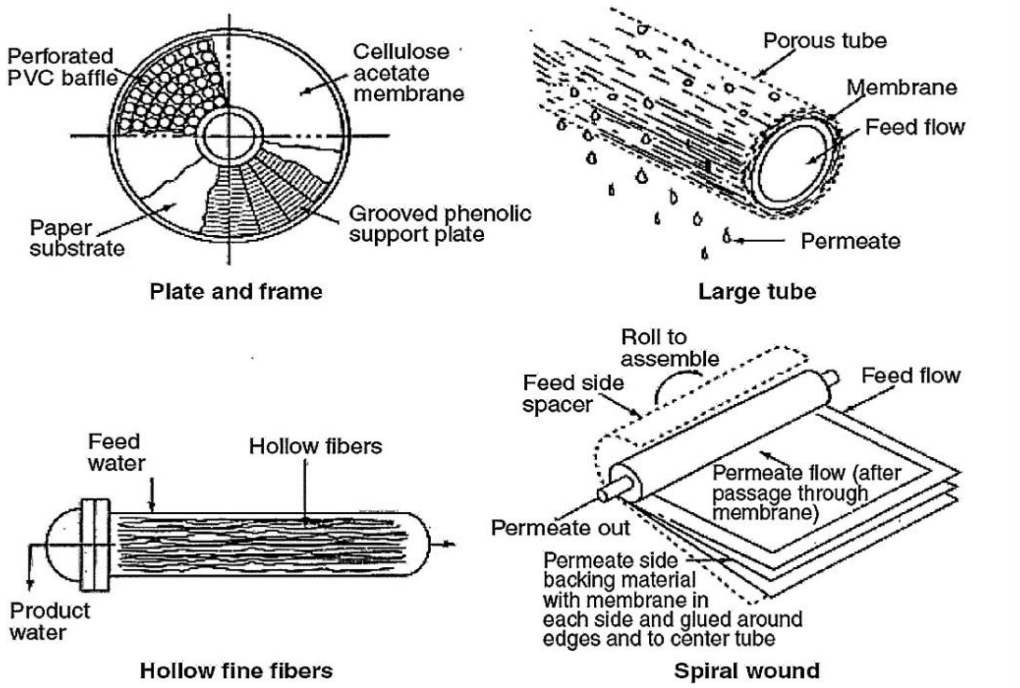

Figure 5: Major types of UF modules: (a) spiral wound and (b) hollow fibre [41]

The source of water and its quality affect the performance of Ultrafiltration. Therefore, Ultrafiltration can be used independently, or it can be combined with other processes. [42]. Ultrafiltration deals with large molecules such as a natural polymer like protein, starch, and gums and colloidally isolated compounds such as clays, paints, pigments, latex particles etc. Ultrafiltration osmotic pressure is very low [421]. Ultrafiltration method is best as compared to conventional filtration methods due to the following reasons [43]].

- Chemicals are not required.
- Feed quality does not affect product quality
- Compact plant size
- Capable of exceeding regulatory standards of water quality

Ultrafiltration is a prefiltration before reverse osmosis process to protect reverse osmosis. Ultrafiltration is recommended for industries that produce highly toxic effluent and large volumes of water. Surface water, sea water and biological municipal treated water are all pre-treated by UF before the process of reverse osmosis [43]. The pore size for the Ultra filtration membrane ranges from 0.005–0.1 μm and UF act as a separation barrier between two sides with different pressure. This pressure difference is the driving force for solutes to pass through the pores from high pressure environment to low pressure environment [44].

Table 3: Ultrafiltration Plant Specifications [45]

Flow rate	Up to 100m3/hr or more
Type of membrane	Hollow Fibre
Make of membrane	Dow, Hydranautics cpa2, Memcor etc.
Dosing system	Electronic dosing or as required
Power options	Mains Electric, Solar system, Generator
Optional	-Flushing system - UF backwash - PLC system - Activated carbon pre filter - CIP system - Feed water tank - Chemical tank - Air compressor - Flow meters

Due to load shedding issue in South Africa as shown in Table 2, Solar system and Generator can be used as an electricity backup. Figure 6 shows a flow diagram of Ultrafiltration. The system consists of a feed pump, strainer, a rack equipped with UF modules, filtrate, and a backwash tank. The pump transfer raw water to the UF modules. The strainer filters the coarse particles before water enters the module to protect the membrane. The strainer gives mechanical protection to the membrane module [46]. An Ultrafiltration plant is different from reverse osmosis plant. It keeps the mineral content of the water while removing bacteria, viruses, and parasites. Ultrafiltration is preferred when compared to traditional filtration methods due to the following reasons [48]:

- Saves energy

- Its product quality is consistent

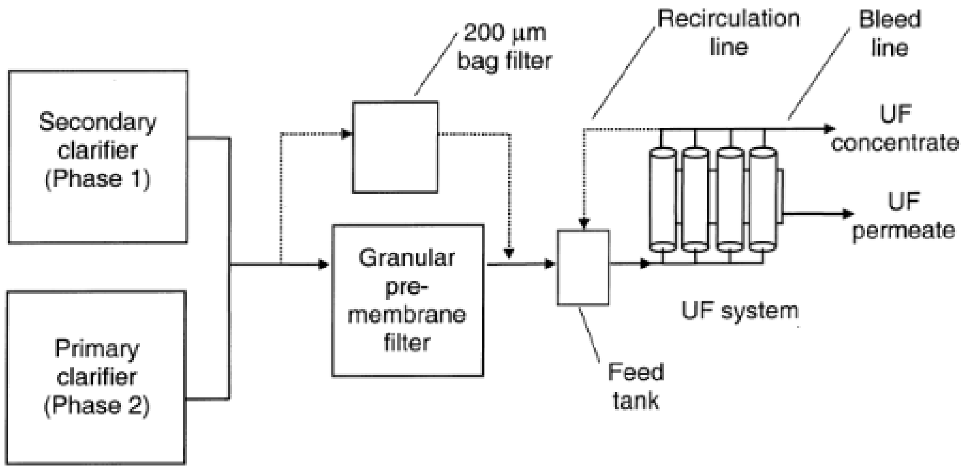

Figure 6: Basic diagram of UF system [47]

Cleaning of the Ultrafiltration membrane is done regularly to prevent the building up of plants. Backwashing is done every 10 minutes to remove any cake layer formed on the membrane surface [48].

6 CONCLUSION

South Africa has developed many water filtration methods. However, the quality of raw water impact what type of filtration method that will be used. Each filtration method can only remove certain types of contaminants. It is important to know the required quality of water before selecting a filtration system.

Filter run time is the most common limiting factor. This factor may be caused by clogging or filter blockages. That is why these filters needs to be cleaned regularly to avoid blockage. The alarming growth in human population put these filtration systems under pressure, there is a need for the development of new technologies that can dispose effluent. These new technologies can be developed such that they are affordable and be used in poor communities.

Reverse Osmosis is the most effective method when it comes to selective removal of much smaller molecular compounds such as chlorine and pesticides from water. The other aspect that makes filtration cheaper is that it does not involve a lot of energy.

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A LOOK INTO THE FUTURE OF 3D PRINTING OF WATER AND WASTEWATER SUBSTRUCTURES IN SOUTH AFRICA

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ABSTRACT

The increase in population and high demand of water has caused a strain to many wastewater treatments plants in South Africa. South Africa's wastewater infrastructure is subjected to aging effect due to poor maintenance and lack of appropriate skills in the workforce. Most wastewater substructures are manufactured using traditional manufacturing methods like CNC machining, lathe machining, bending, rolling etc. This requires cost of tooling, labour, and overhead cost. As the cost continues to rise in the wastewater industry researchers and scholars are looking for alternative ways to save cost but also increase production efficiency. The introduction of 3D printing in wastewater infrastructure stands to change the manufacturing industry due to its ability to reduce waste, rapid prototyping, and its ability to produce complicated geometries in a very short space of time. 3D printing has been introduced in the wastewater infrastructure in Singapore and many western countries by printing membrane filters for Reverse Osmosis. This paper investigates the slow introduction of 3D printing of water and wastewater substructures in South Africa. The paper assesses the market share of 3D printing of water and wastewater substructures in the world to highlight the economic benefits of introducing this technology in South Africa. Current water purification regulations, comparative cost of traditional and 3D printing in the water industry and what this holds for 3D printing in the South African water industry are presented herein.

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1 INTRODUCTION

Wastewater infrastructure is defined as the thread of different process technologies used to recover and restore the floating scums of a city to its surrounding environment. Wastewater is the water that has been used before. It includes water from the sinks, sewage water, industrial wastewater, agricultural wastewater etc. Wastewater is divided into two types which are sewage water and non-sewage water. There are nine wastewater process technologies as follows [1]:

- Pumping and Screening
- Grit Removal
- Primary Treatment
- Aeration
- Secondary Treatment
- Filtration
- Disinfection
- Oxygen Uptake
- Sludge Treatment

For the wastewater treatment plant to run efficiently the plant equipment's must be repaired, serviced, replaced, and maintained. Servicing and replacing these equipment's tend to be costlier than anticipated which results in plants not being serviced and maintained well enough for optimal functioning [2]. Technological advances such as 3D printing can help create ground-breaking technologies to improve our environment and transform communities in need. -03D printing is an innovative and cost-effective technology able to provide solutions for the fabrication of wastewater critical components such as the filtration systems. 3D printing is an addictive manufacturing process whereby a 3-dimensional model is created from digital file, by depositing layers based on the digital model. In a wastewater treatment infrastructure, the manufacturing of filtration systems has been successful over the decades, however the increase in demand of these and other components have caused a strain on manufacturing industries, leading to challenges in maintaining wastewater treatment plants [3]. The ability to manufacture these filtration systems in a very short time and less expensively using 3D printing means that, this filtration equipment can always be available when required. Thus, there is a need to investigate the extent to which South Africa has introduced 3D printing in the water and wastewater management systems and to develop strategies for the effective transition to these systems in the era of Industry 4.0.

2 CURRENT STATE OF WASTEWATER INFRASTRUCTURE IN SOUTH AFRICA

Most of water and wastewater infrastructure in South Africa is redundant and very expensive to repair. Investment in basic water infrastructure like maintenance of pumps and leaking pipes will improve service delivery in South Africa. It has been reported by Engineering News article on 16th of July 2018 [4] that more than two-thirds of wastewater treatment facilities examined did not meet the minimum quality-control standards. The Engineering News article [4] also states that 25% of South Africa's wastewater treatment facilities need an urgent intervention – while about another 25% are defined as 'high risk' in terms of disrepair.

Figure 1: Sebokeng Wastewater Treatment Plant [5]

Figure 1 shows Sebokeng wastewater Treatment Plant in Johannesburg, South Africa in a state of disrepair. Sebokeng's resident Mr Makhashule states that the plant is neglected such that the sewage is flowing through the Municipal streets [5]. This is not the only wastewater treatment plant that is beyond repair in South Africa [6]. Maintenance of these plants is costing government a lot of money. One of the challenges is nonavailability of parts for replacement. The parts are expensive, and their lead time is longer in traditional manufacturing.

Some of wastewater treatment equipment are still manufactured using traditional processes, Figures 2 and 3 shows a screw compactor that is used in wastewater treatment as a dewatering and compacting system. In Figure 2, the component is 3D printed whereas in Figure 3 the component is manufactured using traditional ways. The traditional manufacturing of this component requires long production time and a high cost.

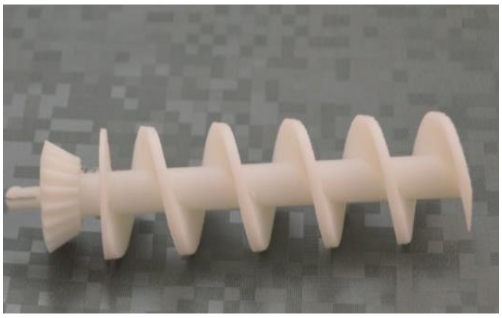

Figure 2: 3D Printed screw [7]

Figure 3: traditional manufactured screw [8]

Although the introduction of 3D printing in the production lines in South Africa has had multiple advantages such as reduced waste, reduced lead time, and improved quality, potential fatal flaw in the application of 3D printing such as compatibility of materials with wastewater must be investigated. Most of the wastewater treatment equipment like Figure 3 is made up of 316 stainless steel which can be easily stolen not protected. The introduction of components that are made up of plastic will reduce theft as plastic is not a valuable material, On the Sunday Times report of 2018 written by [5], it states that vandalism, theft, and lack of funding resulted in poor maintenance of wastewater infrastructure [9]. Due to poor service and maintenance of wastewater treatment plants, only 60 out of 824 plants continue to optimally function. This indicates that only 7% of the total amount of wastewater is being treated [10]. Considering how harmful water pollution is to humans, animals, plant life and other ecosystems that are surrounded by it, the remaining 93% of disfunctional wastewater treatment plants are required to be maintained, repaired, and reconstructed to optimum functioning standards [12-13].

3 3D PRINTED WASTEWATER EQUIPMENT

There has been a noticeable increase in the interest of researchers in 3D printing of components for water and wastewater equipment that includes membrane separation, desalination, and water purification applications, etc [11].

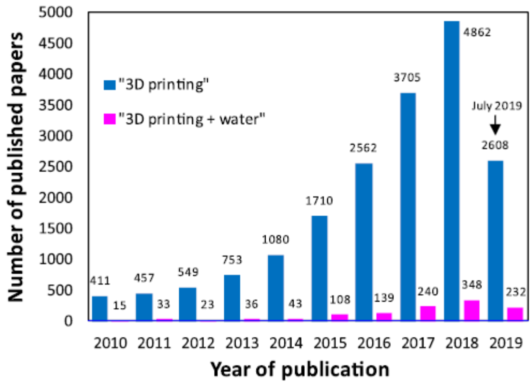

Figure 4: Graph Showing the Increased Amount of Research and Published Papers on 3D Printing and Water Related Applications [11]

Figure 4 shows the increased amount of research and published papers on 3D printing and water related application from year 2010 to 2019. There are lots of business opportunities for 3D printing of water and wastewater infrastructure, however, in the implementation of this technology the progress is very slow. 3D technology has contributed to the production of spacers and membranes used in wastewater treatment. These spacers and membranes have high performance, and they reduce energy consumption during purification process [12]. Feed spacer is a mesh like sheet that is made out from strong polymer, it is inserted between two membrane layers for water to pass through. Companies such as Conwell are specialist in the 3D design of feed spacers that are used in reverse osmosis or water filtration industry, Figure 5. They have performed an investigation on the performance of the 3D printed feed spacer, and they have found out that, these 3D printed filters improve the performance of the reverse osmosis membrane [13].

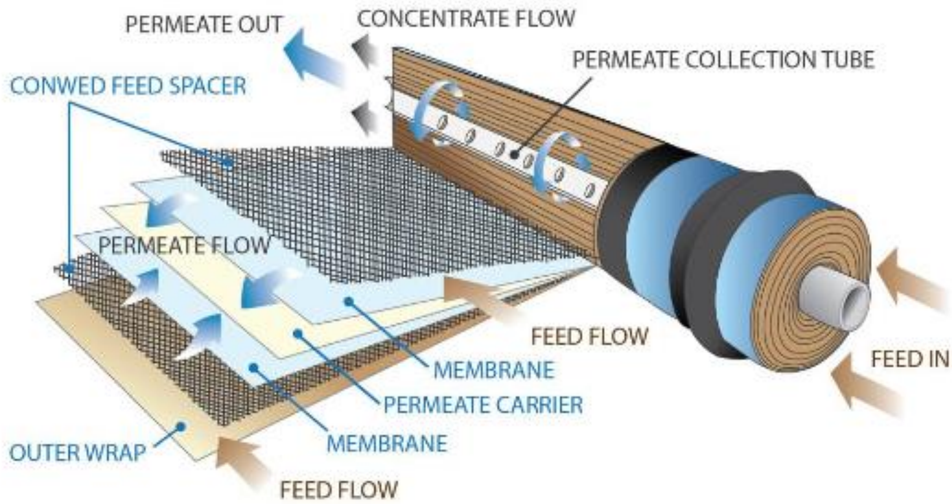

Figure 5: Illustration of feed spacers [13]

3D printing is an alternative strategy for the manufacturing of feed spacers more especially the ones which have complex designs. Another Company known as Nano-Sun based in Singer Poel (in Asia) is using 3D printing to make millions of nano fibres arranged layer by layer. Professor Darren Sun who is the head of Nano-sun says the 3D printing process is more cost effective compared to traditional manufacturing as it is a fully automated process, it requires less space and less labour [14]. The new 3D printed membrane allows for construction of small wastewater treatment plants, it is not easily broken, resistant to biofouling and has greater cost efficiencies [14]. 3D printing process is also used in the production of novel filtration and desalination membranes, adsorbents, water remediation [15]. Photo Fenton reactors for wastewater treatment plant are also manufactured using 3D printing [16].

1. BENEFIT OF 3D PRINTING OVER CONVENTIONAL METHODS

- The use of 3D Printing technologies in different industries has increased noticeably. In the 21st century, 3D printing allows and enables making of restrained to mass quantities of products that can be individually personalised. 3D printing technologies, also known as additive manufacturing, is opening new opportunities in terms of production standards and job market skill sets. Manufacturing lead times will be reduced, and that will increase customer satisfaction as customer demand are met [17]. It has been found that, when manufacturing large complex designs, 3D printing is expensive and, in this case, traditional manufacturing is preferred whereas 3D printing becomes inexpensive when manufacturing products of smaller scale [18-20].
- 3D printing is a new technology that is gaining more trust in business world, the material cost is not affected by 3D printing. However, the variety of materials is increasing, and this can make the material price to decrease over time. The traditional manufacturing process creates lot of waste during manufacturing, this is where 3D printing is needed to reduce waste as it creates exact prototypes in the CAD model.

Table 1: Advantage of 3D printing over Traditional manufacturing [17]

Areas of applications	Advantages
Rapid prototyping	• Marketing time is reduced by prototyping • Product development cost reduced • Motivate companies for innovation
Production of spare parts	• Less labour cost • Repair times are reduced • Avoid use of expensive warehouse.
Small volume manufacturing	• Small batches can be produced as required • Reduce the tooling requiring
Customized unique item	• Quick production of desired prototype less labour time to change tooling
Very complex work pieces	• The complex prototype is produced at low cost.
Machine tool manufacturing	• Labour cost reduced
Rapid manufacturing	• Products are produced directly from AutoCAD model.
Component manufacturing	• Improved quality • Supply chain reduced. • Eliminate excess parts
Onsite and on demand manufacturing of customized replacement parts.	Less storage and reduced transport cost Repair cost reduced Allows for product lifecycle leverage

The negative impact of 3D printing technology in manufacturing industry is the reduced use of labour as it is an automated process. This will affect employment in countries where the industry depends on many unskilled jobs. For 3D printing, high level of skills and fewer workers are required.

Since with 3D printing technology, users can print any design such as knives, guns and dangerous items, the use of this technology should be regulated. 3D printing should be restricted and be authorized to only licensed users to prevent copy right issues and possibility of guns being manufactured and owned by unlicensed personnel [19].

2. ECONOMIC BENEFIT OF 3D PRINTING IN SOUTH AFRICA

There are many chances that 3D printing will grow because of its capabilities. One of its advantages is using less material and creating less waste. With 3D printing the designers can monitor the manufacturing process and they can modify the design without changing tooling. Since 3D printing gives freedom to designers to print a prototype, even when it is complicated, it will be considersd as an alternative option to traditional manufacturing processes [21].

Research shows that 3D printing [22]:

(i) Contributes to job creation in the 3D printing field and skills development.
(ii) Creates opportunities for product development.
(iii) Reduces warehouse storage requirement by producing small batches

3D printing is expected to increase its worth to $32.78 billion by 2023, with an annual growth rate of 25.76%. With that growth there will be a need of skilled people to operate and maintain the 3D printing machines [23-24]. There is a concern that 3D printing will take away jobs. However, 3D printing is bringing up a new revolution where machines will take centre stage of manufacturing and design. Manufacturing jobs have been on the rise in the last decade according to figure 6. However, the manufacturing sector jobs are decreasing at a steady rate, this is due to automation and robotics. Some machines used to have human operator they can operate using computers [24].

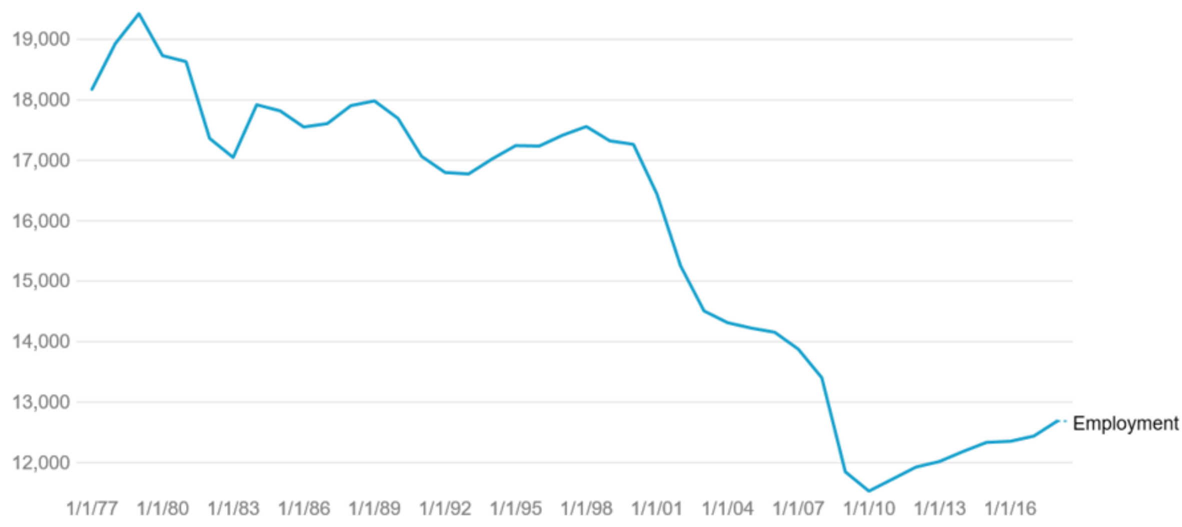

Figure 6 Manufacturing Employment from 1977 to 2018 [23]

South Africa is currently struggling to supply electricity, this has led to very low economic growth and less investor confidence in the economy [25]. The rise in energy cost is a major barrier in the manufacturing industry and this motivates the local sector to find ways to improve manufacturing processes. That is since traditional manufacturing processes not only creates material waste but also has associated amounts of energy wasted [26]. The introduction of 3D printing in manufacturing of components, especially for water treatment plants, will provide the needed improvement in material waste and energy saving.

3. COMPARATIVE COST OF TRADITIONAL AND 3D PRINTING IN THE MANUFACTURING TECHNOLOGIES

As 3D printing processes have many advantages as compared to traditional manufacturing processes, Table 2 shows the difference between Traditional manufacturing and 3D printing on different factors.

Table 2: Difference between Traditional and 3D printing [27-28]

Factors	Traditional manufacturing	3D Printing
Initial cost (cost of machine and set-up)	Cost of tooling is high	3D printing machines are expensive
Production time	Higher, as many hours and many processes are required to complete the job	Lower, as the process does involve only one process
Cost of labour	Higher, as the job requires longer time to complete	Lower as the process is automated
Material waste	High material waste	Low material waste, the plastic can be recycled.
Energy consumption	Each process has its energy cost	Only process, with reduced energy cost.

Manufacturing is a complex process with many factors involved. Comparing 3D printing to traditional manufacturing methods at once need more analyses and research. These two processes are different in terms of cost, speed, geometric complexity, materials, mechanical properties, surface finish, tolerances, and repeatability. Each process is preferred only at certain conditions [29]:

- 3D printing - is best for low volumes, composite designs, and when speed is essential.
- Traditional manufacturing - is best for the high-volume or medium-Volume production of identical parts, simple designs, hard material, and small tolerances.

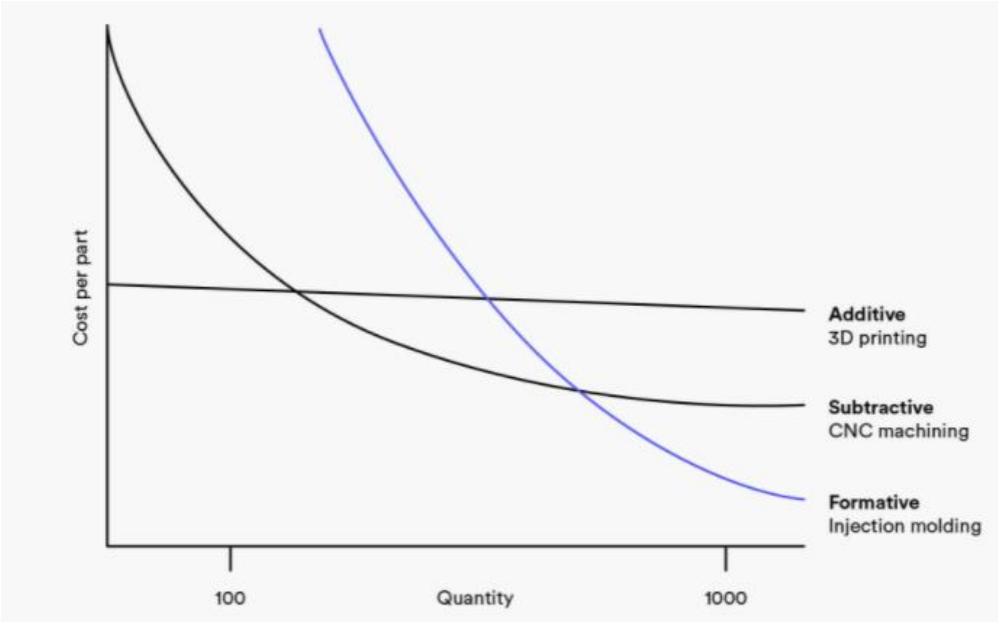

Figure 7: Quantity versus cost per part of manufacturing processes [28]

As shown in Figure 7 Cost per part is usually the main factor defining the best manufacturing process. Manufacturing has a lot of details, and it has many dimensions that needs to be considered. Properties of finished product such as material, surface finish, tolerances need to be accounted when deciding whether to use traditional manufacturing or 3D printing. Figure 7 clearly shows that the cost is the governing factor in determining the best manufacturing process.

4 CONCLUSION

The 3D printing has a potential to transform and develop our communities and make positive contributions to service delivery and economic growth. For this to happen, we need to ensure that our education system does teach about 3D printing and then product development need to be prioritised in wastewater industries to develop this 3D printing technology. It was noted that there is a slow progress in the application of 3D printing in wastewater industry, in South Africa as well as globally. This challenge may not be caused by technology advancement but the lack of fresh thinking in the application of 3D printing technology. This is not only a challenge in the development of wastewater infrastructure, but it is the opportunity for the development of new skills. The employment of 3D printing in South Africa wastewater treatment will improve service delivery.

The introduction of 3D printing to the wastewater infrastructure will not only increase production efficiency at reduced cost, but will ensure adequate service delivery to the people of South Africa.

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IMPACT OF FOURTH INDUSTRIAL REVOLUTION ON WASTE BIOMASS CONVERSION TECHNIQUES

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ABSTRACT

The Fourth Industrial Revolution (4IR), which is an improvement from other previous industrial revolutions, is the application of digital technologies to, among other things improve the quality of life and improve the global economy. Energy from finite sources cannot be relied upon to meet the increased global energy demand needed to improve the quality of life as envisaged by the adaptation of 4IR. Access to clean and affordable energy is one of the determinants for appraising the quality of life. The current effort examines the contributions of the 4IR to the waste biomass conversion technologies in terms of the factors of cost, availability, accessibility, environmental sustainability, ease of conversion, maintenance, and industrial applications of the products. The paper concludes that 4IR will reduce the challenges associated with the conversion of waste biomass into bioenergy and other byproducts, and ensure the availability of clean, affordable, and sustainable energy for industrial and other applications. Going forward, the integration and utilization of 4IR technologies for the conversion of waste biomass into bioenergy and other byproducts are recommended.

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1 INTRODUCTION

The fourth industrial revolution (4IR) is an improvement from the previous industrial revolutions and one of its main objectives is to bring the physical, digital and biological worlds together by advanced technologies [1]. The 4IR is largely driven by the internet of things (IoT), advanced wireless technologies, artificial intelligence (AI), automation, robotics, big data analytics, 3D printing, and cloud computing. By the deployment and application of robotics, AI, IoT, etc. in our private and professional lives, humanity is empowered to make smart choices, almost at the speed of light. The 4IR, when fully and meticulously implemented, will lead to increased activities in the manufacturing sector which will culminate in improved earnings and a better standard of living for the population [2]. The manufacturing system in the 4IR era will be characterized by an integrated, optimized, smart and automated production processes.

However, the evolution of the 4IR should not truncate the global efforts at ensuring access to affordable, reliable, sustainable and modern energy for humanity by 2030 as articulated the sustainable development goal seven [2]. The anticipated increased industrial activities under the 4IR are expected to be accompanied by the use of safe and environmentally friendly energy sources. There is a need to create new energy technologies capable of creating low-cost, safe, and sustainable sources of power. The promotion of clean, affordable, and environmentally friendly energy to drive the 4IR is of immense importance if the technological innovations are to benefit humankind optimally. There is a need to pay great consideration to environmental protection and sustainability through the utilization of zero-emission energy sources which renewable energy offers.

Biomass is a plant or animal material used as fuel for the production of electricity or heat. Notable examples of common biomass include wood, agricultural wastes, farm wastes and energy crops most of which can be used directly as fuel without any form of conversion or modification. This explains why biomass and biofuel are often used interchangeably in some jurisdictions. However, some biomasses are converted into other forms of fuel before they are used. Biomass is one of the most abundant organic resources and a veritable source of renewable energy, bioenergy, chemicals, and other bioproducts and a suitable alternative to fossil-based feedstock [3]. The quest to generate enough clean energy from biomasses to power the current industrial revolutions has dominated research in recent years. Lorenci Woiciechowsk *et al.* [3], Cai *et al.* [4] and Mahmood *et al.* [5] investigated the conversion of lignocellulosic biomass to biofuel and other products using various methods.

In extant research, Li *et al.* [6] reported the deployment of AI for the conversion of lignocellulosic feedstock and waste peanut shells into liquid biofuel while Manikanthan and Pranavanand [7] reviewed the application of cloud computing and IoT were incorporated into the conversion of various wastes for the generation of renewable energy. Also, robots were used for the conversion of feedstocks and effective management of gaseous and liquid biofuels as well as other forms of renewable energy [8, 9]. The common denominator is all these studies is the undeniable positive impacts of the adoption of 4IR on the various technologies for the conversion of biomass to renewable energy fuels. Despite these and other numerous successful conversions of biomass into various types of biofuels, the relevant question to ask which forms the motivation for this current effort is to investigate how 4IR can be employed in the conversion of biomass to various biofuels. The objective of this paper is to examine the contributions of 4IR to various technologies for the conversion of biomass into biofuels. This is to generate enough safe, cost-effective and sustainable fuel to power the industrial sector and ensure a better standard of living without compromising ecological sustainability. This work will be limited to the discussion of how smart technologies can be adopted to improve the conversion of biomass to useful biofuels.

2 BIOFUEL CONVERSION TECHNIQUES

Generally, and from a technological point of view, four major techniques or technologies are used to convert biomass to biofuel. They include (i) mechanical techniques, (ii) chemical techniques, (iii) thermochemical techniques, and (iv) biochemical techniques. As shown in Figure 1, each of these techniques can be accomplished by the listed processes. Sometimes, a particular biofuel might have multiple pathways for production.

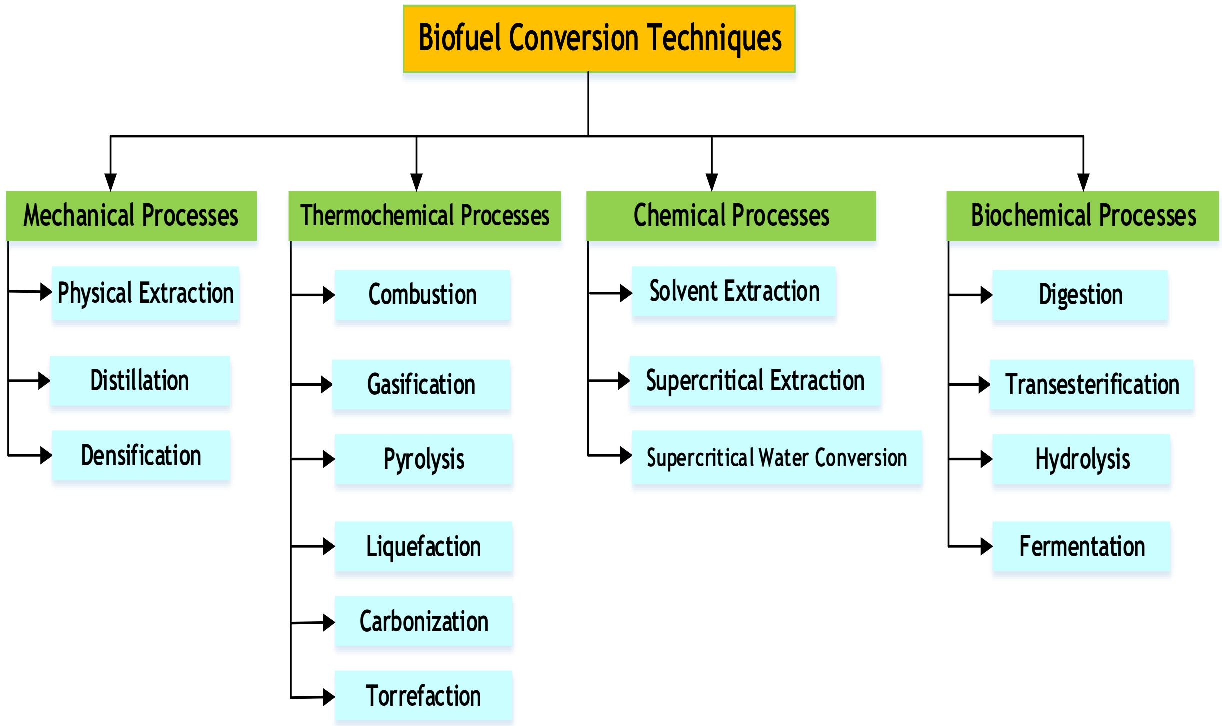

Figure 1: Biofuel conversion techniques and processes

The methodology for each of the listed processes is briefly discussed below.

2.1 Mechanical Processes

Mechanical or physical conversion techniques involve the use of traditional methods to process some woody materials by cutting, fragmenting, or grinding, and the densification of some materials [6]. Examples of mechanical processes include the use of certain mechanical devices to extract bio-oil from some oil crops, separation of some impurities from bio-oil by distillation, and the use of briquette to densify solid fuel.

2.1.1 Physical Extraction

In the physical extraction process, also known as the mechanical extraction process, mechanical devices like a mechanical screw press or an extractor are employed to extract oil from oilseed crops. During the process, oil-bearing seeds like rapeseed, cottonseed, sunflower seed, soybean seed, groundnuts, etc., are crushed and pressed or squeezed to extract the oil. The extracted oil can either be applied directly as a replacement to power ICEs, for heating or converted to biodiesel [3]. To reduce the physical energy and the exhaustion involved in the energy-sapping process, robots can be employed to ensure better efficiency and outputs.

2.1.2 Distillation

The distillation process, also known as briquetting of biomass, involves the separation of components or constituents from a liquid by exploiting the variations in the volatilities of the various constituents of the mixture. This process usually requires boiling, evaporation, and condensation and may lead to partial or complete separation [7]. The partial separation distillation process is to increase the concentration or purity of a particular constituent while the complete separation distillation process will produce an almost pure component of the mixture. During the distillation process, the oilseed is crushed and the oil extracted. The process also involves steam distillation of the oil mixture and vaporization of the essential oil over steam. The vaporized oils are captured and condensed or cooled to obtain bio-oil. Technological advancements, such as those belonging to the 4IR, can be used to ensure that the produced bio-oil meets a acceptable standards. Such data can be stored in the cloud using big data technology and made accessible by producers and consumers.

2.1.3 Densification

The densification process involves cutting, shredding, chopping, grinding, and pulverizing of some solid biofuels like agricultural residues (rice husks, cereal straws, sugarcane leaves), forest residues (wood, tree branches), and other waste materials into small uniform shapes and sizes [8]. The uneven and irregular shapes and sizes of these solid biofuels make them vulnerable to low bulk density and low energy content, hence the need for densification. The densification process, which also includes briquetting and pelletizing, not only improves the energy content and other fuel properties of the solid biofuels but also turns them into high-quality and superior biofuels. The use of robots can be employed as a panacea to the fatigue experienced by humans in the process of manual pulverizing of the biofuel. To ensure uniform particle size, there is a need to automate the machine and the conditions (moisture content, hardness, dimensions) of other inputs into the system.

2.2 Chemical Processes

Major chemical processes for the conversion of feedstocks to biofuels include solvent extraction, supercritical fluid extraction, and supercritical water conversion. Though these processes are facilitated by chemical reactions, advanced technologies can be incorporated to ensure standardization of the operating conditions.

2.2.1 Solvent Extraction

The solvent extraction process involves the dissolution of a given raw material (oil) extracted from biomass containing the needed substance into a selected solvent before the targeted substances present in the biomass are selectively recovered from the solution. Extraction and separation are the two essential processes necessary for the removal of a given substance from biomass [9]. The biofuel extracted from biomass by this technique can be standardized and made to meet global standards. The rate of solvent removal, feeding of the inputs, extraction procedures, and quality of the bio-oil can be monitored in real-time by the application of 4IR technologies.

2.2.2 Solvent Supercritical Fluid Extraction

Supercritical fluids are substances that operate under temperature and pressure conditions higher than their vapour-liquid critical point. The supercritical conditions for H_2O are 644 K and 22 MPa and for CO_2 are 304 K and 7.4 MPa. CO_2 is commonly used for supercritical extraction. One of the advantages of supercritical fluids is that their density, solubility, diffusion coefficient, dielectric constant, etc. can be maneuvered by marginally changing the temperature and pressure to enhance their extraction and reaction capabilities [10]. Secondary metabolites and other chemical molecules can be obtained from woody biomass by employing a supercritical fluid extraction technique. In this particular situation, lignocellulosic biomass (cedarwood, pinewood, etc.) are first extracted to separate the extractives, followed by hydrolysis and then fermentation for the generation of biofuels [11]. The conversion rate of lignocellulosic biomass to biofuel can be monitored with the aid of technologies to ensure reliable metering and pricing. The production plant and storage condition can be monitored by smart technologies like IoT to prevent contamination and adulteration.

2.2.3 Supercritical Water Extraction

The conversion of biomass to biofuels through the use of the supercritical water extraction process is a reliable route to achieve acid and enzymatic hydrolysis. Water maintained at a temperature range of 300 K to 644 K and pressure 200 bar to 250 bar is said to be in supercritical condition. Supercritical water is capable of converting biomass into a blend of oils, organic acids, alcohol, and methane as well as changing cellulose to sugar. At supercritical conditions, the acid (H^+) and the base components (OH) of water are detached and dissolved in the biomass. The dissolved supercritical water promptly fractures the connections of cellulose and hemicellulose to generate small sugar molecules (i.e. glucose, xylose, and oligosaccharide) [12]. These behaviours make supercritical water an extremely encouraging platform for the non-catalytic conversion of biomass to biofuels and other high-value products. Figure 2 shows the processes and products of the supercritical water conversion technique. An increase in the temperature of the water to 873 K will ensure that the supercritical water attains enough strength to completely break down the substrate structure by transferring oxygen from water into the carbon atoms of the substrate. In the process, the hydrogen atom is formed from the water. A characteristic complete reaction is shown in Equation 1 [13]. Smart technologies, like automation, robotics, AI and IoT systems can be employed to monitor and automate the production process to minimize human intervention and achieving better results. The operating conditions of the supercritical fluid can be optimized and monitored to ensure standards by the use of wireless technologies and IoT.

$$2C_6H_{12}O_6 + 7H_2O \rightarrow 3CO_2 + CH_4 + 2CO + 11H_2 \qquad (1)$$

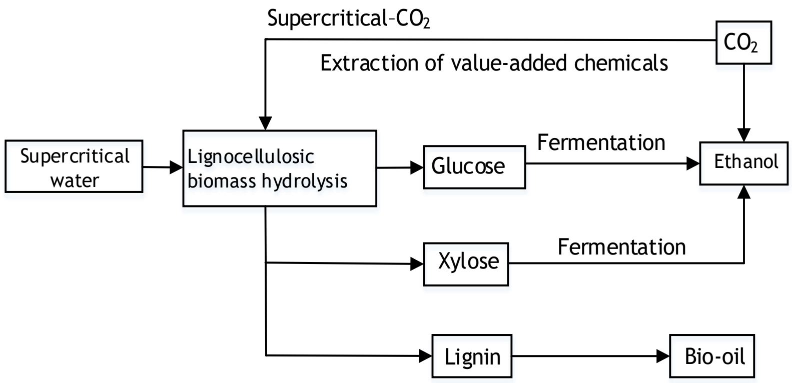

Figure 2: Supercritical water conversion of biomass [13]

2.3 Thermochemical Processes

Thermochemical conversion technologies are capable of converting almost all the organic components of the various forms of feedstocks into biofuels and other value-added products. During thermochemical conversion processes, biomasses are converted into a wide variety of products like H_2, CO, CO_2, CH_4, and other products, as shown in Equation 2, through various conversion techniques [14]. When compared with other conversion technologies such as physical processes, chemical processes, and biochemical processes, the thermochemical conversion process is not only versatile but more efficient [6]. Major thermochemical processes for the conversion of feedstocks to biofuels comprise direct combustion, gasification, pyrolysis, liquefaction, carbonization, and torrefaction.

$$\text{Biomass} \rightarrow H_2 + CO + CH_4 + \text{other products} \qquad (2)$$

2.3.1 Direct Combustion

Direct combustion, also known as burning, is a thermo-chemical process that occurs when fuel reacts with excess atmospheric air or oxygen. The products of such reactions are carbon dioxide, water, and heat. The heat generated during direct combustion is useful for cooking, space heating, and electricity generation. However, direct combustion, despite its efficiency and technological maturity, is not a conversion technology for biofuel production since no biofuels would be generated at the end of the combustion of the original raw material or feedstock [5].

2.3.2 Gasification

Gasification is a high-temperature process involving the reaction between fuel-based carbonaceous substances and gasification or a gasifying agent for the production of syngas [15]. Syngas, which is an abbreviation for synthesis gas, is also called producer gas, or synthetic gas, and comprises mainly H_2, CO, small amounts of CH_4, CO_2, and other gaseous hydrocarbons like ethane (C_2H_4) [15]. The choice of a gasification agent greatly influences biomass gasification processes as it breaks down the biomass into gas molecules under high temperatures and leads to the formation of the syngas. Notable gasification agents include air, oxygen, steam, CO_2, supercritical water, etc. Air is the most popular gasification agent as it occurs naturally, is inexpensive, and requires no storage facility. Syngas produced with oxygen, steam, CO_2 and supercritical water as gasification agents has higher heating values than that produced with air as gasification agent [15]. Steam gasification agent consumes more power but can extract the majority of hydrogen from biomass. Figure 3 shows the schematic description of the gasification process. With the increased utilization of syngas for various applications, there are expectations that the use of improved technology will be required to maximize its benefits. The power consumption of the gasification agent, the constituent of the products, and the generation of the products can be metered and monitored by IoT, robots, and other appropriate smart technologies to ensure transparency and accountability.

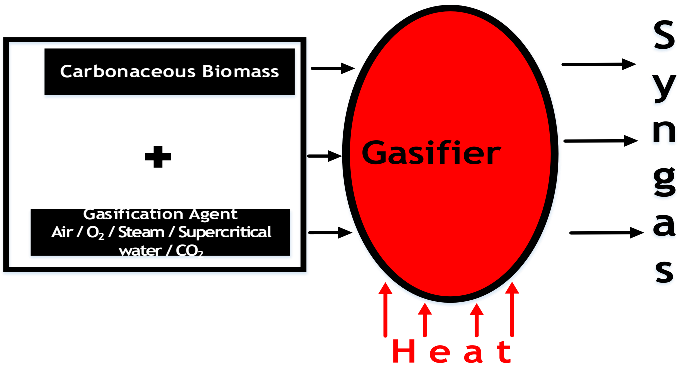

Figure 3: Schematic diagram of the gasification process

2.3.3 Pyrolysis

Pyrolysis is an example of a thermo-chemical conversion process during which biomass feedstock is subjected to temperatures above 400 ℃ under partial presence or total absence of oxygen to generate bio-oil, biochar, biosyngas and other by-products [16]. The schematic representation is as shown in Figure 4. When compared with other thermochemical processes, pyrolysis offers major advantages [17] including: (i) The major product is bio-oil with high carbon content, (ii) yield of 75 % bio-oil is achievable, (iii) higher heating value (HHV) of bio-oil compared with other fuels, (v) brief residence time, (vi) low operational cost, (vi) the desired ratio of bio-oil to biochar to biosyngas can be achieved by altering the operational constraints, (vii) ease of storage and transportation for bio-oil, and (viii) limited pre-treatment of raw materials/feedstock.

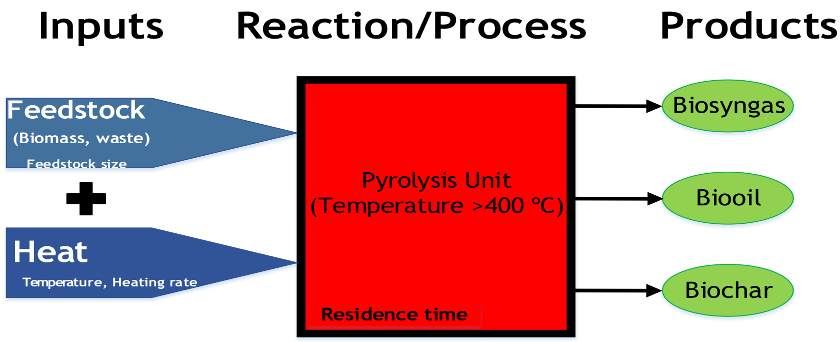

Figure 4: Schematic representation of the pyrolysis process

Advancements in research and technology have brought about the use of microwave-assisted pyrolysis to replace conventional electrical pyrolysis. The advantages of microwave-assisted pyrolysis include low energy consumption, rapid heating, fast response, better control, and improved product yield [18]. Due to the high temperature involved in the process, the process is prone to accidents and subject the operator to thermal exhaustion. The process can be made safer if smart technologies are introduced to replace the existing process. In the wise, robots, IoT, and other suitable smart technologies can be incorporated to enhance the production process. There is a need for proper metering to measure the quantity and quality of each of the generated products to ensure transparency and accountability of the process.

2.3.4 Liquefaction pyrolysis

Liquefaction is a thermo-chemical conversion technique for the production of liquid biofuel, mainly bio-oil. Hydrothermal liquefaction, direct catalytic liquefaction, and pyrolysis offer a proven path for the direct conversion of biomass-to-liquid (BtL) fuels for diverse applications. Most biomass feedstocks are wet with moisture content above 80 %, and the hydrothermal process can convert them to bio-oil without drying. The hydrothermal liquefaction technique employs water as a reaction medium, usually at elevated temperature and pressure, to liquefy wet biomass into bio-oil. The moisture present in the wet biomass facilitates the degradation of the polymer structure of the biomass. The process can be catalysed, using alkali salts, like sodium carbonate and potassium carbonate, to speed up the process and generates a high volume of bio-oil [13]. The process exposes the operator to persistent elevated temperatures and poses health risks. These risks can be minimized when human activity and intervention are reduced and replaced with smart technologies including robots and IoT.

2.3.5 Carbonization

Carbonization is the thermochemical treatment of biomass at a temperature range of 200 ℃ to 315 ℃ in the absence of oxygen, during which the biomass is completely converted into biochar. The product of carbonization has higher density content than raw biomass thereby lowering the cost of transportation of the carbonized biomass [19]. Products of carbonization are not only hydrophobic in nature, but they are also easy to pulverize and have similar features to coal. The introduction of smart technologies, including IoT, AI, smart metering, will ease the process, make it safer, and ensure transparency in terms of the amount of product generated. Proper metering of the product, using appropriate technologies, will allow for transparency and proper monitoring of the process.

2.3.6 Torrefaction

Torrefaction is pyrolysis at low temperatures involving the conversion of biomass to a more efficient form of energy [20]. The torrefied biomass has less moisture, high fixed carbon content, and can be termed as chemical feedstock with a lower cost of transportation. During torrefaction, the hemicellulose in the biomass undergoes incomplete decomposition and, in the process, produces various brittle, dried, and more volatile-free solid products. Just like carbonization, products of torrefaction are hydrophobic, easily crushed, and possess comparable features with coal. Similarly, the torrefaction process translates biomass into a more valuable and efficient energy source thereby reducing the transportation cost. The monitoring of the process needs to be upgraded to allow for the application of technologies to ensure better outcomes and reduce human activity.

2.4 Biochemical Processes

Biochemical conversion processes are the combination of biological and chemical pathways for the conversion of biomass to biofuels. The biochemical conversion processes include digestion, hydrolysis, fermentation, and transesterification. However, the biochemical conversion process is affected by ambient temperature and other environmental conditions like sunlight.

2.4.1 Digestion

Digestion is a biochemical conversion technique where biomass feedstocks are biologically decomposed by bacteria whether in the presence (aerobic) or absence (anaerobic) of oxygen. Aerobic digestion is rarely used or considered because not many useful products are obtained from the conversion of biomass feedstock. During anaerobic digestion (AD), various species of bacteria and specialized microorganisms take part in the breakdown of complex organic matter like manure into smaller molecules that are soluble in water to generate a methane-rich gas called biogas. The anaerobic digestion manure to produce biogas takes place in a digester, an airtight reactor. Biogas contains approximately 55 % to 75 % methane, 24 % to 45 % CO_2, by volume and some trace gases like hydrogen sulfide, ammonia, nitrogen, moisture, etc. After the production of biogas, the leftover substrate is used as fertilizer or reused as a bedding material [21]. The overall anaerobic digestion reaction is shown in Equation 3. The schematic anaerobic digestion process is shown in Figure 5. Production of biogas by AD can be improved by the application of smart technologies for the metering of the biogas generated.

$$C_6H_{12}O_6 \rightarrow 3CO_2 + 3CH_4 \quad (3)$$

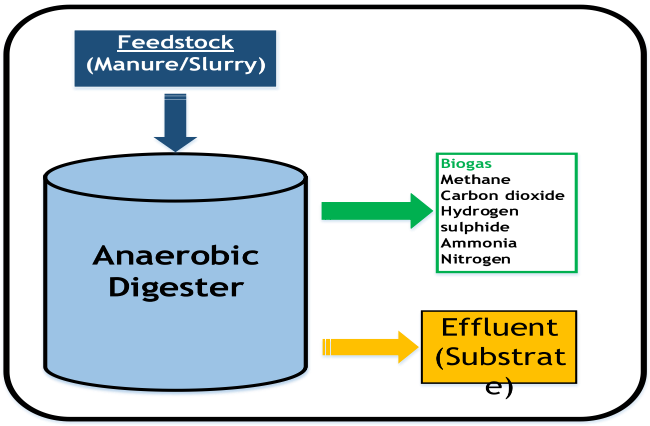

Figure 5: Schematic diagram of anaerobic digestion

2.4.2 Transesterification

Transesterification is a process during which renewable biological raw materials react chemically with an alcohol in the presence or absence of a catalyst. The reaction yields a mixture of biodiesel, also known as fatty acid methyl ester (FAME), and glycerol, which is a high-value co-product. A non-catalytic transesterification process is one in which no catalyst is involved in the conversion process. The non-catalytic transesterification process is believed to occur at a pressure range of

45 bar to 65 bar, temperature of 200 °C to 400 ⁰C, and in the presence of alcohol [22]. Compared with the catalytic transesterification process, the supercritical transesterification process has been found to take place in a shorter time and is a simplified purification process as removal of a catalyst is not needed. However, the non-catalytic transesterification process is limited to the batch process, requires high temperature and pressurized reaction vessels, so has a high energy cost. Figure 6 presents the representation of the three steps involved in the transesterification reaction for the synthesis of FAME. Most of the FAME production reactor operates on a batch scale with all the processes requiring human intervention. This has limited the production and management of biodiesel. The deployment of technologies will ensure the product meets the international biodiesel standards and enhance the process.

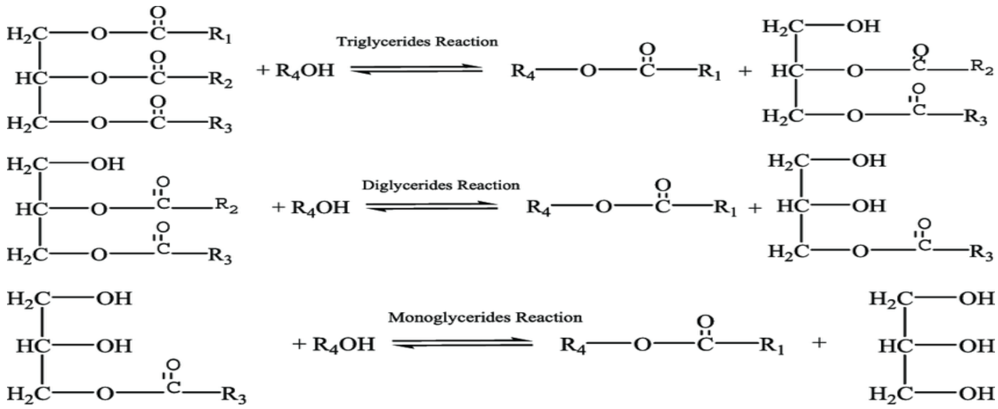

Figure 6: Three steps equation for transesterification reaction

2.4.3 Hydrolysis

Hydrolysis is a biochemical process for the conversion of cellulose and hemicellulose in biomass into simple sugars. These simple sugars are thereafter hydrolyzed into ethanol. Hydrolysis can either be by acid hydrolysis, where mineral acids are used, or by enzymatic hydrolysis where enzymes are used. During acid hydrolysis, also known as chemical hydrolysis, mineral acids react with lignocellulosic biomass (lignocellulosic materials) under specific temperatures and time frames to split the cellulose and hemicellulose into monomers or simple sugars. Enzymatic hydrolysis uses cellulose and hemicellulose enzymes as biocatalysts during the conversion process.

In comparison with acid hydrolysis, enzymatic hydrolysis offers some advantages including [23]: (i) superior product yield, (ii) reduced by-products, (iii) high selectivity, (iv) low corrosion problems, (iv) low utility consumption, (v) low toxicity of hydrolysis products. However, the enzymatic hydrolysis process is adversely impacted by expensive enzymes, long processing time, and high energy requirements for hot water and steam generation. Going forward, smart technologies are to be incorporated into the hydrolysis process to enhance the production and monitoring of the product.

2.4.4 Fermentation

Fermentation is a biochemical (biological plus chemical) process for the anaerobic conversion of the simple sugars obtained from hydrolysis of lignocellulosic biomass into bioethanol. The process of conversion of lignocellulosic biomass to simple sugars is a complicated procedure owing to the existence of long-chain polysaccharide molecules, and therefore demands acids or enzymes. The anaerobic catabolism of simple sugar by microorganisms yields alcohol, gas, or organic acid. The chemical reaction for the fermentation process is shown in Equation 4. The process of bioethanol production should be digitized with the use of appropriate technologies to ensure improved production, metering and storage.

$$C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2 \qquad (4)$$

The summary of 4IR technologies that can be applied in biomass conversion techniques is shown in Table 1. The adaptation of these technologies will improve effectiveness, efficiency and transparency along the value chain to the benefit of the energy producers, consumers and regulatory agencies.

Table 1: Summary of the 4IR opportunities in biomass conversion

Conversion process	Conversion techniques	4IR technology used
Mechanical	Physical extraction	Robots
	Distillation	Robots, AI
	Densification	Robots, automation
Thermochemical	Combustion	Robots, AI
	Gasification	IoT, robots, AI
	Pyrolysis	Robots, AI, IoT, smart metering
	Liquefaction	Robots, IoT
	Carbonization	Smart metering
	Torrefaction	Robotics. AI
Chemical	Solvent extraction	Sensors, cloud computing, AI
	Supercritical extraction	IoT, AI
	Supercritical water conversion	Wireless technology, IoT
Biochemical	Digestion	Smart metering
	Transesterification	AI, IoT
	Hydrolysis	AI, smart metering
	Fermentation	Smart metering

3 CONTRIBUTIONS OF 4IR TO RENEWABLE ENERGY SECTOR

The fourth industrial revolution has contributed to the renewable energy sector in the entire value chain both at production and consumption levels. The application of IoT and cloud computing [7], robotics [8], AI [28] and Big Data [29] have led to simplicity, conversion effectiveness, transparency and safer work practises in biomass conversion. However, the adoption of 4IR requires huge financial investment, stakeholder engagement and high technical knowhow. The attendant labour related issues and the change in the traditional techniques in biomass conversion as a result of the deployment of the 4IR need to be fully discussed and agreed upon by all stakeholders. There must be agreements, compromises, trade-offs and assessments of the process, techniques and the business side along the renewable energy value chain. Some of the specific contributions of 4IR to biomass conversion techniques include:

i. The use of smart products

The use of smart meters, smart grids, smart energy systems has allowed more efficiency, transparency and decentralization of the decision-making in the digital system more than the traditional system. The deployment of AI, IoT, and 3D printing enhances the capability to control the enormous complexities involved in the connection of the energy system value chain. Robots equipped with smart cameras could be deployed to monitor the activities during high temperature pyrolysis of biomass to biofuel to monitor the conversion parameters. Also, the use of these smart products has increased conversion efficiency and enhanced environmental sustainability [8, 28].

ii. Modularization of production

The 4IR has allowed the modularization of energy production, particularly for off-grid energy systems. It has been argued that the modularization of production has given rise to the division of production services and components into ideally independent and interchangeable modules. Industry 4.0 ensures the realization of standardization and increased individualization of power to different consumers at the same time through the use of smart [24]. The digital industry of the 4IR is more service orientated than asset orientated. The deployment of big data and cloud computing in energy systems allow asset-less and seamless data storage to further enhance system stability and the individualization of products and services to the consumers.

iii. Improved transparency and cost reduction

There is increased transparency on the status of the energy system due to the application of 4IR. Energy production and consumption are calculated in a transparent manner through the use of smart meters. This will minimize conflict between energy producers and consumers. With increased transparency and the ability to remotely control the energy generation process using digital tools, there will be greater energy efficiency and consequently, cost reduction.

iv. Prompt fault detection and improved system reliability

The deployment of smart meters, smart grids, etc will allow for effective identification of faults, failures and system collapse within the energy system. Prompt fault identification will allow for the isolation of parts susceptible to failure thereby enhancing system reliability and robustness. By reducing uncertainties in the forecasting of energy utilization in the manufacturing system as well as in the detection of technical breakdowns, the security and reliability of energy supply can increase considerably [29].

v. Flexibility and Hybridization

The advent of 4IR will provide additional flexibility for the production and consumption of renewable energy systems. The adoption of modularization of production will allow for flexible interchangeability, energy coupling and hybridization of energy sources. For example, more than one technique can be adopted for the conversion of particular biomass to biofuel. There is also an opportunity for the transformation from one form of biofuel to another. For example, the energy need of an energy-intensive industry can be hybridized by using either biogas or biodiesel as demonstrated by Li *et al.* [6].

vi. System optimisation

Digital systems will allow for better energy management through cross-company optimization of energy production, consumption and storage in the vicinity of the company. The fundamental innovation is the central IoT, big data and AI platforms that allow complex functions and services. With improved energy management there will be increased energy efficiency and reduction in energy consumption and expenditure.

4 CONCLUSIONS

In this paper, we have chronicled how biomass is converted to biofuel via mechanical, chemical, thermochemical, or biochemical technologies. These are achieved through the application of physical, chemical, biological, thermal, or a combination of two or more techniques. The outcomes of these techniques have been applied as a sustainable alternative to fossil-based fuel to reduce the global CO_2 emissions and its attendant environmental degradation. The deployment of transesterification, digestion, fermentation and pyrolysis processes have yielded FAME, biogas, bioethanol, and biochar respectively which have been used for various applications.

The application of the 4IR into the various biomass conversion techniques will help in the digitalization of the process and improve the conversion efficiency. The use of smart meters, AI, IoT, and 3D printing enhance production and improve transparency in the energy value chain. With appropriate technologies like robotics, automation, cloud computing, smart grid, AI for monitoring, fault identification and detection there will be improved security and system reliability, minimum breakdown and downtime, and system optimization and flexibility. These will improve energy access and hence enhance the quality of life at minimum cost.

Going forward, the symbiotic and complementary relationship between man and 4IR technologies should be further exploited for better biomass conversion and utilization. The use of robotics, big data, AI, IoT, cloud computing, and other innovative technologies should be escalated to cover all aspects of renewable energy generation and utilization as key to implement a sustainable biobased circular economy. The introduction and application of the 4IR technological regime into the renewable energy network will guarantee safe and cost-effective energy accessibility and utilization. There will be increased transparency and openness for both renewable energy producers and consumers. With openness, accountability, safety and less system breakdown, there will be increased funding and investment in the use of technology of biomass conversion. The adoption of 4IR technologies will boost the conversion of wastes and other biomass materials to the more needed renewable energy.

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STEPS IN PROCESS PARAMETER OPTIMISATION AND CONTROL SYSTEMS DEVELOPMENT FOR THE DEEP-DRAWING PROCESS

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ABSTRACT

Deep drawing is a manufacturing process in which a punch draws a sheet-metal into a die to make a part. Effective process control involves optimisation of process parameters to produce desired part quality specifications. However, due to the varying degree of complexity of the parts that can be made from deep drawing, a one size fits all approach to control may not produce desired results. Hence, the study of the deep drawing process shall remain a fertile ground for research. This paper reviews the different process parameters, optimisation methods and control systems that are used in the deep drawing process. The results of the review reveals recommended steps in the optimisation and control of the deep drawing process. The part geometry has greater influence on the key process parameters and that Finite Element Methods are essential in optimising and controlling the deep drawing process. Changes in material properties during deep drawing indicate the need to develop real-time intelligent control systems to maintain good product quality.

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1 INTRODUCTION

Deep drawing is a sheet metal forming process in which a recessed, cup shaped part is produced using a combination of a punch and a die [1]. The punch pushes the sheet metal into the die cavity in order to form the shape as shown in Figure 1. Parts of high strength to weight ratio with varying geometrical complexity can be made through deep drawing [2]. The process is widely used to produce automotive and aircraft parts [3]. Other common applications include the production of household appliances [4]. Maintaining product quality is essential in the production of deep drawn parts. There are generic quality parameters for deep drawn components as well as product specific quality parameters. The generic quality parameters are simply defined by the absence of process defects from the product, while the product specific quality parameters are derived from the customer specifications [5]. The product quality parameters are a function of process parameters that need to be optimised and controlled. This paper is a review of the process parameter optimisation and control systems development for the deep drawing process for enhancing the quality of deep drawn parts. The aim being to propose a formal methodology or a sequence of steps for optimising and building control systems for the deep drawing process.

2 METHODOLOGY

An integrative literature review process was used to get the steps that are followed in process parameter optimisation and control systems development for the deep-drawing process. A review is conducted to give a deep-drawing process overview. The overview revealed the need to further review deep drawing mechanics, quality parameters in deep drawing, deep drawing process parameters, optimisation and control systems. These were reviewed further in order to establish the steps and outline the same.

3 THE DEEP DRAWING PROCESS OVERVIEW

There are various ways of classifying deep drawing processes. The process can be classified according to the number of stages needed to draw the final part that is single-stage or multi-stage [6]. The source of the energy used to drive the press machine can also be used to classify deep drawing for example mechanical, hydraulic or pneumatic [6]. Other scholars classify using a description of the device used for transferring the momentum to the punch for example servo motors or mechanical flywheels [7]. According to Wang et al. [6] the temperature used can also be used to classify the process as described by Callister [8] as cold forming, warm forming or hot forming, with the recrystallisation temperature determining the classification. Cold forming takes place at room temperature, while warm forming takes place close to the recrystallisation temperature and hot forming takes place above the recrystallisation temperature. Swapna et al. [4] also suggest that non-conventional methods can also be used in deep drawing like hydroforming and electromagnetic forming, hence the conventional and non-conventional classification. It is thus important to use a multiclassification criteria to be able to describe the process under study fully as some of the process parameters that influence product quality are a function of how the machine is built. For the purposes of this review, a generic approach is used so as to cover some common process parameters in deep drawing.

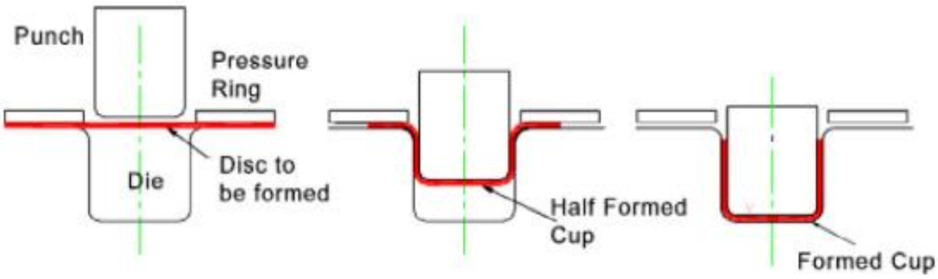

Figure 1: Deep drawing process illustration [1]

3.1 Deep drawing mechanics and material characterisation

In deep drawing parts are produced by deforming the material using a combination of punches and dies as shown in Figure 1. The material behaviour when subjected to different forces and stresses has to be understood in order to determine the process settings. It is thus necessary to understand the material characteristics so as to predict the deformation process. Risonarta et al. [9] recommend the carrying out of materials characterisation and metallurgical analyses to understand the material science before deep drawing. This is because the chemical properties have a bearing on the mechanical properties like tensile strength, elasticity and hardness. During deep drawing the material is subjected to mechanical stresses that cause permanent or plastic deformation, this means the applied stresses are above the normal yield strength of the material and below the ultimate tensile stress [10]. As the stress is applied the atoms in a lattice structure of the material slide against each other by slipping or twinning to find a new equilibrium in a deformed state. Another important metallurgical characterisation for deep drawing sheet metal is the grain size. Grain sizes also have an influence on the mechanical properties [11]. The behaviour of the material when subjected to a stress can be best described by its stress-strain curve. The extent of the deformation depends on the formability of the material. The in-depth study of the material properties will determine the conditions required for deep drawing. The material characterisation should be done at different temperatures in order to make a decision on whether cold, warm or hot forming should be used. Finite Element Modelling (FEM) or experimental measurements can be used to study and predict the behaviour and formability of materials during the deep drawing process [10], [12].

3.2 Deep drawn products quality parameters

The generic approach to define the quality parameters of deep drawn components is using the zero defects definition. According to Sajja et al. [13] there are three major defects in deep drawing namely fracture, wrinkling and earing. Tang & Pan [14] suggest four types of defects that needed to be addressed in order to produce quality products. The four types of defects are necking or splitting, buckling or wrinkling, loose metal without enough stretch, and excessive shape distortion from the springback. Feng et al. [15] define springback as the distortion of the formed shape when it is ejected from the mould due to elastic restoring forces caused by inner stress redistribution. The magnitude of springback is directly proportional to sheet thickness [16]. In order to meet the quality of dimensional accuracy, the springback must be compensated when the production process is designed [17]. Excessive thinning is also considered a structural defect in deep drawn components [18]. In addition to these there are also cosmetic defects like surface scratches that need to be controlled [19]. Figure 2 shows a schematic view of some of the defects as summarised by Groover [11].

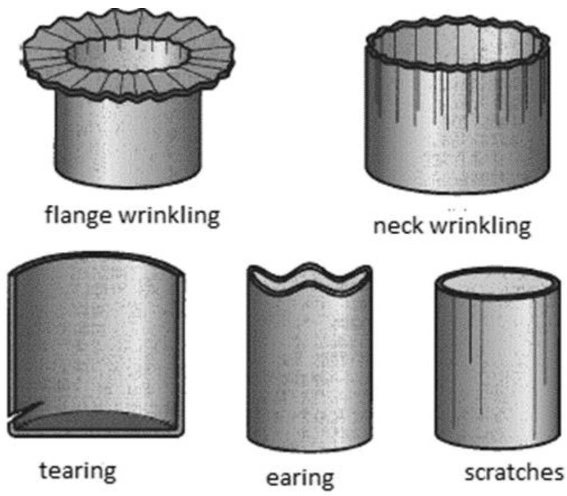

Figure 2: Defects in deep drawing [11]

3.3 Deep drawing process parameters

In order to minimise these defects an optimisation and control of the process parameters is required. The process parameters include forming temperature, blank holding force, drawing force, friction and lubrication, strain rate, dimensions and shape (blank and tool) and Tool velocity [20], [21], [16],[22]. These process parameters appear to be influenced from the material and the tooling and geometry for example parameters like temperature and forces required would be informed by the material characterisation and deformation mechanics while parameters like friction, lubrication and geometrical clearances would be informed by the shape and the tool. As previously noted, deep drawing can be done at elevated temperatures owing to an increased formability of material at higher temperatures [23]. This implies that a stricter control of process temperature would be required, but also the forces applied to deform the material will need to be controlled together with the friction between the tool and the work piece. All these parameters need to be optimised for enhanced quality.

3.4 Process parameter optimisation techniques in deep drawing

Deep drawing process parameter optimisation can take three different approaches, it can be done theoretically, using simulation or experimentally [24]. The theoretical or analytical approach as described by Mamalis et al. [25] has limitations for complex geometries due to the non-linearity of the deformation process. On the other hand, the direct experimental methods can be costly due to trial and error. Thus, simulation using Finite Element Modelling software programs becomes an viable method to reducing experimental costs [26]. According to Chen et al. [27], the effects of process parameters on formability are found by numerical simulation and experimentation can be done to compare and validate simulation results before the full implementation of the optimised parameters. Hassan et al. [28] concurs that numerical modelling and simulation in sheet metal forming software, can help to predict the deep drawing process parameters, improve the product quality, and reduce the defects for deep drawn components. Finite Element Modelling or Numerical Simulation has been applied to solve a number of optimisation problems in deep drawing for example optimising the process design of multi-stage sheet metal progressive stamping by Chen et al. [27], predicting a forming defects such as wrinkling and fracture by Bernai-aguilar et al. [26], predict and analyse deformation conditions by Chen et al. [7] and modelling of deep drawing parameters and characteristics in hot forming by Omer et al. [29] to just cite a few instances in which the FEM techniques have been successfully applied to the deep drawing process.

There are a number of software programs available for numerical simulation of forming process that include deep drawing. Some of the Finite Element Modelling software packages prominent during this review process are DYNAFORM, LS-DYNA, ABAQUS, DEFORM-3D, ANSYS, MARC, COSMOS, PAM-STAMP, AutoFORM, ITS-3D, OPTRIS and FAST_FORM3D to mention a few. Flegler et al. [30] used ABAQUS for the optimisation of dry forming operations while Ramezani & Rip i[31] used the software for deep drawing analysis using a rubber die. This demonstrates that the software can be applied for both conventional and non-conventional deep drawing operations. Chen et al. [7] mentions the use of DYNAFORM, DEFORM-3D, ANSYS, but highlights the application of DEFORM-3D in the prediction and analysis of deformation conditions like the stress and strain as well as flow velocity, and other information. Hassan et al (Hassan, Hezam, El-sebaie, & Purbolaksono, 2014) used MARC in their study on the influence of geometrical parameters on the Limiting Drawing Ratio with view of minimising defects while Omer et al. [29]did a study on hot deep drawing parameters optimisation using LS-DYNA. In another study on optimization of deep drawing process parameters for cylindrical cup by Sandeep [1] used the ANSYS software. In most of the instances highlighted, the results from the simulation were comparable to experimental results later conducted, highlighting that FEM can be used to reduce the number of actual experiments so as the time, costs and defects in the design.

3.5 Control sytems for the deep drawing process

After the optimisation of the process parameters, for robust processes the next step towards zero defects production is the to develop a process control system to ensure the optimum parameters are kept in control. According to Fischer et al. [32], process control is required because of the disturbances that can lead to shifts from the optimised process parameters. Several approaches have been used to develop control systems for the deep drawing process. These include the basic control theory that applies open loop and feedback control with different traditional controllers [32]. It follows that the traditional proportional, proportional integral, proportional integral derivative controllers, programmable logic controllers and other microcontrollers can be used to control deep drawing processes. According to Kott et al. [33] control systems will be composed of various sensors and actuators. It appears from the work of Heger & Abdine [34] that there is room for improvement in the development of feedback control owing to challenges of matching real time data acquisition to the speed of the process. Martin & Mba [35] also cite difficulties in measuring process data in real time. They review a number sensors and actuators that have been used in the control of deep drawing processes for example servo-motor actuators, piezoelectric actuators, induction coil sensors, laser displacement sensors, optical sensors and piezo-force meters. Electromagnetic, micromagnetic and eddy current sensors have also been applied in deep drawing [18], [36].

Optimisation-based algorithms can be incorporated into control systems design for the deep drawing process as they work well in terms of achieving a higher degree of accuracy. The optimisation-based control approaches evaluate the FEM simulation models directly. According to Fischer et al. [32], the input data into an optimisation-based algorithm control systems can also be provided by measured data. If data for designing a control algorithm is coming from a FEM software, then an appropriate model of the process is needed.

Artificial intelligence and machine learning algorithms may also be employed to build intelligent control systems for deep drawing. For example Bernai-aguilar [26] developed a control system for deep drawing operations using genetic algorithm and FEM. They describe genetic algorithms as robust and easy to use since they only need information about the objective function and are not heavily demanding in terms of calculations. Trzepiecinski & Fejkiel [37] acknowledge the use of evolutionary algorithms like neural networks and genetic algorithms in deep drawing. This is reaffirmed by Kott et al. [33] in the control of temperature induced friction effects in deep drawing for automotive parts with high drawing depth using multilayer artificial neural networks. High drawing depth possess a great challenge as the process needs to be operated close to the limits. Other challenges arise because of uncertainties due to unpredictable parameters like material properties, friction and tribology. Hybrid control systems can also be used like the case of Vaz et al. [38] where Particle Swarm Approach and the Sequential Quadratic Programming method are combined. It also appears there are no limitations in the development of control systems for the deep drawing operations as evidenced by the use of CAE-based six sigma robust optimization and control [39].

4 RESULTS

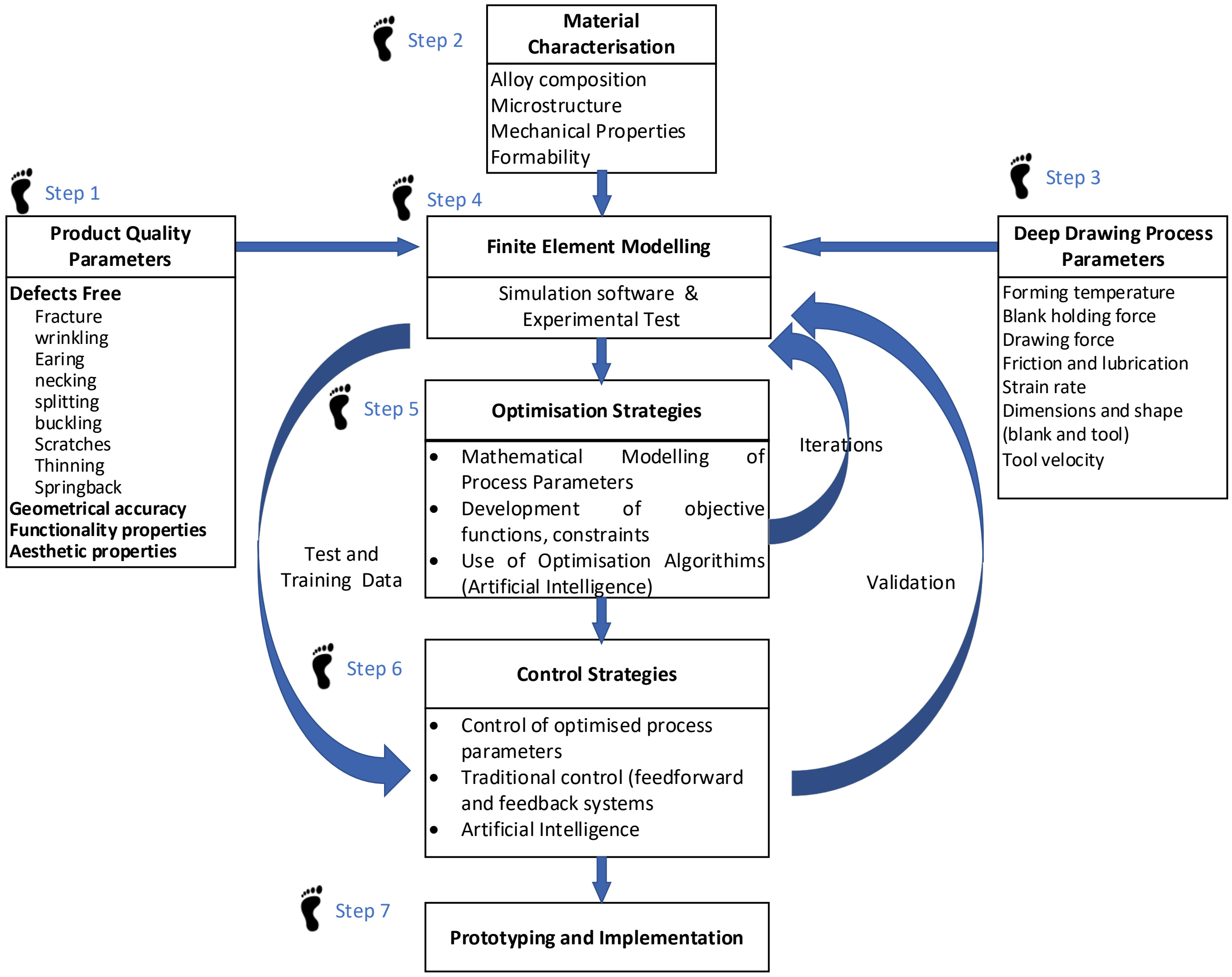

Figure 3: Steps in process parameter optimisation and control in deep drawing

The summary of steps to be taken in process parameter optimisation and control systems development for the deep-drawing process is as shown in Figure 3. Step 1 involves establishing the deep drawn product quality parameters. In establishing the product quality parameters, there are generic ones for all deep drawn components that are related to the deep drawing process. Product specific quality parameters need also be established through quality function deployment. Step 2 requires material characterisation and determination of the formability of the material to be used for deep drawing. Step 3 involves the establishment of deep drawing process parameters. These three steps may be carried out using concurrent engineering principles. In Step 4, the results from the previous three steps become input into a simulation process for FEM. In FEM software, Step 5 and Step 6 that are optimisation and control system development respectively can be achieved after which Step 7 for prototyping can then be done.

5 CONCLUSION

In conclusion, the proposed Steps in process parameter optimisation and control systems development for the deep-drawing process are very important as a systematic methodology in deep drawing. The process parameters are influenced by the material and the product quality parameters. There may be generic quality parameters for deep drawn components and these speak to defects elimination, while deep drawing defects are generic, there is need to augment these generic quality parameters by product specific parameters that are determined by the customers.

FEM software programs play an important role in the optimisation and development of control systems. The development of control systems can be based on feed forward or feedback systems with traditional control hardware or coupled with algorithm-based controllers. The developed methodology acts as a guideline. Since there are a variety of products that can be made through deep drawing, there is need to follow the proposed guideline whilst using product specific parameters.

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IMPROVEMENT OF MATERIAL HANDLING SYSTEM FOR COIL TRANSPORTATION IN THE MANUFACTURE OF ALUMINIUM ROLLED PRODUCTS

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ABSTRACT

The manufacture of aluminium rolled products is characterised by coil transportation, which is a process of moving the metal and lot tickets from one point to another for further processing at other sub-plants. The case study organisation is facing challenges on coil transportation and hence failed to deliver material on time and could not achieve manufacturing targets. The paper aims to identify the factors leading to the failure of achieving targeted schedule and introduce the system to standardize the process. As methodology, a flow diagram was used represent the current process and a failure mode and effect analysis was conducted to document and analyze the failures and implement mitigating factors. Breaking up of batches and delayed material arrivals to processing stations were found to be the key reasons that led to process inefficiency. An improved process flow was proposed and the recommended actions led to a streamlined flow characterised by reduced delayed material arrivals and processing.

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1 INTRODUCTION

The aluminium industry in South Africa is a key industrial pillar of the South African economy that has a significant economic impact through contribution to the fiscus, generation of significant foreign exchange revenues and providing decent jobs to about 11 600 employees [1]. The case study organisation is one of the big players in the aluminium industry that produces aluminium products that include rolled products, extrusions and containers. Rolled products are supplied as a range of specialized and standard aluminium rolled products to customers locally and internationally, for use in packaging, transport, automotive, engineering and construction markets. The container products include rigid aluminium foil containers that are used for the catering industry and household use. Flow is regarded as an essential part of the system to help the organisation to achieve its targeted throughput and deliver material on time and in full to its customers [2]. Batch splitting and delayed material arrival at the destined machines for further processing in a specified sequence, are some of the reasons that lead to inefficiencies in the downstream machine centers. The aim of this study is to identify the root causes of ineffiency in coil transportation and develop measures to ensure proper flow of coils in the production system.

2 LITERATURE REVIEW

The principle of processing aluminium alloy sheet embraces understanding process parameters and the metallurgical effects from sheet ingot or slab casting, homogenisation, hot and cold rolling and annealing [3]. Papanagnou *et al.* [4] conducted a study where aluminium coils production process was modelled and simulated to improve throughput and makespan through timely decision making. The production process was divided into key steps that include scalping, hot rolling, annealing, cold-rolling, side trimming, stretching and degreasing. These steps can be divided into three key phases, the first phase includes delivery of slabs, scalping, hot-rolling and tandem mill process which take place in the Hot-Line shopfloor. The second phase includes integrates temporary storage, annealing and cold rolling processes, in the high-bay area. The last third phase includes levelling, stretching and degreasing, quality control and final storage.

Ganguly [5] used the DMAIC Six Sigma approach to improve the process for rolling mill to address the challenges that were being faced by an aluminium organisation. Considering its existing resources, the company was facing operational challenges when trying to cater to the fast-changing customised export demand for flat-rolled products. Hence, the study was aimed at developing hot rolling mill capability for wider widths hard alloys rolling and remove downtime emanating from strip slippage during hard alloys rolling during hot milling. The team identified the prevailing situation of the rolling mill operations and applying Six Sigma DMAIC methodologies to define the possible causes, identify the sources of variation, and established variable associations and implemented control plans.

Stamatis [6] explained Failure Modes and Effects Analysis (FMEA) as a logical, practical method for the evaluation of a process to ascertain where and how it might fail and as well assess the relative effect of diverse failure modes, with the view to establish the process elements that should be improved. FMEA is therefore characterised by the following steps; failure modes (establishing what could go wrong); failure causes (understanding what would cause the failure to happen); and failure effects (comprehending the consequences of each failure) [7, 8]. On the other hand, Khaloo *et al.* [9] posited that the key to success as well as a critical part of any health and safety programme is grounded on identifying, assessing, eliminating, and controlling hazards at the workplace. An environmental failure mode and effect analysis was employed to identify possible environmental risks, analyse the risks that characterised the environment, and established the highest risk priorities for the aluminium rolling industry.

Stamatis [6] proposed a novel methodology of measuring uncertainty for FMEA assessments and applied the improved model in sheet steel production to verify the reliability and validate the proposed method. Basing on the measure of ambiguity in the evidence theory, the uncertain degree of subjective assessment from FMEA experts was addressed. The uncertainty of FMEA assessment was then transformed into the weight of each FMEA expert and the respective significance of each risk factor. More comprehensively, the assessment from different FMEA experts was thereafter fused through enhanced Dempster's rule of combination and the Gray Relational Projection Method was deployed to derive the ranking of failure modes to overcome the limitation of the traditional RPN-based ranking method.

On the other hand, Pancholi and Bhatt [10] investigated the failure of the aluminum wire rolling mill by using a gray-complex proportional risk assessment and preference section index. The study aimed to establish the extent to which the reliability of an aluminium wire rolling mill can be enhanced by utilising current maintenance and control practices. It was found that it is crucial to prioritise maintenance activities through comparative analysis of results that are derived from diverse failure analysis models.

3 METHODOLOGY

After gathering all the necessary problems concerning the current system as to its inefficiencies, the project was divided into different phases.

- Phase 1 - The current process was studied and represented on a flow diagram for simplification and to be able to visualize the process as a whole. A walk-through the plant was done to identify all the process steps.
- Phase 2 - The As-Is process that was documented in the first phase was then studied for errors and critical failure points and comments to each node were noted and validated against system users. The essence was to ensure and measure its impact on the flow of material and production in the company. The process flow with identified potential failure points were flagged as red stars to highlight possible Kaizen burst events.
- Phase 3 - A Failure Mode and Effect Analysis was implemented to document and analyse the failures and try to implement mitigating factors while also providing a control plan. This was made to ensure that the project would have a positive impact and beneficial to the company.
- Phase 4 - After all the investigation and data gathering, a new method was proposed in a form of a process flow to show some corrections and new changes that were to be introduced on the system. The demarcation were made for facility layout at Plant Z and the paint barcoding system.

4 CASE STUDY BACKGROUND

Coil Transportation is the process of moving the metal and lot tickets from one place to another for further processing (e.g. CDHM to Cold Mills or Coil Processing, S4 to Plate Plant). The manufacture of aluminium rolled products is characterised by coil transportation, which is a process of moving the metal and lot tickets from one point to another for further processing at other sub-plants. Coil transportation is vital for ensuring proper flow of coils in the production system, with flow regarded as the essential part of the system with regards to achieving manufacturing targets, delivering material on time and fulfilling customer orders. From the analysis, the indication is that the process is not meeting the primary targeted scheduled adherence of 100%, with an actual average of 52% in the last 3 months and not meeting the target number of between 80-100 coils per day, the percentage is 58%. The objective of the study is to clarify the measurements, indicate factors leading to the gaps and introduce the system to help standardize the process and extract KPI data to help manage this transportation activity. Figure 1 shows the graph of the trend of the coils sent from hotline to Plant Y (cold mills) over a month. The graph is a representation of the ratio between coils sent to Plant Y that were on the requested list as compared to the initial requirement in the list.

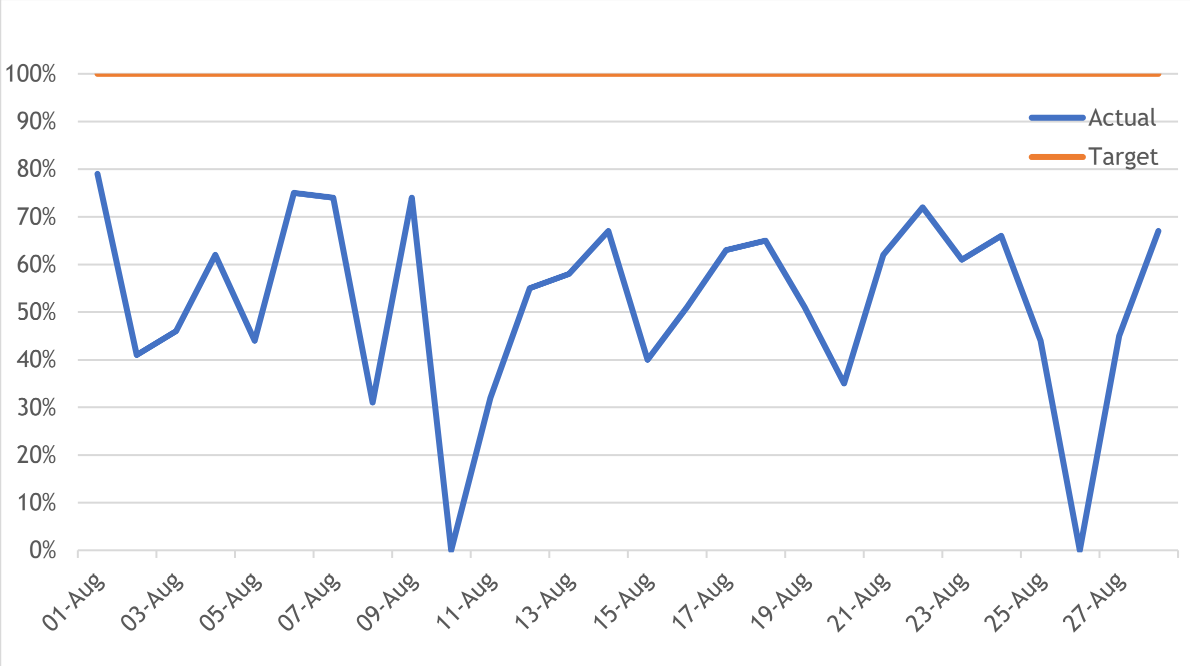

Figure 1: Trend showing the daily performed Adherence to Schedule for August 2019

5 RESULTS AND DISCUSSION

5.1 As-Is Flow critical failure points

The current method is a complicated and tedious process and biased, as it does not measure the rate at which the plant accommodates for delivery of coils. It also does not take into account major activities that might hinder the coil transportation e.g. shearing days(when the mill is occupied with rolling plates thicker than 15mm, the cranes and other supporting equipment get held up on that activity, other tasks like coil transportation do not happen in that period. This activity takes plus or minus twenty-four hours). The black boxed nodes clarify the failure points for each process node. Figure 2 shows the process flow with identified potential failure points shown as red 16 point stars highlighting possible Kaizen burst events.

The coil transportation system is manual, not reliable and human dependent; there are also not enough self-monitoring reports as it relies on individuals to record the information. The logistics coordinator receives the list of requested lots from the Plant Z sequencer. The logistics coordinator will also submit the list to the plant where the truck drivers locate the coils and lot tickets. The crane driver by the instruction of the coordinator and driver loads the coils onto the truck for dispatching to Plant Y, upon departure the truck driver records the exiting time onto the log sheet and records the arrival time when the driver reaches the destination.

The lot tickets are then placed onto the ticket box after delivery to be collected by a sequencer for scanning to confirm lot arrival. If there is, anything that becomes a problem in the system during the task the driver will manually record it on the rear of the log sheet. The log sheets are stored in a box for future reference or when they need to access past information regarding deliveries. Sequencers collect the lot tickets at different intervals for scanning.

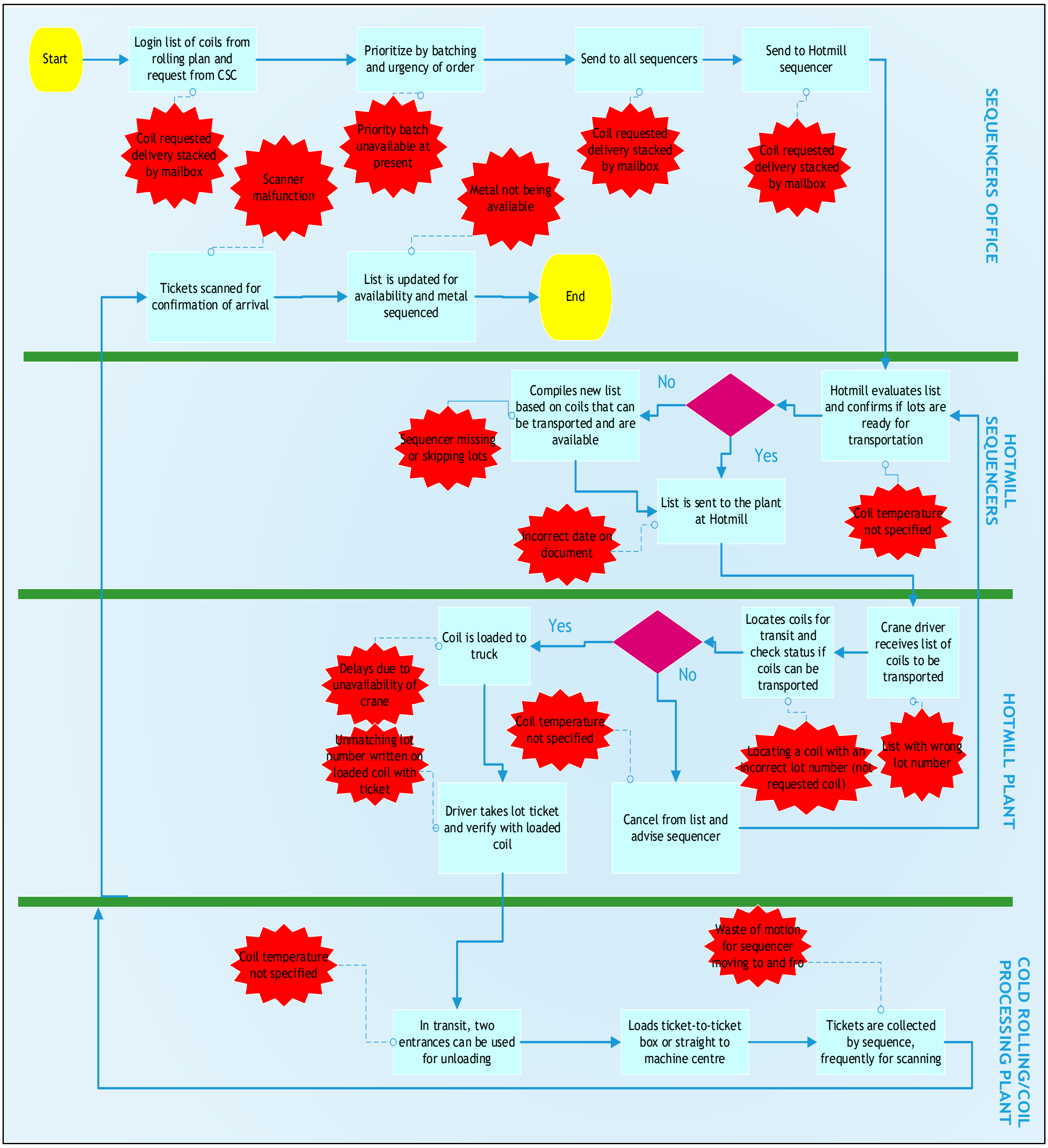

Figure 2: Process Flow with identified potential failure points

The major irregularities in the system include:

- Lack of communication between requester and receiver
- The system is people dependent
- No proper delay logging mechanism e.g. offloading delays
- The system is not mistake proofed thus exposed to mistakes/ human error
- Relies on individuals to generate reports for system usage
- Unable to produce reliable KPI’s

The current system does not allow the full presentation to the business of the effectiveness of the process as it becomes difficult for individuals to agree on the measures because they are not measuring the same thing. The system is static and does not have proper KPIs to report to the business. Most of the coils requested are hot, not ready to be transported. The current system is not monitored, the data is not reliable because some of the coils requested are already on the destination requested to and some requested coils have problems from non-conformance report [11] and quality issues. Coils delivered current performance is recorded on an excel spreadsheet, which is updated by a human, of which sometimes it is not updated due to absenteeism.

5.2 Failure Modes and Effects Analysis

Table 1: Failure Modes and Effects Analysis

Process	Potential Failure Mode	Potential Effects of Failure	Mitigating action	Control Plan
Login a list of coils from the rolling plan	The list is too static and coil status might change	• Coils with NCR might be transported • Coils that may have been transported already might be on the request list	• Coils transported should not appear as available coils to be transported • NCR coils should not be selected when compiling a request list	System
Prioritise by batching and urgency of the order	Batching of unavailable coils to transport	Batches might break and increasing changeover on the next operating machine	Colour-code lots of the same batch to make them easier to spot if there is a deficiency	Have a min and max batching rules for the different specs
Send to all sequencers	Email stuck on outbox folder	Late arrival of email causing delays in the process	Update and send email via BES	Ensuring all participants have access to the coil transportation app
Send to Hotmill sequencer	• Email stuck on outbox folder • Inbox of recipient full	• Not receiving sequence on time • Sending of coils without a proper batching quantity	Send the coil request list via the coil transportation app	Ensure the members utilise the system by using KPIs for coil movement
Hotmill evaluates list and confirm if lots are available for transportation	Disturbance in lot planning request from Plant Y sequencer, thus machine might stand or more changeovers due to different incoming specs	Different specs lower machine throughput rate due to high changeovers	All sequencers must use the coil transportation app to streamline communication flow on requirements and availability of materials	Train users on the use of the coil transportation app and use of different codes for material
Crane driver receives list of coils to be transported	Outdated list sent to crane driver	Time lost due to searching of dispatched coils	Monitor device to view the requested list of coils in real time	Monitor must also be available to sequencer to ensure feasibility of coils requested and compliance of driver
Locates coil for transit and check the status of coil if it can be transported	Locating coil that does not fully match the requested lot number (not requested coil)	Unscheduled coils filling up space in the racks	Coils must have a bar code matching the lot ticket to the lot number and must be scanned for departure and arrival	Colour coded scanner to ensure correct transportation of material

Table 1 shows a summary of the Failure Modes and Effects Analysis. Concerning the list sent to the plant for Hotmill, it was noted that the list might be containing high-temperature coils, with potential effects of failure which include delays in transporting coils, poor adherence to schedule, breaking of batches, and machine idle due to no work. The mitigating action would be to provide the shopfloor with a screen device to view the list on the coil transportation app, provide live data on the monitor for any changes in the batching arrangements, and enforcing the scanning of materials before sending to Hotmill.

It was also noted that the truck driver might load incorrect coils that do not match the provided lot ticket when the coil is loaded to a truck, thereby leading to delays in the batching system for the next operating machine, breaks the sequence flow. As a solution, coils must be clearly labelled for the truck driver to see, coils on the request list must be separately located, coils must have a bar code matching the lot ticket to the lot number, and the shopfloor members must monitor the process continuously from start to end.

5.3 Proposed Process

The proposed continuous improvement initiatives focus on four critical factors to be taken into account for the system and these include:

- The shift patterns for each department
- The number of vehicles available daily
- The time to load and unload coils
- The arrival and departure at the sites

Figure 3 shows the process flow diagram for the proposed systematic procedure and the change put more emphasis on how the coils are requested from/by the sequencer and how the process is carried until shop floor level. Using Outlook as the primary source for the process will be diluted by the introduction of an app that is/will be on BES to help fast track and fool-proof the process. The system that relied on the driver engaging in paperwork and will be subjected to change with the introduction of the scanners and stickers. The system will also fool-proof the transportation of the correct coil against the lot ticket.

The proposed transportation system will be embodied into the system thus communicating with its stated KPI’s to provide a live fed in terms of the progress. Further designs and capabilities will be negotiated with relevant parties.

The driver must be able to scan each coil as it is placed on the tractor. The location of the metal must then become “INTRANSIT” and the time scanned reflected on to the system and logged. If the metal has an NCR the coil must restrict to be loaded on the requested list, in the event of the material changing status to becoming NCR, the operator must be warned and the coil should be taken out of the truck unless there are exceptions. This is to ensure that NCR’d material is not to be transported for further processing. When the driver is ready to leave CD he will scan it out as opposed to recording it on the log sheet, the time of departure is to be logged. When the driver delivers these tickets he will scan them against the coil as a confirmation that the coils have been delivered as opposed to signing in the log sheet. These will again serve as a confirmation that the correct coil with the correct lot ticket has been delivered to the right destination. The delivered coil will then be automatically removed from the transportation list on the app. As soon as the driver scans the last coil a trigger is sent to the loading bay indicating an incoming truck for loading. The process will continue as indicated for further deliveries.

The sequencer must be able to access the daily WIP on the app at BES same as in Oracle Discover (WIP INVENTORY). The sequencer must toggle the list up and down until the desired effect and save plus approve. The driver must be able to scan each coil as it is placed onto the trailer. The location of the metal will change to reflect in transit on the system/app and the time scanned recorded. A sticker should be printed and attached to the lot ticket indicating the next machine and other useful details. Metal containing an NCR will be identified using a different color on the system and it should restrict being loaded to the list.

Should a material status change the information will be updated onto the system and the driver will be warned and he must remove the coil from the trailer, thus ensuring that no NCR'd metal is transported for processing. The system must be uploaded with standard times for all the different activities to enable auto delay trigger should activities last longer than the allowed time.

The coils must be scanned as soon as they arrive by the driver to change the status to delivered in the system and again put to the ticket box.

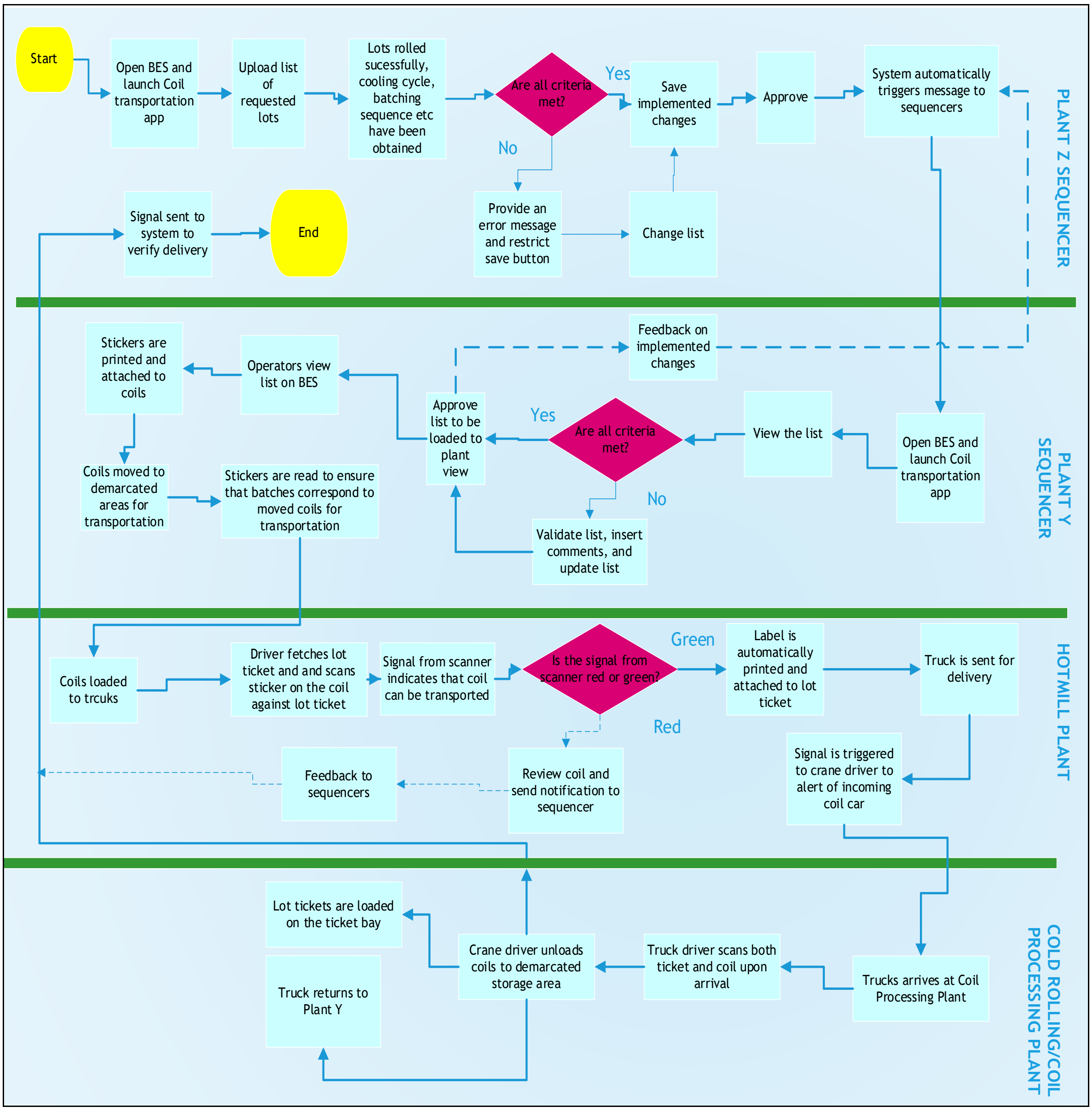

Figure 3: Process Flow showing the proposed systematic procedure

The snag list for coil transportation app would include the following:

- Dispatched lots remain within the system
- There must be color-coding on the system to easily visualize the lots with different statuses e.g. temperature whether the metal is cool or still in the cooling process
- There is a need for two different views of the system as opposed to the current single view
- The system must be able to move or allow the user to drag and drop lots in the system

5.4 Summary of benefits from proposed changes

Table 2 shows a comparison of the scenario before continuous improvement initiatives and after the implementation of proposed changes. The results demonstrate an improvement of schedule adherence from 58% to 80%. The average coil lead time also reduced from 3 hours to 2.2 hours due to elimination of errors such as locating a coil with an incorrect lot number (not requested coil) and reducing waste of motion for sequencers.

Table 2: Comparison of before-and-after continuous improvement initiatives

Parameter	Before continuous improvement initiatives	After implementation of proposed changes
Scheduled adherence	58%	80%
Average coil lead time	3 hours	2.2 hours

6 CONCLUSION

There is always room for improvement of material handling system for coil transportation in the manufacture of aluminium rolled products. FMEA is a handy industrial engineering tool that can be deployed to assess the relative effect of diverse failure modes, with the view to establish the process elements that should be improved. The system was performing at 58% against the targeted 100% due to the systematic manner by which the request was sent through from Plant Y to Plant Z and how the information is filtered through to the shop floor for execution. The BES system was installed and the compliance to the schedule improved from 58% to 80% by end of the year. Facility layout and Paint Barcoding system at Plant Z are the other phases which are part of work-in-process to be completed. The implementation of the coil transportation project was beneficial because it fostered teamwork. The team had to pay attention to detail and identified the root causes of ineffiency in coil transportation and developed measures to ensure proper flow of coils in the production system.

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IMPROVEMENT OF A BEER PACKAGING LINE THROUGH PARETO ANALYSIS, ROOT CAUSE ANALYSIS AND STATISTICAL TRACKING

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ABSTRACT

It is imperative for players in the beer industry to increase efficiency continuously to stay ahead of the competition. The prevailing performance of a beer packaging line in terms of engineering stops at the case study plant was below the target set by management, and therefore improvements were vital. This paper outlines the improvement of a beer packaging line through Pareto analysis, root cause analysis, and statistical tracking at a beer producer. The procedure commenced with gathering the data for the line and conducting a Pareto analysis on beer loss. It was found that bottle conveyors' downtime was caused by bottle breakages which was also resulting in beer loss. A root-cause analysis was conducted for high filler fallen bottle stoppages and possible solutions for process improvement were then formulated and the best solution was implemented. T-Tests were finally deployed as a means of statistical tracking and the results demonstrated a significant process improvement.

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1 INTRODUCTION

The current beer market is heavily characterised by an endless change in consumers' preferences [1, 2]. As a result, the beer production industry is extremely competitive leading to participation by almost all nations in the world. The beer industry thrives for sustained consumer satisfaction by committing to quality and process enhancement to augment unsustainable operating costs and boost competitiveness [3]. The market in South Africa has experienced a surge of smaller and independent breweries, who sell locally and have direct contact with consumers. Therefore, it is imperative that bigger players in the beer industry continuously increase their efficiency and reduce operational costs through the production of more products while utilising fewer resources if they are to remain competitive. Waste during beer production increases production costs and impacts efficiency. It is against the backdrop of rising competition that the case-in-point brewer must ascertain the root causes of beer loss during the packaging process and institute cost-effective measures on the packaging line to reduce or eradicate the loss. This paper adopts a focused improvement approach to improve a beer packaging line through the deployment of Pareto analysis, root cause analysis, and statistical tracking.

2 LITERATURE REVIEW

The beverage industry is one of the world's largest industrial sectors that contributes significantly to national economies [4]. Therefore, the brewing sector holds a strategic economic locus and creates a lof of jobs in these economies. Tsarouhas [5] argued that there is a strong connection between manufacturers and their customers who demand that the products should be delivered on time with the proper quality, basing on market requirements. Modern industrial systems would apply automation such as conveyor systems and other advanced technologies to produce quality goods in the right quantities. This study will focus more on the beer packaging line since the statistical analysis will be carried out using data from this specific process.

A beer packaging line can be described as indicated by Groover [6] as a set of mechanised and automated devices that perform various assembly tasks in a fixed sequence of assembly steps on a particular product being produced in bulky quantities. A beer bottling facility would be characterised by a filling machine with several filling positions, and each filling device would supply the liquid filling material to a specific filling position [7]. A predetermined volume of beer would be injected into the bottle to a predetermined level of beer by a filling device, and the filling process will terminate when the beer has reached the predetermined level in the bottle. Conveyance systems such as conveyors may be used to move bottles between stations [7].

A typical beer packaging line for returnable bottles as shown in Figure 1 is characterised by the movement of palletised crates from the warehouse, depalletisation, decrowning and empty bottle unpacking, bottle and pallet cleaning, bottle filling and crowning, labelling, and palletising [8]. The packaging line consists of four machines that include the filling/crowning machine, conveyor belt, packing machine and palletizer. It is a subsystem of the beer production line and the rotary filling/crowning machine is fully automated and the transmission system is driven by motors, through a synchronization control system. A typical filling/crowning system is characterised by a hopper, which is a container for parts, parts feeder for removing crowns from the hopper, selector and orientor mechanism to assure that crowns are in proper orientation for capping, feed track and escapement and placement devices [6]. The material handling system is characterised by movement of empty bottles to the machines for washing, filling, crowning, pasteurising and labelling ensuring their removal from the machine after their filling [5].

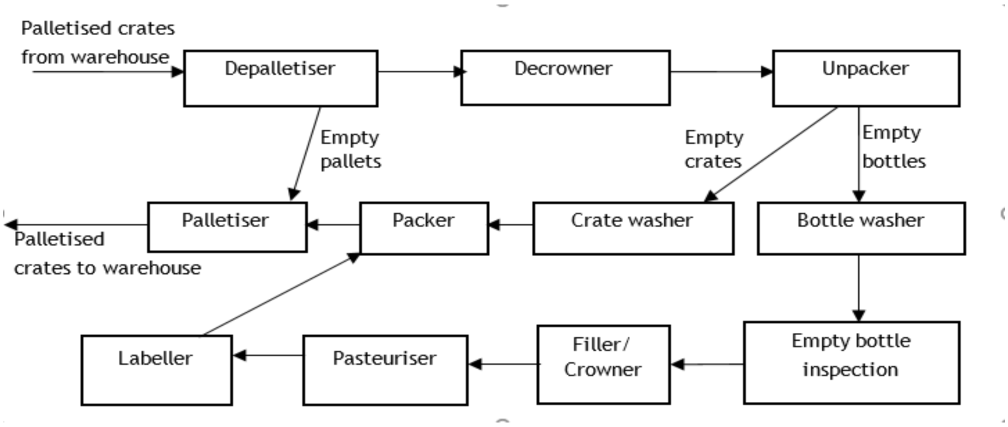

Figure 1: Flow diagram for beer packaging operations, (Adopted from [8])

An organisation must use a maintenance policy that is tailored to meet its maintenance requirements for its packaging line. As posited by [9], high food standards characterise the food industry where production is accomplished by advanced and complex equipment that should operate optimally to meet the demand. Hence, unanticipated failures would lead to emergent stoppages in production and non-compliance with production plans, and that should be avoided. This study focused on the problem of poor packaging line reliability that was manifested as bottle conveyors downtime which was caused by bottle breakages which was also resulting in beer loss. Tsarouhas and Arvanitoyannis [5] conducted a reliability analysis for packaging of beer production and used field failure data to assess the operational management for the beer packaging line. They found that the currently applied maintenance policy of the beer filling and crowning machine was corrective maintenance that was characterised by recognition, isolation, correction and operation checkout. Isolation can be described as localization and diagnosis of maintenance problem, while correction is characterised by disassembly, removal, replacement, reassembly and adjustment.

The Deming Cycle or Plan-Do-Check-Act (PDCA) is a four-step iterative technique for continuous improvement, which is used to improve organizational processes and to solve industrial problems [10]. The beer packaging process efficiency can be improved by exploiting the Deming PDCA Cycle. The planning phase is characterised by the identification of the goal of the improvement project, prescribing the optimal metrics and developing a plan of action. The Do step is characterised by the execution of the plan. The Check step is aimed at monitoring the outcomes to assess the validity of the plan and establish signs of progress or areas for improvement. The Act phase closes the cycle by embracing the lessons that were learnt from the project. These four steps are replicated as part of a continuos improvement process in an organisation [11].

An Ishikawa or cause-and-effect diagram is a Kaizen tool that can be used to identify and display possible causes of a particular problem [12]. Matende [13] conducted a study to optimise packaging operations for a beer production line by using lean manufacturing tools to identify bottlenecks and determine line efficiency loss. An Ishikawa diagram was used to identify root causes of the problem, and palletiser and depalletiser machines were identified as bottlenecks. Adopting a new preventive maintenance strategy and implementation of line balancing techniques resulted in waste reduction for the packaging operations [13].

3 RESEARCH APPROACH

A systematic methodology was deployed to reduce downtime of bottle conveyors which was caused by bottle breakages and thereby resulting in beer loss for the packaging line. The first step in the methodology was problem definition, which was characterised by comprehending the problem by formulating the problem statement, understanding the project scope, and establishing whether the problem was measurable. It is vital to explicitly understand the problem and comprehend its scope since failure to properly define or fully appreciate the scope of the problem would yield a mismatch between the problem and proposed solution, thereby resulting in solutions that do not satisfactorily mitigate the problem at hand. The problem was found to be bottle conveyors downtime which was causing bottle breakages and resulting in beer loss. The project scope embraced all bottle conveyors from the movement of palletised crates of empty bottles from the warehouse to the movement of palletised crates of filled bottles to the warehouse. Using the data for the SAP or data warehouse system, the problem was found to be measurable and was calculated by using the following formula:

Downtime = Filler stoppage time until the filler runs at full speed

The second step embraced gathering the data about the problem and conducting a Pareto analysis to identify the machines or processes that contributed to high bottle conveyors downtime that was causing bottle breakages. The third step in the methodology was to describe the problem accurately after gathering all the data related to the problem and drawing a fishbone diagram for root-cause analysis. Through visual observation, it was vital to verify if the system was operated according to the prescribed standard operating procedures, and as well as to establish if the standard maintenance procedures were being observed.

The fourth key step in the methodology embraced identifying process improvements by applying the verifications that were chosen for exploration in step 3. The fifth step in the methodology was characterised by selecting the best possible solution and implementation of the possible solutions through the Deming's PDCA cycle. The sixth key step in the methodology embraced close the loop and developing a maintenance program to reduce bottle conveyors downtime. Lastly, the results were analysed after the implementation of the Deming's PDCA cycle, and the actual and target values were tracked to verify if there were improvements in reduction of bottle conveyors' downtime figures.

4 DEFINITION OF PROBLEM AND IMPLEMENTATION OF SOLUTIONS

4.1 Problem definition

Historical data on the performance of the beer packaging line was retrieved from performance records. Data was drawn from the SAP ERP system for the brewery and Figure 2 shows a summary of engineering stops for the packaging line. Major engineering stops of above 7000 stops per year were noted for the bottle washer, bottle filler and bottle conveyor. The crowner, palletiser and crate washer experienced the minimum number of line stops per month. In this study, less attention was paid to the bottle washer since the empty bottles did not affect beer loss. The filler and the bottle conveyor were considered for the study since bottle conveyor stoppages affected the filling machine as well.

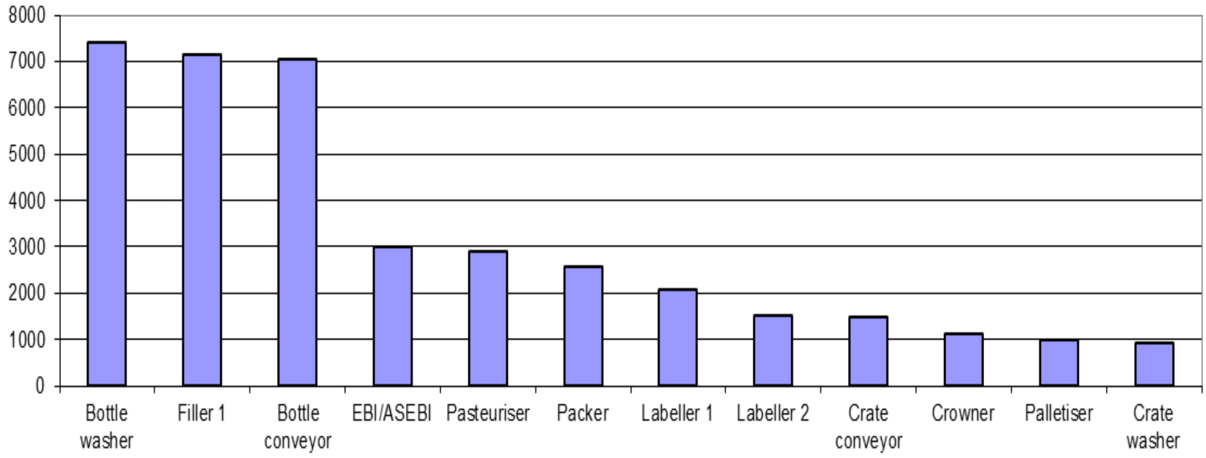

Figure 2: Summary for packaging line engineering stops

Figure 3 shows a summary of bottle conveyor stops for the packaging line. The highest number of stoppages due to fallen bottles were experienced at filler followed by Empty Bottle Inspection (EBI). The EBI system is an inline empty bottle inspection system that is capable of inspecting up to 80000 glass bottles per hour. The inspection checks include bottle mouth inspection, outer sidewall inspections, inner sidewall inspection, bottle base inspection, high-frequency residual liquid inspection, infrared residual liquid inspection, and thread inspection.

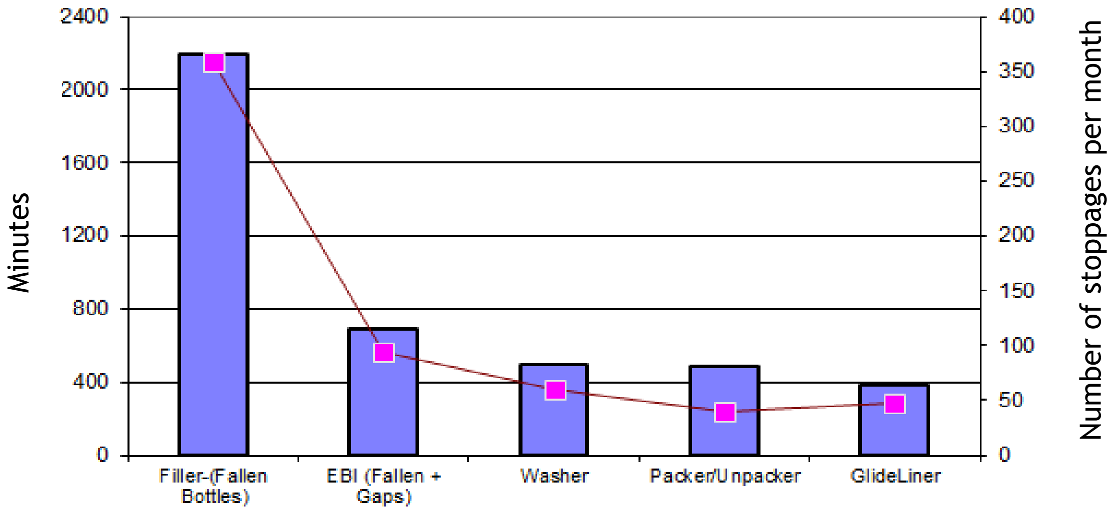

Figure 3: Summary for packaging line engineering stops

Therefore, in line with proper problem definition, the problem was found to be filler fallen-bottle stoppages that were resulting in beer loss.

4.2 Potential causes for filler fallen-bottle stoppages

An Ishikawa or cause-and-effect diagram was used as a continuous improvement tool to identify and display possible causes for filler fallen-bottle stoppages. The causal factors were established from brainstorming sessions and information obtained from the maintenance department. More causes of filler fallen bottle stoppages were noted from man-machine challenges. It was revealed that some of the operators were failing to follow the right operating procedures hence resulting in more filler fallen-bottle stoppages. The operator mistakes include incorrect wear strip fitting; incorrect filler/crowner timing; incorrect neck guide alignment, and incorrect setup guides. The machine causes for crowner fallen bottles stoppages included loose guides; worn guides; burrs on wear strip, worn bottle pads; incorrect transfer dead plates, worn piston springs; broken piston rod; worn compensation springs; and worn crowner star wheel. Other material causes for crowner fallen bottle stoppages would include bottle and crown defects.

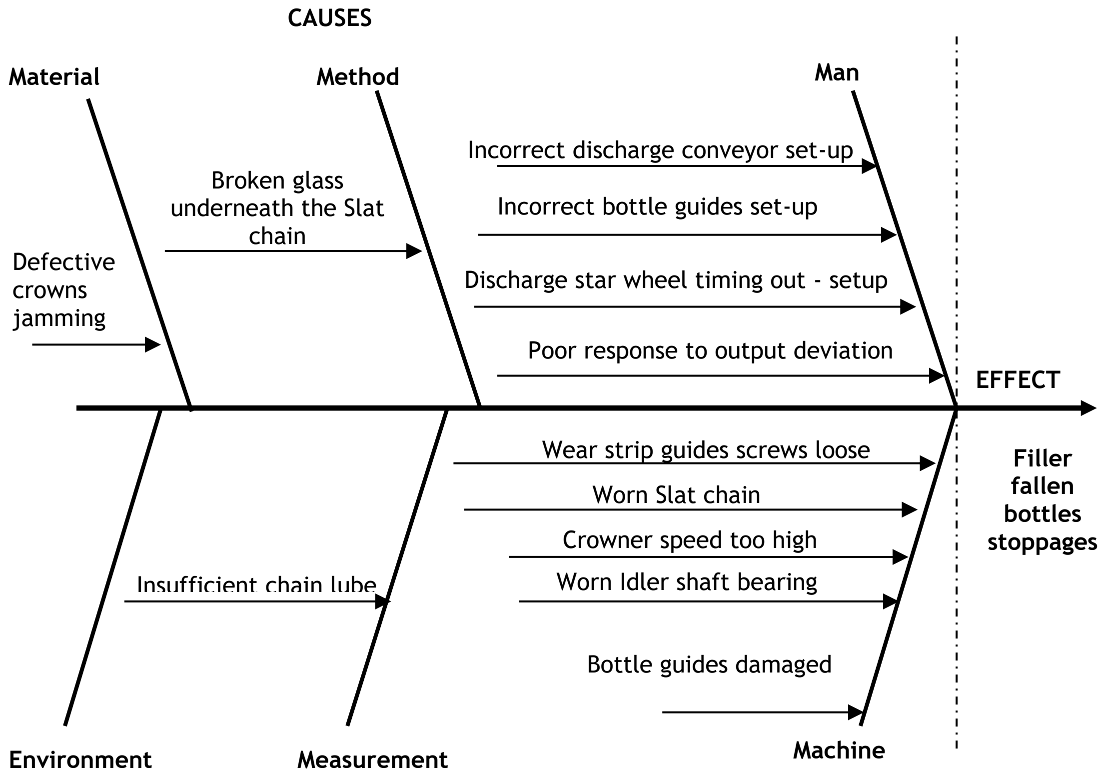

Figure 4: Ishikawa diagram for filler/crowner fallen bottles stoppages

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 incorrectly EBI discharge conveyor set-up and incorrect bottle guides set-up, the essence of periodic job observations (PJO) enhance quality and promote continuous improvement. The team leader and supervisor use an operator instruction sheet (OIS) to observe employees as they are executing their duties doing a job. The OIS is a customised job description for each of the jobs that are executed on the shop floor.

Table 1: Troubleshooting potential causes for high filler fallen bottles stoppages

Potential root cause	Inspection	Observation
Incorrectly EBI discharge conveyor set-up	Perform PJO to check EBI discharge conveyor set-up	No issues were observed
Incorrect bottle guides set-up	Perform PJO to check EBI discharge conveyor set-up	No issues were observed
Discharge star-wheel timing out - setup	Perform PJO to check discharge timing after Pack change	No issues
Broken glass underneath the Slat chain	Check if there is broken glass underneath slat chains after maintenance day	No issues

Potential root cause	Inspection	Observation
Insufficient chain lube	Check if there is enough chain lube on the infeed and discharge conveyor	No issues
Worn Slat chain	Check for worn slat chain	Infeed and discharge slate chains were worn
Worn Wear strip guides	Check for worn wear strip guides	Some wear strip guides we worn
Wear strip guides screws	Check if the wear strip guides screws are	No issues
Worn Idler shaft bearing	Check for worn idler shaft bearings	Discharge idler shaft bearings were worn
Bottle guides damaged	Check for damaged bottle guides	No issues
Worn returning rollers	Check for worn return rollers	No issues
Worn Idler sprocket	Check for worn idler shaft sprocket	No issues

4.3 Implementation of possible solutions

These solutions included creating a schedule to replace slat chains, idler shaft bearings, and wear strip guides. It was also imperative to check if the bottles are still falling due to the worn slat chain and act on any deviation from the plan. Table 2 shows the PDCA steps which were followed for the implementation of possible solutions.

Table 2: Steps for the PDCA cycle

Step	Description	Responsibility	Status
Plan	• Create a schedule to replace the slat chain • Create a schedule to replace Idler shaft bearings • Create a schedule to replace wear strip guides	Industrial Engineer	Completed
Do	• Replace slat chain • Replace idler shaft bearings • Replace wear strip guides	Industrial Engineer	Completed
Check	• Check if the bottles are still falling due to worn slat chain	Industrial Engineer	Completed
Act	• Act on any deviation from the plan	Industrial Engineer	Completed

In order to close the PDCA loop, it was critical to do the following tasks:

- Create a continuous schedule to check slat chain condition or review the frequency;
- Create a continuous schedule to check idler shaft bearings condition or review the frequency;
- Create a continuous schedule to check wear strip guides condition or review the frequency.

5 RESULTS AND DISCUSSION

The implementation of possible solutions led to the improvement of the packaging line in terms of reduction of filler fallen bottle stoppages. These include corrective maintenance procedures such as replacing the slat chain, replacing idler shaft bearings and replacing wear strip guides. Figure 5 shows a comparison of before and after scenarios for filler fallen bottle stoppages. The results demonstrate that there is a noteworthy improvement after the interventions on issues that were highlighted by the Ishikawa diagram for filler/crowner fallen bottle stoppages.

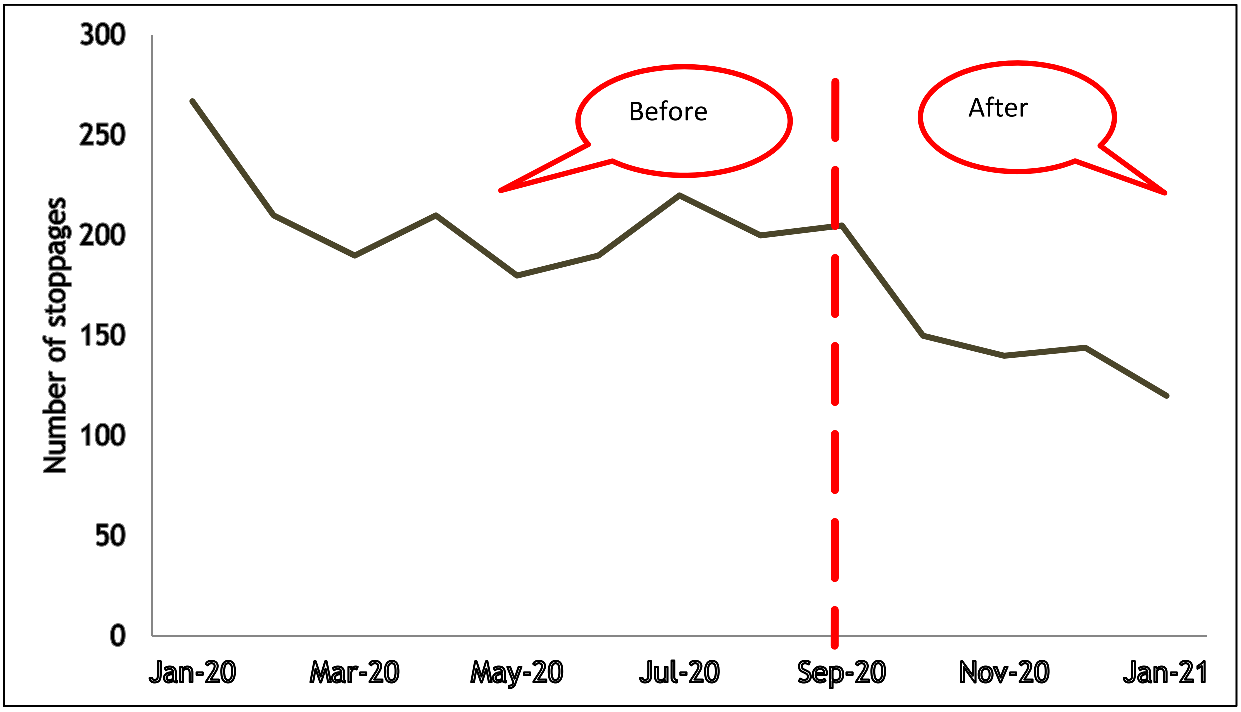

Figure 5: Comparison of before and after scenarios for filler fallen bottle stoppages

The results were also validated to establish whether the process changes were responsible for the decrease in the number of filler stoppages or whether it was all due to chance. T-Test can be used to execute a two-sample data sets from two independent populations with unequal variances and can be either one-tailed or two-tailed depending on whether one population mean is greater than the other or if the two population means are different [14]. After initially stating the null hypothesis as population means for the two samples as equal, an independent samples T-test was then deployed to validate the results. The level of significance was set at p = 0.05 to reject the null hypothesis, hence if the p-value is found to be ≤ 0.05, that means the two means of the before and after scenarios are significantly different. Conversely, if the p-value is > 0.05 then the null hypothesis is not rejected. Table 3 shows the t-test results of the two samples assuming unequal variances.

Table 3: t-test results for two samples assuming unequal variances

	Before	**After**
Mean	208	125.5
Variance	642.25	312
Observations	9	8
Hypothesized Mean Difference	0	
df	14	
	Before	**After**

t Stat	7.853187	
P(T<=t) one-tail	8.49E-07	
t Critical one-tail	1.76131	
P(T<=t) two-tail	1.7E-06	
t Critical two-tail	2.144787	

Statistical tracking was used to validate the results and given that P (T <=t) for the two-tail test is less than 0.05, the null hypothesis is therefore rejected and one can conclude that there has been a noteworthy difference between the before-scenario and the after-scenario.

6 CONCLUSION

The study focused on the improvement of a beer packaging line through the deployment of Pareto analysis, root cause analysis, and the use of statistical tracking to validate the results. It was noted that waste during beer production is a challenge given the escalation of production costs and compromisation of the efficient use of resources. Lean manufacturing tools can be used to identify bottlenecks and determine losses in line efficiency, and thereafter provide solutions to optimise packaging operations for a beer production line. It was also noted that the PDCA is an iterative technique for continuous improvement and can be exploited to improve the beer packaging process efficiency. The root causes of beer loss during the packaging process as a result of filler fallen-bottle stoppages were identified and cost-effective measures on the packaging line were instituted to reduce the loss. Statistical tracking can be used to validate the results of a continous process improvement in production systems. A further research study may embrace recent developments in big data and analytics to foster continuous improvement initiatives in packaging processes for breweries.

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FACTORS IMPACTING SUPPLY CHAIN MANAGEMENT PERFORMANCE: A META-ANALYSIS OF SELECTED SOUTH AFRICAN MUNICIPALITIES

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ABSTRACT

The study examined the factors impacting supply chain management (SCM) performance in South African municipalities. This research main aims were to emphasise compliance with SCM systems by curtailing and separating the functions and duties of all responsible parties in SCM. Quantitative data was collected through a survey sent via e-mails to respondents with a response rate at 100%. The results of this study established that there is no sufficient competence to implement effective SCM systems in municipalities due to unwillingness to comply with relevant policies and regulations and a general disrespect for internal controls and lack of accountability that led to an increase in irregular expenditure. The research suggests that an adherence to SCM systems by municipal officials, municipalities by means of supply chain performance management can prevent non-compliance with relevant policies and regulations and reduce irregular expenditure. Furthermore, municipal officials should undergo training and refresher courses for municipal supply chain management systems and accountability should be enforced.

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1 INTRODUCTION

Supply chain management (SCM) in a municipal environment is described as a provider for infrastructure and goods or services to its community, whether directly or through accredited prospective service providers [1]. The researcher envisioned to study the effectiveness of SCM systems which have contributed to infrastructure development or supplying of goods and services to its stakeholders and this supply chain performance is reinforced by compliance with policies and regulations in local government sphere to avoid committing irregular expenditure.

In terms of Regulation 9(b) of Municipal Finance Management Act no 56 of 2003 Municipal supply chain management regulation for South African municipalities [2], comprises of effective and efficient supply chain management processes which ensures that value is added at each stage of the process that starts from demand management system, which its main domain is to ensure that the needs of the municipality are delivered as per the specifications and lead to the acquisition management system which ensures that processes are followed to procure goods and services, then logistics management system, risk and disposal management system until performance management system as a monitoring tool to determine whether supply chain management processes were followed in all the steps. It is how efficiently and effective these activities are conducted that impacts on supply chain performance. The purpose of this paper was to determine how effective the current systems in the chosen Municipalities are affecting supply chain performance. the value of supply chain management systems in the Municipalities and influences of supply chain performance.

The study therefore analysed the supply chain systems in each of these municipalities to ascertain their impact on supply chain performance and whether municipal officials are capacitated to implement and ensure compliance with policies and regulations. According to Chandak A, Chandak S and Dalpati [3], supply chain performance can be enhanced by value creation to the end user by increasing the profit of supply chain partners with the help of effective and efficient supply chain strategy. Likewise, the goal of any municipality is value creation that the municipalities thrive to achieve through the supply chain management systems, and the situation stands evident that supply chain systems drive supply chain performance and value creation through compliance with policies and regulations to avoid pointless expenditures.

Research objectives:

- The first research objective was to identify factors that do not contribute to the effectiveness of supply chain management systems at a Municipality
- The second research objective was to assess the level to which supply chain management systems impact supply chain performance in the Municipalities.
- The third objective is to ascertain the root causes of non-compliance in SCM legislations and the reasons for increase in irregular expenditure.

2 LITERATURE REVIEW

The intention of this study was to construct a theoretical basis for the research, which connects to the models of supply chain management systems and supply chain management performance in a municipality. It also gave an insight into the topic and provided an analysis of the functioning of the SCM systems to establish their impact on supply chain performance in the municipalities.

2.1 Supply Chain Management Defined

According to Sharma & Rana [4], a supply chain is well-defined as a set of three or more entities wholly participating in the upstream and downstream movements of products and services, funds, or information from a supplier to a consumer. The successful management of the supply chain as mentioned by Nguegan & Mafin [5] has the effect of improving productivity that in turn increases supply chain performance. Maleka and Ambe [6], are of the opinion that supply chain management aims are not constantly properly aligned with government policies, with municipalities facing dire supply chain problems such as governance, lack of appropriate accountability as well as excellent governance and consisted of the planning and management of all actions involved in the goods or services demand, acquisition, and all logistics administration pursuits.

2.2 Supply chain management model for municipalities

The systems for municipal supply chain management in the public sector consists of six elements (figure 1), which are also stated in the Municipal Finance Management Act (Act 56 of 2003) Municipal supply chain management regulation 9(b) [2] in the same way as follows:

2.2.1 Demand management is where the process begins by ensuring that all needs in the municipality are attended to. This is the process that brings the end user and the SCM practitioners together through the procurement process, which Luke and Mofokeng [7], defined as a series of activities that are essential for the procurement of goods and services and would be directly linked towards the goals of an organisation, management plans as well as stakeholder expectations. While Fourie and Mazibuko [8], defined public procurement by way of the supply chain system for the procurement of goods and services required by the state and its organs in the quest of public interest.

2.2.2 Acquisition management, which involves the actual procurement of the required goods and services in accordance with approved practices only which could be done either through a quotation or bid process.

2.2.3 Logistics management deals with the movement and storage of goods, as well as the fulfilment of orders.

2.2.4 Disposal management is when assets are no longer required by the municipality and are removed from the municipality through a pre-planned and approved disposal strategy.

2.2.5 Risk management deals with the management of unintended outcomes ensuring that they are avoided or prevented from occurring.

2.2.6 Supply chain management performance, which monitors the progress to ensure that the desired outcomes have been achieved.

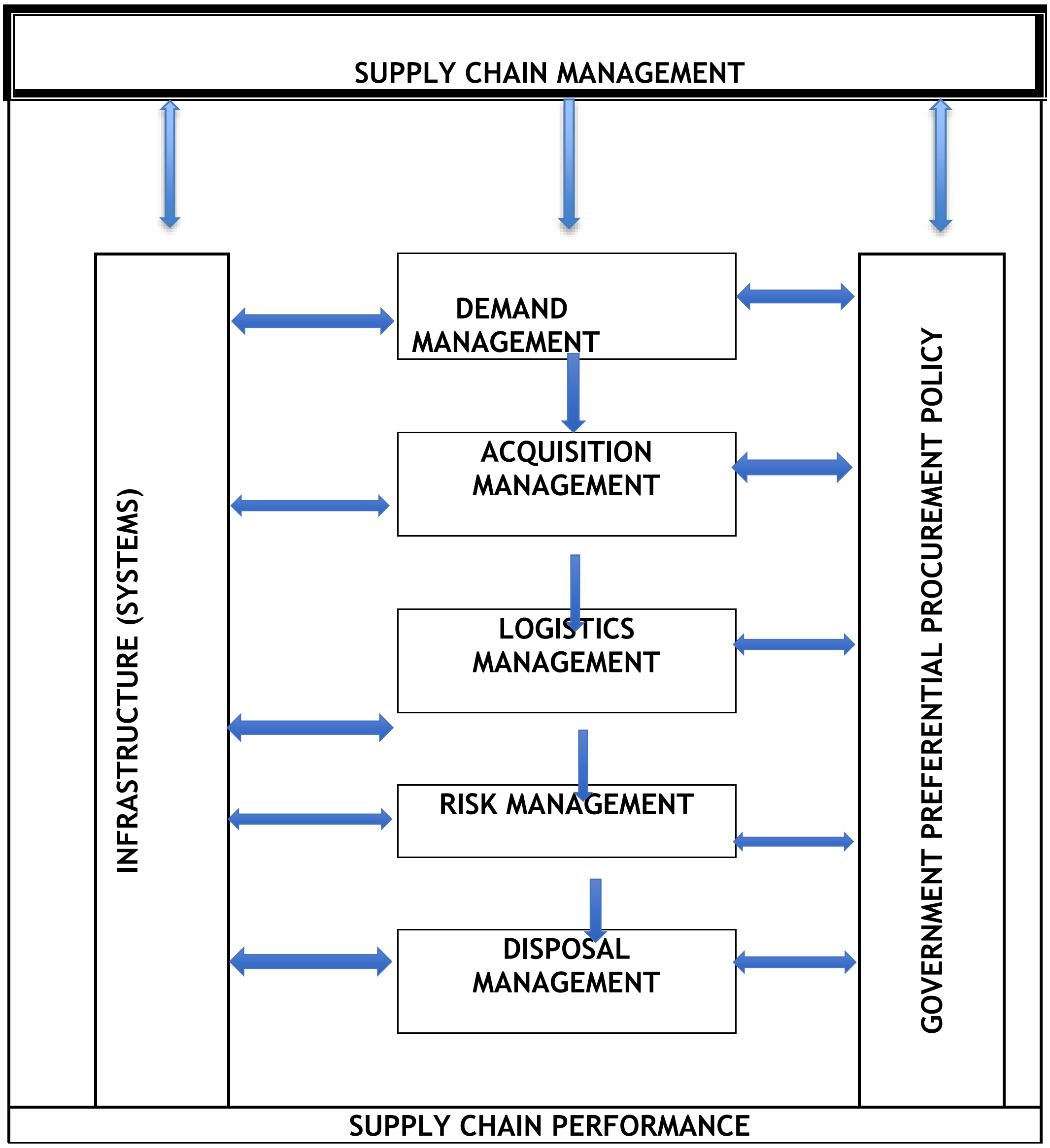

Figure 1: Supply Chain Management System

Source: CDM SCM Policy 2019/2020 Financial Year

2.3 Supply chain management performance in municipalities

Supply chain management performance, according to Mhelembe & Mafini [9] refers to a monitoring procedure of commissioning a retrospective study to determine whether suitable processes have been followed and anticipated results achieved through the supply chain system further state that SCM is meant to drive an organisation's performance by being an important component of the overall plan for the entire chain. According to Sharma & Rana [4], there is still a gap in the performance measurement in supply chain. This is because the currently existing tools to measure performance focus on financial measures, neglecting non-financial measures.

According to Mofokeng & Chinomona [10], the main role that supply chains should play in an organisation is creating value, which can only be achieved through improvement of performance in the supply chain. Figure 1 shows the the value chain creation process.

Figure 2: Value creation process [4]

2.4 Linking supply chain processes with supply chain performance

According to Som, Cobblah & Anyigba [11], Supply chain integration (SCI) is defined by the strategic coordination and collaboration of strategic firm resources with other partners in a shared architecture for the mission-critical role of meeting stakeholder needs. Further, it affects significantly (i.e. on the smooth functioning of the municipality and its competitive advantages, limiting room for innovation and flexibility), on the performance of supply chain but only as an enhancer of the relationship between information integration and supply chain performance. Further indicated that information integration of supply chains has a positive relationship with the overall performance (i.e. integration of processes and sharing of information) of supply chain when two or more parties in an interaction.

2.5 Theoritical framework relevant to the study

2.5.1 Theory of Constraints (TOC)

This theory of constraints(TOC) was developed by Dr. Eli Goldratt around 1980 [13] and it became popular as a problem-solving approach that can be applied to many business areas. Malendez, Malvacias & Almedia [14] state that the principle of Theory of Constraints (TOC) is to establish its application in the weakest links of the chain, considering them equally strong and it is applicable in processes that interfere and prevent companies from reaching their goals.

2.5.2 Value Chain Theory

Jones and George [15] define value chain as the developmental of a set functional-level strategies that support a company's business-level strategy and the functional managers develop the strategies that increase efficiency, quality, innovation, and/or responsiveness to customers. Value chain refer to the concept that each step in the supply chain processes that deliver products and services to customers should create value and if a step does not create value, it should be removed from the process [13].

2.6 Conceptual framework

According to Mezghani and Aloulou [16], a conceptual framework is developed on a conceptual model as well as the generic categorisation scheme which is built on the premise that a business can be defined by the scope of its offerings. Furthermore, SCM Conceptual Framework presented in figure 2 add to the overall success of the Municipality by creating value and graphical demonstration.

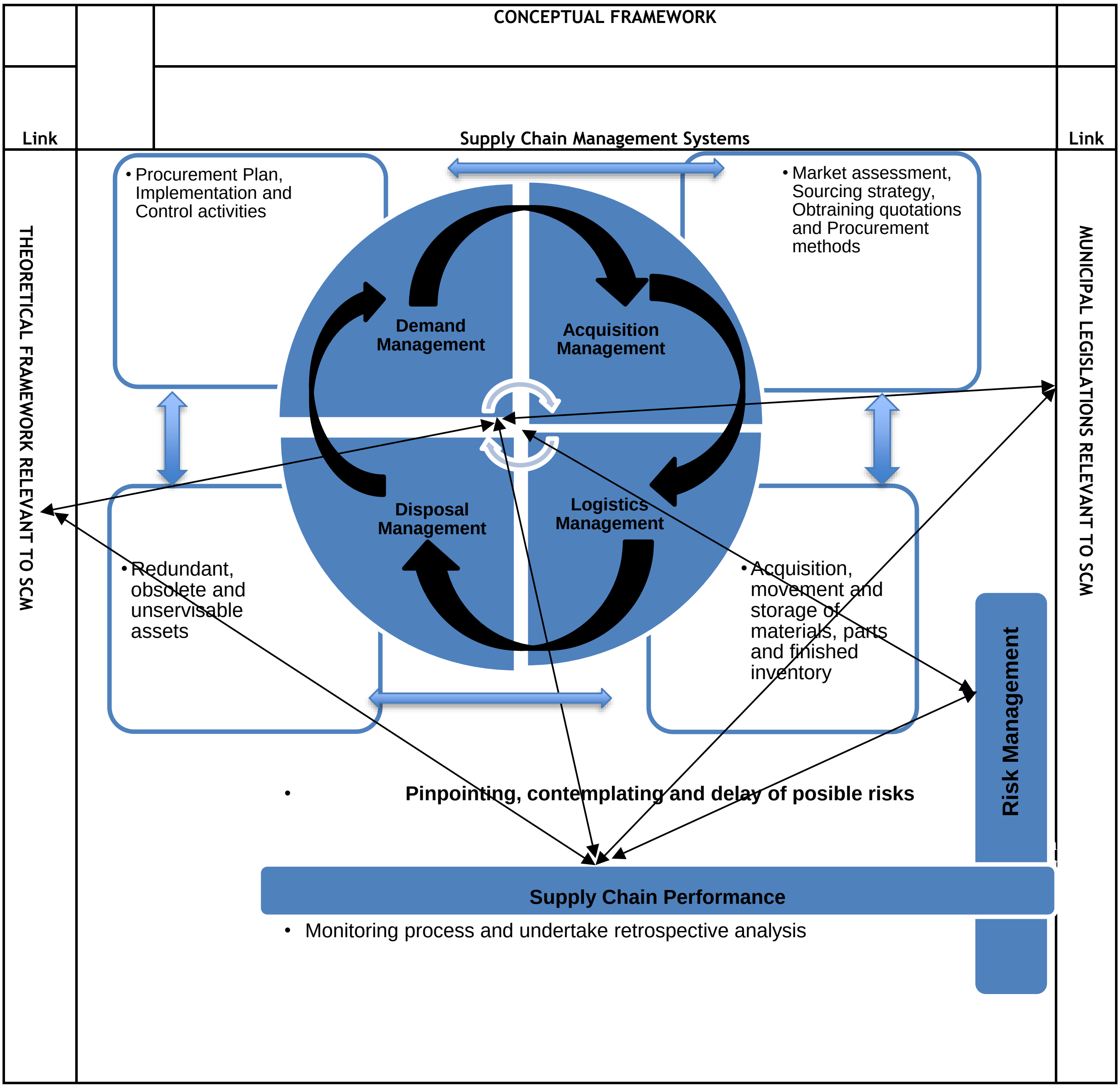

Figure 2: Conceptual Framework

The supply chain concept is described by Abdi, Labib, Edalat and Abdi [17], as a framework that lays the importance on its distinctive structures among the systems which link between demand, acquisition, logistics, risk management, disposal management and supply chain performance systems.

Ngxesha, Ncube, Mafini and Mugwenhi [18], described a conceptual model in supply chain as a presentation of a relationship between the execution of public Supply Chain Management which develops Supply Chain Performance, suggesting that essential internal set of practices in supply chain management can have a direct effect on supply chain performance by supporting the development of SCM practices that in turn affect performance [19].

2.6.1 The Demand Management

Demand management demonstrated in figure 2 above is the first process in the supply chain management system. It is defined as the decision-making process that allows for the procurement of goods and services at the right time, place, and cost. Letshedi [20] mentioned that many government entities in demand management system is still faced with challenges of improper planning and linking demand to budget and it can be attributed to the limited skills and capacity, and that training and workshop would be vital for successful implementation of other SCM systems.

2.6.2 The acquisition Management

Acquisition management refers to the buying or purchasing of goods and services by the government or a public organisation [12]. The Municipal supply chain management regulation 11 [2] prescribes that the SCM's policy "must provide for an effective system of acquisition management". It was noted by Matemotsa [29] that uncompetitive or unfair procurement processes were common in municipalities where officials failed to invite three written quotations, or to follow a competitive bidding process. Maleka and Ambe [6], noted incompetency related to acquisition of goods and services through municipal supply chain management systems. According to Boshomane [21] appointment of unqualified contractors, and utilisation of incorrect acquisition process and extension of validity periods lead to poor performance were part of the problems identified during the acquisition process and will lead to unsuccessful implementation of other SCM systems.

2.6.3 Logistics Management

Ngxesha [22] described logistics management as part of the SCM system that plans, implements and controls the efficient, effective forward and reverse flow and storage of goods, services and related information between the point of origin and the point of consumption. Deka [23] mentioned the common challenges faced by the system where the suppliers of materials often take advantage of the public sector by hiking prices of materials due to ignorance of ineffective supply management and results in the high prices paid for goods and services, non-performance of the contract, provision of poor and substandard materials and other unethical behaviours. The study further revealed that failure to involve suppliers in inventory planning could raise failure to balance current inventory requirement with future demands.

2.6.4 Disposal Management

Disposal management described by Ngxesha [22] that it deals with the discarding of assets that are of no use or no longer needed by the institution and may be used or given to other users with a need. Ambe and Maleka highlighted that there were ineffective databases available for unserviceable items and lack of adequate processes when implementing disposal of obsolete inventory.

2.6.5 Risk Management

According to Chang and Lin [30], risk management in supply chain has gained considerable attention in recent years among both academics and practitioners with an aim to minimize the impact of sudden disruptions and to resume operational normality in a timely and cost effective manner. Letshedi [20] viewed lack of internal control in government departments as a major challenge, as well as well as lack of implementation of risk mitigation procedures through the effective utilisation of SCM policy and procedure.

According to Pienar [31], when government organisations fail to follow regulations, it can have adverse effects on the supply chain unit. While Matolong [32], indicated that poor risk management leads to lack of internal control on areas such as monitoring and compliance with legislation.

2.6.6 Performance Management

According to Mhelembe & Mafini [9], performance management system is the monitoring process, undertaking a retrospective analysis to determine whether the proper processes have been followed and whether the desired objectives were achieved, and further stated that improved performance is enhanced by the flexibility of the supply chain systems, which they define as the ability to respond to short term changes in either demand or supply chain situation or any other disruptions in the process.

Letshedi [20] stated that supply chain management policies and regulations are complex and impact significantly on the functioning of the SCM systems. According to Mokotedi [24], poor performance in supply chain management is a result of ineffective monitoring and evaluation of the supply chain systems which is linked to poor control mechanisms. The poor control mechanisms and inadequate application of appropriate consequences for breach of legislation lead to other problems such as irregular expenditure. A well-structured and organised supply chain system will contribute positively towards supply chain performance in an organisation [25].

3 RESEARCH METHODOLOGY

The study focused on quantitative approach which according to Creswell and Creswell [26], is used for testing objective theories through examining relationships among variables.

3.1 Research problem

The research problem identified for this study was to determine factors that impact supply chain performance in the selected Municipalities. Furthermore, a review of the relevant literature to provide appropriate information to the Municipalities to utilise SCM systems effectively by testing of quantitative method to confirm whether collaborative skill is applicable.

3.2 Research Design

Research design according to Leedy and Ormrode [27] provided the overall structure for the procedures to be followed by the researcher, data to be collected as well as data analysis to be conducted. Baran [35] indicated the study model is a framework or outline which gives structure and guidance to show how all the major parts of the research project work together to try to address the research question. Furthermore, Creswell and Creswell [26] describes designs as "methods for gathering, analysing, clarifying, and reporting data".

3.3 The Population and Sample Framework

The population and sample framework consisted of SCM practitioners in the five municipalities. This included employees that have access to the supply chain management systems, who understand how the systems should function and how their effectiveness would impact the supply chain performance.

According to Leedy & Ormrode [27], a minimum sample of 100 is appropriate for a quantitative research, therefore the sample is as follows:

Table 1: Participant Sample

Municipality	No of respondents
Municipality 1	20
Municipality 2	20
Municipality 3	20
Municipality 4	20
Municipality 5	20

3.4 Data Collection Method

Data collection is a way in which the researcher approaches answering the research question [33]. Bryman and Bell [34] described data for quantitative purposes was collected using self-administered close-ended questionnaires, respondents were able to complete the questionnaires at their own convenient time without the supervision of the interviewer.

The questionnaires were distributed to the respondents using an email with a link to a platform called google forms: free online surveys which is used for administering questionnaires. Once the respondents were identified, an email was sent to them with a link to the questionnaire and required to complete them online at their convenience.

3.5 Data Analysis Method, Techniques and Instruments

According to Khanyile [28], data analysis relates to the processing of collected data into usable information.

3.5.1 Quantitative data analysis

For the quantitative approach, data was analysed using the SPSS version by means of descriptive and inferential statistical techniques. The sample are described using the descriptive techniques, while the inferential statistics used to analyse the relationships between variables. The researchers constructed their own questionnaire.

3.5.2 Sample size

Due to the population being 100 respondents, a census sample was undertaken.

3.6 Protection from harm and tight to privacy

The questionnaires were completed on google forms and responses sent directly to the interviewer anonymously and ensuring that respondents are not subjected to physical or mental discomfort.

3.7 Ethical considerations

Respondents were informed about their voluntary participation in the study and that they can withdraw at any time should they wish to do so.

4 RESULTS AND DISCUSSION

4.1 Reliability Statistics

• Effective Supply Chain Management and impact on SCM Performance

The reliability statistics for the first construct, "Effective Supply Chain Management and impact on SCM Performance", are shown in Table 2 below. Except for item, "The municipality has a demand management system" (r=0.4403), all item test correlations are high which augurs well for the construct. The results indicate that for all the items, the Cronbach's Alpha of each item (if deleted) is over .9; the minimum is 0.9682 (for The municipality request goods or services from suppliers that are listed on the central supplier database (CSD)) and the maximum is 0.9725 (for The municipality has a demand management system), which means that none of the items has a Cronbach's ¤ out of the recommended range of over 0.7 . Hence, none of the items were excluded. The results indicate that the reliability of the construct is good at Cronbach's ¤ of 0.9708. See table 2.

Table 2: Reliability statistics

Ser. No	Item	Item test correlation	Alpha
11	An effective Supply Chain Management Unit has been established in your municipality.	0.8174	0.9692
12	The size and responsibilities of a Supply Chain Management Unit (SCM Unit) has been determined.	0.8426	0.9689
13	The municipality has access to the central supplier database (CSD).	0.7389	0.9702
14	The municipality request goods or services from suppliers that are listed on the central supplier database (CSD).	0.9010	0.9682
15	The municipality verifies all documents submitted with relevant institutions, e.g. CIPC, SARS and Central Supplier Database for Government.	0.8793	0.9684
16	The municipality retains a directory of all potential service providers whose name appear on the National Treasury's database as persons banned from doing business with the public sector been disallowed.	0.8931	0.9683
17	The municipality aligns all acquisition requirements to an approved budget.	0.6937	0.9707
18	All terms and conditions of the contract are monitored, and a contract register maintained.	0.8293	0.9690
19	Work performed by appointed suppliers is reviewed and evaluated to ensure that it is in accordance with the Service-Level Agreements.	0.8679	0.9686
20	Monthly report on work performed by appointed suppliers been submitted to the Municipal Manager.	0.8463	0.9688
21	The municipality ensure that goods, services, and works are procured in a manner that is fair, equitable, transparent, competitive, and cost effective.	0.8575	0.9687
22	The municipality has a demand management system.	0.4403	0.9725

Ser. No	Item	Item test correlation	Alpha
23	The demand management system ensures that the goods or services required are delivered at the correct time, at the right price and at the right quantity and quality.	0.8966	0.9683
24	The municipality has an effective system of acquisition management.	0.7767	0.9696
25	The acquisition management system ensures that goods and services are procured by the municipality in accordance with authorised processes only.	0.8518	0.9688
26	The municipality has an effective system of acquisition management that ensures that the procurement process is in accordance with applicable legislation and Treasury guidelines.	0.7325	0.9700
27	The municipality has an effective system of logistics management.	0.8099	0.9693
28	The municipality has an effective system of disposal management.	0.8237	0.9691
29	The municipality has an effective system of risk management.	0.8048	0.9693
30	The municipality has an effective system of Performance management.	0.7952	0.9694
31	The municipality has an effective team implementing the supply chain management duties.	0.5191	0.9719
	Test Scale		**0.9708**

This section aims to determine elements that contribute to the effective Supply Chain Management operations and impact on SCM performance.

4.1.1 Mean scores and t test

The statements or items were measured by indicating to what extent the respondent disagreed or agreed with the statements, using the five-point scale 5, with 1 (Strongly disagree) and 5 (Strongly agree) by ticking on the appropriate number(s) of his/her choice on the scale. The Cronbach's Alpha coefficients of the variables were high, all over .9, which may have indicated some systematic or random ticking of the answers on the questionnaire. The t distribution was applied to compare the mean scores on the Likert scale with the undecided score of 3 (which was the mid-point between strongly disagree and strongly agree) by using the one-sample t test.

4.1.2 t- test

Where is the mean score, μ is the assumed mean value (in this case, it equals to 3), S is the sample standard deviation of the scores, Xi's (where i = 1, 2,…, n) and n is the sample size.

The following hypothesis was tested:

H_0: The mean score of a particular variable is equal to 3.

H_1: The mean score of a particular variable is less or more than 3.

Table 3: Mean score and t - test results

Item		Strongly Disagree	Disagree	Neither	Agree	Strongly Agree
		1	2	3	4	5
11	An effective Supply Chain Management Unit has been established in your municipality.	41	25	0	28	7
12	The size and responsibilities of a Supply Chain Management Unit (SCM Unit) has been determined.	37	27	1	28	8
13	The municipality has access to the central supplier database (CSD).	32	21	0	36	12
14	The municipality request goods or services from suppliers that are listed on the central supplier database (CSD).	46	18	0	32	5
15	The municipality verifies all documents submitted with relevant institutions, e.g. CIPC, SARS and Central Supplier Database for Government.	52	15	0	28	6
16	The municipality keeps a list of all prospective service providers whose name appear on the National Treasury's database as persons prohibited from doing business with the public sector been disallowed.	53	11	0	31	6
17	The municipality aligns all acquisition requirements to an approved budget.	28	19	0	37	17
18	All terms and conditions of the contract are monitored, and a contract register maintained.	46	19	0	28	8
19	Work performed by appointed suppliers is reviewed and evaluated to ensure that it is in accordance with the Service-Level Agreements.	52	15	0	27	7
20	Monthly report on work performed by appointed suppliers been submitted to the Municipal Manager.	49	15	0	30	7
21	The municipality ensure that goods, services, and works are procured in a manner that is fair, equitable, transparent, competitive, and cost effective.	39	26	2	28	6
22	The municipality has a demand management system.	7	17	2	65	10

Item		Strongly Disagree	Disagree	Neither	Agree	Strongly Agree
		1	2	3	4	5
23	The demand management system ensures that the goods or services required are delivered at the correct time, at the right price and at the right quantity and quality.	21	37	0	37	6
24	The municipality has an effective system of acquisition management.	21	33	0	41	6
25	The acquisition management system ensures that goods and services are procured by the municipality in accordance with authorised processes only.	27	40	0	27	7
26	The municipality has an effective system of acquisition management that ensures that the procurement process is in accordance with applicable legislation and Treasury guidelines.	28	45	0	22	6
27	The municipality has an effective system of logistics management.	28	39	0	29	5
28	The municipality has an effective system of disposal management.	32	37	0	28	4
29	The municipality has an effective system of risk management.	35	36	0	26	4
30	The municipality has an effective system of Performance management.	41	34	1	19	6
31	The municipality has an effective team implementing the supply chain management duties.	42	34	0	24	0

If the variance between the two values was statistically significant from zero, then the null hypothesis would be rejected and the alternative hypothesis that the mean score of the variable was less or more than 3 would be accepted. If the mean score were less (more) than 3, this would imply that the respondents disagreed (agreed) with the statement. Otherwise, if the variance were not significant the null hypothesis would not be rejected. This would imply that the respondents were neutral or undecided with the statement. The level of significance used was 0.05.

As an example, for question 11, the mean score was 1.158 (which was less than 3), and the t-test analysis produced the following results: t = -44.286 (p=.000<.05).

The null hypothesis that the mean score = 3 was rejected because the P – value (0.000) for probability of the t value of -44.286 to occur was less than 0.05, the level of significance, and the alternative hypothesis that the mean score was less than 3 was accepted. This implied that the respondents disagreed with the statement that "An effective Supply Chain Management Unit has been established in your municipality". Table 3 below presents the mean scores of the different statements as well as their independent one sample t-test results.

According to the results in table 3, only item or statement 22 (i.e., The municipality has a demand management system) was agreed upon; they were neutral for statements 13 (The municipality has access to the central supplier database (CSD)); 17 (The municipality aligns all acquisition requirements to an approved budget) and .24 (The municipality has an effective system of acquisition management); and disagreed with all the remaining statements. In total or generally, the respondents indicated that there are no effective Supply Chain Management operations and SCM performance in the municipalities.

5 CONCLUSIONS, RECOMMENDATIONS AND LIMITATIONS

5.1 Discussion on findings

To authenticate the aim of the study the following research findings were obtained:

The aim of this chapter was to build a theoretical foundation for the study, which relates to the concepts of supply chain management systems and impacts on supply chain management performance in a municipality. The chapter discussed, and reviewed literature related to these concepts in relation to the research in the municipalities, namely District and Local Municipalities and achieved that by reviewing previous studies and identified gaps that emerged which gave an insight into the study objectives and provided an analysis of the functioning of the SCM systems to establish their impact on supply chain performance in the municipalities.

The results of this study linked the findings of the 100% data analysed which is in agreement with findings of data obtained from municipal employees agreeing that SCM units size and responsibilities are limited in their municipalities and do not support the effectiveness of the SCM operations and impacts on SCM performance, a lack of monitoring of the contract and maintaining a contract register by SCM unit officials and absence of performance measures affect it negatively and advertisement of bids are not within the minimum periods, bids submission closing dates are less than the requirement stipulated in SCM regulations and bid specifications are biased and do not allow all potential providers to compete and advertisement of the bids are not placed in local papers, on the official web sites and notice boards for all potential providers to bid and undeserving bidders are awarded other than the one recommended. Municipal Manager and/ Chief Financial Officer not approving of deviations from Supply Chain Management Processes nor reporting to next council meeting, sourcing of written price quotations from potential providers are not obtained in line with Supply Chain Management Processes and lack of action plan to follow up on the non-compliance issues raised.

5.2 Conclusions

This research pursued a fact-finding study into the root causes of Non-Compliance with SCM Legislations and increase in irregular expenditure by municipalities in the district. The study fruitfully established that there is no SCM capacity for effective SCM systems in municipalities and impact SCM performance.

This section merges the study's objectives with the outcomes attained based on the results during the study are as follows:

5.2.1 The first research objective was to identify factors that do not contribute to the effectiveness of supply chain management systems at a Municipality. The results revealed that respondents originated from five municipalities and the proportion distribution of the ages of respondents indicated that none of the respondents were below the age of 18 years and very few respondents were above 58 years, according to table 4.6 and figure 4.3 a high percentage of the respondents were females and that almost all the respondents were blacks. Most of the respondents had a 2-3 year national diploma, a 3 years degree came second and some hold a post graduate degree with most respondents had more than 2 years of experience as the period of time a respondent spent at the municipality implementing effective SCM systems. Table indicates that most of the respondents said that the municipality has a council approved SCM policy in place; only few said that their municipalities reviewed the SCM policy annually or ensured that SCM Standard Operating Procedures is aligned to the council approved SCM policy.

5.2.2 The second research objective was to assess the level to which supply chain management systems impact supply chain performance in the Municipalities.

This respondents disagreed with the statement that "An effective Supply Chain Management Unit has been established in their municipalities but agree that their municipality has a demand management system they were neutral for statements that their municipality has access to the central supplier database (CSD, the municipality aligns all acquisition requirements to an approved budget) and disagreed that the municipality has an effective system of acquisition management and in conclusion generally, the respondents indicated that there are no effective Supply Chain Management operations and SCM performance in the municipalities.

5.2.3 The third objective is to ascertain the root causes of non-compliance in SCM legislations and the reasons for increase in irregular expenditure.

The respondents agreed with statements that says the Municipal Manager appointed a Bid Specification, Evaluation and Adjudication Committee members, they are undecided for statements that indicate that Bid Specification Committee consist of officials from the department requesting the goods and services and an advertisement been prepared with unbiased specifications, and only few respondents agree that an advertisement indicating required minimum period is sited and clear specifications is placed in local papers, on the official web sites and notice boards when inviting prospective suppliers for competitive bids). Only few respondents agree that the Bid Evaluation Committee consist of chairperson of the committee, consisting of officials from the department requesting the goods or services and at least one (1) SCM practitioner); and the Bid Evaluation Committee evaluate bids according to approved specifications and disagreed with all the remaining statements. In conclusion the respondents indicated that there is a non-compliance in SCM legislations and an increase in irregular expenditure.

5.2.4 Limitations of the study

The research was limited to only five municipalities in Limpopo Province and limitations were encountered due to the requirements to adhere to the global pandemic of coronavirus disease 2019 (COVID-19) regulations and prompted the researcher to follow only quantitative method and equally it was carefully considered the most suited and relevant method to use in collecting data during the national state of disaster regulations gazetted by government. Data was collected through a survey sent to municipal employees by an e-mail and WhatsApp to avoid face-face contacts and representing the study sample of n=municipal employees. The study fully focused on municipalities based on Auditor-General reports that stated an increase in irregular expenditure which is stated in literature review and the researcher experienced lot of challenges during the study were municipal managers were unwilling to grant permission for the study due to sensitive nature of supply chain management in local government but persisted to conduct the study to add value and benefit the municipalities.

5.3 Recommendations

Based on the findings of the study, it is apparent that the municipalities are faced with non-adherence to supply chain management systems which impact on supply chain performance.

5.3.1 It is vital for the municipalities to effectively utilise:

An effective Demand management system to ensure that needs assessment is embarked on and that the municipality request goods or services from suppliers that are listed on the central supplier database (CSD).

An effective Acquisition management to ensure that bid committee members are appointed by Municipal Manager and ensure that the evaluation and adjudicating criteria applied to evaluate and adjudicate the bids are in line with SCM regulation.

An effective Logistics management to ensure that processes and procedures are effectively implemented to administer demand of resources, acquisition, storage, receive and issue of materials and a flow of goods and services.

An effective Disposal management to ensure management and disposal of redundant movable, immovable assets and materials is in line with the SCM regulation.

An effective Risk management to ensure that supply chain management risks are identified, managed, and mitigated to avoid non-compliance with SCM regulations and other applicable legislations.

An effective Supply chain performance is evaluated and monitored to determine whether the supply chain management systems mentioned above are effectively implemented to meet their objectives.

5.4 Recommendations for further studies

A further study can be done to other municipalities in the country to reach a definite finding of all municipalities within a specific province.

Research can be further extended to gain in-depth understanding about the effectiveness of SCM systems and how they impact SCM performance to other municipalities in the country. As the study only collected quantitative data, a repeated research can be conducted using different research strategy.

The essential due diligence for this study was embarked on in conditions of approval and ethical clearance. This consent activity contained the research design, the research method, and the recommended carefully chosen research sample for data capture.

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DEVELOPMENT OF A CONTINUOUS QUALITY LOSS FUNCTION MODEL FOR COAL PROCUREMENT FOR THERMAL POWER STATIONS IN ZIMBABWE

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ABSTRACT

The global quality trend is evolving from the traditional goal post philosophy to the modern continuous loss philosophy. In quality assurance, loss functions are used to reflect the economic loss associated with deviations from the target value of a product specification. This paper outlines the development a costing model for coal procurement based on its calorific value. A mathematical costing model based on an asymmetric quadratic loss function was developed using historical data on the coal procurement and quality. The model captures quality losses that can be adopted to penalise coal suppliers for coal that does not meet the target quality level. Simulation results of the model using Microsoft Excel indicate that savings of upto 25 % can be achieved by migrating to a loss function-based procurement. Two-year coal procurement data revealed that 5.5 % savings could have been realised.

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1 INTRODUCTION

Loss functions are used in decision theory applications and quality assurance settings to quantify losses associated with deviation from a desired target value. In decision theory, loss is generally defined as a function of the deviation of an estimator from the parameter value to be estimated [1]. In quality assurance, loss functions are used to reflect the economic loss associated with variation about, and deviations from, the process target or the target value of a product characteristic [2]. In manufacturing, loss functions express the economic consequences associated with deviations from target. Since different processes have different sets of economic consequences, a flexible approach to developing loss functions is desirable [1]. The global quality trends migrated from the traditional goal post philosophy to the modern continuous loss philosophy [3]. The notion of continuous loss is based on the premise that each unit whose quality characteristic deviates from its stated target value inflicts a loss which is measured in economic units. This notion is in contrast with the conventional method of using the specification limits to measure the cost of nonconforming units, where each unit whose quality characteristic measures outside of the specification limits is assumed to inflict a fixed loss equivalent to the cost of its replacement or correction, and each unit that measures within these limits is assumed to inflict no loss at all [4]. This paper explores the different types of loss functions that can be applied in the procurement of coal for thermal power stations by penalising the suppliers for delivering coal with specifications that deviate from the target value. The approach seeks to minimise losses to the power stations by paying for only delivered value. The desire to only pay for value in the delivered coal is premised on the fact that coal is one of the major cost drivers in thermal power production.

The objectives for the study were to:

i. Determine the relevant quality loss functions in the procurement of coal.
ii. Develop a costing model for coal procurement.
iii. Evaluate the applicability of the model in coal procurement.
iv. Estimate the financial implications of adopting the model.

The paper begins with a review of different quality loss functions. Plant data on coal procurement from a selected power station in Zimbabwe was used to test the application of continuous quality loss function to the procurement of coal.

2 LITERATURE REVIEW

Quality is often very difficult to define because of its subjective nature, hence it is more experienced that it can be described. The quality gurus have defined quality in complementary and sometimes contrasting perspectives in the quest to objectively unpack quality issues. Some of the prominent definitions from the quality gurus include quality being defined as fitness for purpose, zero defects, minimum variability and conformance to specifications among others [5]. Another quality guru Taguchi developed a method of calculating the cost of quality. Taguchi, Chowdhury and Wu [6] measured quality through the loss imparted by the product to the society from the time the product is shipped in what was to be popularly known as the quality loss function. The quality loss function is quantitative evaluation of loss caused by functional variation of a product [6]. The quality loss function translates the qualitative terms, which affect the customers into quantitative terms such as monetary values [7]. A number of quality loss functions have been developed and presented in literature as the approximate representation of quality conformance of products, processes, and systems. This study reviewed the step loss and the continuous quality loss functions.

2.1 The Step Loss Function

Traditionally, non-conforming product is defined as the out-of-specification quality characteristic [8]. In this traditional view, a step loss function is used for measuring the cost of non-conformance. Chen [9] presented a piecewise linear quality loss function for a product to describe the deviation of the quality characteristic from its specification. The conventional loss function, commonly referred to as the step-loss function, was almost universally accepted as the ideal model for quality loss due to its mathematical simplicity. By using product specification limits, manufacturers place acceptable bounds on the degradation of the product performance. If the product performance falls within these limits, the product is satisfactory; if it falls outside these limits, the product is unsatisfactory [10]. Figure 1 shows the graphical representation of the step-loss function and Equation 1 represents the mathematical model of step loss function.

$$L(x) = \begin{cases} 0, \text{when LSL} \leq x \leq \text{USL} \\ \\ A \text{ , Reject , otherwise} \end{cases} \tag{1}$$

Where: L(x) is the quality cost associated with quality characteristic x,

A is the rejection cost, and

LSL and USL are the lower and upper specification limits respectively.

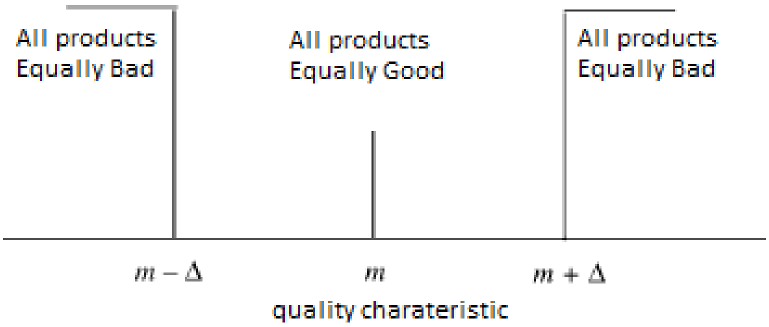


Figure 1: The binary system of the step-loss function [6]

The quality characteristic has been graded depending on how close its value is to the target or ideal value denoted by m. In most situations, the difference in quality between a product that is just within the specification limits and the one that is just outside may be very slight. However, one is called conforming and the other is called non-conforming. Consequently, this go/no-go system for quality evaluation may not adequately reflect the customer perception of quality. Similarly, associated with every quality characteristic is a best or target value. Quality loss occurs whenever the quality characteristic deviates from this best value, evaluated as a function of deviation of a characteristic from target [6].

2.2 Continuous Quality Loss Function

Loss is made up of incremental excess manufacturing costs incurred up to the point that a product is shipped [11]. After manufacturing cost linked loss, society and / or the customer bears the cost for loss of quality.

Depending on the situation, the continuous quality loss function takes three forms:

i. **Nominal-the-best (NTB)** - the nominal value is best because it is the one that satisfies the customer's need. The characteristic value away on either side of the calorific value target is undesirable.
ii. **Smaller-the-better (STB)** – a smaller value is better and higher values are undesirable.

iii. **Larger-the-better (LTB)** – a larger value is better and smaller values are undesirable [11].

2.2.1 The Quadratic Quality Loss Function

In 1986 Taguchi proposed a quadratic loss function to predict continuous quality losses. The quadratic quality loss function approximated the continuous loss function using the Taylor series expansion up to its quadratic term [4]. The loss function L can be expanded in a Taylor series around the target value m as shown by Equation 2 [12].

$$L = L(m) + \frac{L'(m)}{1!}(x-m) + \frac{L''(m)}{2!}(x-m)^2 + \frac{L'''(m)}{3!}(x-m)^3 + \cdots \quad (2)$$

Where: L is the loss when the quality characteristic is equal to x
m is the target value of x
x is the quality characteristic
L^' is the loss at the first derivative
L^" is the loss at the second derivative
L^"' is the loss at the third derivative

The loss value L is a minimum at $x = m$, therefore $L'(m) = 0$. The term $L\,(m)$ does not change with quality characteristics and is always a constant, it thus can be ignored since its effect is to raise or lower the value of L uniformly at all values of x. Taguchi suggests that the term $(y - m)^2$ is the dominant term in the equation and neglects the higher-order terms. Therefore, the loss function equation is simplified to the quadratic format represented by Equation 3 [13].

$$L = \frac{L''}{2!}(x-m)^2 = K(x-m)^2 \quad (3)$$

According to Zhang et al. [13], the constant K is calculated as follows;

$$K = \frac{A}{\Delta^2} \quad (4)$$

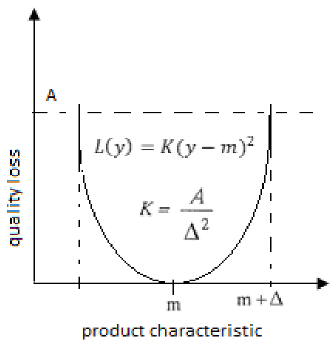
Where: Δ is the deviation from the target value and A is the corresponding loss.

According to Dev and Jha [3], the shape of the quadratic loss function appears into two major forms, namely the symmetric shape and the asymmetric shape as shown in Figure 2. The symmetric shape is only suitable for the process where the deviations from the target value on either side cause an equivalent loss [14]. The symmetric case provides a straightforward technique, it requires one to determine the maximum loss and corresponding deviation with respect to the target [2]. This version of the loss function is useful in the nominal the better situation in which the loss increases symmetrically as the performance characteristic deviates from the target.

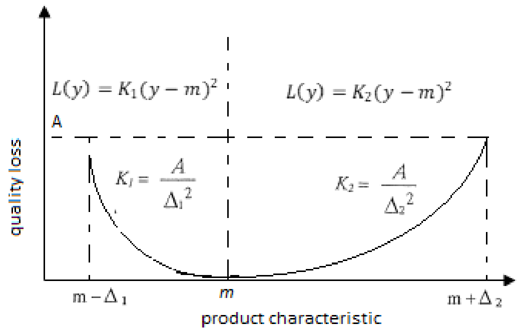
However, in many cases, the distribution of quality loss is asymmetrical [15]. Asymmetric quality loss exists in the environment where the deviation of quality characteristic in one direction is more harmful than that in the opposite direction as shown in Figure 2. In cases of asymmetry, the normal quadratic loss function is maintained but slightly adjusted with two different coefficients for the two directions [16]. Thus, possible quality losses would be approximated by the asymmetric quadratic loss function as shown by Equation 5. The overall equations for quadratic loss functions are summarised in Table 1.

Table 1: Quadratic Loss Function Equations

Symmetrical Quadratic Loss Function	Asymmetrical Quadratic Loss Function
$L = K(x-m)^2$ *(3)* $K = \frac{A}{\Delta^2}$ *(4)*	$L = \begin{cases} K_1(x-m)^2, \ x < m, & K_1 = \frac{A}{\Delta_1{}^2} \\ K_2(x-m)^2, \ x \geq m, & K_2 = \frac{B}{\Delta_2{}^2} \end{cases}$ *(5)*



Symmetric Quadratic Loss Function



Asymmetric Quadratic Loss Function

Figure 2: Symmetric and Asymmetric Quadratic Quality Loss Functions [14]

2.2.2 The Cubic Quality Loss Fuction

The asymmetrical distribution of quality loss functions can also be solved by retaining the third order term of Taylor expansion in Equation 2 to produce what is known as the cubic quality loss function [12]. Figure 3 and Equation 6 represents the graphical and mathematical model of the cubic quality loss function respectively.

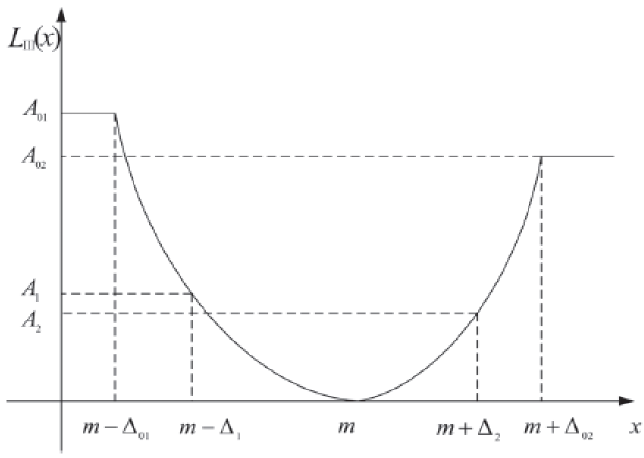


Figure 3: Cubic Quality Loss Function [12]

$$L''' = \begin{cases} A_{01} & x < m - \Delta_{01} \\ k_1(x-m) + k_2(x-m)^2 + k_3(x-3)^3 & m - \Delta_{01} \leq x < m \\ k_1(x-m) + k_2(x-m)^2 + k_3(x-3)^3 & m \leq \ x \leq m + \Delta_{02} \\ A_{02} & x > m + \Delta_{02} \end{cases} \qquad (6)$$

Where: L is the third derivative loss when the quality characteristic is equal to x
m is the target value
A_{01} and A_{02} are customer losses
k_1, k_2, k_3 are quality loss coefficient for $x \ < \ m$
k_4, k_5, k_6 are quality loss coefficient for $x \ > \ m$

$m - \Delta_{01}$ is the lower specification limit
$m + \Delta_{02}$ is the upper specification limit

The cubic quality loss function can be applied to managing tolerances in machining, and helps in reducing the difference between calculated and true value of quality losses, hence improving the precision of estimating quality losses [12].

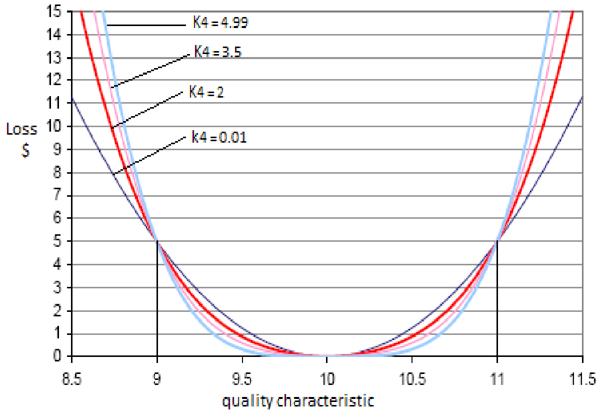
2.2.3 The Quartic Quality Loss Function

Retaining the fourth order term of the Taylor series expansion generates the quartic loss function [4]. The quartic loss function also presents itself in two versions, the symmetrical and the asymmetrical quartic loss functions. Figure 4 shows the basic shapes of the quartic loss functions. According to Fathi and Poonthanomsook [4], retaining the fourth order term of Taylor series from Equation 2 yields Equation 7 as shown;

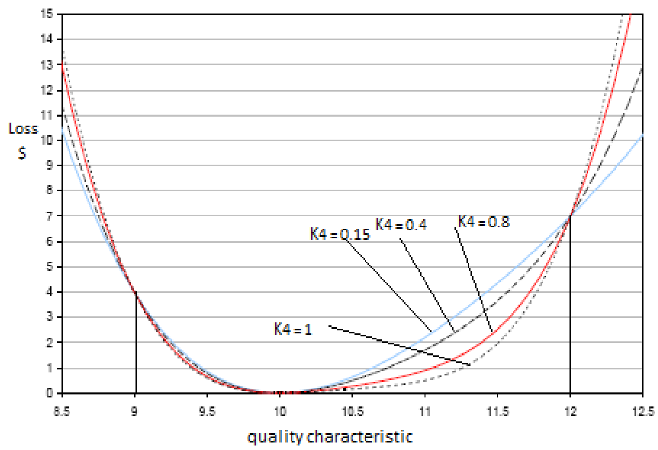
$$L = k_2(x-m)^2 + k_3(x-m)^3 + k_4(x-m)^4 \quad (7)$$

Where: k_2, k_3, k_4 are second, third and fourth order loss coefficients

The shape of the quartic functions depends on the value of k_4 which can also be described as the shape parameter. Quartic loss functions covers a range between the shape of the quadratic loss function and the shape of a conventional step function [4].



Symmetrical Quartic Loss Function



Asymmetrical Quartic Loss Function

Figure 4: Symmetric and Asymmetric Quartic Loss Functions [4]

In the symmetric case, the value of the shape parameter k_4 decreases within its range, in the vicinity of the target value this loss function approaches the quadratic loss function as shown in Figure 4. For the case of an asymmetric loss function, this functional form has the advantage that it can easily fit the situation at hand without the need to specify the two sections of the loss function separately like the parametric equations in the quadratic loss function. Therefore, the quartic function provides a unifying format for approximating both symmetric and non-symmetric continuous quality loss functions. However, the quartic loss function has the drawback that it increases rapidly outside of the specification limits [4]. After the review of the different continuous loss functions, the next section is to adopt a suitable model that can be applied to coal procurement.

3 MODEL DEVELOPMENT

Coal procurement at the case study power station supports the adoption of an asymmetric function as opposed to a symmetric quadratic function since there are different financial penalties for coal that is below specifications and that which is above specifications. Apart from their complexity, the cubic and quartic loss function are still under development and refinement and have not yet reached maturity for adoption in real life situations. Hence, the model was developed based on the asymmetric quadratic loss function.

3.1 Determination of the plant operation parameters

The process parameters for the case study power station were optimised and coal quality requirements were determined during design and continuous operation of the power plant over the years. The power station process design points the research towards adopting the nominal-the-better (NTB) form. For coal calorific value the levels away on either side of the target are undesirable, as shown in Table 2.

Table 2: Proximate Analysis (Calorific Value)

Coal Proximate Analysis	LCL (GJ/t)	UCL (GJ/t)	Optimum Value (GJ/t)
Calorific Value	22.67	27.51	25.09

Source: Optimum calorific value for Case study power station

3.2 Determination of the coal pricing structure

The basic price of the coal in US$ per tonne was determined to be a product of the starting price and the typical Calorific Value. The delivered price in US$ per tonne is determined from the product of the starting price and the weighted average calorific value of the relevant coal as shown by equation 8. At the case study power station, the starting coal price gleaned from the coal supply agreements and was pegged at US$ 1.13 per gigajoule per tonne of coal. Therefore the cost of coal was calculated using equation 8.1.

$$Coal\ Price = tonnage\ delivered\ \times weighted\ calorific\ value\ \times price\ per\ GJ/t \quad (8)$$

$$Coal\ Price = tonnage\ delivered\ \times wCV\ \times 1.13 \quad (8.1)$$

3.3 Determination of an appropriate quality loss function coal pricing structure

The power station had an existing policy already on the supply of coal that was out of specification and it was pegged at 50 % of the price for coal below the lower limit and 75 % for coal above the upper limit. These penalties were adopted into the continuous loss function pricing model and favours the adoption of an asymmetric quadratic loss function.

3.3.1 Asymmetric quadratic loss function model development

An asymmetric loss function curve is represented by the Equation 5;

$$L = \begin{cases} K_1(x-m)^2, & x < m, \quad K_1 = \dfrac{A}{{\Delta_1}^2} \\ K_2(x-m)^2, & x \geq m, \quad K_2 = \dfrac{B}{{\Delta_2}^2} \end{cases}$$

Where:

x is the value of the quality characteristic, in this case the calorific value
L is the loss when the calorific value is equal to x
m is the desired target calorific value of 25.09 Gigajoules per tonne in this case
K_1 and K_2 are the quality loss coefficients to the left and the right of the target value, respectively
A and B are the financial loss to the company per Gigajoule per tonne of deviating calorific value, to the left and to the right of the target value m.

$\Delta_1$and Δ_2 are the allowable maximum deviations, to the left and to the right of the target value m.

3.3.2 Determination of loss function coefficients

The allowable maximum deviations $\Delta_1$and Δ_2 were calculated as follows;

$$\Delta_1 = 25.09\ GJ/t - 22.67\ GJ/t = \ 2.42\ GJ/t$$

$$\Delta_2 = 27.51\ GJ/t - 25.09\ GJ/t = \ 2.42\ GJ/t$$

The financial losses (A and B) to the company per Gigajoule per tonne of deviating calorific value, to the left and to the right of the target value were calculated based on the existing company policy of paying 50 % of the price for coal below the specifications and 75 % for coal above the specifications. It follows that when the company pays 50 % of the price there is a loss of 50 % and when the company pays 75 % of the price there is a loss of 25 %. Hence A and B were calculated as follows

$$A\ = 50\ \%\ of\ US\$\ 1.13 = US\$\ 0.565$$

$$B\ = 25\ \%\ of\ US\$\ 1.13 = US\$\ 0.283$$

Therefore, the quality loss coefficients, K_1 and K_2, were determined as follows;

$$K_1 = \frac{A}{\Delta^2} = \frac{0.565}{2.42^2} = 0.0965$$

$$K_1 = \frac{A}{\Delta^2} = \frac{0.283}{2.42^2} = 0.0483$$

3.3.3 Model Conditions

The Asymmetric Quality Loss Function Model satisfies the following conditions;

i. $L\ =\ 0.0965(x - 25.09)^2,\ for\ x\ <\ 25.09$
ii. $L\ =\ 0.0483(x - 25.09)^2,\ for\ x\ >\ 25.09$
iii. $L\ =\ 0, for\ x =\ 25.09$
iv. $Reject\ calorific\ values, x\ <\ 22.67\ and\ x\ >\ 27.51$

and can be expressed as follows;

$$L = \begin{cases} 0.0965(x - 25.09)^2, & x < 25.09 \\ 0.0483(x - 25.09)^2, & x \geq 25.09 \end{cases}$$

4 SIMULATION AND RESULTS

The model was constructed in Microsoft Excel, and produced an asymmetrical curve. Plant data on coal procurement for two years was used in the simulation. The model was first tested and validated before being used.

4.1 Model Validation

The developed model was tested using a unit value of 1 tonne for tonnage and calorific values ranging from 22.67 GJ/t to 27.51 GJ/t. The losses $L(y)$, were determined using the model conditions and a curve of losses against calorific value was plotted in Microsoft Excel as shown in Figure 5. As predicted by Taguchi et al. [6], the plotted quality loss function curve is similar to the asymmetric curve reviewed in literature This validated the model as true and capable of functioning and producing valid results.

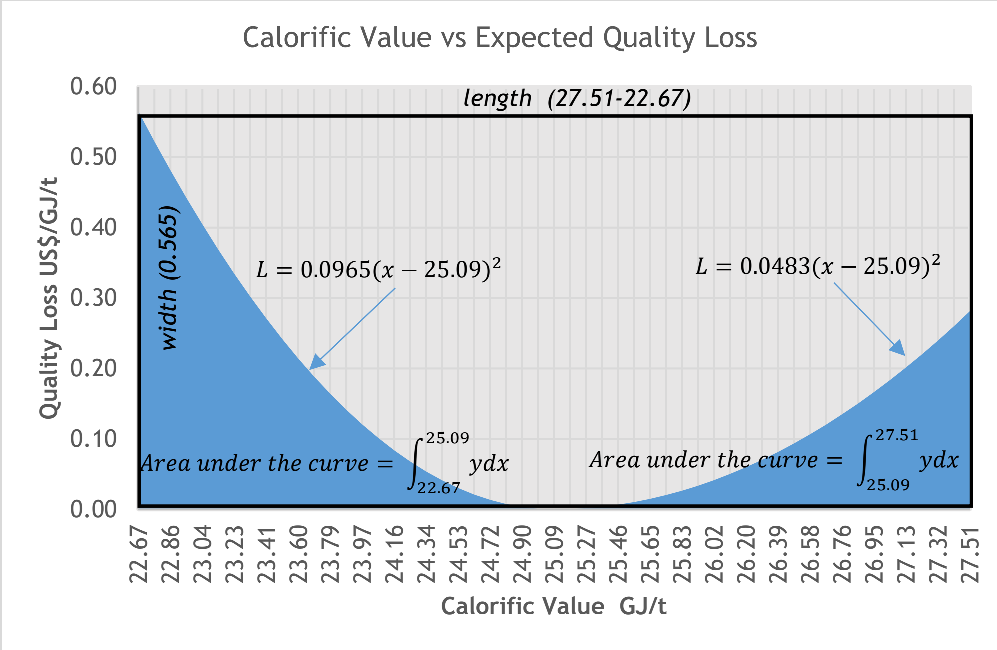


Figure 5: Asymmetric Quadratic Loss Curve for coal procurement

4.2 Simulation

The area bounded by the rectangle in the graph shown in Figure 5 shows the cost of quality under the prevailing conditions of a step loss function. Introducing an asymmetric quadratic quality loss function removes the shaded regions bounded by the two quadratic functions on both sides of the nominal value.

The cost savings made are determined as follows:

$$\frac{Area\ under\ quadratic\ functions}{Area\ of\ rectangle}$$

The area of the rectangle $= Length \times width$

$$= 0.565 \times 4.84$$

$$= \$\ 2.735$$

The area under the quadratic functions $= \int ydx$

$$= \int_{22.67}^{25.09} 0.0965\ (\mathrm{x}-25.09)^2 \mathrm{dx} + \int_{25.09}^{27.51} 0.0483\ (\mathrm{x}-25.09)^2 \mathrm{dx}$$

$$= 0.456 + 0.228$$

$$= 0.456 + 0.228$$

$$= \$\ 0.684$$

Therefore, the total percentage savings would be

$$= \frac{0.684}{2.735} \times 100$$

$$= \mathbf{25}\ \%$$

The calculation shows that there is possible savings of up to 25 % when quality loss function is adopted in the procurement of coal. Historical coal procurement data was collected from the case study power station for a period of two years. The data consisted of the tonnage and calorific value that had been procured by the power station. Revenue losses were calculated using the developed loss function model and the results are as shown in Table 3.

Table 3 shows that a total tonnage of 1,812,164.80 was delivered in year 1 at a cost of USD49,422,871.17 as was determeined by equation 8.1. This was based on a step loss function of USD1.13/GJ/t. The total cost price indicate a weighted carolific value of 24.14 GJ/t for the coal. The calorific value was then used to calculate the loss function price based on the developed model and indicated that the average quality price should have been USD45,575,586.28 instead of USD49,422,871.17 that was paid. This led to a financial loss of USD3,847,284.89 for the year.

Simiraly for year 2 a total tonnage of 1,157,988.06 was delivered in year at a cost of USD32,203,645.52 as was calculated using equation 8.1. This also was based on a step loss function of USD1.13/GJ/t. The total cost price indicate a weighted carolific value of 24.61 GJ/t for the coal. The calorific value was then used to calculate the loss function price based on the developed model and indicated that the average quality price should have been USD31,571,646.10 instead of USD32,203,645.52 that was paid. This led to a financial loss of USD632,001.42 for the year.

The results show that a saving of 5.5 % would have been possible with the adoption of continuous loss function-based procurement of coal. The results are also a testimony that there is a difference between the calculated and the true value of quality losses.

Table 3: Case study summary results

Year	Total Tonnage (t)	Total Paid (US$)	wCV (GJ/t)	Average Quality Based Price (US$)	Total Financial Loss (US$)
Y1	1,812,164.80	49,422,871.17	24.14	45,575,586.28	3,847,284.89
Y2	1,157,988.06	32,203,645.52	24.61	31,571,646.10	632,001.42
Total	2,970,152.86	81,626,516.68	24.32	77,147,230.38	4,479,286.31

5 CONCLUSION AND RECOMMENDATIONS

In conclusion, the results show that the Asymmetric Quadratic Loss Function can replace the predominantly used step quality loss function in the procurement of coal for a power station. Microsoft Excel simulation of the quality loss function model developed produced a quality loss curve similar to the theoretical asymmetric quality loss curve in literature. Therefore, the model was validated. Continuous loss function models can be very helpful in introducing savings in coal procurement. The theoretical model indicated savings of up to 25 % while the plant data for two years revealed that savings of up to 5.5 % are possible.

In order to derive full benefits of implementing a continuous loss function model in the procurement of coal in a power station, it is recommended that researchers develop a customised asymmetric quality loss function model that captures variables specific to a power station. This helps in determining the quadratic loss function coefficients for the model. After developing the model, the model should be validated before using it. Though the savings calculated are specific to the case study power station, the philosophy can be applied to other power stations. Further investigations are required for application to other raw materials directly linked to the production of electricity, such as water, chemicals, diesel for combustion support, spare parts among other areas The applicability of the quality loss function philosophy can also be extended to other functions and services such as internet, equipment hire and labour as well. Furthermore, for ease of implementation, it would be ideal to embed the loss function into usable and friendly platforms such as enterprise resources planning, blockchain distributed applications and smart contracts.

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RAPID SAND CASTING IN SOUTH AFRICA: STATUS QUO AND FUTURE: A LITERATURE REVIEW

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ABSTRACT

Sand casting is the oldest method of producing castings in the foundry industry. This process involves various laborious and time-consuming steps in producing moulds of high quality. Due to this, it is difficult for the local foundry industry to meet global demand and maintain competitiveness. It is therefore important for the local foundry industry to adopt the additive manufacturing technology, which is more efficient and opportune in production of complex moulds cavities and processes. This paper reviews the literature on rapid sand-casting applications in South Africa and reflects on what has been achieved in terms of research and industrial implementations and current ongoing investigations. Finally, the paper attempts to forecast the future of rapid sand casting in South Africa.

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1 INTRODUCTION

Metal casting is one of the foundry's oldest traditional processes used to produce metal parts found in virtually every industrial sector in the world [1]. Sand moulding as one of the major metal casting processes is still very prevalent for the production of ferrous and non-ferrous metallic components in major industries, such as the automotive, general engineering and mining industries [2]. The sand casting process essentially consists of pouring liquid metal in a refractory sand cavity. The liquid metal solidifies to produce the casting, which is then machined to the final product. There are various steps that are considered in the traditional sand casting process and they include; pattern making, core making, mould making, melting, pouring and cleaning [3] as shown in Figure 1.

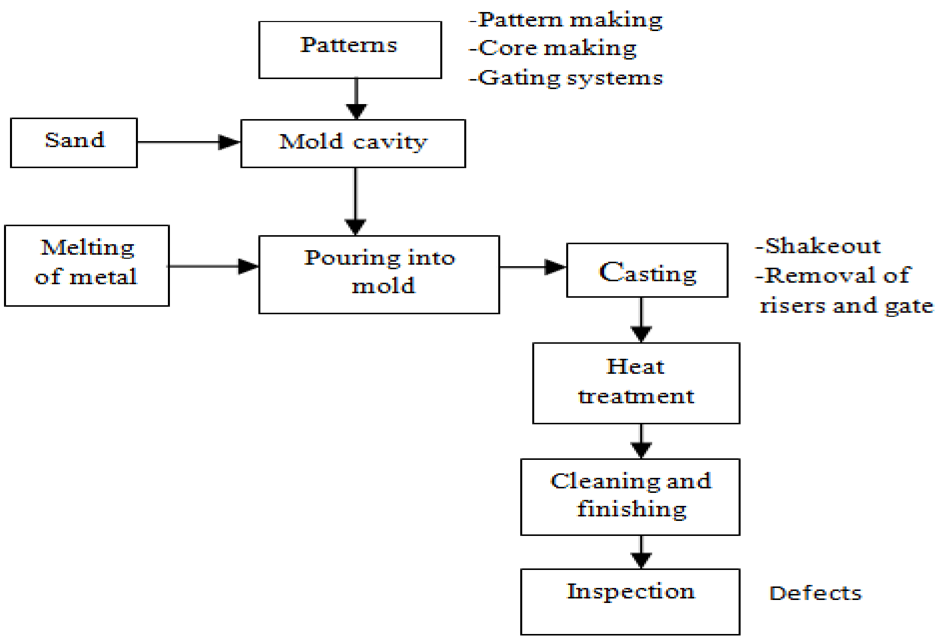

Figure 1: Typical sand casting process [3]

According to Krieg [4] the South African foundry industry is essential for the re-industrialisation of the country and can drive the casting industry due to its capacity, advanced technology, high standards and sustainability. Locally, the foundry industry is larger than other competitive industries of metallic components including forging, wire-drawing and rolling. Metal casting is an important industry to drive the infrastructure development promised by the Government. In addition, the foundry industry is one of the fundamental industries of manufacturing sector which significantly impacts the economy of the world. In South Africa, this industry accounts for more than 180 operational small to medium companies affecting economies of scale and capacity of parts produced as compared to other countries [5].

Considering the automotive industry, one of the manufacturing sectors which is reliant on metal casting, it is expected to grow at 4% per annum until 2025 and casting production is therefore expected to increase to 14Kt by 2025 [4]. This can be a challenge for the local foundry industry to remain globally competitive in the face of competition from other Brics countries, including China, India and Brazil. With this predicted increase in demand, it is important for the South African foundry industry to manage its supply chain and operations and be competitive with international foundries by keeping up with rapid changes in the business environment. These rapid changes in the business environment require the adoption of latest technologies such as the rapid sand casting, which can assist to increase the scale of production of metal casted parts through sand moulding processes while maintaining costs.

This paper focused on the rapid sand casting technology, which is a specialised application of the additive manufacturing technology. The latter is part of the fourth industrial revolution which is evolving at an exponential pace and disrupting almost every industry in every country [6]. This technology could represent a step forward in the modernization of the traditional sand casting method.

2 ADDITIVE MANUFACTURING

Additive manufacturing, a type of three-dimensional printing (3D printing), is a process of physically fabricating a part layer by layer from computer-aided design data [7]. Davies [8] outlined that additive manufacturing technologies are widely used for a variety of applications in various fields such as prototyping, electronics, automobile, etc.

During the 1980s where 3D printing technology emerged, it was predominantly used to construct prototypes in various industries [9]. A prototype of the original part was produced for shape analysis, measuring of fit and tolerance, shrinkage analysis for molten metal and to enable necessary changes considered to meet the desired outcome [10]. Once the dimensions and analysis had been finalised, an additive manufacturing pattern that could be used for moulding would be created.

Rapid prototyping then evolved into rapid tooling and rapid manufacturing, where patterns, core boxes, dies, moulds and short runs of actual finished products were made [11]. Since then this technology has expanded from its prototypying beginnings to taking over the conventional manufacturing processes due to its processing speed, dimensional accuracy, surface finish and the repeatability [12].

Additive manufacturing can be divided into five steps as shown in Figure 2, these are the general steps of additive manufacturing that may differ according to the printing method used [6] . These steps involve the creation of a CAD model using three-dimensional computer-aided design. This CAD model is then converted to an STL file format which describes closed surfaces of the original CAD model and forms the basis for the calculation of the slices [12]. Using different softwares, this information is transferred to the printer. The final printed part is then cleaned (post processing) and the quality of the printed part evaluated.

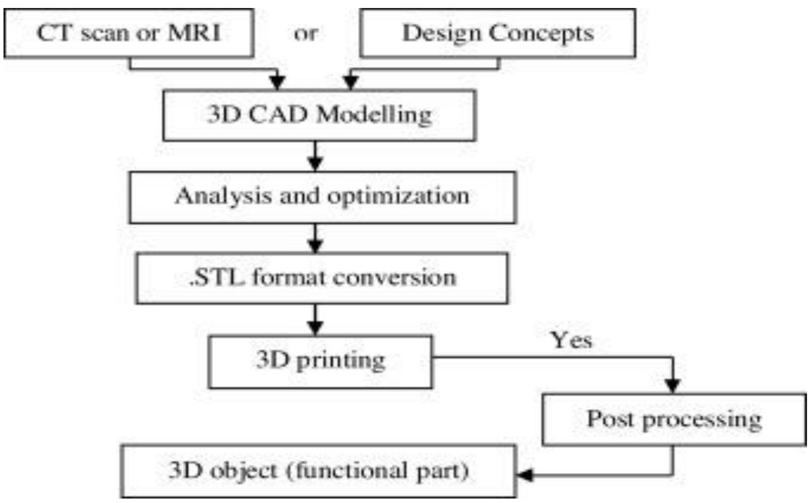

Figure 2: Additive manufacturing process [6]

2.1 Advantages of additive manufacturing technologies

Additive manufacturing offers numerous advantages as compared to traditional forming or removal processes, including:

- Assistanting product manufacturers to survive and adapt quickly to market fluctuations [13].
- Short supply chain due to eliminated processes, activities, and movement of resources.
- No pattern is required for mould production [14] and a part can be directly fabricated, which decreases wastage and saves on material [15].
- Geometries of printed parts can be quickly modified through CAD systems meaning low volume custom production [16].
- Producing lighter parts and reduce energy consumption and ultimately lower production costs [17].

3 ADDITIVE MANUFACTURING FOR THE FOUNDRY INDUSTRY

The direct production of sand moulds and cores using additive manufacturing technology is called rapid sand casting [14]. This process has revolutionised traditional sand moulding methods [18]. This means additive manufacturing technology can now be adopted by the local foundry industry for the production of moulds and cores of different sizes and shapes. This technology has proven to be more advantageous than traditional methods of manufacturing because of its efficiency and cost effectiveness. It can be used to fabricate highly accurate complex moulds in one part, which are impossible to create using traditional methods [19].

3.1 Rapid sand casting

There are seven types of additive manufacturing technologies, each classified according to the type of material used during bonding mechanism and the deposition technique for fabrication of the part. Each technology has its own capabilities, limitations and applications in fabrication [20]. Common additive manufacturing used worldwide are stereolithography apparatus (SLA), selective laser sintering (SLS), three-dimensional printing (3DP, also known as binder jetting), polyjet printing (PP), selective deposition lamination (SDL), fused deposition modelling (FDM) and direct metal deposition (DMD). SLS and 3DP technologies are currently used for the production of moulds in South Africa by research institutions.

SLS consolidates sand particles by using heat to melt them into a mould, while 3DP bonds sand particles together using a liquid bonding agent [21]. Figure 3 shows a typical process for rapid sand casting where a recoater firstly distributes the sand on the building platform followed by the inkjet head which selectively distributes the liquid binder in the part to be printed and the same process continues layer by layer until the mould has been printed completely [22].

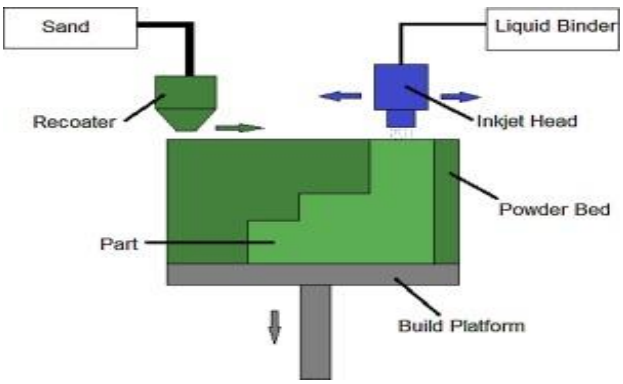

Figure 3: 3D printing for rapid sand casting – A review [22]

4 ADDITIVE MANUFACTURING IN SOUTH AFRICA

Additive manufacturing has been active in South Africa for over 25 years and has gained traction in academia, research and industry due to the various advantages associated with this technology [23]. This technology started as rapid prototyping, introduced as 3D systems SLA 250, followed by two FDM 1500 machines in South Africa in 1994 and, through government (CSIR) and university collaboration, the technology started to grow over the years [24]. Rapid protyping is one of the applications under the additive manufacturing umbrella. The Council for Scientific and Industrial Research (CSIR) and the Central University of Technology (CUT) were the first institutions to purchase these machines, followed by the Vaal University of Technology (VUT). According to Campbell [14] the CSIR is the main player in additive manufacturing in terms of research and development, followed by CUT, whose Centre for Rapid Prototyping and Manufacturing (CRPM) focuses on plastic, metal and the medical industry, and lastly VUT which focuses on tooling and casting factors. Other institutions that are involved and active in the research and development of additive manufacturing in South Africa include the University of Stellenbosch and North West University [25] . The diversity and complementary nature of these machines allows for collaborative and efficient planning in conducting research [24]. South Africa is one of the countries on the African continent that promotes additive manufacturing research and the government has shown great support through its Department of Technology and Innovation by investing in additive manufacturing research over the years [26] .

The information presented in this paper on the rapid sand casting has been collected from different sources, including local conference proceedings, peer-review journals treating the topic at hand. The point of origin has very often been studies published in the annual conference proceedings by the Rapid Product Development Association of South Africa (RAPDASA) [27], which is a vibrant organisation essentially focusing on Additive Manufacturing processes in South Africa. The proceedings of the annual conference of the South African Institute of Industrial Engineers and the related journal were also an important source of information as they featured a number of articles on the topic of rapid sand casting process [2], [12], [28], [29], [24], [26], [30], [28].

4.1 Rapid sand casting in South Africa

South African foundries play a significant role in the manufacturing sector as they produce and supply non-ferrous and ferrous products to key industries namely; automotive, mining, chemical and general engineering [5]. There are various types of machines available for rapid sand casting in South Africa, namely Voxeljet 500 &1000, EOSINT S 750 and Z Corporation Spectrum 550 housed at the Vaal University of Technology, Central University of Technology and University of Johannesburg respectively. These machines use the SLS and binder jetting technologies to produce moulds. CUT currently has ten additive manufacturing machines and two of these machines, the EOS and 3D systems, are used to produce sand moulds for the local foundry industry and for research purposes [31]. VUT also has various additive manufacturing machines covering the four additive manufacturing technologies: binder jetting (3DP), selective laser sinter (SLS), fused deposition modelling (FDM) and stereolithography apparatus (SLA). Vaal University of Technology, Central University of Technology and University of Johannesburg are the only institutions in South Africa that have adopted rapid sand casting process and no local foundry has adopted this technology yet. The CSIR is mainly focused on the aerospace industry and produces printed parts for this industry and mainly titanium-based alloys. There is certainly room for growth in rapid sand casting and the widespread adoption of additive manufacturing technology is considered an important part of the 4th industrial revolution.

5 INVESTIGATIONS DONE ON RAW MATERIALS

Due to its flexibility in manufacturing, sand casting process is used to produce over 70% of metal castings including automotive, mining and engineering components [32]. This shows the significance of refractory sand in casting process and the role it plays in the production of sound castings. It is therefore important to understand the sand properties for casting processes as they affect the quality of the final casting.

Various studies have been conducted and are still on going in South Africa on the properties of local sand for additive manufacturing applications to produce moulds and cores. These investigations include studying the “possible sand casting defects resulting from local implementation of rapid sand casting” [29] , “assessment and comparing of local and imported silica sand to consider using local sand for rapid sand applications” [33], “studying the physical properties of silica sand since they contribute to quality of the final casting produced through printed moulds" [28] , "assessment of quality parameters of surface finish and dimensional accuracy of tools made by rapid sand casting process" [34] and "sustainability of South African silica sand for three-dimensional printing of foundry moulds and cores" [28]. The quality of moulds also in terms of dimensional accuracy and good surface finish, plays a vital role in the final casting produced [12].

The investigations listed above have contributed to a better understanding of the fundamental properties of silica sand and its behaviour during the layer by layer manufacturing to produce moulds and cores used to manufacture sound castings. In this regards, the Cape Flat sand, which has round and spherical shaped grains was found to produce superior moulds and cores with higher mechanical properties than imported sand from Germany using locally available three-dimensional printing systems. This sand is considered as potential alternative as compared to imported sand and has the potential to reduce the operational cost of rapid casting in South Africa and foster the adoption of the technology by the local foundry industry.

Current investigations, essentially conducted at the University of Johannesburg in collaboration with the Advanced Manufacturing Centre of the Vaal University of Technology are now focusing on the reclamation of used sand from rapid sand casting processes to make it more economic and environmentally friendly. Various reclamation processes are being considered, including dilution, mechanical and thermal. Chromite sand, an abundant refractory sand in South Africa is also receiving considerable attention as an alternative material to silica sand for rapid sand casting applications. This is due to some unique properties of this sand including its high refractoriness, its resistance to scabbing defects and chemical inertia [35] . Finally, feasibility studies are also under way as to expand the adoption of rapid sand casting in the local foundry industry. Various financial techniques, including the payback period and the discounted cash flow methods are being explored to demonstrate the economic feasibility of adopting additive manufacturing as a mainstream mould or core making process in local foundries [36] .

All the studies mentioned are aimed at elevating the knowledge and understanding of the local foundry industry around rapid sand casting processes for its possible adoption. The University of Johannesburg in collaboration with the Advanced Manufacturing Centre at the Vaal University of Technology (VUT) are very active in the local research initiative of rapid sand casting with research funding obtained from the Collaborative Project on Additive Manufacturing project (CPAM) [37] of the Council of Scientific and Industrial Research (CSIR) [38]. Two additive manufacturing systems, respectively of type EOSINT S 750 and Voxeljet 1000 are available at VUT for rapid sand casting applications. At the time of writing this paper, no other rapid sand casting system was available in local private foundries.

6 PERFOMANCE OF RAPID SAND CASTING

Rapid sand casting has been shown to be more advantageous as compared to traditional methods of mould production as illustrated in Table 1. The application of additive manufacturing technology to mould production has been shown to reduce lead time and to produce complex parts without using internal geometry [22] and [19].

Table 1: Additive manufacturing vs traditional manufacturing [15]

Additive Manufacturing	Traditional Manufacturing
Shorter production time	Longer production time
Reduced material waste	Increased material waste
Easy to customise	Difficult to customise
Cheaper prototype production costs	Expensive prototype production costs
Reduced labour costs	Increased labour costs

7 INDUSTRIAL APPLICATION

Three-dimensional printing technology can be successfully used in developing patterns for casting processes in the foundry where integration and gating systems are easily produced which optimises the process or supply chain [2]. Die casting pattern for engine sump was fabricated as foundry tooling for sand casting using 3D printing system to avoid the expenses of producing tooling in a traditional way [12]. Engine pump is a complex component with internal geometries, and, with layered manufacturing, it is possible to create very complex shapes with high dimensional accuracy without material waste. Moulds can therefore be produced through rapid sand casting in South Africa for the local foundry industry casting processes.

8 CONCLUSION

The manufacturing sector will be the next industry to experience a radical technological shift, brought about by additive manufacturing technologies in the following areas: true rapid prototyping, rapid design iteration, mass customization, low volume production, production innovation and virtual inventory. With support from various government initiatives, following global trends, there is already a rapid increase in the production of parts using additive manufacturing systems. Due to its far superior advantages over traditional manufacturing systems, additive manufacturing has a great potential to contribute to the renaissance of South Africa's tooling and foundry industries by increasing tool performance and time to market. This will benefit the foundry industry as it plays a significant role in the manufacturing sector. Current research, specifically of rapid sand casting, should stimulate innovation and lead to fuller understanding of this technology, leading to improved application and increased adoption of this technology in the local foundry industry.

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EVALUATION OF LOCAL CHROMITE SANDS FOR RAPID SAND CASTING APPLICATIONS

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ABSTRACT

Applications of Three Dimensional Printing to perform metal casting referred to as Rapid Sand Casting have been well established in the last two decades. The preferred raw material used for rapid sand casting to date has been silica sand. As metal casting is transforming towards the environmentally friendly industry, alternative refractory raw materials are being considered. Chromite sand is one such material abundantly available in South Africa. This paper investigates the suitability of South African Chromite for Rapid Sand Casting. Characterization of Five different chromite sand samples from different South African mines was performed according to American Foundrymen Society testing standards. The results of this study will investigate the suitability of South African chromite sand for additive manufacturing of sand casting tools.

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1 INTRODUCTION

Additive manufacturing (AM), commonly known as three dimensional (3D) printing is the process used to fabricate 3D parts layer by layer. Rapid Sand Casting as an application of Three Dimensional printing in Foundry Technology is direct manufacturing of sand moulds and cores without the use of patterns. As an alternative to traditional moulding, Rapid sand casting offers an increased design freedom of metal delivery systems (gating, sprue, risers) **[1]**. Elimination of pattern making processes and draft angle design to allow for stripping creates an opportunity to save costs and lead design time [2].

One of the modern processes used for Rapid Sand Casting is based on binder jet technology. Binder jet process begins with CAD design of the 3D model of the final mould or core and transferring of model data to the printer. Specific quantity of sand is charged in a sand hopper "Recoater" where it is coated with catalyst. A layer of catalyzed sand is deposited on the printing bed. The inkjet then sprays the bonding resin on the deposited layer of sand according to the CAD model data.

The process also involves controlling of setting time for first layer of sand to properly bond before the following layer [3]. Rapid sand casting typically applies Furfuryl alcohol resin bonded sand hardened with Sulfonic acid which forms part of the Furan No Bake binder system [4]. Furan No-Bake is a nitrogen free binder therefore it is acceptable in all alloys. It has low sulphur content therefore reducing the SO_2 emissions during casting. Furan resins are reported to have much less smoke emissions values [5].

Silica sand is the most frequently used moulding material in both traditional moulding and Rapid sand casting mainly because of its great abundance on earth hence lowest cost. However alternative moulding materials should be investigated due to the fact that silica sand possesses non negligible technical disadvantages that do not make it suitable for all castings including low refractoriness, high thermal expansion coefficient and chemical reactivity with certain cast alloys [6]. Chromite sand, a naturally occurring spinel primarily consisting of the oxides of chrome and iron [7], could be an alternative and sustainable raw material in the place of silica sand and hence it will be investigated in this paper.

Chromite sand is the by-product of chromite ore mineral processing by gravity concentration processes and is used as moulding material. Statistics indicates that the vast majority of Chromite sand used in Foundry industry in the world originates in South Africa [8]. Since there is very little use of Chromite sand as a moulding material in South Africa, this byproduct is disposed in landfills. Utilizing of chromite sand could be a sustainable way of making use of the abundant beneficiation waste product from chromite ore mineral processes.

Sand properties significantly impact the quality and the mechanical properties of the resultant mould or core. Therefore, it is essential to characterize the moulding sand as part of quality management systems. Acceptable physical properties of moulding sand include an American Foundry Society Grain Fineness Number (AFS-GFN) between 44 and 56, LOI content less than 1.5%, Acid Demand value of less than 6ml, and the sand should comprise of a mixture of rounded and angular grains [9]. The size and shape of grain particle influences the packing density of sand henceforth its bonding capacity. A decrease in particle size increases the sintering activity of the sand and as a result reduces the distortion potential which is not desired in a refractory material for sand moulding purposes. Finer particles tend to agglomerate due to their high capillary forces which affect the packing density and flow ability of the sand which will cause printing issues such as re-coater clogging [10].

A number of studies have been conducted on the effectiveness Rapid Sand Casting process. By comparing rapid Sand Casting and Conventional mould manufacturing process, Hawaldar and Zhang discovered that Rapid prototyping offers significant savings in the cost and lead time with minimal material wastage. In 2016 K.D Nyembwe et.al [2] concluded that South African silica sand can be used in Rapid sand casting.

Furthermore K.D Nyembwe et.al [11] also studied the mechanical properties of 3D printed sand specimen and discovered that it is possible to produced sand moulds with required quality through rapid sand casting. Most literature is based on the use of Silica sand on Rapid Sand Casting as there is a limited literature on utilizing of chromite sand in rapid sand casting in both convectional casting more especially in South Africa.

In this research paper a Quality Assurance Framework (QAF) developed by P.M.J van Tonder [12] based on critical quality attributes for the development of procedures to determine the quality of chemical coated sand for 3D printing which will serve as a guideline for the evaluation of sand properties for their suitability and use in rapid sand casting applications. As such a quality assurance checklist was used in order to evaluate the quality of commercially available South African chromite sand grades for rapid sand casting applications. The QAF followed for this research is summarised in Figure 1 below.

		Design space				
Process	Procedure	CPP	CMA	CS	CIS	QTPP
Chemical coating	Physical classification		50 ≥ AFS GFN ≤ 60 *	AFS GFN 1106-12-S	Implement ISO 9001 (PDCA cycle)	❖ Reliability - The coated sand consistently performs within specification. ❖ Conformance - Adheres to the requirements of the target group.
			3 – 5 Sieve sand			
			Rounded to sub-rounded grains	AFS 1107-00-S		
			AFS clay content < 0.3%	AFS 2110-04-S		
	Cleanliness		Sand moisture < 0.2%	AFS 2216-00-S		
	Chemical composition		Sintering temperature ≥ 1450°C	VGD-Merkblatt p26		
			ADV ≤ 6 ml	AFS 1114-00-S		
	Resting period	Min 2 days				
	Catalyst verification		0.3 % BOS ±0.1%.	AFS 5100-12-S		
	Flowability		Angle of repose ≤ 45°	ASTM C1444-00		

CCP Critical Process Parameter
CMA Critical Material Attribute
CS Control Strategy
CIS Continuous Improvement Strategy
QTPP Quality Target Product Profile

Figure 1: Quality Assurance Framework [12]

2 METHODOLOGY

This section covers two aspects of the methodology, namely the raw materials used in the study and the experimental procedure in terms of the test performed.

2.1 Raw Materials

Five commercially available South African chromite sand samples (A, B, C, D and E) of the same grade were obtained from South African suppliers for use in this study. The suppliers are the top five producers of foundry chromite sand in the country.

2.2 Experimental procedure

The methodology of this project involved the moulding sand characterisation of South African chromite sands for Rapid Sand Casting Applications. Each of the chromite sand samples underwent the six tests shown in Figure 2 to confirm if South African Chromite sand meets the required sand specifications for rapid sand casting applications. All tests were done according to the ASTM and AFS standards testing procedures [11].

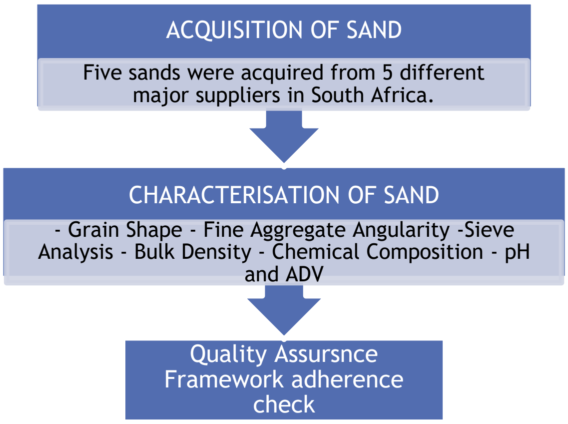

Figure 2: flowchart presentation the methodology

2.2.1 Grain shape

Grain shape of each chromite sand sample was analyzed using the SEM, it displays images of the sample through scanning the sample with a high energy beam of electrons.

2.2.2 Fine Aggregate Angularity (FAA)

ASTM C1252 standard testing and calculation procedures were used to determine the angularity of the sand samples. The Fine aggregate angularity determines the amount in percentage voids in un-compacted fine aggregate material that fall within 1.18mm, 600µm, 300µm, and 150µm standard sieve sizes. Sand was allowed to pass through a funnel into a 100ml cylinder at the bottom. The weight of the sand and the cylinder was recorded. The un-compacted void percentage was then calculated using the following equation:

$$U = \frac{\left(V - \left(\frac{F}{G}\right)\right)}{V} X100$$

Where:

U= Un-compacted void percent in the material

V= Volume of Cylindrical measure (mL)

F= net mass of fine aggregate in measure

G= bulk specific gravity (G_{sb}) of aggregate

2.2.3 Sieve Analysis

Sieve analysis tests were performed to determine the grain size distribution of the sand samples as well as the AFS Grain Fineness number and fines percentages. The tests were performed according to AFS 1105-00-S using US standard testing procedure using the ASTM E-11 standard sieve sizes. Grain fineness Number (GFN) and percentage of fines were calculated according to AFS 1106-00-S. Table 1 shows sample A's sieve analysis results only to demonstrate the calculation that was carried out on all five samples.

Table 1: Sieve analysis results

Sieve #	Mesh size	Retained (g)	Factor	Product
1	1700	0	6	0
2	850	0,16	12	1,92
3	600	2,33	20	46,6
4	425	16,88	30	506,4
5	300	35,92	40	1436,8
6	212	31,02	50	1551
7	150	11,69	70	818,3
8	106	1,76	100	176
9	75	0,39	140	54,6
10	53	0,02	200	4
11	Pan	0	270	0
	Total	100,17		4595,62
	AFS	45,878207		
	% Fines	0,41		
	Screens	3,5		

2.2.4 Bulk Density

Bulk density measures the packing efficiency of the sand grains. AFS 1130-00-S standard testing procedure for untapped dry sand was used.

2.2.5 Chemical Composition

X-ray fluorescence (XRF) technique was used to determine the elemental composition of the sand samples.

2.2.6 pH and Acid Demand Value (ADV)

The pH and Acid demand value tests were done to determine the chemical activity of the sand. AFS 5113-00-S pH testing procedure was followed, and for acid demand value AFS 114-00-S

3 RESULTS

This sechtion highlights the characterization resuls the tested different chromite sand samples locally sourced. The following properties of moulding material have huge impact on the processibility and quality of binder jet manufacutured parts.

3.1 Grain Shape

3.1.1 SEM

Figure 3 below shows the sand grain SEM images for five (5) locally sourced chromite sands labelled samples A, B, C, D, and E respectively. The shape of the sand grains influences the bonding effectiveness of the aggregate in Rapid Sand Casting. There are different classes of grain shapes according to AFS 1107-00-S Namely: Very angular[1], angular[2], sub-angular[3], sub-rounded[4], rounded[5] and very rounded[6].

Samples A, B and C comprise of sub-angular grain shapes while D and E comprise of rounded grain shapes. The acceptable grain shape for rapid sand casting is sub-angular to rounded, therefore all the tested samples are within the acceptable range.

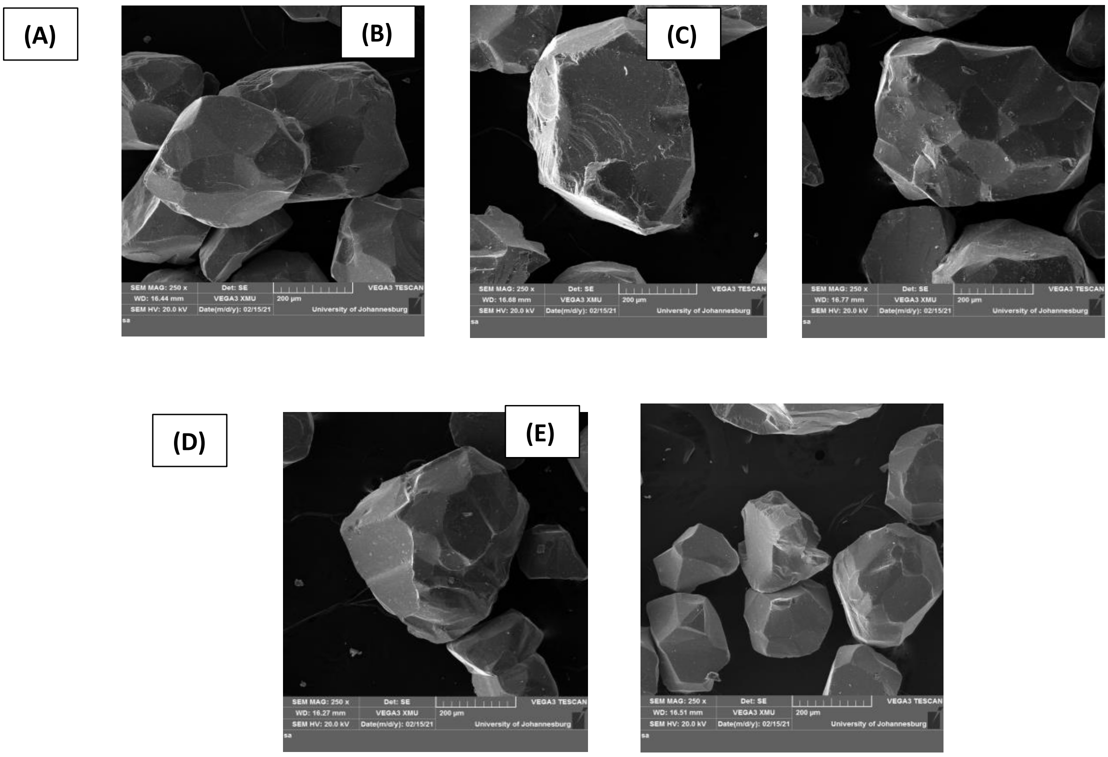

Figure 3: SEM image displaying the grain shapes of the five chromite sands

The grain shape significantly influences the packing density, contact mode between the grains and permeability of the final part. Sand with rounded grains gives good flow ability due to less inter-particle friction and require minimal amount of binder and catalyst due to low surface area as compared to Angular grains [12]. Good sphericity allows free flow of grains during layer by layer additive manufacturing and high sand grain packing density which allows for high strength at low binder content [13].

3.1.2 Fine Aggregate Angularity (FAA)

Figure 4 shows Fine Aggregate Angularities of the five tested chromite sand samples. ASTM C1252 standard testing and calculation procedures were used to determine the angularity of the sand samples. The fine aggregate angularity test determine amount in percentage voids in an un-compacted fine aggregate materials that falls with 1,18mm,600µm, 300µm and 150µm standard sieve mesh sizes

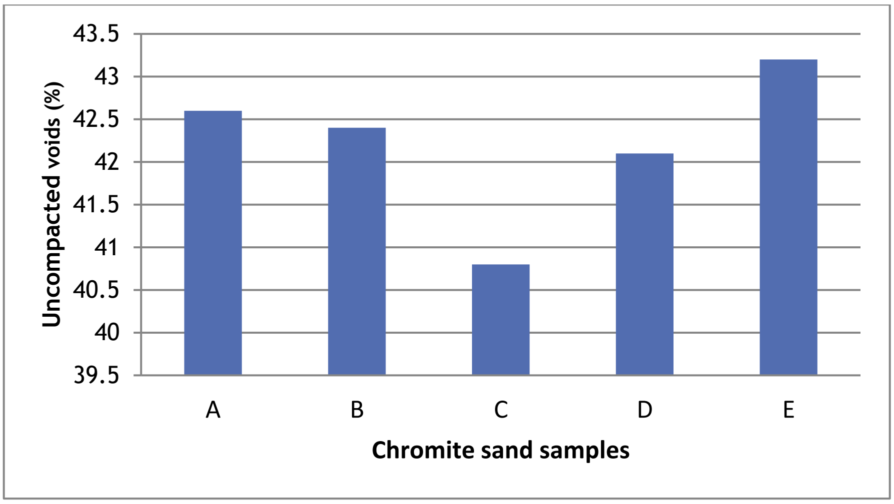

Figure 4: F.A.A of the five locally sourced chromite sand samples

Fine aggregate angularity test gives a calculated angularity of sand grains. The uncompacted void percentage of very rounded grains ranges from 32 to 33%, sub rounded grains ranges from 35 to 38 % and sub angular grains is from 38 to 45% and anything greater is angular [1]. As can be seen in Figure 4, the percentages of uncompacted voids for all samples lie between 40 and 43 %, the results show that the grain shapes of all samples falls under the sub-angular category which is an acceptable angularity for moulding sand.

3.2 Sieve Analysis

3.2.1 Grain size distribution

Grain size distribution shows the grains distribution profile of the collected sand in different sieves of different mesh sizes as shown in Table 1. Figure 4 below shows grain size distributions of the five (5) tested chromite sand samples. All samples have good particle size distribution with most retained sand in sieve 5, 6 and 7 or 300, 212 and 150 µm standard sieve mesh sizes respectively.

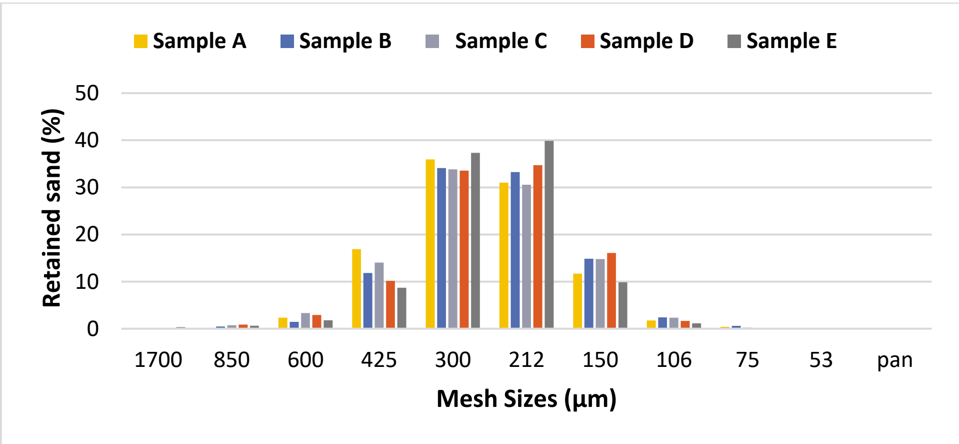

Figure 5: Grain size distribution chart

However Sample D has the steepest curve having approximately 77% of sand retained in mesh size 212 and 300 microns, such sand is prone to segregation which is not desired in moulding sand. Narrow curves show grains with similar sizes and broad curves show wide distribution or evident grain size differences. A moderate size distribution (not too narrow or broad) is a preferred type of sand distribution for rapid sand casting as it prevents sand segregation during printing which will result in parts that have no too little visible ditches [14] giving good tap density of the final mould.

3.2.2 Grain Fineness Number

Figure 5 shows Grain Fineness Numbers (GFN) of the five (5) tested chromite sand samples. All samples have good AFS-GFNs and percentage fines retained as presented with their corresponding chromite sand samples respectively.

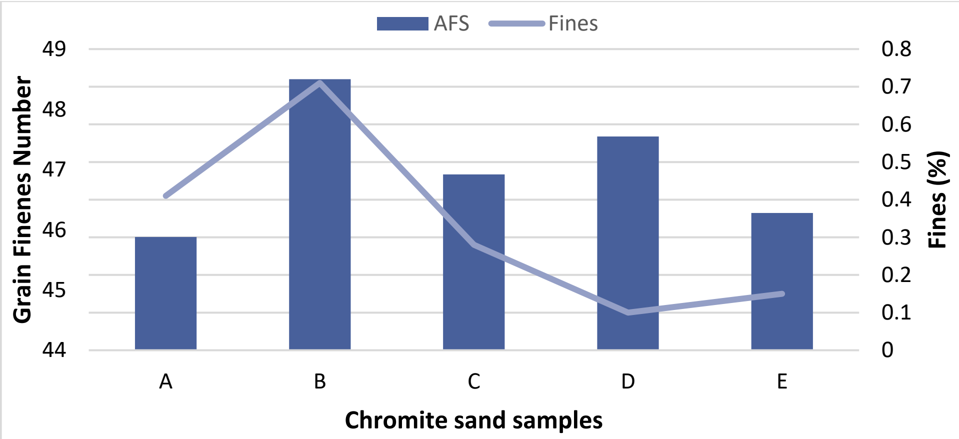

Figure 54: Grain Fineness number and percent fines with their corresponding chromite sand samples

The acceptable GFN for foundry moulding sand is between 44 and 56 and the maximum percent fines in the foundry is 2% [9]. The results in Figure 4 reveal that all samples meet the GFN and percent fines specifications required for additive manufacturing on most commercial printers. A high GFN indicates finer grains which result in a high surface area which requires more binder to properly coat the sand to maintain a similar strength to sand with a lower GFN, this is not desired as it increases overall production costs [15].

The fines percentage is the sum of the percentage of sand retained in sieve sizes 75 and 53 µm, and the pan. Sample C shows the highest percent fines and D has the lowest. Powder deposition during printing depends on the flow characteristics of the sand, which is governed by the force of gravity. Fine particles reduce the flow ability of the sand due to inter-particle cohesiveness [17]. With reduction in particle size, the magnitude of the electrostatic force between particles tends to supersede gravitational force resulting in the decrease of flow ability and spread ability which is not desired in moulding sand [12].

3.3 Bulk density

Figure 6 presents the untapped bulk densities of the tested South African chromite sands available commercially. A theoretical bulk density of Chromite sand is 2.60 g/ml. Sample C has the highest bulk density of 2.64 g/ml and the lowest corresponds to sample E at 2.51 g/ Bulk density is used in industry to measure the efficiency of sand grains which is essential to Rapid sand Casting as it impacts the flowability of the sand grains during recoating process.

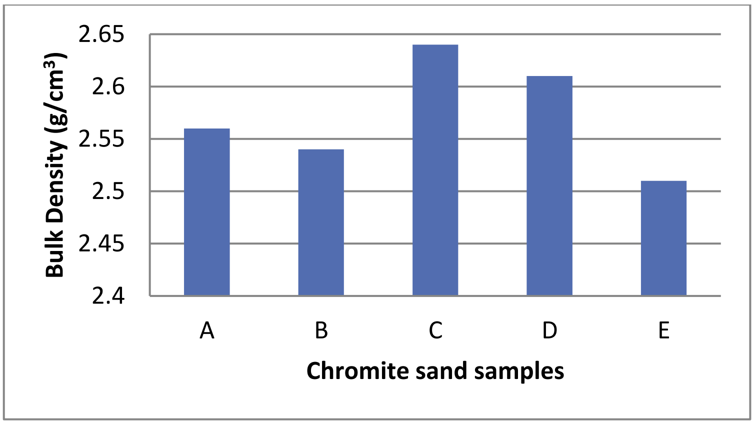

Figure 6: Bulk Density measurements

Bulk density is affected by the shape and particle size distribution of the grains. large and more angular grains and a narrow particle size distribution yield low bulk density, as was seen in the local silica sand study conducted by Dady et al. [16] on a local silica sand with a bulk density of 1.52g/ml used for rapid sand casting This bulk density of silica sand is almost do that of the lowest density recorded for chromite sand, namely sample E. This means that printing parameters on the commercial printer will need to be adjusted in order to accommodate this difference as it will negatively affect the strength of the final sand-printed part.

High bulk density results in sand being heavily compacted which influences the mould permeability. Mould with low permeability results in casting defects. The high density of chromite sand could impose restrictions on the size of sand moulds and cores to be printed in additive manufacturing equipment due to the weight limit typically associated with a 3D printer/material handling limitations.

3.4 Chemical Composition

Figure 7 below shows X-Ray Fluorescence results in terms of chemical compositions of the local chromite sands which are commercially available in South Africa, composition of sand affects the refractoriness of the moulding sand, the pH and the acid demand value, hence they need to be quantified [17].

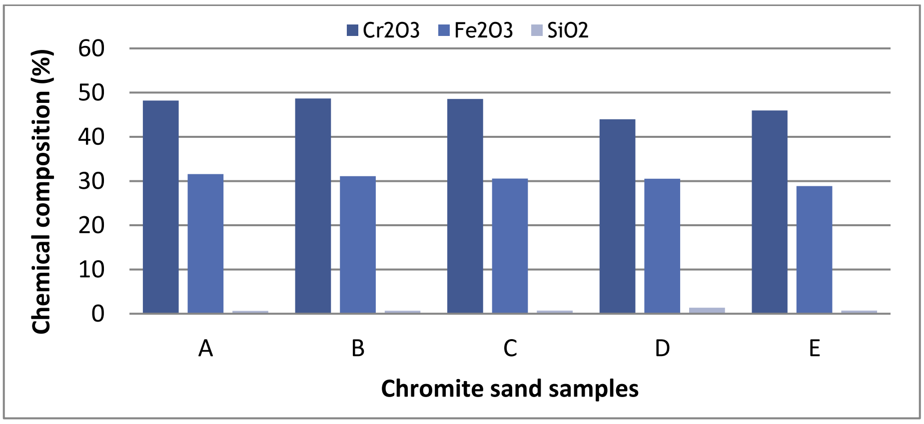

Figure 7: chemical composition results of the chromite sand samples

For the chromite sand to be used as foundry sand its chrome ore has to meet the following specification, chromium oxide content (Cr_2O_3) has to be above 46% and Silica (SiO_2) content must not exceed 1% if not its chilling properties will be inadequate. The SiO_2 content greater than 1% affects the sintering properties of chromite sand, hence reducing the quality of the sand. The above results shoes that sample D is out of the required quality standard with silica content of 1.36% and chromium oxide of 43.96 and it is therefore unacceptable for Rapid Sand casting applications. The presence of silica in chromite sand reduces the refractoriness, lowers the pH and increases the Acid demand of the moulding sand pH and Acid Demand Value.

3.5 pH and Acid demand Value

Figure 8 displays both the pH and ADV results of the chromite sand samples. Chromite sand is generally basic sand with a pH range between 7 and 9. All the chromite sand samples fall within this range. Figure 8 also shows that the pH stays relatively constant for all sands whereas the ADV tends to fluctuate, this could be as a result of different amounts of acid soluble or basic material in the different chromite sand samples.

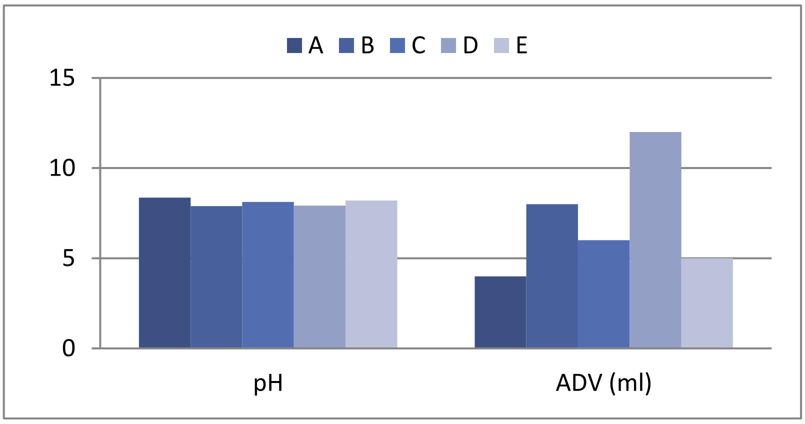

Figure 8: pH and Acid Demand Value measurements

The ADV ≤6 ml is suitable for acid catalyzed binder systems but and requires less amount of aid. The ADV between 6ml and 10 ml is also suitable for but will require high amount of acid additions, anything greater than is deemed unacceptable **[2]**. Sample B and D is acceptable and will require less acid additions, sample A and C is also acceptable but will require high acid additions, whereas sample E is not acceptable. All within the acceptable range. The pH and acid demand value of sand is directly related to the binder system's curing and setting time. Sand with a high acid demand value is found to have increased curing and setting times. Furfuryl alcohol resin is an acid-catalyzed binder; therefore the presence of basic materials in the sand affects the bonding ability of the sand and increases the resin and catalyst requirements.

3.6 Findings Summary

Table 2 below shows a summary of the findings in this research paper. The checklist shown in table below recaps the consideration of input variables or parameters to evaluate the quality of chromite sand for rapid sand casting applications.

Table 2: Summary of the findings (Acceptance and rejection of samples)

Sample	Grain Shape	FAA	Grain size distribution	% Fines	Bulk density	Chemical composition	pH and ADV
A	√	√	√	√	√	√	X
B	√	√	√	√	√	√	√
C	√	√	√	√	√	√	X
D	√	√	√	√	√	X	√
E	√	√	√	√	√	√	X

The QAF highlights the crucial aspects that should be investigated in order to ensure the quality of sand and the performance of the refractory material, used in making moulds and cores, as it plays an essential role in producing high quality castings. Therefore samples B and D met all the requirements and A, C and E did not meet the requirements for moulding sand and essentially for 3D printing as well.

4 CONCLUSION

The aim of this project was to use well-established refractory sand characterization testing methods to evaluate the quality of commercially available South African chromite sands for rapid sand casting applications. From the results it can be concluded that a most samples of local chromite sand are suitable for 3D printing applications in that the foundry properties complies with the moulding requirements and production of parts in a layer by layer manufacturting. Two sand samples had a defeciciencies related to the ADV values. The study lays the path for a quality assurance framework for chromite sand as a refractory materiaql for rapid sand casting.

5 FUTURE WORK

Future work will focus on further analysis of the local chromite sands, including tensile, bend, compression as well as friability strength testing. SamplesTest specimens using the Voxeljet VX1000 3D printer machine available at Vaal University of Technology Southern Gauteng Science and Technology Park will be produced and tested to assess whethere they comply with the specifications prescribed by the 3D printer manufacturer.

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IMPLEMENTATION OF THE MOBILE SMART FACTORY CONCEPT TO LOCALISE SPARE PARTS PRODUCTION IN THE SOUTH AFRICAN MANUFACTURING SECTOR

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ABSTRACT

Many companies in various manufacturing sectors struggle with spare parts management. The major challenge in managing spare parts lies in the uncertainty and volatility of demand. At times, companies experience unplanned downtime while waiting to replace a broken spare part, which negatively affects productivity. In other instances, there is high capital invested in inventory that may not be useful at that time. On the other hand, Additive Manufacturing (AM) is a promising technology for effectively optimising spare parts management. AM allows manufacturers to produce parts directly from digital models, resulting in shorter supply chains. The mobile smart factory is a modular container unit that covers the entire AM process chain, enabling metal and polymer spare parts production on-site. This paper aims to investigate the impact of applying the mobile smart factory to produce spare parts for the South African transport sector.

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1 INTRODUCTION

The growing demand in urban transport causes continuous change in vehicles' design, manufacturing, and maintenance [1]. To deliver high quality services, proper maintenance procedures should be put in place, including the availability of spare parts [2]. In most cases,

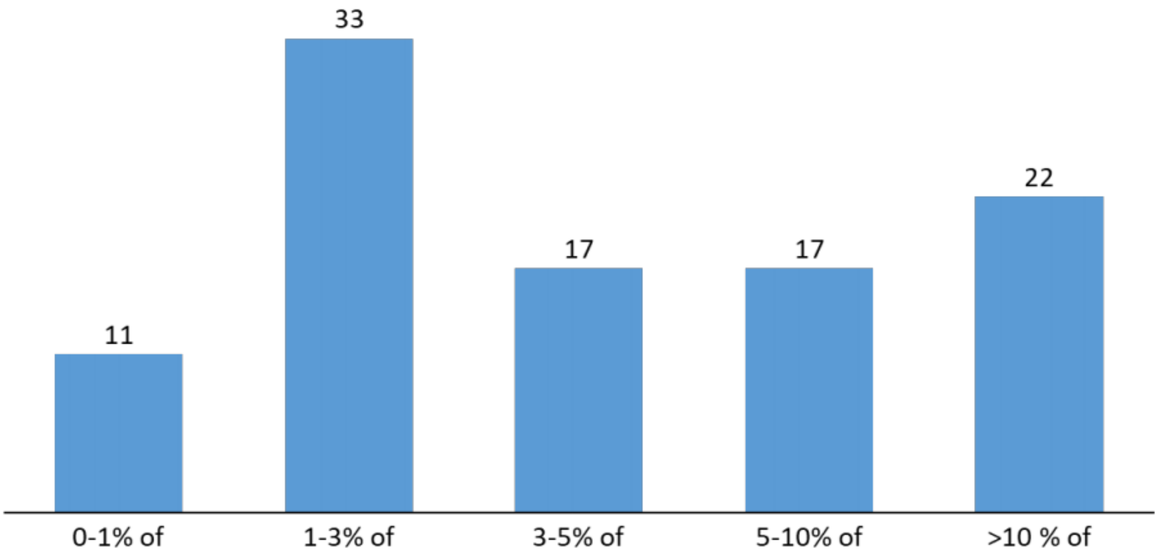

Figure 1: Obsolete spare parts [7]

companies often find it challenging to manage spare parts inventory due to rapid changes in demand patterns [3], which makes demand forecasting difficult. Unavailability of spare parts can lead to significant downtime. In the case of the transport sector, this can lead to a lot of losses when the vehicle is not in service. The operating life of vehicles such as trains can be very long (35- 45 years) [1]. As a result, some parts can become obsolete, and it can be expensive to reproduce them through conventional methods because of the tooling costs [4]. Most companies in the transport-manufacturing sector often keep high inventory levels to avoid the downtime associated with sourcing a required spare part [2], [5]. However, this leads to an increase in working capital [6]. Also, considering the current trends in technology, the parts can become obsolete while in stock, thereby leading to further losses. A study by PwC Strategy [7] revealed that a quarter of all companies interviewed stated that more than 10 percent of all spare parts they keep in stock are obsolete or do not contribute positively to profits, as shown in Figure 1.

Although most spare parts warehouses have a high proportion of fast-moving items, many items will rarely be used, and some may never actually be needed. In South Africa, most of the spare parts used in the transport sector are imported. According to the report made by the Observatory for Economic Complexity, $3B worth of spare parts were imported in 2019 [8]. There is a need to explore AM as a viable technology for increasing local production of spare parts on demand. This will help to reduce the downtime and costs associated with importing spare parts or excess inventory. Despite the many benefits of using AM to produce spare parts, adoption is limited partly due to a lack of suitable, easy-to-handle and cost-efficient technologies. The Mobile Smart Factory is a modular container unit with Additive Manufacturing (AM) machines to ensure production of parts when they are required. It can offer solutions to the challenge of spare parts management. Thus, this study aims to investigate the impact of applying an AM based mobile smart factory for the on-demand production of spare parts for the South African transport sector. In its structure, the paper firstly demonstrates how AM is suitable for spare parts production. Secondly, the mobile smart factory concept is explained. Thirdly, the article highlights the need for the South African transport sector to adopt the Mobile Smart system. The paper ends with a discussion, recommendations and conclusions.

2 AM AS A PROMISING TECHNOLOGY FOR PRODUCING SPARE PARTS

Additive Manufacturing (AM) is a promising technology for producing spare parts on demand [9]. AM technology allows parts to be produced directly from digital models without the need for tooling [10]. The American Society for Testing and Materials (ASTM) defines AM as a process of joining materials to make objects from 3D model data, usually layer by layer as opposed to subtractive manufacturing methodologies.[11]. Typical examples of subtractive methodologies include milling, turning and drilling [12]. AM is regarded as a key technology driving Industry 4.0 through digital models to create parts [13]. Within the context of Industry 4.0, AM is emerging as an important manufacturing technology that offers opportunities for mass customisation [14]. In addition, the technology offers many possibilities in different industry sectors. Some companies recognised the potential of AM in the field of spare parts early and started to establish their skills and competencies to make use of AM. For example, the German railway operator Deutsche Bahn has implemented more than 7,000 printed spare parts, reducing lead times and logistics cost significantly [15]. A study recently published by PwC Strategy estimated that more than 85 percent of spare parts suppliers will incorporate 3D printing into their business [7]. Nevertheless, until today AM adoption levels remain low. Some of the main reasons are the challenges of identifying suitable use and business cases. In addition to concerns regarding certification and part qualification, unclear IP as well as legal and regulatory issues and the shortage of well-trained and skilled technicians [16].

2.1 AM processes and materials

According to the classifications developed by the ASTM F42, AM can be grouped into seven significant processes depending on the type of material and power source and process mechanism, as shown in Figure 2 below.

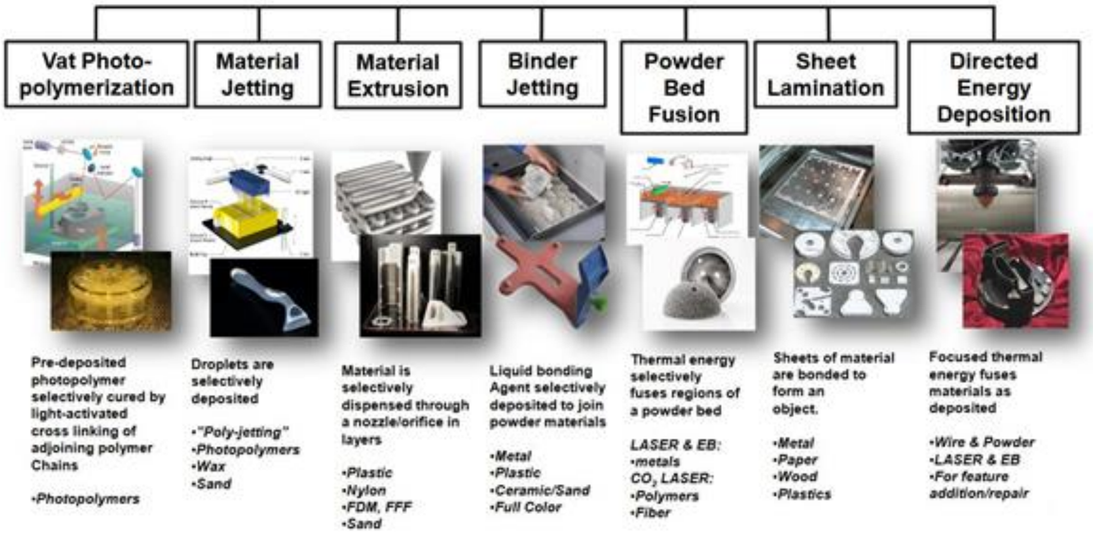

Figure 2: ASTM F42 Types of AM [17]

2.1.1 Material Extrusion

The Fused Deposition Modelling (FDM) process is a typical example of a material extrusion process. Material is extruded with a nozzle or orifice and deposited layer-by-layer until the part is complete[18]. The material is in a filament form, heated by the nozzle to form a semi-molten material that hardens after extrusion and forms a bond with the subsequent layer. This is the most common AM process because of its low cost and ease of use.

2.1.2 Vat Polymerisation

In this AM process, a liquid polymer is solidified through curing by light-activated polymerisation. The light is emitted using a highly focused Ultraviolet Light (UV) or laser beam. When struck by the energy source, the polymer hardens and forms a layer lowered into the Vat so that the second layer can be traced. The process is repeated layer by layer until the part is complete [19].

2.1.3 Material Jetting

The process involves using droplets of material selectively deposited through a nozzle [20]. The deposited material solidifies, forming a layer that is cured using UV light. The process is repeated layer by layer until the part is complete.

2.1.4 Sheet Laminating

The process involves the use of sheet material which is joined using adhesives or heat to form a three dimensional part [21]. Typical examples of sheet lamination include laminated object manufacturing (LOM) and Ultrasonic additive manufacturing (UAM).

2.1.5 Powder-bed fusion

The powdered material is fused by sintering or complete melting using a thermal energy source such as a laser beam or electron beam [22]. Typical examples of powder bed fusion processes include Selective Laser Melting (SLM), Selective Laser Sintering (SLS) and Electron Beam Melting (EBM).

2.1.6 Directed Energy Deposition

The process involves depositing molten powder or wire-based material using a thermal energy source [23]. The energy source can be in the form of a laser beam, plasma arc or electron beam. The process can also be used to repair damaged equipment[24]. Typical examples include Laser Engineered Net Shaping (LENS), Laser Metal Deposition (LMD) and Wire Arc Additive Manufacturing (WAAM)

2.1.7 Binder Jetting (BJT)

The powdered material is firstly spread over a platform using a roller or scraper. A print head is then used to deposit a binding material to join the powder selectively. This is done layer by layer until the part is complete [25].

2.2 AM as a suitable technology for producing spare parts

Previous studies indicated that AM is a suitable technology for producing spare parts. Some of the reasons include that AM allows for a reduction in tooling and set-up costs, enabling flexible production of components with the same machinery [26]. Secondly, AM can help to overcome the challenges associated with the traditional manufacturing of spare parts. These include low demand, wide variety, long lead time and high stockout costs [27]. Thirdly, AM allows for on-demand production of spare parts, eliminating the need for increased inventory [28]. Fourthly, the flexibility offered by AM will enable engineers to modify the design of features, allowing for improved functionality or integrated components [29], [30]. Integration of components helps to eliminate assembly costs and time. The distinct characteristics that make spare parts suitable for production with additive manufacturing include variable demand and low volume [31]. Also, AM can be an economical method of producing spare parts when compared to conventional methods. The latter evaluated the economic viability of using AM to produce spare parts. The results of their study confirm that end of life use of AM is an economically viable strategy. Different companies in the transport equipment manufacturing sector have already started exploring AM for producing spare parts. These include Alston, a French railway company that is currently using AM to produce lightweight spare parts [32]. Dubai's national railway company is also using AM to produce spare parts. In an article published in their local media, the engineers at the company stated that AM can reduce the time to source a part by 90% [33]. Webtech is a British rail company that is using the Binder Jet technology in their spare parts production [34]. Dutsche Bann, a German rail company, is using Wire Arc Additive Manufacturing (WAAM) and Fused Deposition Modelling (FDM) for spare parts manufactured.[35].

3 THE MOBILE SMART FACTORY CONCEPT

The Mobile Smart Factory (MSF), also known as a factory in the box, is used to print parts on-site. It is a modular container factory equipped with AM devices to produce parts on demand. Figure 3 shows the complete unit of the MSF.

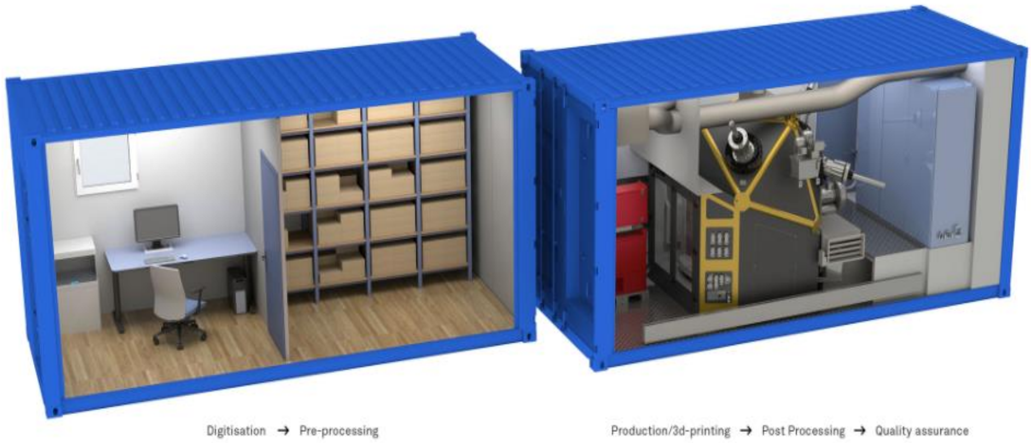

Figure 3: Mobile Smart Factory complete unit [36]

The MSF is a practical example of a mobile AM system. The factory is made out of shipping containers that are weatherproof and durable. The MSF allows production of metallic and polymer spare parts. All the processes from the design stage to the final machining are conducted in the factory. As a result, this eliminates transportation costs associated with producing parts elsewhere and reducing production downtimes. The MSF can easily be transported using a truck, railway or ship. I is structured in a way that allows expansion of production capacity. It is necessary to find the most suitable applications for the MSF system to achieve profitability [36].

3.1 Technologies in the factory

It is essential to select the suitable AM process for the envisaged application context of mobile AM technologies. The most popular metal based AM processes are powder bed fusion (Laser Beam Melting or Electron Beam Melting) and wire-based processes (Wire Arc Additive Manufacturing or Directed Metal Deposition) [37]. Powder bed technologies are not suitable for mobile 3D printing solutions, mainly because of the challenges in handling the powder, which is highly flammable and toxic. In addition, the powder-bed fusion processes have slow production speed and build rate and limited part size. In the MSF, Wire Arc Additive Manufacturing (WAAM) printing technology is used, which uses arc welding to build up the parts using layer by layer with the process flow, as shown in Figure 4.

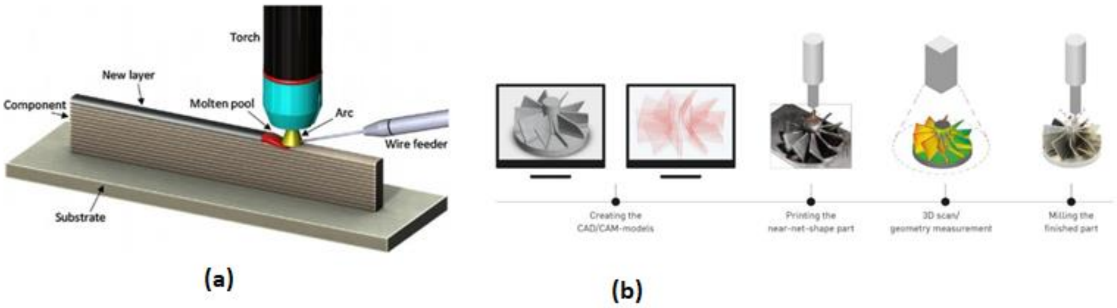

Figure 4a) Wire Arc Additive Manufacturing (WAAM) [38] b) WAAM process chain [39]

When compared to powder bed systems, WAAM is more applicable for the MSF. This is because of its advantages which include high build rates and large build volumes [38]. The WAAM system also has a well-established welding technology that is easy to handle. Unlike powder bed fusion, WAAM is more environmentally friendly because of the usage of wire, which is not toxic. Apart from near-net-shape manufacturing, WAAM is also used for repair and maintenance operations. There is also a wide variety of material applications since all wieldable wire materials are applicable. The other technologies in the MSF include a Fused Deposition Modeling (FDM) machine for producing polymer parts on-site and a portable handheld scanner for reverse engineering and the design of components. This device allows all the digital files to be directly transferred and stored in the Mobile Smart Factory's virtual / cloud storage and printed on-demand.

The MSF makes use of a digital inventory of spare parts as opposed to the conventional physical inventory. Many factors are considered when selecting parts to be digitalised. Those include procurement cost, geometry and failure history.

3.2 Application of the MSF

The MSF is used to produce components and spare parts in many industrial sectors. These include automobile, aerospace, mining, power generation, agriculture, railways, maritime and oil and gas. The MSF may be used as a key tool for education, research and skills development, even in remote locations. This provides an opportunity for advanced research in additive manufacturing, raising the bar in the manufacture of teaching aids, visualisation of conceptual innovations, repair of own components, and training competent critical personnel in the area of additive manufacturing using augmented reality feature.

The MSF can be customised regarding the process, technology, equipment and even design. For example, a MSF may consist of metal and polymer 3D printing technology and only metal or polymer. The decision as to which system is more suitable for a customer depends on the available product portfolio. The MSF can cater for different degrees of automation. This is important since many countries still struggle with a shortage of skilled AM workers and mechanical engineers and thus require an easy to operate, automated system. The MSF is suitable for industries that operate in remote areas that are often associated with logistical challenges.

4 DISCUSSION ON THE NEED FOR THE SA TRANSPORT SECTOR TO ADOPT THE MOBILE FACTORY

According to the World Bank statistics, the South Africa Gross Domestic Product (GDP) shrank by 7% in 2020 [40]. Unemployment remains a challenge in the nation and this places a burden on the economy. Localisation is a key driver for creating employment and improving manufacturing competitiveness. As shown in Figure 7, vehicle parts and accessories are the second largest group pf imports in South Africa. Those include imports from the rail, shipping and aerospace vehicles. The value of the imports increased by 13 % from 2010 to 2020 [41].

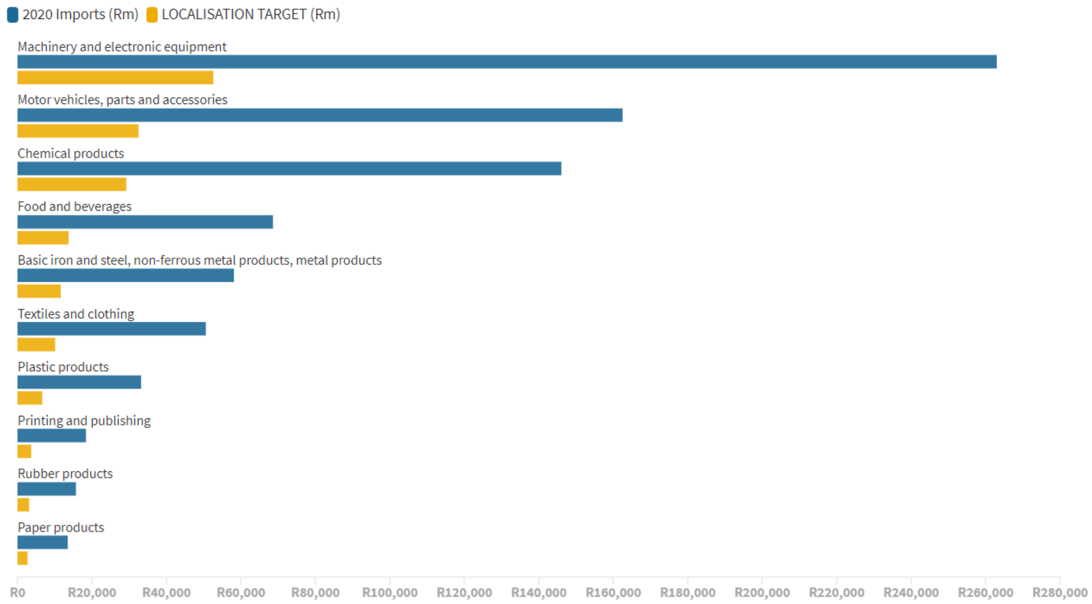

Figure 5: Localisation targets [41]

The South African Automotive Masterplan (SAAM) has raised a target to raise the local content in the manufacture of automotive parts from below 40% to 60% by 2035 [42]. Rapid technological changes in the nature of vehicles are taking place; these include development of electric cars, connected and driverless vehicles. It is important to take advantages of flexible manufacturing technologies such as the MSF system to remain competitive in the industry.The Department of Trade and Industry (DTI) has set a target for the rail industry to have a local content of 65 % (DTIC, 2021). However, the industry has a challenge of ageing infrastructure. Lessons on revitalising the industry can be derived from international rail companies such as Duetsch Bann and Alstom. They have taken advantage of the flexibility offered by AM to produce spare parts that were absolute and costly to manufacture with traditional methods.

Error! Not a valid bookmark self-reference. shows the Promising deployment scenarios for the Mobile Smart Factory in the transport equipment manufacturing sector.

Table 1: Potential impact of the MSF in the transport sector

	Rail sector	Aerospace	Automotive	Shipping
Background	The long service life of trains (35- 45 years) requires operators to ensure proper maintenance through a demand supply of spare parts. Companies in the rail sector struggle to keep inventory stock. There are situations in which rail operators are required to procure replacement parts that are considered obsolete	The aircraft industry demands products of high quality using costly materials. It is often time-consuming and expensive to produce some of the parts using conventional methods. Also, the parts often have long procurement times	The demand for customised cars calls for more efficient and quicker ways of producing parts. Spare parts management is also a challenge for automotive manufacturers	Equipment is capital intensive, and downtime can lead to serious financial losses. Considering that ships are continuously moving, the provision of spare parts becomes a challenge
Operational scenario	Providing spare parts on demand will eliminate the logistical costs of procuring parts elsewhere or the tooling costs associated with conventional manufacturing of obsolete parts.	The MSF can ensure the production of high-quality spare parts on demand. This eliminates the time associated with procuring parts elsewhere	Ability to make customised parts cost-effectively with AM. In addition, the reliability of spare parts supply using the MSF is guaranteed.	Decentralised production of parts and components at selected service points.
Potential implications	Printing and repair of spare parts and other functional parts Producing tools	Producing critical spare parts with high quality Repair of worn-out parts Providing functional, optimised parts	Producing customised parts using cost-effective approaches On-demand production of spare parts	Production and repair of spare parts Providing functional, optimised parts

When such a concept emerges, especially in SA, industrial sectors tend to be slow on adoption and implementation. Most technology implementation is always emerging and driven by universities and research institutions as they play a technology incubator. Tapping from the strengths of additive manufacturing and modular/flexible production systems, the MSF is envisioned to revolutionise the knowledge and market for AM technologies. South Africa would venture into innovations, generating customised products that will spur the 4th industrial revolution, eliminating typical societal problems such as unemployment and poverty. The MSF provides an opportunity to produce components when needed. This will be established through leveraging the strengths of AM to produce complex designs, reduce lead time, mass customisation, reduced inventory and integration of functions into existing designs.

Institutions of higher learning can help to pioneer the mobile smart factory in SA. This will help to upscale research and training capabilities. In addition, the paradigm shift of technology from traditional to 4IR, aging and/or broken machinery and research facilities necessitates the institution to venture into the MSF to keep abreast with the changes and for the critical repairs of the existing machines through additive manufacture of new components and spare parts.

Such facility concept implementation would complement the operations of the engineering workshop and revamp the South African industrialisation mandate to prove conceptual innovations and subsequent generation of end-use parts. However, highly qualified faculties are available to oversee the establishment and operationalisation of the MSF. This will help the higher learning institutions contribute to the government's plan on the localisation of manufacturing. Other benefits of establishing the MSF in the university or science council are listed below.

- Enhancing research and development in the South African priority areas (Engineering, Technology, and health care sciences)
- Upscaling skill development and training of critical masses in the area of additive manufacturing fulfilling the mandate of the university
- Fabrication of spare parts for broken down or worn out machines saves on downtime and the high cost of purchasing such parts. It will also help revive machines that lack spare parts where manufacturers have closed business, thereby generating income for the institution
- The institution can offer local/ regional short course training in additive manufacturing, thus empowering the youth and generating some income.
- Waste materials (plastics) can be utilised in the facility after recycling. This will alleviate plastic waste pollution. Also reduction in chip volume is achieved for metallic components
- It will strengthen Information Communications Technology (ICT) through enhanced point cloud sifting.

5 CONCLUSION

Mobile and modular AM systems are a promising way to optimise spare parts management in a cost-efficient manner. Across various industries, companies can significantly shorten spare parts lead times and reduce the need for cost-intensive storage space. Instead of holding all parts physically in stock, a digital inventory of spare parts can be created. The ability to manufacture parts at the point of consumption with mobile 3D printing systems ultimately shifts from a "make-to-stock" to a more cost-efficient and sustainable "make-to-order" approach for low-volume production of spare parts. In addition, companies can expect significant supply chain cost savings through localised production. The MSF system also allows for a quick and cost-effective introduction of AM technologies.

The MSF has many promising industrial applications when printing spare parts on demand. Companies using mobile AM solutions can gain competitive advantages by reducing logistics efforts and cost while simultaneously improving operational efficiency. The following steps for a profitable operation of the MSF lie in finding sufficient applications/parts for the system within the frame of a part-screening project.

This is a concept stirring the strategies to adopt in setting up an MSF in SA. Government or private companies need to come together to establish the-state-of-the art facility in South Africa. The facility is a model mobile factory consisting of a modular shipping container equipped with point cloud data capturing and 3D printing devices to offer real-time and on-site manufacturing solutions.

The MSF ensures flexible and reliable production of components whenever and wherever needed. The establishment of this facility will positively impact various industries and companies through capacity development and improved research and developments in additive manufacturing technologies, and reduced supply chain costs.

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THE EFFECT OF COVID-19 AND THE NATIONAL LOCKDOWN ON ENGINEERING STUDENTS' EXPERIENTIAL TRAINING AT UNIVERSITY IN SOUTH AFRICA

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ABSTRACT

Experiential learning is important for engineering students to gain work experience. Engineering students who study towards a National Diploma must work for one year as part of their training. This paper investigates the effects of Covid-19 on the experiential learning of mechanical engineering students at a University in South Africa. Students who are doing experiential training at a University workshop participated in the study through a questionnaire. The questionnaire was e-mailed to 27 students who are doing in-service experiential training. The results show that students did not participate in training activities send to them during the lockdown because they did not have access to computers and some could not access the internet because they stay in rural areas without network coverage or could not afford to buy data. It was noticed that Mechanical Engineering training cannot be conducted online as it is a hands-on training and require students to be in the workshop for the duration of the training. Students lost a year of training and others could have completed the National Diploma in 2020 and enroll for an advanced diploma.

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1 INTRODUCTION

Open and Distance Learning (ODL) is a mode of tuition without daily contact between the learner and the lecturer; however, there is an equally effective exchange of knowledge [1]. Online teaching and learning are emerging as a growing trend in ODL and are gaining wider popularity among higher education institutions in Africa. Distance learning, which is a formal or institutional education activity that brings together students, lecturers and education materials in different locations via interactive technologies, is a well-known education method that is used worldwide [2].

Distance education throughout the world is increasingly using e-learning, given the changing face of educational provision and technological advancements around the world [3]. All countries within the Southern Africa sub-region have at different times in the late 20th century embraced ODL to capitalize on its perceived benefits [4]. Quality assurance in higher education has received considerable attention of late and gained serious attention among stakeholders, such as employers of graduates and funding institutions [5].

Experiential learning is defined as "creating the knowledge through the transformation of experience" [6]. "Experientially based learning strategies, in general, have a long history rooted in the early work of John Dewey (1938), and later evolved in work by Piaget (1950), Kurt Hahn (1957), Paulo Freire (1970), Vygotsky (1978), Kolb (1984), Jarvis (1987), and many others" [7]. The study of engineering education through experiential learning reported that to make engineering students more employable and valuable, the course structure of undergraduate education should be industry oriented [8].

Baker and Robison in 2016 conducted the Effects of Kolb's Experiential Learning Model on Successful Intelligence in Secondary Agriculture Students and found that students who received the experiential learning treatment produced higher domain-specific creativity scores. They also scored higher in their practical use of knowledge when compared to their direct instruction counterparts [9]. Some researchers have distinguished between "experiential learning" and "experiential education" in that experiential learning relies solely on the individual and does not necessarily require a teacher, whereas many others have used the two terms interchangeably [10]. Experiential learning is based on the notion that understanding is not a fixed or unchangeable element of thought and that experiences can contribute to its forming and re-forming [11].

The outbreak of novel coronavirus 2019 (COVID-2019) was first reported in Wuhan, Hubei Province, China in December 2019 [12]. Coronaviruses are a group of viruses belonging to the family of Coronaviridae, which infect both animals and humans [13]. Respiratory infections can be transmitted through droplets of different sizes: when the droplet particles are >5-10 μm in diameter, they are referred to as respiratory droplets, and when they are <5μm in diameter, they are referred to as droplet nuclei [14].

The South Africa government implement a national lockdown at the end of March 2020 to decrease the spread of the coronavirus. Everyone had to stay at home, people stopped going to work and students were not allowed to go to school. This paper investigates the effect of the Covid-19 lockdown on mechanical engineering students who were doing experiential training at an ODL university to obtain practical experience.

2 METHODOLOGY

A descriptive research survey method was used in this study. The objective of descriptive research is to describe a phenomenon and its characteristics [15]. This study collected data through a structured questionnaire that was organised and worded to encourage respondents to provide accurate, unbiased, and complete information. The questionnaire was specifically designed to target mechanical and industrial engineering students who were doing practical training at the university.

The questionnaire consisted of three sections: The first section described the objective and importance of the questionnaire, contact person and the duration to complete the questionnaire;

the second section was about student's identification; and the last section contained the questions relating to the lockdown and the Covid-19 pandemic.

Twenty-seven electronic copies were e-mailed to students who were doing work-integrated learning at the university. These were students who could not find companies to do experiential training, met minimum requirements such as register students and passed all semester two modules. They had a week to complete the questionnaire and on the last day of the week, 11 responses were received. The distribution of participants in the study is presented in table 1. A limitation of the study was the small sample available due to the number of students who were doing their experiential training at the workshop of the Department of Mechanical and Industrial Engineering. Some of the questions asked on the questionnaire are tabled in table 2. The data collected from the questionnaire were analysed with Microsoft Excel to generate descriptive statistics.

Table 1: Questionnaire distribution and responses

Number of students involved	Number questionnaires sent	Number of responses
27	27	11

Table 2: Some of the questions asked on the questionnaire

Questions
1. Do you think the closure of the University was essential to prevent the spread of the covid-19 virus?
2. What do you believe the most difficult obstacle is in efficiently utilising educational technology during the COVID-19 crisis?
3. Since national lockdown, how often have you communicated with your instructors about P1 or P2 online training?
4. During your P1 or P2 training, did you rent a place to stay or staying at home?
5. Is it possible to conduct Mechanical Engineering in-service training online? If yes, how would you go about doing it?

3 RESULTS AND DISCUSSION

Out of the 27 questionnaires sent to students, 11 were answered and returned within the stipulated time. Figure 1 contains the questionnaire distribution and responses, showing that 41% of students responded to the questionnaire and 59% did not respond. It is unclear that those students who did not respond to the questionnaire had no access to computers or laptops, could afford data or experienced network connection challenges.

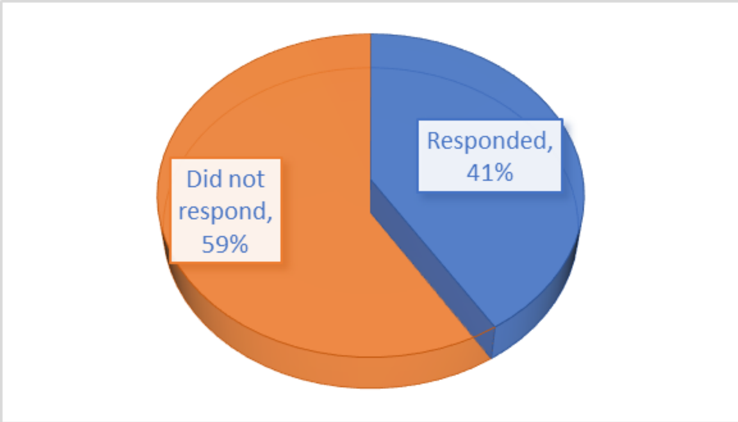

Figure 1: Questionnaire distribution and responses

Figure 2 presents the importance of closing the university as all the students thought it was essential for the government to close universities to prevent the spread of the coronavirus. The suspension of teaching and learning activities affects learning and the academic calendar and implies less economic opportunities and human capital in the future as well as the increasing number of teenage marriages [12]. People can catch Covid-19 from others who are infected with the virus. The disease can spread from person to person through small droplets from the nose or mouth, which are spread when a person with Covid-19 coughs or exhales. Everybody thought it was a good idea when the government announced the national lockdown to minimise the spread of the coronavirus.

Figure 2: Closing universities to prevent the spread of the virus

Figure 3 shows the biggest challenges of using educational technology effectively during the lockdown. 27% of students do not have laptops or computers at home and normally rely on the university or friends for access to computers. 9% of students did not have any access to laptops or computers during the national lockdown; not all students can afford to buy a computer or laptop due to different financial challenges. Students come from different areas and some are staying in rural areas where there is no or little network connection. 27% of students experienced connection challenges due to the areas where they live. As we know, data is expensive in South Africa and 36% of students could not afford to buy data during the national lockdown.

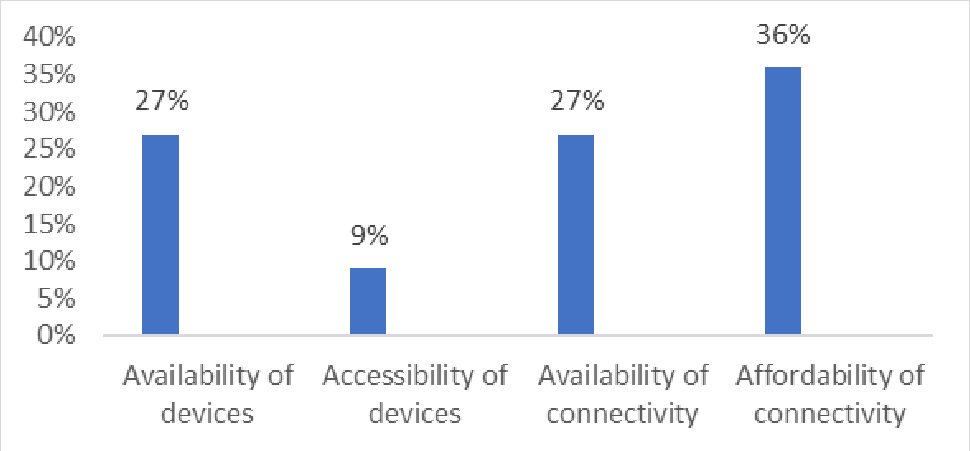

Figure 3: Challenges of using educational technology effectively during the lockdown

Figure 4 presents students' communication with their training instructors during the lockdown. It is imperative for the students to always communicate with their instructors during their in-service training to discuss their challenges during and after training. The discussion could be on how to approach the given activity, how to use certain machinery, tools, material, dimensions, design and report writing, to name a few. During the lockdown, students were given activities to do at home. 27% of students never contacted their instructors during the national lockdown, due to connectivity challenges they experienced in their area and 45% of students communicated with their instructors twice or thrice a month to discuss certain things on their training activities. The other 27% of students contacted their instructor once a week for assistance on their training.

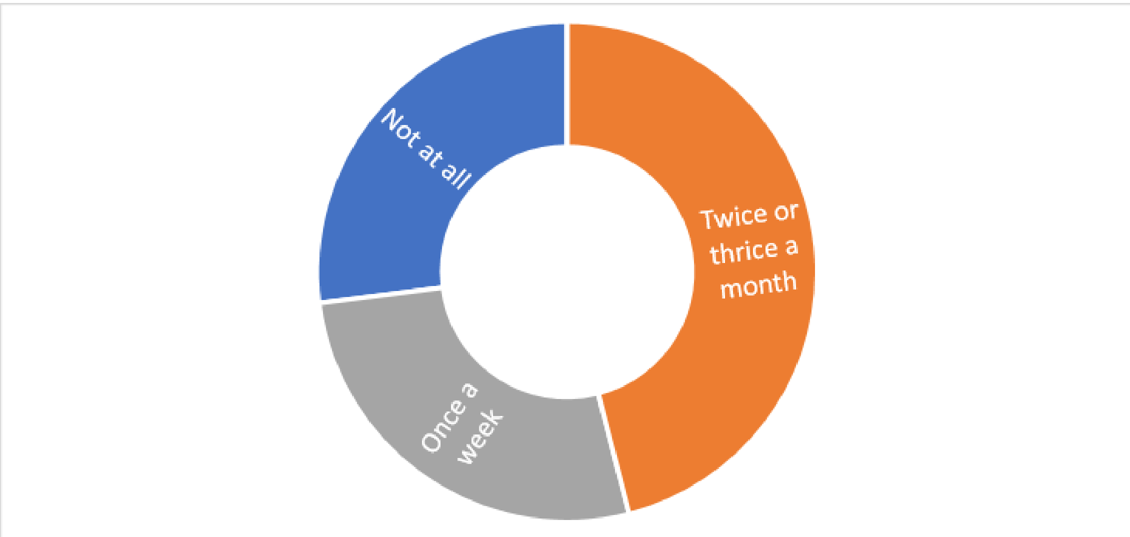

Figure 4: Student communication with their training instructors during the lockdown

On the question of how Covid-19 affects their education plans, all the students indicated that sitting at home for a year negatively impacted their education plan as it adds a year to their academic plan. Some were supposed to complete their National Diploma at the end of 2020 and enroll for an advanced diploma; some could not access the library to get additional study material and an internet connection, and others found it difficult to study alone as they are used to studying in a group.

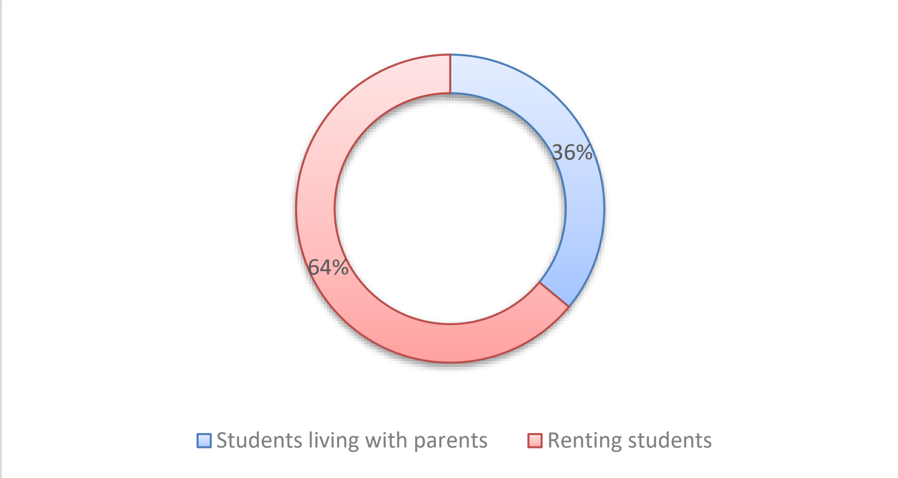

Figure 5: Student accommodation during in-service training.

Figure 5 represents students' accommodation during in-service training. 36% of students were staying with their parents during their experiential training and 64% of students rented rooms closer to the university to reduce traveling costs and to be on time. Students who are studying at this university come from different provinces. Those students who live close to the university with their parents, do not pay rent or buy their own groceries. The students who were renting kept on paying the rent during the lockdown while they were not around. This is a financial loss to students as they are paying for something they are not using. Some could not go home due to financial challenges and other students left their study material behind when they went home; consequently, they could not study and submit assignments during the lockdown.

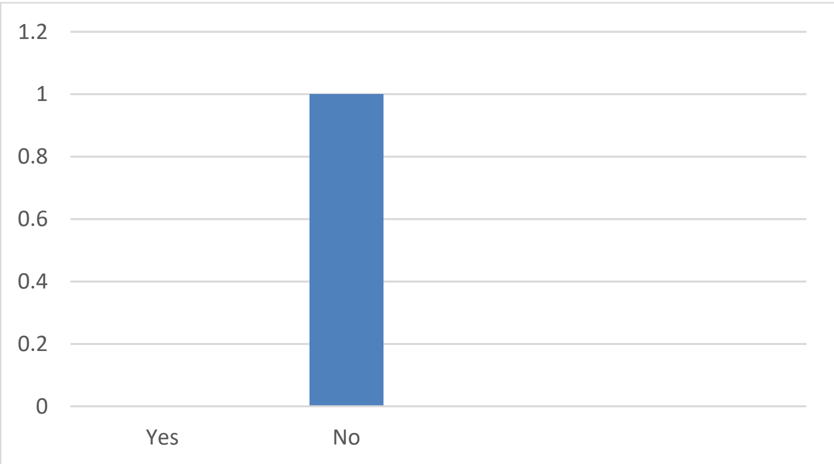

Figure 6: Possibility of conducting Mechanical Engineering In-service training online

Handtools, welding machines, power tools, lathe machines, milling machines, auto CAD inventor training, pneumatics, and hydraulic benches are all part of mechanical engineering in-service training. The prospect of providing Mechanical Engineering training online is depicted in Figure 6. Because a program of this sort cannot be conducted online, all of the pupils answered no. Mechanical Engineering training is a hands-on course that requires students to spend time in the workshop performing a number of exercises. Take, for example, hand tools training. Students will require a workbench with a vise and a toolbox with all hand tools necessary to cut the material required for that specific project.

4 CONCLUSION

The study aimed to investigate the effects of the Covid-19 pandemic on engineering students' experiential training. Although the government took the right decision to introduce the national lockdown in South Africa to reduce the spread of the coronavirus, it affected students negatively as they come from different social and financial backgrounds. Some rely on university facilities to study and do research because they do not have access to computers or laptops and cannot afford to buy data. Some students come from rural areas where there is no network connection, which prevented them from participating in online activities during the lockdown. It is not possible to conduct Mechanical Engineering training online as training of this nature requires hands-on training. Students need to be in the workshop at all times. Students lost an entire year of training and are now behind schedule. Some could have completed their studies in 2020 and enrolled for a higher qualification or could have been employed by now. Covid-19 negatively affected the entire world emotionally and financially. Apart from losing the academic year, some people lost loved ones. Continued national lockdowns have not affected academics only, it also affected the GDP of the country and makes it imperative for the government at all levels to reassess and re-evaluate the effects of lockdown as the pandemic unfolds.

Students should take their study materials with them when heading home due to National lockdown in the future so that they can study and submit assignments while at home. It is advised that students who come from remote areas with no network access do not return home or visit relatives who live in places with the network coverage. They should have their own computers or laptops rather than relying on the University's PCs.

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INVESTIGATION OF THE UNIVERSITY ELEVATORS MAINTENANCE QUALITY CONTROL USING C-CHART METHOD

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ABSTRACT

University education is more than the next level in the learning process; it is a critical component of human development worldwide. Buildings are very important to any University as they accommodate students, staff and equipment. Majority of building are several floors therefore, there is a need for elevators to take people from one flow to the other. The elevators are widely used as an important part of the building and its sales volume and usage have continued to grow. This paper study the abnormality in the occurrence of maintenance related defects of the University elevators using C-chat method. The results show that all the plots fall within upper and lower control limits. Therefore, there was no abnormality in the occurrence of maintenance related defects of the elevators under study. The equipment is expected to have maintenance related defects twice in seventeen months.

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1 INTRODUCTION

Traditionally, maintenance, with its multifaceted activities, resources, measurement, and management, has been important to Universities [1]. Maintenance is an important means of securing targeted performance of the production process and is therefore given an increasing attention [2]. In many companies including Universities, the maintenance function is seen as an expense account with performance measures developed to track direct costs, even though it is a vital factor for achieving a reliable production process and correct deliveries to the customers [2].

It was discovered in Second World War that there have been profound advances in engineering and scientific technology that have highlighted the need for more attention to be paid to maintenance of engineering systems [3]. Maintenance can be classified into the following types: corrective, proactive, preventive and predictive. Corrective maintenance consists in an intervention made after the occurrence of the failure [4].

Organizations are facing a lot of challenges such as optimization of operation and maintenance function due to the continual evolving world of technologies, global competitiveness, environmental and safety requirements [5]. Nowadays maintenance is a strategic factor to guarantee high productivity of industrial systems as well as universities, but the global economic crisis has brought companies to reduce maintenance expenses with critical consequences for long-term reliability [6].

The importance of maintenance function has increased due to its role in keeping and improving the availability, product quality, safety requirements, and plant cost- effectiveness levels [7]. Building maintainability has significantly affect building's cost, risk, and performance. A review of building performance of construction industry was undertaken, and it expressed building maintainability is substantially affecting building performance [8]. Most of these maintenance approaches or strategies are built on similar basic maintenance tactics, making it difficult to understand the differences between them [9].

An elevator is an extremely complex system with hundreds of parts that must be maintained. The elevator machine room is the heart of the elevator system. It contains the elevator hoisting machines, motor generator sets or solid-state power supply, and control equipment. The control equipment is an essential part of the total operating mechanism that accelerates, decelerates, and levels the car at each floor.

Public concern over elevator safety and quality has been growing [10]. In elevator techniques, proper installation, ongoing maintenance, and inspection are required. Long-time continuous usage increases fault-occurrence probability, which requires troubleshooting quickly [10]. Studies have been contacted by several researchers on elevators. Siti et. al in 2018, investigated the maintainability issue of elevator system by recognizing the type of operational defects or malfunction that could be found in the elevator system and the possible causes of each defect detected.

By understanding the common defects found and the possible causes, this helps the maintenance management team to make a prediction of possible more damages resulted from independent defects of each elevator's components [8]. Research study on optimal maintenance strategy of elevators within finite life from the perspective of preventive maintenance to reduce the failure rate of elevators was conducted by Liu and Wu in 2018. They found the number of elevator preventative maintenance and the time interval by establishing a target programming optimization model [11].

In 1987, Hitachi developed a remote elevator monitoring system that used the public telephone network. system had a function that automatically notified the control centre of equipment problems, enabling prompt dispatching of maintenance engineers [10]. Reliability Evolution of Elevators Based on the Rough Set and the Improved TOPSIS Method study was done by Zhang et. al. 2018. They combine the grey number theory with the TOPSIS method to build an improved TOPSIS evaluation model, to evaluate the reliability of elevators and determine the optimal ordering [12].

Universities have huge building which have several floors. They employ people and enrolled students of different age and disability. Therefore, they rely on elevators to move from one floor to the other to perform their different work. It is imperative for the elevator to be available at all times. The objective of this paper is to investigate the abnormality in the occurrence of maintenance related defects of the elevators under study using C-chat method.

2 METHODOLOGY

In this study, one-year elevators maintenance history was obtained and analysed. In this University, elevators are maintained by an external company which has a contract with the University. The University admin person keeps maintenance records. Telephonic request was made to maintenance department and after three weeks elevators maintenance records were emailed in the form of excel spreadsheet. The records were from four different buildings of the same campus and are presented in table 1. Elevator's maintenance history was studied and mathematically analysed using C-chart method.

Table 1: Elevators maintenance history

Machine No.	No. of Maintenance related defects
1	5
2	3
3	1
4	0

2.1 C-chart method

Walter A. Shewhart developed control charts in 1924. Today such charts are used for many purposes: to determine whether or not the process is in the state of control, to provide information for decisions concerning inspection procedures or product specifications [13]. The control chart can be described as a graphical method used to evaluate whether a given process is in a "state of statistical control" or out of control [13]. C-chat in maintenance is used to control the occurrence of several maintenance related equipment defects and is given by:

$$C = \frac{MD}{N} \quad (1)$$

Whereby;

C is the Poisson distribution mean.

MD is the total number of maintenance related defects.

N is the total number of equipment.

The relationship given in equation (1) show the system mean Poisson distribution and the system total number of maintenances being related to defects. It is shown that the mean Poisson distribution of the system is directly proportional to the effect number of maintenances in the system and the process is comparably related to the defects that takes place in the system during operation which is inversely proportional to the total number of equipment being used. From the mean Poisson distribution as given by equation 1, the standard deviation can be computed as:

$$\sigma = \sqrt{C} \quad (2)$$

The model shown in equation (2) revealed the standard deviation of the system during maintenance process. The model revealed that the relationship on the system standard deviation is directly proportional to the control upper limit in which the system is design to operate within. The expression for the upper control limit is given as:

$$UCL = C + 3\sigma \quad (3)$$

From the derived model in equation (3), it is shown that the system upper control limit is directly proportional to the maintenance mean Poisson distribution and the system standard deviation during operation. The lower control limit is given by:

$$UCL = C - 3\sigma \quad (4)$$

The maintenance lower control limit during operation is directly proportional to the mean Poisson distribution of the system as defined by equation (4) above. The University elevators maintenance quality control was mathematically analysed using equation 1 to 4 and the results are shown in table 2.

3 RESULTS AND DISCUSSION

Table 2: Results obtained from C-chart model

Description	Result
MD	9
C	2.25
σ	1.5
UCL	6.375
LCL	-0.375

From results in table 1, it was noticed that the total number of maintenance related defects were 9 and the standard deviation was reported to be 1.5. The average number of maintenance related defects per machine was 2.25. As per the duration of data collection in this study, which was one year and five months, each elevator is expected to have 2 maintenance failures. The results in table 1 and 2 are graphically presented in figure 1.

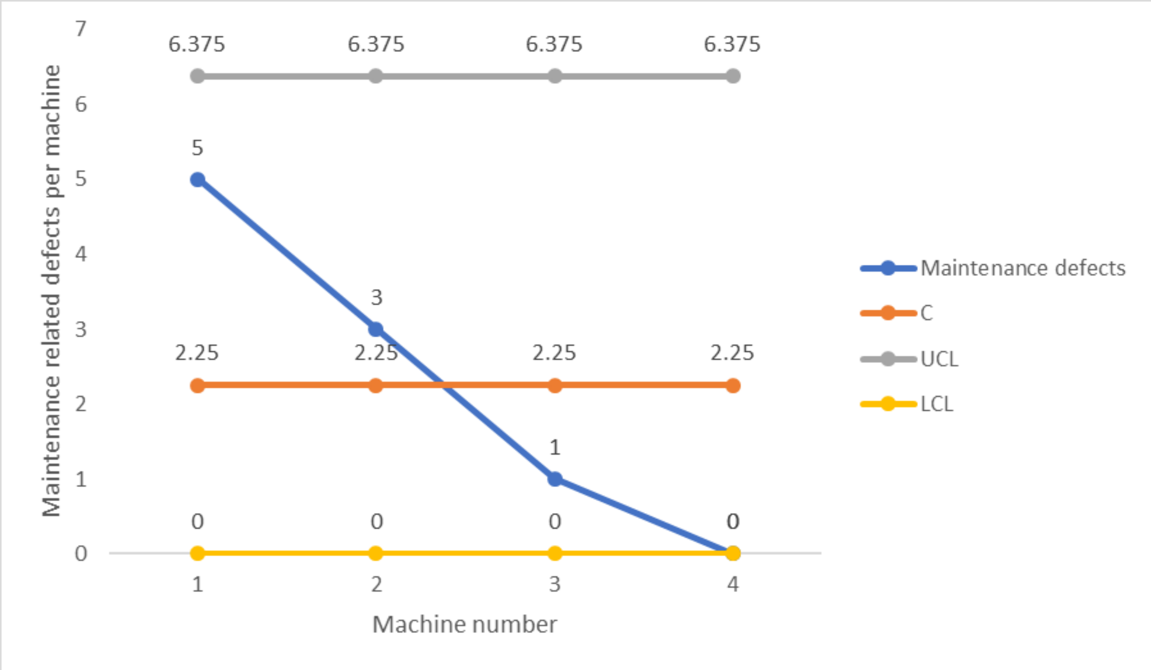

Figure 1: C-chart

Figure 1 shows a C-chart which was drawn based on mathematical results obtained from equation 1 to 4. From this figure, it was observed that all the plotted data points fall within the upper and lower control limits which were reported to be 6.375 and -0.375 respectively. This implies that there was no abnormality in the occurrence of maintenance related defects of the elevators under study. The same results were reported by [13]. The quality of maintenance of the University equipment was noticed to be under control. When a plotted point falls outside the control limits either upper control or lower control limit, the process is declared out-of-control [14]. This Control chart was used to routinely monitor maintenance quality of equipment under study [15]. The good maintenance and safety practices of a company should serve as the foundation for risk management, making decisions more assertive for a project or implementation process [1]. This equipment is of high importance as they transport normal and disabled people from one level to the other. Therefore, maintenance quality control must be assessed to check the occurrence of elevator maintenance related defeats. Equipment should be properly maintained, if it is to fulfil its intended purpose [2]. It is normal that Elevator equipment will inevitably fail because of the accumulation of running time and service age [3].

4 CONCLUSION

The paper presented mathematical description of maintenance quality control of elevator equipment using C-chart method. The control chart used in this study was a graphical method to evaluate whether this University elevators are in a state of statistical control or out of control. in this research work, this chart was used to control the occurrence of several maintenance-related equipment defects of University elevators. Poisson distribution was used to obtain expressions for the upper and lower control limits for the chart. The results show that all the plots fall within control limits. It was the indication that the maintenance quality of this elevators was under control. There were no unusual maintenance related incidents. The equipment is expected to have maintenance related defects twice in seventeen months. The management and control of maintenance activities are equally important to performing maintenance. This control chart can be used in maintenance work to control the quality of the work performed in any equipment. Elevators are essential equipment, therefore it is imperative to make sure that their maintenance quality control is within acceptable limit at all times.

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STEPS TOWARDS IMPROVING EDUCATIONAL PERFORMANCE WITHIN SOUTH AFRICA USING DESIGN THINKING

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ABSTRACT

The South African Basic Education statistics indicate that steps need to be taken to address the educational performance gaps, especially at the lower grades. Results show that 38% of the learners who start Grade 1 do not make it to their Matric year after 12 years– which is reflective of learner stagnation and dropouts. This paper investigates the factors that affect Grade 1 learners' performance using design thinking methodologies. Design thinking is an empathetic approach, used to gain in depth understanding of the factors. Emphasis is placed on the first grade because this is where the foundations of learning are laid. Interviews were held with foundation phase educators, the results identified 6 context specific factors that influenced the learners' performance. This study highlighted the need for user-context centred social value creation and the effective use of design thinking for problem solving within the education sector.

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1 INTRODUCTION

The importance of education is undeniable in our current day society as it empowers people. Education is a tool that can be used for the eradication of limitations that restrict people from participating and performing at their full capacity [1]. Education enables one to flourish economically and socially [2].

> *"From 2003 we had 147 000 students starting Grade 1, by Grade 12, that number reached 91 000, which is 62 per cent throughput."*
>
> -Gauteng HOD of Education, Edward Mosuwe [3].

Only 62% of the learners who enrolled for Grade One in 2003 made it to Matric in 2015 [3]. This statistic is reflective of learner stagnation and dropout. Research also shows that learners who are unsuccessful in attaining their matric had fallen behind in their academic achievements in their foundation phase learning [4] .

Educational performance

At the Gauteng provincial Primary Education Summit (held in March 2020) the Gauteng Education MEC, Panyaza Lesufi highlighted concerns with regard to the extremely high failure rate in the foundation phase in 2019 [3]. Out of 149 461 learners who were registered in the Gauteng province for the 2019 academic year [5] 21 000 failed grade 1 (which is reflective of a 14% failure rate). It is important to note that the number of registered learners in 2019 mentioned reflects the number of learners registered as of November 2018, it is not reflective of dropped outs and late registrations.

The MEC mentioned that the Department of Education would look into eradicating the factors that contribute to poor performance [3]. Some of the predominant factors which were mentioned were those within the school and classroom context. These included: school infrastructure, quality of educators and the material taught [3]. Past studies have shown that there is a need to focus on the factors that emerge outside of the classroom such as poverty, family structure and parental involvement [6]. A dual focus on both the factors inside and outside the classroom is necessary to effectively identify the effect of each, prevalence of multiple factors and the impact thereof. However, due to limited time to conduct the research, this research places emphasis on the factors outside of the classroom.

Critical attributes such as ethical conduct, good manners and crucial learning styles are introduced to the learner at entrance level [7]. This raises the need for research and design in aims to assist those who are struggling at this level.

Design thinking for social problems

Design thinking also known as human centred design is an approach to research and design that is user specific [8]. User specific solutioning refers to the inclusion of the user in every step of the design process to gain insight and for co-designing based on the users' context [9]. A common theme throughout the design thinking process is empathy; therefore this methodology can be described as an empathetic approach to solving for the needs of the end user [10]. The benefits of the approach are that solutions are tailored to the user [8]. Design thinking is a fivefold process with the first step is called "Empathise", which involves gathering of information through observation, questioning and empathetic engagement to develop an understanding of the users' experience and motivation [8]. The second step is called "Define", in which the observations made and the data collected in the empathise step are analysed to identify a root cause. Once the human centred problem has been identified the formulation of possible solutions is done in the third stage known as "Ideate". From the possible solutions, prototypes are built and tested in the last stages ("Prototype" and "Test" stages) [10]. This study will focus primarily on the use of the Empathy and Define phases to better understand the factors which influence learner performance.

1.1 Problem statement

Today leaders are faced with progressively more complex problems which cannot be easily solved by utilising traditional problem solving processes or hegemonic systems of inquiry such as science [8]. This study focuses on a school located in a disadvantaged community that is characterised by poverty and gangsterism [11]. At the school of interest, a total of 30 learners out of a population of 160 failed Grade one in 2019. This represents a failure rate of almost 20%. The failure rate at the studied school is significantly higher than the provincial failure rate of 14% [5]. Past studies show that the background of a learner has significant consequence on the learners' academic performance [12, 13, 14]. Additionally, studies also indicate that the academic performance of learners coming from disadvantaged background lags that of the more financially well off learners [14]. The focus of the study is placed where there is a great need for intervention, in an environment where learners are faced with a plethora of factors that impact their educational journey.

1.2 Research aims and objectives

1.2.1 Research aims :

The aims of the research were to use design thinking methodologies in identifying what external [outside of the classroom] factors, do educators at the selected school, perceive to affect grade 1 learners' academic performance.

1.2.2 Research Objectives

- To identify the factors that affect the grade one learners' performance as per the educators' perception. (The study was based on the performance of minors who might not be able to explicitly express themselves and have thus been excluded from the collection of data. The educators of the learners are the primary supervisors of the learners' formal school education).
- To rank the identified factors to determine which have the biggest effect on the performance of the learners.
- To explore the measures currently underway to assist struggling grade one learners in order to provide recommendations.

As a broad objective, the study intended to illustrate the benefits of using a user centred approach in identifying context specific factors.

2 LITERATURE REVIEW

2.1 Background of education in South Africa

The history of education in South Africa has strong bearing on socio-economic outcomes and the impact thereof is still observed in present socio-economic inequalities. The various financial and social stratifications bear significant influence on the educational attainment of a learner, as affluence has strong positive correlation with quality of education [15]. Education is used as means to transform one's economic status [16]. However, learners who are more well-off perform better than those living in poverty, this gives rise to a poverty trap. A poverty trap can be characterised by the perpetuation of inequality through unequal education as a result of poverty, thus continuing the patterns of poverty [17].

2.2 Barriers to education in a South African context

The factors that affect the learners' performance are not exhaustive or limited to the below mentioned. For the scope of this study the factors mentioned are from outside of the classroom and within a disadvantaged community. The table below lists the factors:

Table 1: Barriers to education

Factor	Effect
Lack of incentive such as subsidies for learners to attend early childhood development centre	The effects of learners not attending pre-primary education are seen in the exponential growth in learning deficits as a result of poor learning foundations laid at an early age [18] .
Learner's educational profile	The learners'education is defined by grade repition and absenteeism. Grade repetition negatively affects the learner's confidence, failure weighs heavily on a learner's academic motivation as well as their social relations and engagement [19]. The increase in class population makes it difficult for educators to provide sufficient individual attention to the learners in the class. The large age variations within a grade induce difficulties in managing the class and requires the educator to apply increased differential teaching methods to cater for the various developmental stages of the learners [16]. Grade repetition was found to have weak correlation with the learners' abilities [20] The reduction of time spent learning may result in dissatisfactory learner outcomes [21].
Language barrier (different language of instruction and home language)	The results from the second SACMEQ [21] on learners'whose language of instruction is English, showed that learners whose home language was English performed better than learners who did not conversated in English at home by 37.5 points on a literacy test and having similar correlation for the numeracy scores. The transition between languages could be challenging for some learners because the prime window for the development of language grammar and syntax closes at six years old. Learning a language outside of this window would require significantly greater time and effort [22].
Socio economic status	Money is important for the provision of educational resources and facilities as well as for the running of a successful education system [15]. Learners raised in poverty are more likely to conform to the social standards due to the amount of challenges that they are faced with 'their brains have adapted to suboptimal conditions in ways that undermine good school performance' [23]. Children raised in poverty are most likely to be faced with emotional and social challenges, acute and chronic stressors, cognitive lags and health and safety issues.
Nutrition	The physical and cognitive development of children is stifled by malnutrition resulting in a shorter concentration span and decreasing their capability to learn and perform well [24]. These impediments cause the affected learners to perform poorly, repeat grades or even drop out.
Quality of educators	The number of days the educator is absent contributes to insufficient time spent on academic tasks for learners [20]. The SACMEQ III identified, through content based assessments that were written by teachers that there is a relationship between the teachers' knowledge of the content that they teach and the learners' academic outcome, furthermore the study showed that the teachers' training/ experience level contribute to poor academic outcomes [20].
Overpopulated classrooms	Smaller classes are better disciplined, enable learner individualization and good learner concentration and attention are better achieved [25].

The aforementioned factors are identified by Taylor and Yu [14] to have the largest impact within the South African context.

3 METHOD

3.1 Research method

This study was conducted with a primary school located in a disadvantaged community in Gauteng. The grade one learner population is 160 and there were 4 educators allocated to each grade. In the Empathise stage, four grade R educators, four grade one educators and four grade two educators were interviewed, in total there were 12 participants. The research participants are reflective of the full population of educators that engage with learners within a biological age group of 5-8 years old. The age cohort range was restricted to reflect learners in Grade one and to avoid large variation in developmental levels and support levels of the learners [16]. The interviews were conducted with grade one educators to obtain insight from their experience and perception from direct interaction with grade one learners. The grade two educators were interviewed to attain what they perceive to be the cause of failure and/ or poor performance and good performance of grade one learners as the recipients of those who have passed grade one. The grade R educators were interviewed to attain what they perceive to be the factors impeding the outcomes of the learners that proceed to grade one. The research method that was followed to attain the necessary data will be qualitative and design thinking tools will be used for the analysis of the data. The below table summarises the data collection and analysis techniques which were applied in the study. Techniques from both design thinking and more traditional Industrial engineering tools were used in the study.

Table 2: Research method

Design Phase	Overview	Data collection	Data processing	Data analysis
Empathise	The Empathise stage requires the researcher to immerse themselves in the lives, culture and environment of the end user to develop an understanding of the people. This was achieved through ethnographic mapping and observations.	The data was collected through the use of semi structured interviews. Interviews are a direct approach used to capture the users' experiences [26].	The information was processed through ethnographic mapping. Experience mapping is used to identify the main themes and critical information from the interviews [27].Mapping depicts the relationship and interactions between people and information as well as how the information is spread. An observations tool, POEMS ,was used as a guiding framework to understand the engagements and influences that the stakeholders are faced with [28].	The data was analysed through the interpretation of the maps, processed data and the use of a Pareto chart.
Define	Within the "Define" stage the root cause is identified and characterised. This was achieved through the analysis of the findings from the empathise stage. The tools used were content analysis tallies and graphic representation.	The data used in this phase was derived from the current state analysis.	The data was categorised using an Ishikawa diagram.	An interrelationship diagram was used to analyse the data and to identify the focus area. An extreme persona analysis was conducted to root out the factors which were outliers by identifiying factors that were mentioned by less than 20% of the participants.

The scope of the research was limited by time and access limitations. The research was conducted during a time of pandemic and COVID 19 restrictions. As a result, the research findings are based on one school with compliance with the regulations. It is important to therefore note that the results may not be indicative of the whole South African population and that the nature of design thinking is user centred thus the findings of this study are specific to the user, their environment and conditions.

3.2 Validity and reliability

The process of validation assessed whether the interview successfully extracted the required information without infringing on any ethical considerations. The reliability method assures the dependability of the acquired data set. The validation and reliability methods were decided based on the nature of the study being qualitative. A face validation of the semi structured interview questions was conducted by the project supervisor in alignment with the research objectives and ethical considerations.The reliability of the data collected was ensured through member checks, through which, interviewees checked that their views had been correctly documented. A risk assessment was conducted and ethical clearance was granted for the study by the university of the Witswatersrand. The following ethical considerations were made:

- The participants were not obligated to answer any or all questions that made them uncomfortable or they felt infringe on their privacy.
- Participants were informed that they are allowed to withdraw from the interview at any time.
- The participants were made aware that all of their answers as well as their identity will remain confidential.
- Ethical clearance protocol was followed as per the Witwatersrand ethics office.

4 RESULTS

4.1 Experience mapping

The experiences and perceptions of the educators in relation to the educational journey were captured through a user journey map (Table 3). The learning process was divided into 5 main phases, from A to E which detail the main interactions between the educator, learners and parents. The journey map expands on the learning process and areas of opportunity. The user journey map identifies parts of the process that are satisfactory as the points of fuel. The points of friction on the map highlight areas which are unsatisfactory.

Table 3: Journey Map

	A. Introduction to class	B. Begin curriculum work	C. Identify the weaker learners	D. Remediate	E. Offer extra support
Actions	Engage with the learners as a class andattempt to identify behavioural patterns and individual characteristics.	Follow the learning schedule and curriculum. Conduct benchmarking test to determine the amount of knowledge the learners have acquired.	Study and understand the individual learner and identify the cause of weak performance. This is achieved through the analysis of the learners' benchmark assessment and otherclass assessments as well as theirengagement in class.	The remediation process begins with categorizing the learners by their performance then applying differentiated teaching methods. This process is done by all the educators, for every class in the school.	The extra support plan is co-created by the educator, parent and school support team. In the event that the learner needs special supportwhich is non-academic, they are sent to the remedial educator. The school basic support co-ordinator educator is responsible for all the non- academic remediation for all the learners in the school.
Points of fuel	The educators are filledwith curiosity and excitement as they welcome a new cohort of learners.	The educators enjoy engaging with the learners and getting toknow each individual.	The educators are fueled by thepotential the learners have and their strong desire to observe thelearners' improvements.	Observing learner's academic performance and engagement within a class setting improve.	Observing learner's constant improvement from the support programme.
Points of friction	The disinterest shown by the children and parents for the learningprocess.	The learners' lack of discipline.	Large number of learners lackbasic knowledge that should have been instilled in the previous Grade.	An estimated 10 out of 25 learners' academic performance is not significantly improved by remediation. The failed remediation is, in some cases a result of factors outside of the classroom and the educators struggle to identify the cause of failure for each individual	Parents are reluctant to plan and permit their children to participate in the extra support programme due to the stigma that learners who attend these programmes are seen as failures or incapable.
Opportunities	Engage community in school related activities.	Conduct health and psychological assessments of the learners. The school nurse and school social worker that are provided by the government can conduct these assessments.	Implement out of school learning system to drill the information learned.	Assess the effectiveness of the non-academic remediation.	Workshop the parents as means to get them more engaged with their children'sschoolwork.

4.2 Barriers to successful learning

The research identified 17 factors that impeded successful learning. The significance of the factors was measure though a content analysis count basis and tallied as per the number of times each factor was mentioned by the interviewees. The factors that were predominantly mentioned are assumed to have a relatively bigger influence. A PARETO analysis was used to aid in identifying those factors that have the greatest influence.

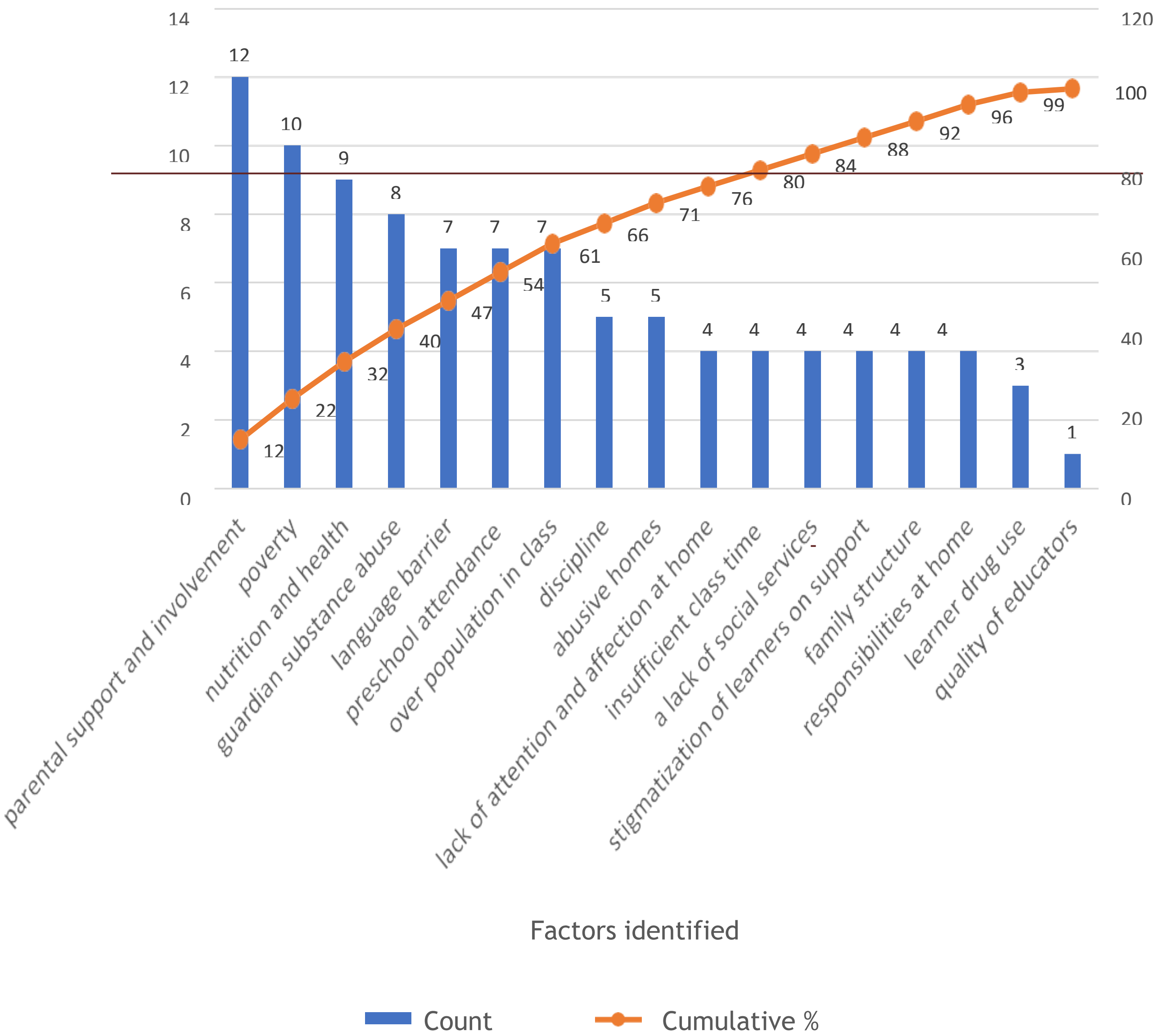

Figure 1: Pareto Chart

A combination of the Ishikhawa diagram and interrelationship diagram tools was used to identify the focus area. The ishikawa diagram was used to categorise the factors from the Pareto Analysis into 4 main categories. The 4 categories were family background, child's cognitive development, learning environment and the child's physical factors.

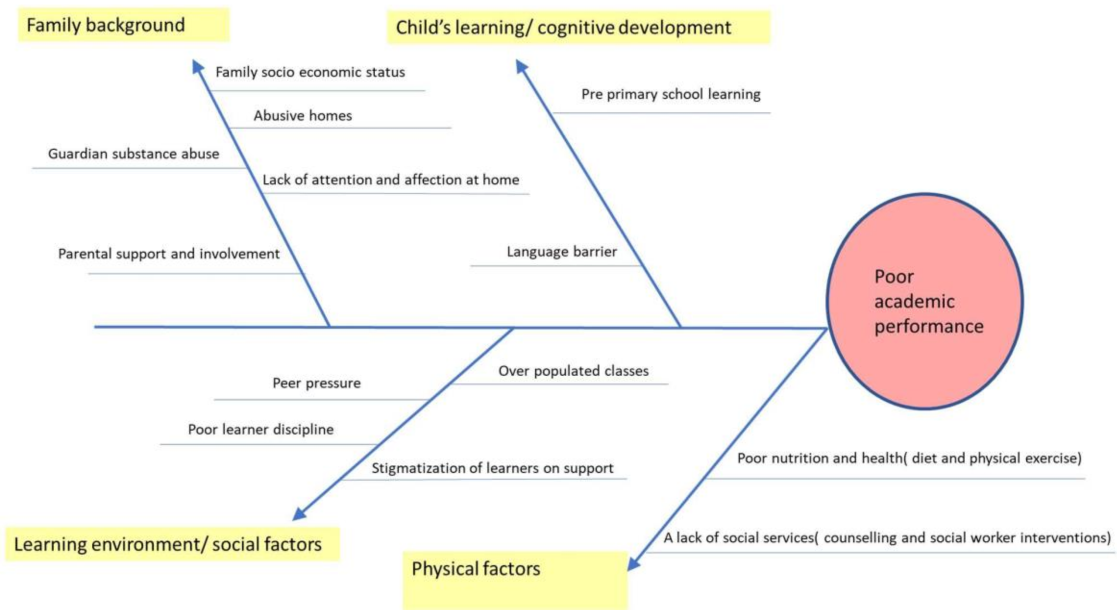

Figure 2:Ishikawa

An interrelationship diagram was formulated from the categories derived in the Ishikawa diagram to identify the drivers of poor performance. Although the factors identified are intrinsically rooted within a circular problem and a poverty trap the analysis for this study shows the unidirectional approach granted the project scope and limitations and the complexities involved in solving a wicked problem.

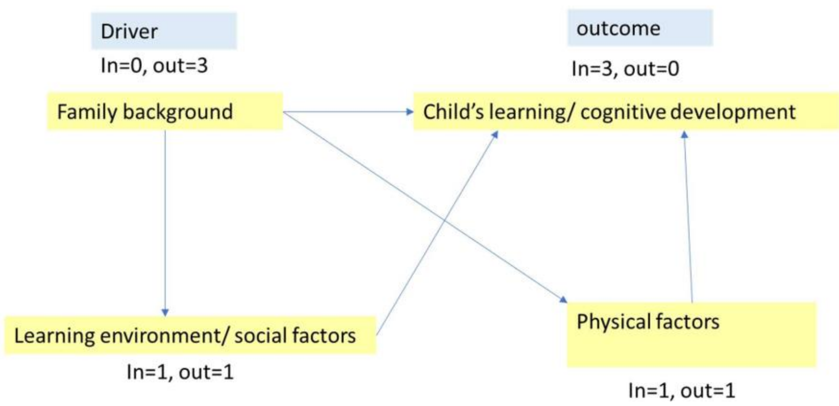

Figure 3:Interrelationship

From the interrelationship diagram one can observe that family background is the biggest driver, the learning environment and physical factors are partial drivers and the child's learning is driven by all other factors.

5 DISCUSSION

It is important to note that all of the factors outside of the classroom that affect the academic performance of the learner that were found in literature were prevalent within this community. In addition were 6 factors that are unique to this school (noted in Section 5.1). Thirty five percent of the factors identified were unique to this school. This is indicative of the effectiveness of the design thinking approach in finding out the user specific pain points.

5.1 Predominant factors affecting learner performance

5.1.1 Parental involvement

The predominant factor that was brought up by the educators is the lack of parental involvement. The educators accredit this to a number of issues faced by the community. The education level achieved by the parent plays a huge role because in some cases the parent is willing to assist the learner but fails to because they do not understand the content of their studies, in some cases the parents were taught the content in a different method and they are unfamiliar with the current methodologies and in a lot of the cases the parents work late hours and are unable to assist the learner. This factor is closely linked with the family structure, parental education level and the household socio economic status. The structure of the family dictates who the learner is left with and who is available to assist them. The parental educational attainment dictates the level at which the parent can assist the learner and the socio-economic factors dictate whether or not the household can afford extra tuition to compensate as well as low educational attainments are often associated with low levels of income.

5.1.2 Socio-Economic status

The second most impactful factor that was identified by the educators was poverty. This factor was characterised by the parent's occupation, family structure, educational level and parents in jail. The educators mentioned that learners coming from poor backgrounds were identified through poor hygiene, withdrawnness and they are dependent on the school feeding scheme for a meal.

5.1.3 Health and nutrition

The educators highlighted that the food that the learner's consumers are a huge hinderance to the learning process. The attention span of the learners in class is affected by the quality of food ingested prior to the lesson as the food consumed dictates the energy levels experienced by the learner. The learners are seen consuming junk food in the morning before school, during lunch time learners consume the junk available at the tuckshop. The educators perceive that the parents opt for their children eating junk food due to its convenience and affordability.

5.1.4 Substance abuse

In the particular area in which the school is located in, drugs and alcohol usage is rife . This has been a contributing factor to parents' lack of participation in the learners' academic work as well as a contributing factor to the attitudes, norms and a sense of hopelessness within the community. These traits are common for communities living in poverty [23]. Due to the shortage of positive role models within the community, the learners fall into the same patterns as their parents as the educators have indicated that cases of learners in the age group of 6 to 8 years old using drugs. .

5.1.5 Language barrier and preschool attendance

The educators highlighted that learners whose home languge is not the language of instruction (English) take longer to process information. Learners who do not attend preschool come into the class lacking the learning basics and thus their education and absorption of information lags within the class.

5.1.6 Class size

The educators have reported that the class size is too large and this ties in with the lack of time to engage thoroughly with learners needing support as there are too many learners needing individual attention. An unexpected finding was the stigmatization of learners on support programmes, educators stated that the parents were reluctant to approve their children being on an extra support programme as they believed that it meant that their child was not capable or bright and would fail the year. The educators reported that this was a contributing factor to parents non cooperative behaviour as they were in denial of their children's academic.

5.2 Other factors to be considered

The extreme persona analysis roots out the factors less predominantly mentioned and for this study there was only one factor and it was in reference to the quality of the educators. The factor mentioned was that the poor performance of the learners could be due to lack of training of the graduate teachers. This outcome could reflect some bias and subjectivity of the participants.

The discipline of the learners is largely due to the within peer and community influences characterised by poverty [23]. The learners who experience abuse at home are often time difficult to identify however, this has been a reoccurring factor for poor performance and may also be linked to the substance abuse that is rife in the community.

5.3 Opportunities for improvement

The experience mapping out comes brought forth areas of improvement in the generic tasks of the education process at the selected school. The possible opportunities for improvement include:

- initiating engagements and workshopping of the community and parents on the educational journey and getting them more involved in school related activities.
- holiday classes for the learners who need extra tuition,
- conduct health and psychological assessment on the learners and to assess the effectiveness of the non-academic remediation methods currently conducted.

The opportunity to educate the community and parents on the educational journey will help aid the lack of involvement of parents and the attitudes that learners and the community have on the educational process. The educators indicated that a drill method is effective for learning and the more time that the learners have to engage and drill the work content would be beneficial to their academic outcomes. Literature shows that the drill method is a reliable method but is more suitable for practice based subjects such as numeracy [29].The educators reported that they have little to no information on the possible health and psychological barriers that the learners in their classes might be faced with, these assessments would aid the educators in differentiating their teaching method on a case by case basis.

5.4 Future design phases

In assessment of each individual factor, ceteris paribus, the characteristics of each are significant enough to impede a learner's academic outcome, however the likelihood of a learner in South Africa being faced with only one of the factors at a time is highly unlikely. The factors are closely linked, and they mostly trace down to household finances. The South African reality is that a learner whose education is affected by extrinsic forces, is likely to be dealing with multiple factors. At the school of study, the school receives sufficient teaching material, the school premises are operational and in a good state. However, there is a lack of social services such as health checks and social workers. Remediation is largely based on the intrinsic factors and less investment is placed on remediating on the extrinsic forces.

The key insight that can be drawn from this study is that the identified problem is a wicked problem. The factors identified are interrelated and complex problem solving techniques are required for further studies. Additional key insights that can be drawn from this study and used in further studies and design are that the biggest contributor to the poor performance of the learners is the involvement and support from the learners' parents. The use of design thinking is beneficial for the identification of factors that are unique to a studied group. Therefore, there is a need for the implementation and application of design thinking for problem solving to ensure that user context specific factors are not overlooked and that the end user is involved in the solutioning.

5.5 Study improvement

Weaknesses of the study are that the collection of the factors that affect the learners' performance as per the educators' perception excluded the perceptions of other stakeholders such as the parents and the learners as well as the exclusion of factors within the classroom. A strength that can be observed from this approach is that the methodology applied required engagement with the users that resulted in in-depth and inclusive information, thus the outcomes of this study are very specific. Thus further studies can be conducted including the various stakeholders, factors within the classroom as well as finding the relationship between all (inside and outside the classroom factors).

5.6 Recommendations

The recommendations stem from the experience and challenges that were encountered during this study, the following recommendations address the aforementioned weaknesses:

- Inclusion of the perspectives of x variety of stakeholders, as opposed to limiting the study to the perception of the educators as done in this paper.
- The inclusion of quantitative data from the school would have added in the reduction of bias that may arise from perceptions.

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EQUITABLE E-LEARNING ACCESS IN SOUTH AFRICA: TESTING FOR STATISTICALLY SIGNIFICANT DIFFERENCES BETWEEN ANDROID AND IOS USERBASES TOWARDS A LOW DATA-USAGE, COST-EFFECTIVE ONLINE TUTORING PLATFORM

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ABSTRACT

The Covid-19 pandemic has shown that steps must be taken to ensure more equal access to e-learning platforms in South Africa. Little is known about the differences between Android and iOS userbases in South Africa (an Android-dominated market) and how these may inform e-learning platform design. This study tests for statistically significant differences between the Android and iOS userbases of a large, South African e-learning app and presents the results of a follow-up e-learning platform pilot test. A survey instrument (n = 1028) allowed for analysis at a 95% confidence level and 5% MoE. The results showed that a) *Lower internet data and device access*, b) *Lower household income*, and c) *Lower access to private and online tutoring* could be major barriers to e-learning for the Android userbase. Based on these results, suggestions are made for more inclusive mobile software design practices.

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1 INTRODUCTION

1.1 Background and Objectives

In 2017, a mobile educational application (app) for Android and iOS called was released by *Quadrupole (Pty) Ltd* to the South African high school market, providing over 3000 past papers, memoranda, and content summaries. By April 2021, the app had been used by over 100 000 South African high school learners with the Android userbase growing from 40% to 67% of the userbase. Over 2018/19, the app only generated ~R12 900 in revenue via banner advertisement. Although this covered the operating costs of the app, the company wanted to develop and grow new revenue streams from the app's significant usership and had committed R350 000 in feature-development funding to pursue this. The company had identified online tutoring as a high potential market, given that the global private tutoring industry is worth an estimated $110 billion and is growing at 7.1% per annum – driven by developing nations [1]. Furthermore, factors such as the outbreak of Covid-19, the subsequent mass movement to online learning, and emerging disparities between well and poorly resourced schooling communities had highlighted and supported the need for lower cost online tutoring in South Africa.

The broad objective of the study was to identify the statistically significant differences between the Android and iOS userbases. This was necessary to determine before the development capital could be deployed. The identification of these differences would help the company understand whether there were userbase-specific challenges to the implementation of a tutoring feature. Each version of the app was developed natively; which allowed the developers to adapt each version to respond to the constraints that could affect adoption of any updated version of the app.

1.2 Scope considerations (Study delimitations)

There is a need for generalisable studies of the differences between Android and iOS userbases (and resulting software development implications) in Africa. Although this paper establishes a first (n=1028) view in this regard, it does so within the scope of a single userbase, albeit one of South Africa's largest e-learning platforms by userbase size.

This study did not aim to establish causal links or predictive relationships between any factors investigated. Rather, focusing on establishing a baseline view of differences between the userbases which are both statistically significant and which have substantial business strategy and software design implications for e-learning platforms in South Africa.

Several factors - besides those highlighted in this study – have been shown in the literature to account for some variation in the use of e-learning platforms. However, they have not been included in the scope of this study given their lower relative significance.

2 LITERATURE REVIEW

2.1 What factors have a significant impact on e-learning platform usage habits?

Factors for comparison between the two userbases (Android versus iOS) were selected based on literature. Technology Acceptance Modelling (TAM) has, in the past, identified factors that most heavily influence whether a user is likely to adopt a new piece of software [2]. Although a full TAM analysis was not conducted given the broader focus of this study, the modified TAM 3 framework shown in figure 1 was used to ensure completeness of the variables selected for testing. This simplified variant of the TAM 3 model has been applied in the e-learning context and was found to account for over 42% of variance in actual use of the e-learning platform [3].

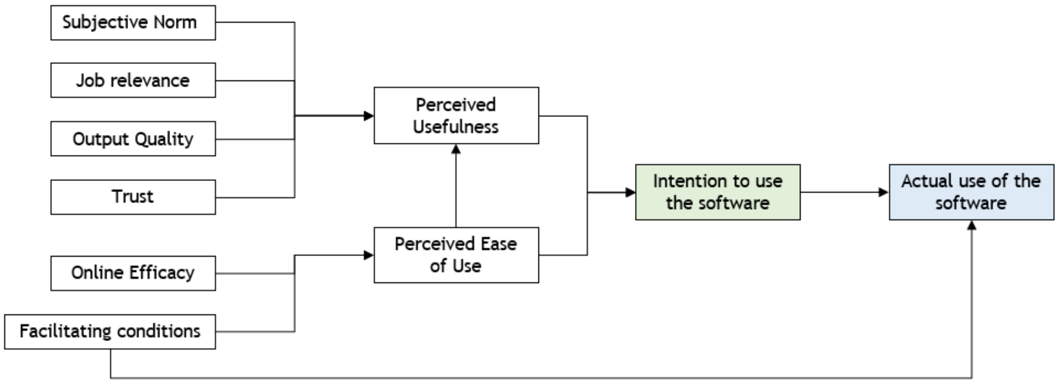

Figure 1: Simplified TAM 3 model applied in e-learning context [3]

2.1.1 Facilitating Conditions

Facilitating Conditions describe the degree to which the user believes technological or other infrastructure is in place and accessible enough to facilitate the use of the service [4].

2.1.1.1 Internet access

A 2002 US National Bureau of Economic Research study into internet access as an e-learning facilitator found no statistically significant influence of increased public school internet access subsidisation on e-learning platform usage [5]. However, it was noted that this result was heavily influenced by the widespread inexperience of teachers in internet-enhanced learning [6]. Conversely, a University of Michigan study of 130 low-income households in the US found a strong relationship between increased internet access and e-learning usage, however, social influence factors may be just as important as internet infrastructure [7].

A University of Maryland study (n=339) found that South African users, across a range of income levels, value mobile data highly and actively employ data-saving measures when using their phones. This included an avoidance of apps that were perceived to use a large amount of mobile data (such as video streaming apps or apps with heavy graphical interfaces) [8].

2.1.1.2 Income levels and smart-device access

The 2017 US Mobile App Report from ComScore found that the median iOS app user earns 40% more than the median Android user, spends twice as much on in-app purchases, and is more likely to make purchases on a regular basis [9]. Another US-based analytics firm, Liftoff LLC, found that 8.1% of iOS users made purchases on apps containing purchasable items, versus 5.7% on Android, while iOS users were 65% more likely to sign up for paid app subscriptions than Android users [10]. Similar analyses for the South African market are unavailable, justifying the inclusion of income proxy variables.

A 2012 Harvard University study found that proxies such as television, car, refrigerator, and cell phone ownership accounted for 58% of variation in predicted household expenditure [11].

2.1.2 Online self-efficacy

Online self-efficacy is a user's confidence in their ability to use the internet and online tools (such as websites or mobile apps) to achieve their goals [12]. A 2016 Brunel University London study (n=569) concluded that online self-efficacy was an important factor in predicting a user's level of engagement with a new online learning platform [13]. This conclusion was supported by a 2015 Illinois Institute of Technology study [14]. Contrary to these findings, researchers from Maastricht University employed a similar framework (n=93) and found no significant relationship between online self-efficacy and engagement with online learning platforms [15]. It has been noted that the strong contradictions between these two studies may be due to the use of low-income versus high income samples, however, this has not been verified. Regardless, online self-efficacy and specifically previous use of e-learning platforms emerges as a variable worth considering.

2.1.3 Subjective Norm

Subjective norm is an individual's belief that a particular behaviour (i.e., using an e-learning platform) would be supported by people they see as important [16]. A 2018 University of California, Berkeley study (n=103) found that parental encouragement to use *Khan Academy* had a significant effect on time spent on the e-learning platform – more so than teacher and peer encouragement [17]. A 2012 Chinese University of Hong Kong report (n=262) found that teacher encouragement, reputation of the software platform amongst peers, and ease of use of the platform accounted for 93% of variance platform adoption [18].

2.1.4 Job relevance, Output Quality and Trust

Job Relevance is described as the user's perception of how relevant and helpful the software product is to their job or role [19]. Given that the majority of the app's users are in grade 11 or 12 it can be reasonably assumed that academic support is of relevance, however, past levels of engagement with private tutoring will likely influence how relevant they see an online tutoring service as being and is therefore worth including as a test variable.

Output Quality is the user's perception of how well the product will perform the tasks that match their 'job relevance' [20]. Trust is a closely related concept, interrogated in a 2003 Drexel University paper that found that trust between customer and vendor on an online platform is crucial and is established through the following: "(1) a belief that the vendor has nothing to gain by cheating, (2) a belief that there are safety mechanisms built into the website (ensuring Output Quality), and (3) by having a typical interface that is easy to use" [21].

2.2 What this study may contribute

A 2019 literature review in British Journal of Educational Technology found that previous studies into acceptance of e-learning platforms among different group are limited due to small sample sizes (n=50-300), and factors that limit the ability for results to be generalised (i.e. all participants originating from the same institutions) [22].

The analysis of variation between iOS and Android userbases is even less developed. Although studies have been conducted of the US market, no meaningful statistical analysis, within the e-learning context specifically, has been conducted. Furthermore, there is currently little understanding of the differences between Android and iOS userbases in South Africa (or most developing economies). This study and the app's substantial userbase, provided an opportunity to conduct larger sample analysis, that covered a wider range of socio-economic parameters and which is representative of a large South African mobile application userbase. The power of the sample and its specificity to the South African e-learning context may allow for further statistical analysis in future studies.

3 METHODOLOGY

3.1 Research Design

The data required to fulfil the research objective was collected using an online survey of 2018/2019 users. The proxy values used, and type of data collected (continuous, ordered, categorical and qualitative) to compute t- and Chi-square test values when comparing the Android and iOS userbases are listed under each of the main factors to be studied in Table 1. Measures of internal consistency such as Cronbach's alpha for Likert scale questions were used during survey development and during the final data analysis.

Table 1: Breakdown of variables and procedures for userbase comparison analysis

	Variables for statistical testing	Proxy measures to be tested & analysed	Analysis procedures
Facilitating Conditions	1. Access to Internet and Internet-Connected Devices	a) Home Wi-Fi network access (Categorical) b) Monthly mobile data allowance (Continuous) c) Smartphone and Laptop Ownership (Categorical)	a) Descriptive, Chi-square test b) Descriptive, T-test c) Descriptive, Chi-square test
	2. Income Level	a) # cars owned by household (Continuous) b) Household Refrigerator and TV ownership (Categorical)	a) Descriptive, T-test b) Descriptive, Chi-square test, comparison with national data
Online Self-Efficacy	3. Experience with e-learning	a) Perceived e-learning usage (Ordered) b) # e-learning platforms used (Categorical) c) e-learning platform preferences (Qualitative)	a) Descriptive, T-test, Cronbach's alpha b) Descriptive, T-test c) Content analysis
Job/Role Relevance	4. Experience with private tutoring	a) Tutoring used in high school? (Categorical) b) How tutoring was accessed (Categorical) c) Why tutoring was not accessed (Qualitative)	a) Descriptive, Chi-square test b) Descriptive, Chi-square test c) Content analysis
Subjective Norm & Trust	5. Social influence to engage with e-learning	a) Perceived parental influence (Ordered) b) Perceived teacher influence (Ordered) c) Perceived peer influence (Ordered)	a) Descriptive, T-test, Cronbach's alpha b) Descriptive, T-test, Cronbach's alpha c) Descriptive, T-test, Cronbach's alpha
Output Quality & Trust	6. Use of the app	a) Avg. number of resources downloaded per user on the app	a) Descriptive, T-test, comparison with userbase population data

3.2 Instrumentation

Most of the data to be used in the analysis was collected via an opt-in online survey, using the Survey Monkey email collector tool to distribute the survey to ~10 000 randomly selected users. Additional data used to describe the population and validate reported sample data (such as userbase age, gender, location, operating system, and number of resources downloaded) was extracted from the app's *Google Firebase* database.

3.3 Sampling

The study population consisted of ~45 000 students who used the mobile app in either 2018 or 2019. The population was roughly 54.8% female and 45.2% male; 39% iOS users and 61% Android users and was distributed throughout South Africa, but concentrated in urban metropolitan areas such as Johannesburg, Pretoria, Durban, Cape Town, and Bloemfontein. The sample was stratified according to platform (Android versus iOS). The required sample sizes to achieve analysis at a 95% confidence level and 5% margin of error are calculated using equation (1) [23]. This confidence level is seen as providing valid insights in a business context without resulting in excessive survey distribution costs [24]

$$Sample\ size = \frac{z^2p(1-p)}{e^2} \Big/ 1 + \frac{z^2p(1-p)}{Ne^2} \qquad (1)$$

Required sample size 1 (Android): n = 379; Required sample size 2 (iOS): n = 376

3.4 Analysis Procedures:

Data gathered from unordered, closed responses were used to create contingency tables to test significance between the Android and iOS samples, using the Chi-square test equation:

$$\chi^2 = \sum \frac{(O-E)^2}{E} \qquad (d.f = 1\ for\ 2x2\ table) \qquad (2)$$

Data gathered from numerical scale or numerical response questions were represented using frequency distributions. The mean and variance for each strata were calculated and tested for significance using two-tail, unequal variance t-tests, according to the following equation:

$$t = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{\frac{s_1{}^2}{n_1} + \frac{s_2{}^2}{n_2}}} \qquad (3)$$

All statistical testing was performed using the *Minitab 19* statistical software package. Qualitative survey responses were coded and categorised and frequencies of each ‘type of response’ calculated. This analysis mainly served to inform the ways in which the app may be developed in response to findings.

3.5 Reliability and Validity

3.5.1 Reliability

Cronbach’s alpha was calculated in *Minitab 19* to determine the reliability of two sets of Likert-scale questions in the survey, using equation (4):

$$\alpha = \frac{N\bar{c}}{\bar{v} + (N-1)\bar{c}} \qquad (4)$$

Two sets of Likert scales were tested:

1) To gauge the ‘data-consciousness’ of the app’s userbases, participants were a) asked to indicate the extent to which they worry about how much mobile data websites and applications use and b) asked to indicate their willingness to stream high-definition videos online. Cronbach’s alpha for this ‘data-consciousness’ scale (N=2): α = 0.8249

2) To gauge the level of social influence to engage with e-learning, participants were asked to rank the extent to which a) teachers, b) peers, and c) parents influenced them to engage with e-learning platforms. Cronbach's alpha for this 'social influence' scale (N=3): α = 0.5782

A Cronbach's alpha greater than 0.7 is viewed as an 'acceptable' level of reliability in most social science research contexts [25]. The second scale falls below the 0.7 threshold; however, this is to be expected given that each scale is measuring a unique type of social influence (parental versus peer versus teacher). The highest correlation coefficient, r = 0.363 existed between the between the teacher and peer scales, indicating that each scale is indeed measuring a unique perspective.

3.5.2 Validity

3.5.2.1 Criterion validity

Surveys were sent to ~10 000 randomly selected user email addresses, from which 1 062 responses were received. To confirm that the sample was representative of the population, the ratio of Android to iOS sample respondents was compared to the population ratio recorded on the app's *Google Firebase* database between 2017 and 2019. Figure 2 shows the results and verifies the criterion validity of the survey.

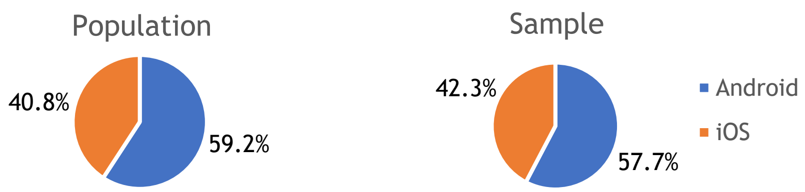

Figure 2: Android and iOS population versus sample proportions

Furthermore, to confirm the validity of data provided in continuous response questions, sample results to a question asking participants how many resources they had accessed on the app were compared to the population average from the app's *Google Firebase* database. It was found that the average number of resources that sample respondents estimated they had accessed on the app (16.23 resources) was within 10% of the actual average number of resources accessed per application user between 2017 and 2019 (17.87 resources).

3.5.2.2 Content validity

Validity of the survey instrument was tested via review of the questionnaire by statistics and industrial engineering staff members at University of the Witwatersrand, before the questionnaire was pilot tested with a group of 30 users, and changes were implemented to enhance question clarity. Specifically, terminology used in the questionnaire was simplified to ensure that second or third language English speakers could correctly interpret each question. The pilot test also allowed for preliminary Cronbach's alpha values to be calculated as a check.

Ethics was granted for the study.

4 RESULTS

4.1 Summary of results

Table 2: Summary of inferential testing results

Factor (Confidence Level; MoE)	Proxy measure	Test applied	Significance
1.Internet Access (CL = 95%; MoE = 4%)	Monthly Data Allowance	T-test	**Significant (P = 0.000)** $\mu_{Android} < \mu_{iOS}$
	Sensitivity to data use (1-5 scale)	T-test	**Significant (P = 0.000)** $\mu_{Android} > \mu_{iOS}$
	Access to Household Wi-Fi network	Pearson chi-square	**Significant (P = 0.000)** $\mu_{Android} < \mu_{iOS}$
	Laptop/PC Ownership (Y/N)	Pearson chi-square	**Significant (P = 0.000)** $\mu_{Android} < \mu_{iOS}$
2.Income Level (CL = 95%; MoE = 5%)	# cars owned by household	T-test	**Significant (P = 0.000)** $\mu_{Android} < \mu_{iOS}$
3.E-Learning Experience (CL = 95%; MoE = 6%)	Perceived extent of internet use in studies (1-5 scale)	T-test	Not Significant (P = 0.81) $\mu_{Android} \neq \mu_{iOS}$
4.Social Influence (CL = 95%; MoE = 5%)	Perceived peer influence to engage e-learning (1-5 scale)	T-test	Not Significant (P = 0.16) $\mu_{Android} \neq \mu_{iOS}$
	Perceived teacher influence to engage e-learning (1-5 scale)	T-test	Not Significant (P = 0.88) $\mu_{Android} \neq \mu_{iOS}$
	Perceived parent influence to engage e-learning (1-5 scale)	T-test	Not Significant (P = 0.47) $\mu_{Android} \neq \mu_{iOS}$
5.Private Tutoring (CL = 95%; MoE = 6%)	Use of private tutoring in high school (Y/N)	Pearson chi-square	**Significant (P = 0.000)** $\mu_{Android} < \mu_{iOS}$
	Primary reason for non-usage = cost (Y/N)	Pearson chi-square	**Significant (P = 0.000)** $\mu_{Android} > \mu_{iOS}$
6.Use of Don't Fail app (CL = 95%; MoE = 5%)	# resources accessed on the app during usage	T-test	**Significant (P = 0.000)** $\mu_{Android} < \mu_{iOS}$

In the following sections, only factors that showed statistically significant differences between the Android and iOS userbase samples are explicitly referenced.

4.1.1 Internet Access and Data Sensitivity: Key descriptive results

Only half of the Android sample had access to a home Wi-fi networks compared to over 80% of the iOS sample (Figure 3). On average, Android users had access to 39% less data each month than iOS users and 12% of Android users reported having access to less than 200MB of data per month, versus on ~3% of iOS users (Figure 4). This trend extends to sensitivity to data usage, with 34% of Android respondents indicating they are "Always worried about how much data a website uses" versus just 14% of iOS users.

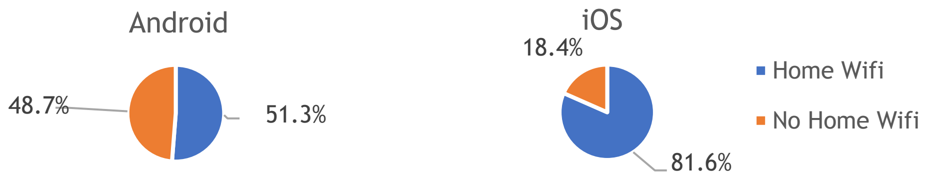

Figure 3: Percentage of each userbase sample with household Wi-Fi networks

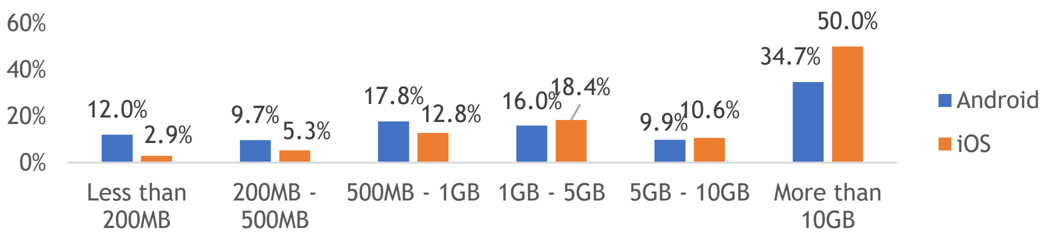

Figure 4: Percentage of each userbase sample with different levels of data access

4.1.2 Income Level: Key descriptive results

100% of respondents that indicated that their family owned neither a refrigerator or television were Android users (Figure 5). Roughly 75% of families in the iOS sample owned more than 2 or more cars versus 41% of Android sample families (Figure 6). This ownership trend extends to smart-device ownership, with only 57% of Android respondents owning a laptop or PC versus 79% of iOS users.

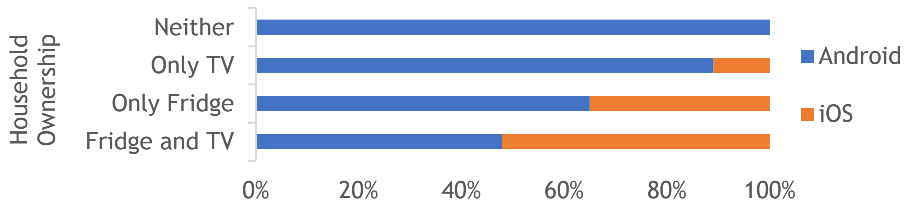

Figure 5: Relative percentage of each sample stratum in each ownership band

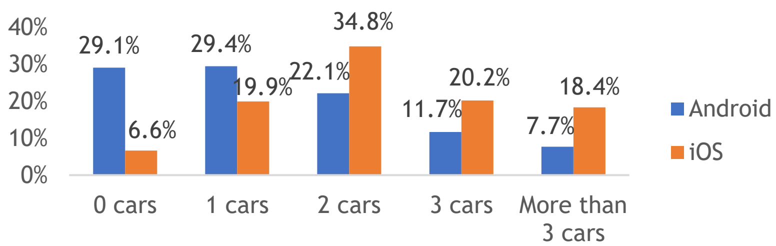

Figure 6: Relative percentage of each sample stratum in each ownership band

4.1.3 Access to Private Tutoring and Usage Levels of the App Being Studied

~39% of Android respondants used a private tutor in high school versus 68% for iOS (Figure 7). 50% of Android respondents who had not used private tutoring indicated that it was because it was too expensive, versus 34% for iOS users. On average, iOS respondants downloaded 29% more resources from the app than Android respondants.

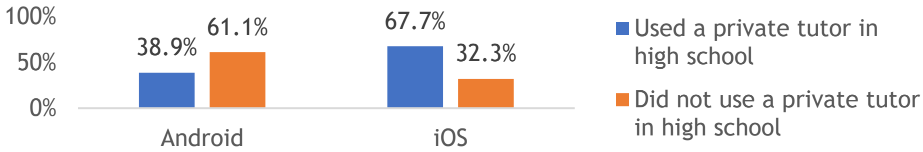

Figure 7: Percentage of strata that received private tutoring in high school

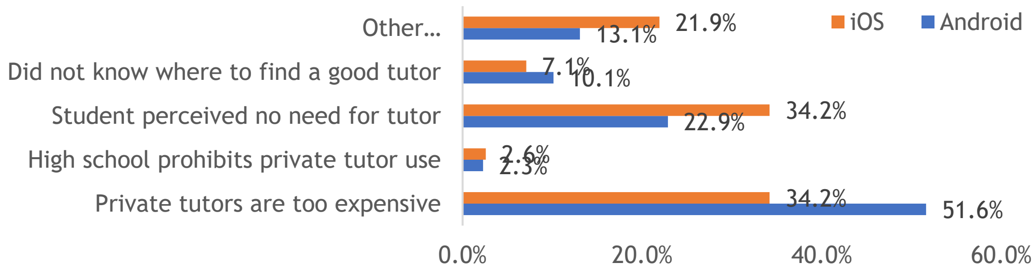

Figure 8: Reasons for sample participants not using private tutoring

5 DISCUSSION

5.1 Discussion of Results and Design Recommendations

a) Access to the internet and data sensitivity: Android users have access to less data than iOS users, have lower access to Wi-fi networks, and are significantly more worried than iOS users about web application data usage. These discrepancies are statistically significant and confirm literature - [26] and [8] - finding that internet users in South Africa, particularly in low-income communities, are highly conscious of online data usage. ***Recommendation:*** Different versions of the new app update should be designed for the Android and iOS platforms. The Android version should be designed to limit data usage – potentially through higher media compression, finding alternate means of interaction to live video calling, requiring the user to manually load media and removing non-essential features that consume data in the background. Zero-rated status from a national network provider may be pursued.

b) Household income: iOS users display statistically significantly higher car, smart-device, and household item ownership levels than Android users. Given the strong correlation between car ownership and household income in South African (Venter & Mohammed, 2013), it is concluded that Android user households in the study are generally lower income than iOS. This supports findings from [10] and [9], but contradicts those of [27] – granted that these where studies of US and UK markets. ***Recommendation*:** The revenue model of the new version should ensure the inclusion of iOS and Android userbases (potentially by subsidising initial tutor interactions or introducing a bargaining system to the tutoring feature to increase competition and reduce prices). Certain sections of the app should be made freely accesible as a gateway for users to become familiar with the new version.

c) Experience with e-learning No statistically significant differences in previous experience with online learning platforms were observed between the Android and iOS userbases and both showed an acute willingness, in general, to use the internet as a tool to supplement their learning. Roughly 60% of both Android and iOS users reported "Using the internet daily to help with studies". ***Recommendation:*** With a clear willingness to engage with multimedia and interactive platforms, it is crucial that changes to make the revenue model more inclusive and reduce the data usage of the Android version do not limit the usefulness of the platform as a multimedia-rich and interactive environment.

d) Perceived social influence to engage in e-learning: There were no statistically significant differences between the Android and iOS userbases in this regard. Over 75% of both Android and iOS users perceive their teachers and peers as having a moderate to very high influence on the e-learning platforms they use, compared to just 62% for parents. This aligns with the literature that highlights the correlation between teacher familiarity with e-learning platforms and the increased use of those platforms by students [18]. ***Recommendation:*** The marketing strategy of the business should include teacher-directed campaigns, and further study of the marketing channels through which users found out about the app should also be conducted to better deploy the marketing budget.

e) Experience with private tutoring: Android participants were less likely than iOS participants to use private tutoring, with 52% of Android users indicating that this was due to the high cost of tutoring, compared to just 34% of iOS users. These differences were found to be statistically significantly different between the two userbases. This is troubling given a review by the World Bank that concluded that educational outcomes in developing nations are improved through the widespread use of private tutoring [28]. ***Recommendation:*** Not only is there a significant portion of the Android market looking for a more cost-effective model of tutoring, but there may be an opportunity to drive substantial improvement in South Africa's secondary education outcomes Quadrupole Pty Ltd design an update that harnesses the online platform to increase inclusivity in the tutoring market.

f) Level of app use: The average number of resources accessed by iOS users was found to be 29% higher than by Android users – a statistically significant difference. ***Recommendation:*** These results may point to a predictive relationship between discrepancies in internet access and income level (independent variables), and average usage rates of e-learning platforms in South Africa (dependent variable), however, such a regression analysis was not performed as part of the study – but may be taken up in further research.

6 BUSINESS IMPLICATIONS – E-LEARNING PLATFORM UPDATE AND TESTING

This Section describes how the results and recommendations as discussed in Section 5 were applied to further enhance the e-learning platform. The Section aims to respond to the initial business proposition which was introduced in Section 1, and to share how the findings were used to advance the suggested design development and enhancements to the e-learning platform.

6.1 Minimum Viable Product (MVP) Testing

Over the course of 5 weeks (14 September - 18 October) a rudimentary version of the update design as proposed in Section 4 was developed. This version was only developed for Android and did not include a subscription feature, public 'explore' section of past interactions, nor search capabilities. This version also only ran on a small testing server, and usership was thus capped at a maximum of 300 users. Users were given 1 free question, after which they set the price they would pay for each answer.

6.2 Financial Modelling

Cashflows were modelled using a multiple-linear regression forecast of 28-day active userbase numbers (with months used as dummy independent varaibles). This model was developed using 3 years of historical 28-day usership data between September 2017 and September 2020. This model proved to be strong, with a multiple R statistic of 0.918 and an R Square statistic of 0.842.

Table 4 presents the projected Net Present Values (NPV) of the development investment for the new version of the app for different Weighted Average Cost of Capital (WACC) values and assuming 1) the commission charged by the app is 35%, and 2) the percent of users paying, average number of questions asked per paying user, and average price offered per question are the same as the figures gathered for the minimum viable product test.

Table 4: Projected NPV over 3 years

	Optimistic (Discount rate = 6%)	Realistic (Discount rate = 12%)	Pessimistic (Discount rate = 20%)
3-Year NPV	R 174,213.31	R 124,570.77	R 70,812.33

These projections indicate a positive return on the initial development investment required to developed the full new version of the app. Sensitivity analyses of net cashflow were conducted to determine the influence of changes in userbase size and tutor commission rates on cumulative net cashflow and breakeven for the new version of the app.

The model was found to be insensitive to fluctuating usership but sensitive to tutor commission rate change. If this rate were reduced to 55% or 60%, the break-even time would reduce from 22 months to 13 months and 17 months respectively. An increase to 70% tutor commission would increase the break-even time drastically, from 22 months to 33 months.

6.3 User Feedback

A short poll was sent to the MVP testers to gauge their feedback. 81% of respondents rated the new version as either 'Better' or 'Much Better' than the original version (Figure 10) and 80% of users said they were "Likely" or "Very likely" to recommend the new app version to their friends.

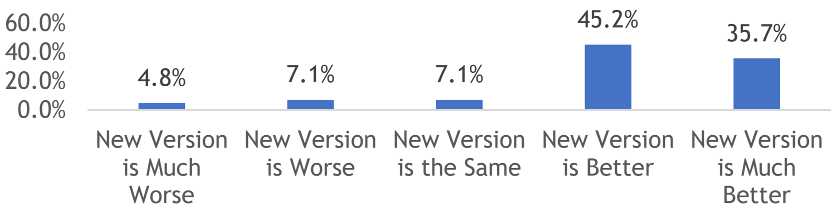

Figure 10: Participant ranking of new version of the app versus original version

6.4 Considerations for continuing forward

80% of participants communicated that they have access to a debit/credit card, but only 55% had made online payments in the past year. This suggests that 20% of the userbase cannot make online payments, requiring a different approach if they are to be serviced commercially. Although most respondents preferred the current pay-per-question model, it was by a slim margin. A follow-up question revealed that many respondents would like to be able to choose between the pay-per-question and buying in bulk model, as their preference is context dependent. Beyond user convenience, a bulk purchasing mechanism would save the app a substantial amount in payment transaction fees – their most significant variable cost besides tutor commission.

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INVESTIGATING THE EFFECT OF CONSOLIDATION IN AN IMPORTED PHARMACEUTICAL LOGISTICS SYSTEM

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ABSTRACT

Logistics efficiency and cost are important considerations in pharmaceutical supply chains, where high costs can hinder the availability and accessibility of life-saving medicines. It is therefore important for pharmaceutical companies to continuously improve logistics operations by reducing cost. One way to achieve this is to consolidate shipments. This paper investigates the potential of consolidation in an imported pharmaceuticals logistics system. Four scenarios are modelled and compared using Mixed Integer Linear Programming and Analytical Hierarchy Process techniques. The first scenario models the system without consolidation. The second scenario considers the impact of consolidation in Europe before shipment to ports in South Africa. The third scenario considers the impact of consolidation at a South African port before inland distribution. The last scenario considers a combination of consolidation in Europe and South Africa, and direct shipment. Results confirm that consolidation can lead to improved cost of logistics operations in pharmaceutical supply chains.

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1 INTRODUCTION

There are many pharmaceutical companies in South Africa responsible for supplying a wide variety of pharmaceuticals from all over the world to South Africans who require accessible and affordable medicine. To ensure availability and accessibility of medicine to citizens, it is essential for these companies to ensure that the right pharmaceuticals reach citizens at the right time, place, quantity and the lowest possible cost [1,2].

Logistics efficiency and cost are important considerations in pharmaceutical supply chains where high costs and inefficiencies can hinder the availability and accessibility of life-saving medicines. It is therefore important for pharmaceutical companies to continuously improve logistics operations and reduce costs.

Many of the pharmaceutical companies in South Africa receive imports from all over the world. However, many specialised pharmaceuticals must be imported from Europe. Because of the specialised nature of these products, they are mostly imported in small shipments. For shipments of specialised products from European suppliers, the trend of larger pharmaceutical companies is to ship various smaller quantities from different suppliers independently by ocean to a centralised depot in South Africa from where pharmaceuticals are distributed to customers in the country. The implication of this is that for every order from Europe, a Less Than Container Load (LCL) or Full Container Load (FCL) is shipped with zero collaboration between suppliers.

To illustrate the problem, the shipments from Europe can be seen as a group of people that depart from the same general location and arrive at the same destination at approximately the same time every week, but they travel with separate vehicles. This can be a more expensive way of shipping and it is worth investigating what effect consolidation can have on European pharmaceutical import logistic systems and cost. As a result, three potential opportunities for improvement of pharmaceutical logistic systems in South Africa were identified as indicated in Figure 1.

Figure 1: Potential opportunities for improvement

The first opportunity for improvement is to reduce the cost in European pharmaceutical import logistic systems through shipment consolidation. There are many suppliers in Europe that send small, expensive shipments of specialised pharmaceuticals to South Africa. One way to reduce the cost of imported European pharmaceuticals is to reduce the transportation cost by consolidating pharmaceutical from various suppliers in Europe and then shipping consolidated FCL shipments rather than more LCL shipments from different suppliers. This reduces the shipment cost because larger shipments are more cost-efficient than small shipments.

The second opportunity for improvement is to reconfigure routes by consolidating shipments in Europe. This could reduce the transportation costs of the system, because consolidated products can potentially be sent directly to the South African port closest to the customer.

The third opportunity for improvement is to use the routing option with the smallest environmental impact of the logistic system. Since the transportation modes used in the logistics chain generate large volumes of emissions, reducing the number of shipments from Europe could reduce air pollution. This could potentially reduce the negative effect the pharmaceutical logistic system has on the environment.

This paper therefore investigates the potential of consolidation in an imported pharmaceutical logistic system by evaluating the impact of three potential improvement opportunities included in

Figure 1. This paper was based on a case study of a large pharmaceutical company in South Africa. However, but many of the findings can be applied to pharmaceutical companies across the world.

2 LITERATURE REVIEW

There are many different approaches to solve logistic problems. Based on a review by Craighead et al. [3], Operations Research (OR) stood out as one of the most commonly used approaches to these types of problems. Most of these approaches use one or a combination of Linear Programming (LP), Non-linear Programming (NLP), Mixed Integer Programming (MIP), Markov Decision Process, Vehicle Routing Problems, Transportation models, and/or Multi-criteria analysis [4]. However, the majority of the contributions focusing on logistics consolidation use one or a combination of NLP and MIP models.

2.1 Shipment cost reduction through consolidation

Consolidation has been used for many years to optimise logistic chains, with consolidation defined as combining multiple items into a more effective whole. There are many different approaches to achieving this, such as supply chain redesign [5], or lot-sizing models [6]. These models typically aim to minimise the total cost of the logistic system whilst considering the trade-offs between shipping cost and inventory carrying cost.

Building on the basic formulation of a consolidation model, systems that resemble a pharmaceutical logistic chain from Europe to South Africa are reviewed. These systems typically have multiple suppliers, multiple different products and multiple outlet depots. Furthermore, the focus of the literature review is on models that include transportation costs in the total cost of the system and focuses on using consolidation centres to improve the logistic chain.

Glock and Kim [7] present a Mixed Integer Non-linear Programming (MINLP) consolidation model for a case where a single buyer orders products from multiple suppliers and uses consolidation methods to reduce the cost of a system. Even though their study is similar to the case investigated in this paper, Glock and Kim [7] address a slightly different problem than that of pharmaceutical companies, because it assumes that all the suppliers supply the same type of product, which is not typically the case. In addition, the transport route and environmental impact of the system are not considered, limiting the applicability of their model to the case presented in this paper.

To address some of these limitations, Glock and Kim [8] present a case where consolidation, transport routing and fuel emissions are considered in a supply chain with multiple suppliers, multiple different types of vehicles, and a single buyer. They developed a model to minimise the total cost of the system and carbon emissions produced, whilst considering the effect that carbon tax could have on the total cost of the system.

Unfortunately, the models presented by Glock and Kim [7], and Glock and Kim [8] only consider one product type with constant demand. Pharmaceutical supply chains typically have many different suppliers of a wide variety of products, requiring the use of multi-commodity models. In addition, the demand for each product type in these systems is not constant. During each time period the demand for product types and demand volumes vary.

A MIP model presented by Melo et al. [9] considers these characteristics of a supply chain and selects the location and capacity for manufacturing plants and distribution centres and also assigns the specific demand for each product throughout the chain of distribution. In contrast to the model by Glock and Kim [8] the model by Melo et al. [9] presents a multi-commodity dynamic demand model which makes these models favourable models to use for a pharmaceutical logistic chain of imports from Europe to South Africa.

2.2 Environmental impact investigations

Logistic system optimisation models generally aim to find the most cost-effective solution to a problem. However, just as much as logistic systems impact costs that arise from production and distribution, logistics operations also produce emissions that are harmful to the environment.

Consolidation can provide a means to reduce the amount of emissions produced by a system. If a company uses a consolidation centre closer to its suppliers, frequent direct shipments from its suppliers to the customers can be avoided. This can reduce the amount of carbon emissions produced by the system.

Two examples of this are presented by Cholette and Venkat [10] and Ülkü [11]. In these studies, various small shipments are consolidated into one combined load and distributed in a single larger vehicle, instead of many smaller vehicles. In this way, consolidation can help to reduce carbon emissions. The case presented in this paper also aims to measure the impact of the emissions on the system. The emissions of each scenario are measured and considered with various other criteria when the best scenario is selected, requiring a multi-criteria decision making technique.

2.3 Multi-criteria decision making

In this paper, four different scenarios are identified, and the results for each scenario are recorded. The results are then evaluated to determine if consolidation can improve a pharmaceutical logistic chain. However, the pharmaceutical industry is complex, therefore various criteria must be considered when evaluating the benefit of specific scenario to the logistic chain.

The main considerations of these decisions are the cost and the environmental impact of each scenario. These are quantitative criteria calculated. When comparing different scenarios, a decision-making method is used to guide the complex selection process. The decision must be made without compromising on key criteria.

A compensatory method allows for comparing different attributes of the logistic chain while ensuring that each attribute contribute proportionally to the final recommendation. There are several compensatory methods techniques for multi-criteria decision making, such as Multiplicative Exponential Weighting, Simple Additive Weighting, Technique of Ordering Preference by Similarity to Ideal Solutions (TOPSIS), Analytical Hierarchy Process (AHP) [12].

AHP is a popular approach to use because it provides a framework to deal with multi-criteria situations involving qualitative and quantitative aspects. More importantly, AHP is a good approach to use because it can be easily understood and applied by operating managers. In addition, the hierarchical structure used in this method can enable decision-makers to evaluate the problem systematically [13]. Therefore, this paper applies the AHP method to compare the different scenarios investigated.

This paper focuses primarily on cost and environmental impact, but there are many other quantitative and qualitative criteria in a logistic chain that can be evaluated to inform decision-making. Based on an article by Chan [14] on performance measurements in Supply Chain, other performance measures that can be considered for future work is quality, resource utilization, flexibility, visibility, trust, and innovativeness. Leadtime is also a key consideration as described in Lean Thinking [15] using Value Stream Mapping as technique to reduce wastes described in this approach.

3 RESEARCH METHOD

To investigate the potential impact of shipment consolidation and route reconfiguration on the cost of an imported pharmaceuticals logistics system, four scenarios (Refer to Figure 2 for the first three scenarios) are modelled and compared using Mixed Integer Linear Programming (MILP). The MILP used in this project was uniquely built based on the logistic chain of a pharmaceutical company in South Africa.

1. Base Case: A model built to represent the typical system that is currently used to compare the different scenarios. The comparisons are used to formulate conclusions about the effect of consolidation on the logistic chain.

2. Scenario A: Consolidation only in Europe with no change to the ocean freight routes. This scenario considers the impact of consolidation in Europe without any consolidation or route changes in South Africa.
3. Scenario B: Considers the impact or reconfiguring the ocean freight routes with no consolidation in Europe or South Africa. This scenario changes the routes in South Africa.
4. Scenario C: Uses consolidation in Europe and in South Africa. The suppliers that are closest to the warehouse in Europe send the shipments to the warehouse in Europe to be consolidated and sent straight to the customers. However, the suppliers that are not in close proximity to the warehouse in Europe send their products to the consolidation centre in South Africa. From here the products are consolidated and distributed to customers in South Africa. Finally, for some suppliers, it may be more cost-efficient to send their products straight to the customers in South Africa. In principle scenario C should be an optimal combination of the base case, scenario A, and scenario B. This is tested in this case study.

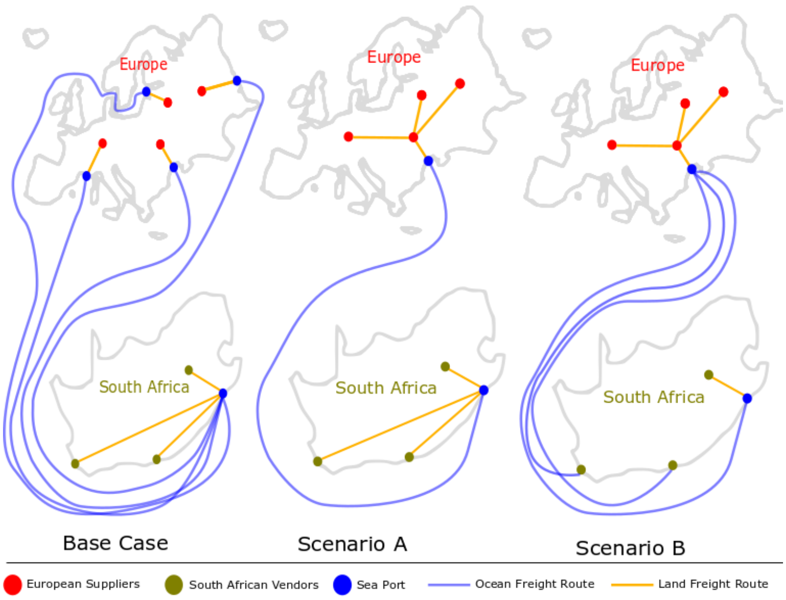


Figure 2: Selected consolidation scenarios

The results from each model will indicate how much each scenario costs. These results are then used to select the best performing scenario considering different factors impacting the decision-making process for a pharmaceutical logistic chain. To achieve this, the AHP method is applied.

4 MODEL FORMULATION

Consider the case of a large pharmaceutical company that imports different products from multiple suppliers in Europe who ship individual orders via ocean freight to a depot in Durban, South Africa from where it is distributed by land freight to three other depots in Johannesburg, Cape Town, and Port Elizabeth. These depots (referred to as *customers*) then distribute pharmaceuticals to various pharmacies and stores in the country.

Each of these depots has a different demand which varies monthly. When an item reaches a port, handling costs and inventory carrying costs are incurred. There are two different modes of transport, and for each of these modes, there are three different container sizes in which the products are shipped. In addition, the following aspects are considered:

- Every supplier supplies one type of product, and every supplier supplies a different type of product.

- The demand for products is dynamic in the sense that it is different for every product during each period.
- Pre-determined transportation modes are used. Thus, the cost is predetermined by a logistics service provider.
- The consolidation centre can be outsourced. Thus, the pharmaceutical company only pays predetermined handling and carrying cost determined by the consolidation centre.
- A predetermined consolidation centre is used to formulate the scenarios. This consolidation centre location is selected using the centre of gravity method, considering both distance and load [16].

4.1 Model inputs and assumptions

The model is formulated based on the following inputs and assumptions:

- A set of identified suppliers is used.
- This model includes multiple different products.
- This model assumed that the products can be consolidated. This is practically applicable for the products used in the case study but this might not be true for all products in other supply chains. An example would be when one include cold storage/shipping.
- The lead time from when the order leaves the supplier until it arrives at the depot is one month. One-month lead time is in line with industry operational norms [17] as well as the standard operational lead times used for this case study. However, for other supply chains that are more time-sensitive, the model will have to be further developed to have varying consolidation periods.
- The vehicle payload is not taken into account. This means that the cost of operating a vehicle is not dependent on its velocity. Rather, a constant cost per shipping leg is used.
- Holding costs were determined based on the case study and guidelines from MDS-3 [18]. Different holing costs will apply to different logistic chains.
- All parameters of the model are deterministic and constant over time.

Before the model can be formulated the sets, variables and parameters are defined in the following section.

4.2 Model sets, variables and parameters

Sets:

K	Set of heterogeneous suppliers in Europe where $k \in K$
I	Set of customers (end of chain warehouses) in South Africa where $i \in I$
J	Set of consolidation warehouses in where $j \in J$
T	Set of time periods in the cycle time (a year) where $t \in T$
P	Set of the number of pieces in the linear piecewise costing formulation where $p \in P$

Variables and parameters:

Z_{kit}	Volume of product that comes from supplier $k \in K$ and goes straight to customer $i \in I$ and arrive in time period $t \in T$
V_{kjit}	Volume of product that comes from supplier $k \in K$ and goes to the warehouse $j \in J$, to customer $i \in I$ and arrive in time period $t \in T$
C	Given cost of shipping a load on a specific leg of the logistic chain. This cost is predetermined by the pharmaceutical company or third-party logistics company. The transportation leg is specified by the subscript of *C*
W_{pkt}	The weighting used in the piecewise costing formulation for piece $p \in P$, supplier $k \in K$ and time period $t \in T$. This is specifically for the costing of the supplier to warehouse leg

X_{pkt}	A binary variable for piece $p \in P$, supplier $k \in K$ and time period $t \in T$. This is specifically for the costing of the supplier to warehouse leg
D_{kit}	Volume of demand for product that comes from supplier $k \in K$ of customer $i \in I$ in time period $t \in T$
H	Given average annual holding cost per cubic meter of goods stored as determined by the pharmaceutical company of third-party warehousing company.
b_p	The volume at the breakpoint $p \in P$ on the piecewise linear function
B_p	The cost at the breakpoint $p \in P$ on the piecewise linear function

4.3 Base case

The base case forms the basis of all the other scenarios and can be formulated at follows:

$$min z = \sum_{t \in T} \sum_{k \in K} \left[\sum_{i \in I} C_{ki} Z_{kit} + \sum_{j \in J} \sum_{i \in I} C_k V_{kjit} + \sum_{j \in J} C_{kjt} + \sum_{j \in J} \sum_{i \in I} C_{ji} D_{kit} + \sum_{i \in I} D_{kit} H \right] \quad (1)$$

Subject to

$$\sum_{j \in J} V_{kjit} = D_{kit} - Z_{kit} \qquad \forall k \in K, i \in I, t \in T \quad (2)$$

$$C_{kjt} = \sum_{p \in P} b_p W_{pkj} \qquad \forall k \in K, j \in T, t \in T \quad (3)$$

$$\sum_{i \in I} V_{kjit} = \sum_{p \in P} B_p W_{pkt} \qquad \forall k \in K, j \in T, t \in T \quad (4)$$

$$\sum_{p \in P} W_{pkt} = 1 \qquad \forall k \in K, j \in J, t \in T \quad (5)$$

$$W_{1kt} \leq X_{1kt} \qquad \forall k \in K, t \in T \quad (6)$$

$$W_{7kt} \leq X_{7kt} \qquad \forall k \in K, t \in T \quad (7)$$

$$W_{pkt} \leq X_{pkt} + X_{(p+1)kt} \qquad \forall k \in K, t \in T, p \in \{2 \dots 6\} \quad (8)$$

$$\sum_{p \in P} X_{pkt} = 1 \qquad \forall k \in K, t \in T \quad (9)$$

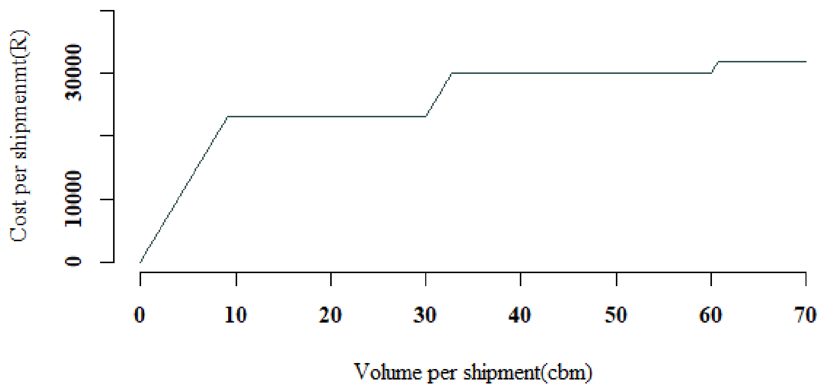
$$X_{pkt} \in (0,1) \qquad \forall k \in K, t \in T, p \in P \quad (10)$$

$$V_{kjit} \geq 0 \qquad \forall k \in K, j \in J, i \in I, t \in T \quad (11)$$

$$Z_{kit} \geq 0 \qquad \forall k \in K, i \in I, t \in T \quad (12)$$

$$C_{kjt} \geq 0 \qquad \forall k \in K, j \in J, t \in T \quad (13)$$

The model minimises the total cost of the system in Equation (1). The first term represents the ocean freight cost to move products straight from the supplier to the customer. The second term is the land freight cost in Europe from the suppliers to the nearest port. The third term calculates the ocean freight cost from the customer to the supplier. This is done using a piecewise linear



function. The fourth term represents the cost of transporting goods from the warehouse in Durban to end-customers. The final term represents the holding cost of the system. Equation (2) ensures that all customers' demands are met, either via a warehouse or directly from the supplier to the customer. This equation also determines the volume of products that must flow through the warehouse, and what volume goes directly to the customer. To include the piecewise linear cost of transporting from the supplier to the warehouse, Equation (3) to Equation (10) is included. This ensures that the cost of each shipment depends on the volume being shipped. The cost function is shown in Figure 3.

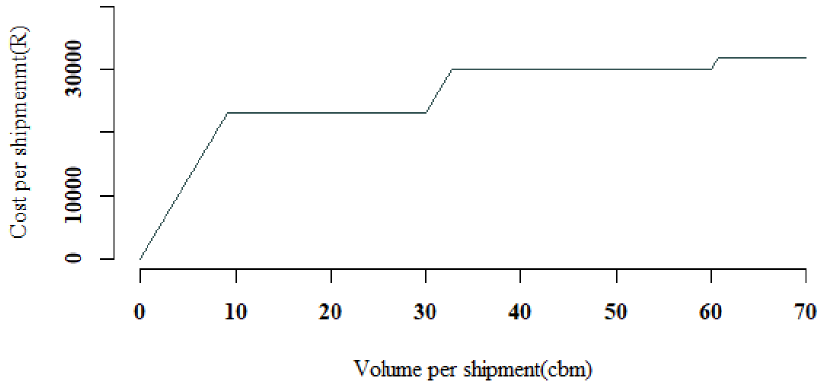


Figure 3: Piecewise linear costing

The cost function represents how the LSP in the case study price shipments, the approach is summarised in Table 1.

Table 1: Shipping Cost per Container

Container Size	Capacity [m^3]	Cost [R]
20'	30	23 000
40'	60	30 000
40' High Cube	70	32 000
1 m^3 (LCL)	1	2 500

4.4 Scenario A

Scenario A considers the impact of consolidation and reconfiguring the routes in Europe. For this scenario there is no consolidation in South Africa. Scenario A also changes the routes in South Africa because all the products flow directly to the customers, except for Johannesburg. All the demand for Johannesburg is sent from Durban because it is the nearest port.

A consolidation point in Europe is selected to minimise land transportation costs, using the centre of gravity method [16]. This technique considers both the location of the suppliers and the quantity that is shipped from them. Results from the center of gravity method recommends that an outsourcing warehouse in Germany and the port Bremerhaven are used (indicated in Figure 4).

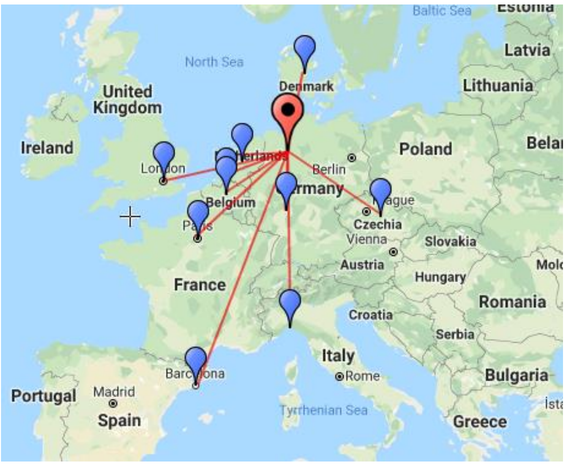


Figure 4: Center of gravity results

To model this scenario, the objective of the base case model must be adjusted as shown in (14). The first term of the objective function (14) refers to the total cost of sea freight transportation. The second term is the cost of total land transport by the supplies that moved through the centralised depot in Europe. The third term represents the total land cost of the supplies the are shipped straight from the suppliers to South Africa. For Scenario A the third term is zero because there are no supplies shipped directly from the supplier to the customer. The final term represents the holding cost in the centralised depot in Europe.

$$minz = \sum_{t\in T}\sum_{i\in I}\sum_{j\in J}\left[C_{jit} + \sum_{k\in K} V_{kjit}\left(C_{kj} + C_{ji}\right)\right] + \sum_{t\in T}\sum_{k\in K}\sum_{i\in I}\left[\sum_{j\in J} Z_{kit}\left(C_{ki} + C_{ji}\right) + D_{kit}H\right] \quad (14)$$

This scenario aims to test what the effect of consolidating in Europe can have on the system. For this scenario, there is a decrease in the amount of ocean freight shipments from Europe. However, there could be an increase in land freight cost inside Europe because all the products are shipped via the warehouse in Germany. However, land freight costs inside South Africa are also reduced in scenario A.

4.5 Scenario B

Scenario B considers the cost without any consolidation. This scenario just adjusts the ocean freight routes. Scenario B also changes the routes in South Africa because all the products flow directly to the customers, except for Johannesburg. All the demand for Johannesburg is sent from Durban because it is the nearest port. The products are not kept in any warehouses anywhere during shipment. Thus, there is no holding cost. The objective function for scenario B is given by (15).

$$minz = \sum_{t\in T}\sum_{k\in K}\left[\sum_{j\in J} C_{kjt} + \sum_{j\in J}\sum_{i\in I} V_{kjit}\left(C_{ji} + C_{k}\right) + \sum_{j\in J}\sum_{i\in I} Z_{kit}\left(C_{ji} + C_{ki}\right)\right] \quad (15)$$

The first term in (15) calculates the total cost of sea freight transportation. The second term determines the land freight cost of all the supplies that would have passed through a consolidation point. For scenario B, the second term is zero because there are no supplies flowing through a central consolidation point. The third term determines the land freight cost of all the supplies that move straight from the warehouse to the customers.

In scenario B, all the products flow straight from the supplier to the customer. To include this in the model, constraint (4) in the base case model is adjusted to allow each supplier to ship directly to each customer, as indicated in (16).

$$V_{kjit} = \sum_{p \in P} B_p W_{pkt} \qquad \forall k \in K, j \in J, i \in I, t \in T \qquad (16)$$

4.6 Scenario C

Scenario C is a combination of all three models. Scenario C investigates the optimal flow of products in the logistic chain. This scenario allows products to flow from the suppliers to the Durban warehouse (as in the base case). It also allows products to flow from suppliers through the warehouse in Germany (as in scenario A). In addition, this scenario also allows products to flow straight from suppliers to customers (as in scenario B). The flow of the products is determined based on the lowest cost in (17).

$$minz = \sum_{t \in T} \left(\sum_{k \in k} \sum_{j \in J} C_{kjt} + \sum_{k \in K} \sum_{i \in I} \left[Z_{kit} C_{ki} + \sum_{j=DBN} Z_{kit} C_{ji} \right] + \sum_{k \in K} \sum_{j=DESTR} \sum_{i \in I} V_{kjit} C_{kj} + \sum_{j=DBN} \sum_{k \in K} V_{kjit} C_k + \sum_{k \in K} \sum_{j \in J} C_{kjt} + \sum_{k \in K} \sum_{j \in J} \sum_{i \in I} V_{kjit} H \right) \qquad (17)$$

The first term represents the ocean freight cost of shipping products straight from the supplier to the customer. The second term calculates the land freight cost of shipping products straight from the suppliers to the customers. Every shipment that does not go straight to the supplier is shipped via a warehouse. This can either be the Durban warehouse in South Africa or the Bremerhaven warehouse in Germany. The third term calculates the land freight cost for the products shipped via Bremerhaven and the fourth term calculates the land freight cost for the products that shipped via Durban. The fifth term determines the ocean freight cost from Europe to South Africa. The final term calculates the total holding cost of the system.

4.7 Carbon Emission Estimation

The carbon emissions generated by the system are also estimated and is related to the cost calculated by the model. This is measured in order to get an indication of how the carbon emissions of the system is affected by different routes selected by the model. The carbon emissions are not calculated using the MILP model, instead the emissions are calculated from the model results. The estimated emissions produced are used in the decision making process as outlined in section 5 to determine the best scenario. This paper models the cost of the system and not the distance, therefore, each leg of the logistics chain is multiplied by a cost to carbon emissions factor (g/R). This factor relates a leg's cost to the weight of carbon emissions. There are two transportation modes used in this case, ocean and road transportation. However, land freight in Europe and the land freight in South Africa have different cost to carbon emissions factors because the average cost per kilometre is different. A summary of the values is given in Table 2. The data used for this calculation was specific to the case study investigated and therefore for another pharmaceutical company the values might differ significantly based on the transport modes and the cost of transport.

Table 2: Translating Carbon Emissions to Cost

Transport Mode	Cost to emissions factor[g/R]
Ocean freight	310
EU land freight	19
SA land freight	11

5 RESULTS AND DISCUSSION

Each scenario is solved in LINGO optimisation software for the case presented in this paper. The aggregate results are summarised in Table 3 with the additional carbon emissions estimation.

Table 3: Model results summary

Scenario	Ocean freight cost [R]	Land freight cost [R]	Inventory holding cost [R]	Total cost [R]	Carbon emission [tonnes]
Base Case	5 806 000	4 175 000	10 965 000	20 941 000	1 845 000
Scenario A	5 232 000	3 564 000	10 965 000	19 761 000	1 670 000
Scenario B	27 928 000	2 033 000	0	29 960 000	8 679 000
Scenario C	5 356 000	1 940 000	10 894 000	18 190 000	1 709 000

The base case, scenario A and scenario C have similar total ocean freight costs, because all three uses a warehouse where the shipments are consolidated and then distributed to the customers. However, scenario B has a higher ocean shipment cost because every shipment done directly from suppliers to customers, resulting in suppliers sending three different shipments to each of the three ports in South Africa.

The land freight cost is the total cost incurred for shipping products via land. The base case and scenario A both have similar land freight costs, because both of these scenarios send all their products through a consolidation centre. This requires substantial land shipments. Scenario B and C minimise land shipments by sending the products directly to suppliers.

The inventory holding cost of the base case and scenario A have the same holding cost because all products are sent through a warehouse, incurring inventory holding cost every month. Scenario C has a slightly lower inventory holding cost, because not all the products are sent via a warehouse. Scenario B does not incur any inventory holding cost because none of the products in are sent via a warehouse.

The carbon emission cost of each scenario is also estimated for the purpose of comparison. From the results the base case, scenario A, and scenario C produced a similar carbon amount of emissions. This is expected because the distance travelled in each scenario are similar. However, scenario B produces significantly more carbon emissions than the other three scenarios. Once again, this makes sense when taken into consideration that each supplier must send each order to South Africa in three separate shipments. Scenario B uses up to three times more ocean freight than the other models, and ocean freight is over a much greater distance, and therefore increases the carbon emissions of the system.

6 SOLUTION EVALUATION

Each of these scenarios has different costs and environmental impacts. However, in a logistic system, qualitative criteria can (and should) inform decisions. Therefore, AHP is used to select the best scenario for the case presented in this paper.

6.1 Scenario selection

AHP follows five distinct steps to select the best scenario, these steps are discussed in more detail in this section.

6.1.1 Step 1: Define goal and criteria

The first step is to define the AHP goal (to select the best scenario) and criteria to compare the different scenarios. Each scenario is rated based on specific criteria as indicated in Table 4. The criteria used in this case are derived from the case study's business objectives and various pieces of literature discussed in section 2.3, but when applying this to other logistic chains, criteria should be determined in consultation with the company's management team and business objectives.

Table 4: Criteria

Criterion	Description
Cost	The cost of the system as it is calculated using the model.
Environmental impact	The quantity of Carbon Dioxide (CO_2) emissions as estimated for each scenario.
Infrastructure	Evaluates how well infrastructure can utilised. It refers broadly to whether the infrastructure is used in line with business requirements. It speaks to how the infrastructure is used to maintain the quality standards throughout the logistic chain. For instance, infrastructure owned and operated by the company can be must better regulated in terms of risk and quality standards, where outsourced infrastructure introduces risk and quality control issues.
Ease of implementation	The degree of ease by which a scenario can be implemented. In other words, addressing low hanging fruits such as re-routing can be easier to implement than vetting and forming new partnerships with third party logistic companies in Europe.
Efficiency of transport modes	How efficiently are the modes of transport utilised. To what degree is the modes of transport efficient in meeting the demand.

Each scenario is evaluated based on the criteria using pairwise comparisons to determine a final score for each scenario.

6.1.2 Step 2: Structure the decision hierarchy

The next step is to structure the decision hierarchy into the respective levels. Each criterion supports the goal of the AHP, and there is a relationship between each scenario and all the different criteria as shown in Figure 5. For the hierarchy structure of this paper, the first level is the goal of the AHP.

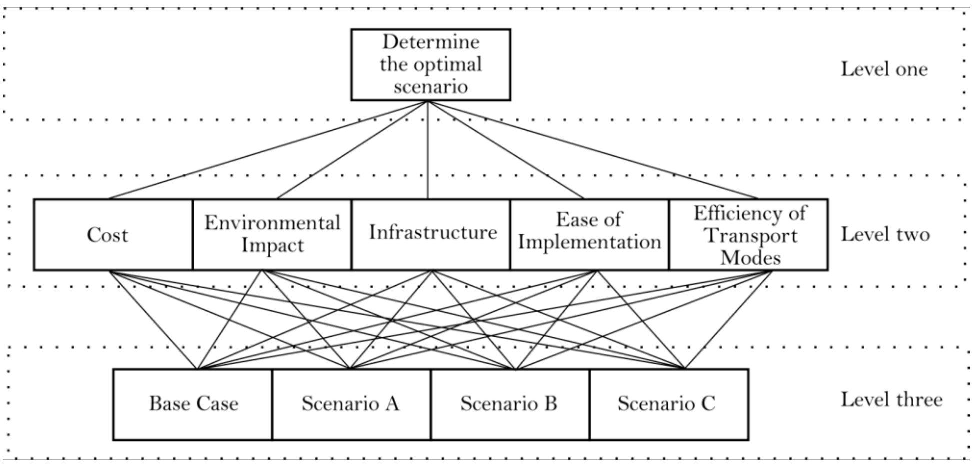


Figure 5: Hierarchy Structure

6.1.3 Step 3: Construct a set of pairwise comparison matrices

Firstly, a scale is used to define how the different criteria are measured relative to each other. This is important because the criteria are a mixture of qualitative and quantitative attributes and have different units of measure. For this paper, a scale from 1 to 9 is used as indicated in Table 5.

Table 5: AHP scale

Scale	Numerical Rating	Explanation
1	Equal Importance	Two activities contribute equally to the objective
3	Moderate importance	Experience and judgement slightly favour one activity over another
5	Strong importance	Experience and judgement strongly favour one activity over another
7	Very strong or demonstrated importance	An activity is favoured very strongly over another; its dominance demonstrated in practice
9	Extreme importance	The evidence favouring one activity over another is of the highest possible order of affirmation

This scale is used to set up a pairwise comparison between all the criteria, as shown in Table 6.

Table 6: Pairwise comparison of the logistic chain criteria

Criteria	Cost	Environ-mental impact	Infrastructure	Ease of implemen-tation	Efficiency of transport modes
Logistic chain cost	1	7	6	4	4
Environmental impact	1/7	1	1/4	1/3	1
Infrastructure	1/6	4	1	1/3	2
Ease of implementation	1/4	3	3	1	1
Transport mode efficiency	1/4	1	1/2	1	1

After the matrix is defined it is used to find a ratio for each priority. The results are summarised in Figure 6.

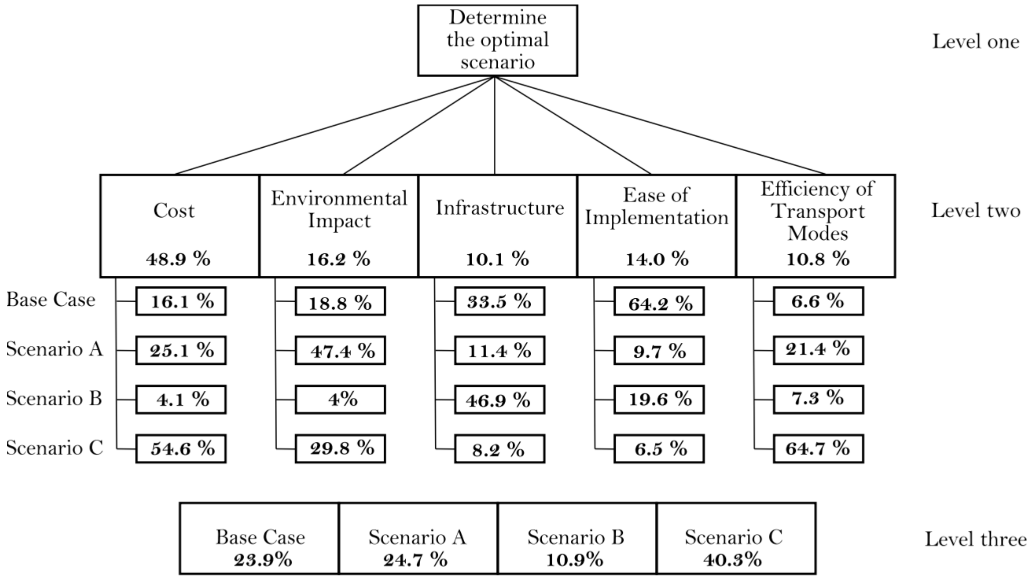


Figure 6: Respective criteria ratios

The ratios in level three of Figure 6 indicate how well each scenario scored relative to the other scenarios. These ratios are used in the next step to obtain the optimal scenario.

6.1.4 Step 4: Select best scenario

In the last step, the best scenario is selected. This is done by comparing the scores of the different scenarios as calculated in step three. From the results, scenario C has performed the best in the AHP. This means that scenario C is the superior alternative when cost, environmental impact, infrastructure, ease of implementation and efficiency of modes of transport are considered.

4 CONCLUSION

This paper investigates the potential of consolidation and other improvement opportunities in an imported pharmaceuticals logistics system. Three improvement opportunities are considered: the reduction of shipping cost with consolidation, the reduction of transportation cost with re-routing, and the reduction of carbon emissions. To achieve this a literature review was conducted. The literature points towards the use Operations Research techniques to model and evaluate these alternatives. As a result, a MILP model is formulated and used to measure the economic impact that consolidation could have on a logistic chain and to determine the best combination of consolidation, direct shipment and shipment routes.

Three different scenarios are investigated. The results of these scenarios are measured against a base case. Compared to the base case, scenario C performs the best, since it uses a consolidation centre to reduce the total cost of the system. Furthermore, scenario C uses an optimal routing configuration reducing transportation cost, distance and carbon emissions. However, it is important to consider both quantitative and qualitative aspects in the analysis, so AHP is used to score each scenario's performance based on various quantitative and qualitative criteria.

Results indicate that scenario C outperforms the other scenarios and the base case and addresses all three opportunities for improvement. This confirms that consolidation can potentially lead to significant cost and emission reductions in an imported pharmaceutical logistics chain.

These results are based on only one case derived from literature and knowledge of the industry, so it will add value to evaluate these models with other cases in the future to see how results compare with the case presented in this paper. Future work could include the analysis of the quality control risks introduced through consolidation when increasing handling and outsourcing sections of the logistic chain. Additionally, more accurate calculation of carbon emissions can be used such as fuel consumption analysis and fleet/fuel selection. The model can also be refined by using more lean principles such as reducing lead-times and other forms of waste that are not addressed in this paper. Nevertheless, this investigation provides a step towards reducing the cost and environmental impact of imported pharmaceutical logistics systems.

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BECOMING A PROFESSIONAL ENGINEER: ASSESSING WHAT DRIVES GENERATION Y ENGINEERS TO REGISTER

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ABSTRACT

Upon completion of an engineering qualification, professional registration with the Engineering Council of South Africa (ECSA) is a crucial step before practice. However, empirical evidence shows that there is currently a challenge experienced by ECSA regarding the low conversion rate of candidate engineers to professional engineers. This raises questions about the sustainability of the pipeline of registered engineers in South Africa. The quantitative study reported in this paper outlines the perceived relevance that registration as a professional engineer holds for Generation Y (or Millennial) engineering graduates (who are presently not obligated to do so by their employer). The survey framework covered the areas of knowledge and awareness; competence and experience; career relevance; and the benefits and incentives, as perceived by the Generation Y engineering graduates' participants from a single organisation. The results highlight the value and opportunities which inform potential strategies to support the professional registration of this specific group.

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1 INTRODUCTION

Through the conception of the Professional Engineers Act No 81 of 1968, the Engineering Council of South Africa (ECSA) was established as the designated regulatory body for professional engineers in South Africa. This mandate has since been expanded by new legislature, the Engineering Profession Act No. 46 of 2000 to include all levels and occupations within the field of engineering [1].

According to the ECSA, there were over 21 000 registered professional engineers as of 2019. By this number, the ratio between professional engineers and people living in South Africa sat at 1:2 800, whereby internationally, many developed countries have a ratio of 1:310 [2]. This would mean South Africa will need to produce nine times more professional engineers to match international benchmarks. To achieve this, an increase in the intake of engineering students in South African institutions, as well as improving turnover at all points of the pipeline of professional engineers is required.

Growing the membership, specifically, increasing the number of professional engineers remains a top priority for ECSA in order to support the national development goals set by government. The need to increase the number of registered professional engineers was justified by the ECSA CEO at the time, who stated that, "the increased pool of registered persons means an increased number of competent engineering practitioners, which in turn translates to improved quality of engineering work within our communities." [3]

This priority is at risk as the existing crop of registered engineers consists of engineers who have either retired or are soon to retire as seen in Figure 1. In contrast there is a large pool of Candidate Engineers in the 20 – 29 age group and the 30 – 39 age group (the joined age group often being referred to as Generation Y) as seen in Figure 2. The targeted timeframe from registering as a Candidate Engineer to becoming a Professional Engineer is three years [4]. Using an average graduate age of 23, this would mean candidate engineers would be registering as professionals before age 27, though Figure 1 shows this is the smallest group of registered professionals. This is particularly compounded by the low conversion rate of candidate engineers to professional engineers, with as many as approximately 3 800 practising engineers having been registered as candidates for 6 years or more; hence, questions about the existing pipeline of registered engineers in South Africa and its sustainability are at the forefront when critiquing the role of ECSA [2].

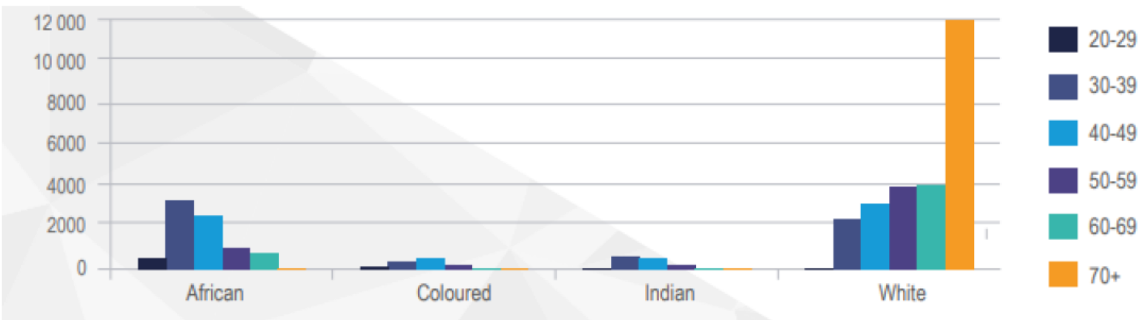

Figure 1: Professional Category Age Analysis [2]

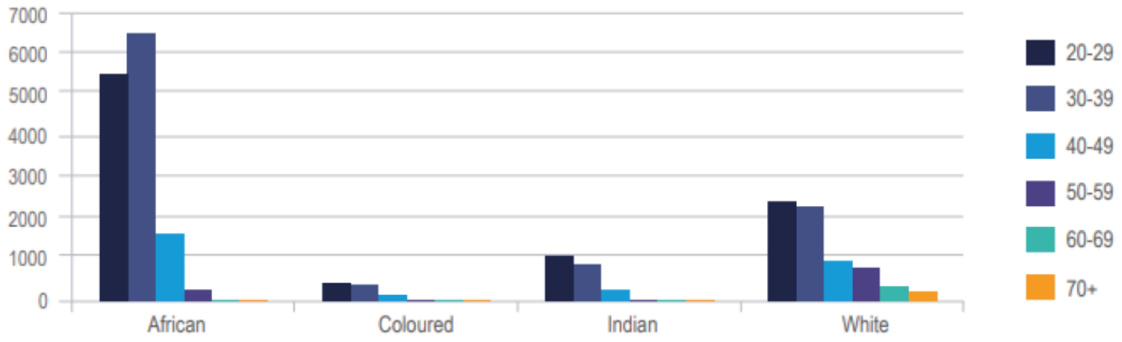

Figure 2: Candidate Category Age Analysis [2]

This paper aims to study the South African pipeline of Professional Engineers, (focussing on engineers practising in the private sector within the 20 – 29 age group in particular) by determining what relevance, registering as a professional engineer holds for Generation Y engineers (who are not obligated to do so by their employer). The essential contribution for this investigation aims to give an understanding of key factors which drive or influence Gen Y engineers to register professionally. When Gen Y engineers register professionally, this can have a potential ripple effect on companies employing them, ECSA and the nation at large.

The paper is structured as follows: the literature review is outlined in section 2 and it will cover the theoretical overview of the research topic and the related themes. Thereafter, the research methodology and data analysis strategy are detailed in section 3. Furthermore, the results are assessed relative to the research question in section 4. Section 5 concludes the paper and recommendations regarding how Generation Y Engineers can be encouraged to register professionally with ECSA, are provided, based on the results and discussion.

The study's objectives were as follows, to: 1) evaluate Generation Y's knowledge of ECSA and the process of registering as a professional; 2) determine the key factors which drive the early career development ambitions of Generation Y engineers working in the private sector; 3) determine the benefits which Generation Y engineers derive from professional registration and which benefits they expect to extract from it.

2 LITERATURE REVIEW

ECSA has reported that of the 21 446 engineers registered professionally in South Africa in 2019, 11 181 are engineers who are above the age of 60 and are approaching retirement or no longer of working age [2]. This directly affects ECSA's growth targets as the current annual rate of registration of professional engineers would require 20 years to replace this group of engineers as seen in Figure 3. The net increase of Professional Engineers was 125 professional engineers, which indicates that this process will take longer than the calculated timeframe. There is also evidence of a low annual conversion rate of candidate engineers to professional engineers which indicates a lack of intention from the current group of young engineers to register professionally – the generation which is expected to replace the large group of retiring engineers. When comparing the registration of candidate engineers to the registration of professional engineers from 2008 to 2018, the average turnover over a five year period of the pipeline of registered professionals ranges from 30 – 55% indicating that many candidate engineers are electing not to register professionally and or are leaving the profession completely [2].

Professional Engineer						
		Total registrations to date	**2018/2019 registrations**	**Candidate transfers**	**Cancellations**	**Refusals**
	Totals	21446	549	480	424	173
Gender	**Male**	20315	480	412	389	144
	Female	1131	69	680	35	29
Race	**Black**	2338	190	169	40	71
	White	17932	271	231	351	77
	Indian	926	70	67	28	22
	Coloured	250	18	13	5	3

Figure 3: Statistics of registrations in the 2018/19 Financial Year [2]

For the pipeline of registered professionals to be sustainable, ECSA needs to establish what the root cause of Generation Y tending to not register as professionals and what internal and external changes can be made to address this problem.

As has been said by the Minister of Public Works in South Africa, there is a vast need for more professional engineers in South Africa in order to reach our national development goals [2], with previous ministers focussing in particular on the need for more engineers involved in water and sanitation, airports, railways and electricity generation and distribution [5]. As the designated regulatory body, ECSA needs to ensure that their existing pipeline of professional engineers enables this target set by government, most importantly being the bridge between the public sector and engineers practising in the private sector. Hence, this investigation is motivated by the need to address and minimise the risk of a “lost generation” in the pipeline of registered engineers in South Africa, to ensure the profession continues to grow and serves the people of South Africa in its intended manner.

2.1 The role of regulatory bodies

The primary role of regulatory bodies is defined through the concept of professional self-regulation. Randall [6] describes professional self-regulation as a model which empowers governments to regulate the requirements to practise a profession by creating legislature to be administered and enforced by an occupation group, these being regulatory bodies. ECSA is given jurisdiction to govern all legal matters pertaining to the engineering profession through the Engineering Professions Act No. 46 of 2000. This includes governing engineering education through the accreditation of engineering programs in South African institutions, registration of engineering practitioners and taking disciplinary actions against professionals in the interest of public [8]. In the Act, it states that no person can do any engineering work without being registered as one of the categories defined in [1].

Table 1: Categories of registered persons as defined in section 18 of the EPA [1]

Professional	Professional Engineer Professional Engineering Technologist Professional Certified Engineer Professional Engineering Technician
Candidate	Candidate Engineer Candidate Engineering Technologist Candidate Certified Engineer Candidate Engineering Technician

Though Meisen [8] defines engineering work as "any act of planning, designing, composing, evaluating, advising, reporting, directing, supervising, or managing any of the foregoing that requires the application of engineering principles", the legislation in South Africa does not provide any clear definition of engineering work, nor has it been defined by ECSA. This should be a cause for concern for ECSA as Pullen [10] writes that not enforcing a limitation around which work can be done by registered individuals diminishes the intent of registration being a means to protect the public.

2.2 Comparing evaluation methods and criteria for Engineering Professionals

Khulief [7] breaks down the evaluation methods of becoming registered professionals for the United States of America (USA), the United Kingdom (UK) and Canada. In addition, work by Lawrence [8] summarised the evaluation method employed in Australia. This is summarised in Table 2.

Table 2: Summary of international registration criteria [7]

United States	Engineering practitioners who are seeking licensure write the Fundamentals of Engineering and the Principles and Practice of Engineering examinations.
Canada	Criteria to register includes an academic qualification from an accredited university, post-graduate work experience in their engineering discipline through an Engineer-in-Training program, fluency in the language of the province in which they practice, remaining of good character and understanding of ethical and professional practice.
United Kingdom	Criteria to register as a Chartered Engineer include a Master's degree from a recognised and accredited institution, practical training and work experience. Criteria to register as an Incorporated Engineer include a three-year undergraduate degree from a recognised and accredited institution, practical training and work experience.
Australia	Registered through peer assessment following three years of post-graduate work experience [8]

The USA model is also described by Lawrence [8] as being specific to each US state, involving post-graduation and post-practical training examinations, with the expected timeframe being 8 years to be eligible to register [8]. In Australia, engineering practitioners become registered through peer assessment following three years of post-graduate work experience [8]. In South Africa, initial registration as a professional engineer is done through peer assessments by members of ECSA committees according to each engineering discipline [9]. Theron [10] details the steps to become a professional engineer as shown in **Error! Reference source not found.**. The peer assessment introduced by Maqubela [9] is referred to as the Professional Review in Theron's diagram.

3 RESEARCH METHODOLOGY

The methodology followed to conduct this investigation was through quantitative methods, based on data collected through an online survey. One of the benefits of this approach include that they can be easily distributed over the internet, which allowed the researchers to reach the intended participants in a relatively short time. One of the limitations of this research instrument is participants not being fully knowledgeable about the survey subject matter. This was addressed by providing additional reading material to the participants to describe the competence outcomes detailed by ECSA to be able to register as a professional engineer.

3.1 The population and sampling in the study

The sample group for the survey was designed to be generation Y engineers who work in the private sector and are within the 20 – 29 age group. Purposive sampling was applied to target this group for the following reasons: they fall in the Generation Y bracket, they are still in the earlier stages of their careers, and it is not mandatory for them to register as a professional engineer. Due to accessibility constraints, the investigation was redesigned to use a single company as a case study, which focused on Company A. Company A is a multi-national company which employs over 600 engineers (within which the target population of Generation Y graduate engineers within age group 20 – 29 was identified) within the South African region of its operations. Engineers employed by Company A range from different disciplines of engineering, different engineering roles and type of work. This provided a large range of potential participants who all practice traditional engineering roles.

The basis of the participant selection was from information provided by the Human Resources department at Company A to limit participants to persons between the ages of 20-29. By means of the minimum requirement for employment as an engineer at Company A, it was assumed that all participants have a minimum of either a BEng or BSc degree (as per ECSA Policy Document R2/1A) in any ECSA accredited field of Engineering.

3.2 Research instrument

The study's three objectives (as described in the Introduction) formed the basis of the survey design, and they informed the different sections of the survey.

The survey had 24 questions in total and divided across 4 pages titled into the following sections:

1. Demographic Details (6 Questions)
2. Degree of familiarity with ECSA (5 Questions)
3. Career Development for Generation Y engineers (5 Questions)
4. Relating professional registration with desired career paths (7 Questions)

The basis of the questions in each section was a framework which was developed from the statements and findings identified in the literature review. This included the following areas:

- Knowledge and Awareness
- Benefits and Incentivising
- Competence and Experience
- Career Relevance

3.3 Data Collection and Analysis Procedures

The method of data collection was through a online survey which was open from 17 August 2020 to 30 September 2020. Participants were granted access to answer the survey anonymously by invitation only, through an email sent to their business email addresses. The email introduced the purpose of the investigation, along with a URL link to the online survey. Participants approached were kept anonymous from one another by sending blind carbon copies (bcc), with the email being restricted from being forwarded to others.

The research instrument was a multiple-choice survey which was compiled and disseminated using Survey Monkey. Data on collecting the participants' IP addresses was deactivated in the survey set up on Survey Monkey. The data could only be accessed through the password protected account on which the survey was developed.

As the survey questions developed used primarily closed-ended questions, a 5-point Likert scale ranging from Strongly Agree to Strongly Disagree was implemented. There were open text fields for questions which required individual 'Other' responses, which were included into the demographic details as additional information. The independent variables were the questions in the survey, and each answer was the dependent variables.

3.4 Data processing and analysis

Upon closure of the survey, the dataset was transferred from the Survey Monkey report into a spreadsheet format using Microsoft Excel, according to the percentages of answers within each scale. Thereafter the responses were assigned their data value for ease of analysis. Descriptive statistical analysis was used to present the results. Cronbach's alpha was used to measure internal consistency of the instrument and to support the reliability for the study. Face validity was used through consultation with the research supervisor on the constructed survey questions. Ethical clearance was granted for the study.

4 FINDINGS AND RESULTS

This section will present the findings and analysis thereof. A total of 52 participants (out of 257 target group 20 – 29 selection Generation Y engineers in the company), completed the survey; resulting in a 20.2% response rate – which falls between the acceptable response rate of 20 – 30%.

4.1 Demographic Details

The percentage of respondents registered with ECSA (either as Candidate Engineers (CE) or Professional Engineers (PE)) are indicated as per type of primary work (Table 3). It must be noted that the few respondents who categorised themselves as working in Engineering Research and Technology, Business Improvement and Software Development must be identified as outliers when observing their status as being registered with ECSA or not, due to the relatively low number of respondents in each category. The CE and PE registration figures are combined because they both represent registration with ECSA.

Table 3: Percentage of respondents registered with ECSA (as either CE or PE) per type of primary work

Type of Primary Work	Total responses	Yes %
Production & Maintenance Technical Support	19	58%
Engineering Design/Consulting	16	63%
Production & Maintenance Operations	8	63%
Business Process/Software Development	2	50%
Project Management	5	20%
Business Improvement	1	0%
Engineering Research & Technology	1	0%
Grand Total	**52**	54%

The majority of respondents (62.5%) with 4 – 6 years' experience have been found to have registered with ECSA as candidate engineers, while it is an even break (of 50% each) of registered and non-registered respondents with 0 – 3 years' experience, as seen in Table 4. Of the respondents who have registered with ECSA, only 6.25% of the respondent were recorded as being professional engineers.

Table 4: Breakdown of respondents registered with ECSA

	% Total CE	% of No registrations	% of Total PE
0 - 3 years	50	50	0
4 - 6 years	62,5	31,25	6,25

The following colour coding has been applied to graphical representations of the four core frameworks being followed in the report:

Table 5: Key for Tables 6 - 8

Framework	Colour
Knowledge and Awareness	Red
Benefits and Incentivising	Blue
Competence and Experience	Yellow
Career Relevance	Green

4.2 Degree of familiarity with ECSA

The questions in this section of the survey aimed to understand how familiar respondents are with ECSA, its processes as well as its degree of engagementwith engineering practitioners.

Table 6: Survey results – Degree of Familiarity

	Degree of Familiarity				
	Knowledge and Awareness			Competence and Experience	
	Familiarity with ECSA's role	Familiarity with Process to PE	Adequate engagement by ECSA	Roles and resp. of PE	Outcomes to become PE
Strongly Disagree	8%	10%	22%	8%	6%
Disagree	16%	16%	32%	14%	20%
Neither Agree nor Disagree	10%	16%	24%	18%	8%
Agree	56%	46%	20%	52%	52%
Strongly Agree	10%	12%	2%	8%	14%

4.3 Career Development for Generation Y engineers

The questions in this section of the survey aimed to understand the career development preferences of young engineers based on literature on Generation Y employees and the findings from literature on the benefit preferences motivating engineers to register professionally.

Table 7: Survey results - Career development

	Career Development for Gen Y - Choice in Career should offer opportunities for:				
	Career Relevance			Benefits and Incentivisation	
	Multiple career progression	Continuous formal training	Further studies in Higher education	External financial benefits	Travel, work internationally
Strongly Disagree	0%	0%	0%	0%	0%
Disagree	2%	0%	2%	16%	2%
Neither Agree nor Disagree	10%	6%	8%	22%	16%
Agree	42%	46%	34%	32%	36%
Strongly Agree	46%	48%	56%	30%	46%

4.4 Relating professional registration with desired career paths

The questions in this section of the survey aimed to understand how the career desires of Generation Y workers and identifying if respondents feel that said desires translate to the benefits and value of becoming a professional engineer.

Table 8: Survey results - Professional registration and Career paths

	Professional Engineering (PE) and Career Paths						
	Competence and Experience	Career Relevance			Benefits and incentivising PR gives adequate access to:		
	Sufficient work	ECSA Outcomes aligned to career	PR essential to become SME/ specialist	PR essential to become senior manager	Training opportunities	Financial benefits	International benefits
Strongly Disagree	0%	0%	10%	10%	8%	18%	6%
Disagree	2%	8%	16%	32%	26%	28%	14%
Neither Agree nor Disagree	18%	24%	24%	30%	46%	28%	32%
Agree	50%	52%	44%	22%	20%	12%	40%
Strongly Agree	30%	16%	6%	6%	0%	14%	8%

4.5 Reliability Analysis

The method selected to perform the reliability analysis for the instrument used was Cronbach's Alpha, which measures internal consistency of measurement instruments like scales, specifically those which use scales for responses [18]. The recommended number of items for questionnaires with small samples is between four to six items to minimise the possibility of alpha inflation and misinterpretation [19].

The Reliability statistics for the investigation for each subset were found to be over 0.7 for all the constructs tested for reliability, indicating a good level [21] of internal consistency for the scale. (These were calculated per subset of questions using Siegel's Reliability Calculator [20]).

5 DISCUSSION

5.1 Knowledge and awareness

The results pertaining to this framework relate to the first objective of the study to evaluate Generation Y's knowledge of ECSA and the process of registering as a Professional Engineer.

The results shown in Table 6 (see section 4.2) indicated that young engineers from Company A understand the role ECSA plays in the engineering profession, and the steps necessary for them to register as a professional engineers with ECSA. Hence, it can be suggested that a lack of knowledge about ECSA and the process to become a professional engineer cannot be attributed to be a key impediment to young engineers progressing to register as professional engineers, contrary to Theron's [10] suggestion of reluctance to register being due to a lack of information [10]. Looking at the results regarding engagement with ECSA, respondents indicated the organisation's presence is primarily felt in University environments, where initiatives to encourage more graduates to practise engineering have been implemented as a key strategy put in place by ECSA [3], in comparison to a lack of engagement with ECSA being experienced post-qualification.

Various articles have discussed that the Generation Y workforce is primarily characterised by their strengths in using digital communication and by placing emphasis on being part of a community more than previous generations. They desire constant feedback on their performance, indicating the strong desire from this generation to be consistently engaged with in all aspects of their professional careers [22], [23]. Evaluating the digital presence of ECSA, the organisation is heavily reliant on its website, distribution of engagement surveys and journal article contributions to communicate with their existing and potential community. As these are forms of media which solely involve publishing for consumption, if compared to the consistent interaction associated with social media platforms such as Facebook, Twitter and LinkedIn, it can be suggested that the methods of engagement currently utilised by ECSA appeal more to the Baby Boomer and Generation X generations but do not resonate with Generation Y [23].

5.2 Benefits and incentivising

The results pertaining to this framework relate to the third objective of the study to determine the benefits which Generation Y engineers derive from becoming a Professional Engineer and which benefits they expect to extract from it.

In the listed benefits of professional registration identified by the then ECSA President, individual benefits included 'international recognition', wherein ECSA's involvement in the Washington, Dublin and Sydney Accords facilitates the recognition of South African engineers in foreign countries for employment and educational opportunities; as well as increased 'employability' domestically, wherein registration as a professional engineer with ECSA provides evidence of an individual's competence to potential employers [9].

Based on results depicted in Table 7 (see section 4.3) pertaining to the Benefits & Incentivising framework highlighted in blue, suggestions that incentives identified by Gamede [3] as ECSA's value-add to practising engineers such as 'international recognition' resonate with young engineers, with an overall positive response to wanting a career which gives access to international opportunities. Generation Y engineers see this as a benefit which is facilitated through registration as a professional, as seen through the results shown in the blue highlighted columns of Table 8 (see section 4.4), presenting a more positive response to this value-add when compared to other benefits young engineers believe should be extracted from being a professional engineer. Nayak's journal article [17] notes methods of incentivising registration as a professional engineer for individuals working within private institutions, include introducing a premium for employees who are registered professionals [17]. Observing the results presented in Table 7 there is an outwardly negative belief that registration as a professional provides adequate access to financial benefits, within Company A and externally through various financial institutions.

One notable comment provided by a respondent to the survey was that the cost of registration and annual fees are expensive. ECSA's primary source of funding is through annual membership fees, wherein the cost of being registered is R4480 for Professional Engineers and R1810 for Candidate Engineers (based on 2020 amounts) [11]. In the instance that companies do not pay for this expense, it reduces the value many young engineers expect to extract from being registered as a professional engineer.

5.3 Competence and experience

The results pertaining to this framework relates to the first objective of the study, with particular focus on the respondents' knowledge on the process of registering as a professional engineer.

Observing the overall results pertaining to thoughts on 'Competence and Experience' young engineers do not believe a lack of competence in the outcomes defined by ECSA is a setback to them becoming a professional engineer. In the columns highlighted yellow in Table 6, respondents believed they were aligned with the roles and responsibilities of professional engineers, as well as the outcomes associated with being declared competent by ECSA.

In Rooplall's research, it was found that 54% of respondents who were already registered with ECSA as Candidate Engineers believed 4 – 7 years was an adequate timeframe to obtain enough experience to register as a professional engineer, whilst 24% believed three years' post graduate work experience was sufficient [4]. This is congruent with the trend in responses relating to the Competence and Experience column in Table 8, indicating a vast majority of young engineers from Company A believe the work they perform is sufficient to be a professional engineer; a response which was evenly distributed amongst those registered with ECSA in any capacity and those who are not, as well as across the years' experience demographics. Observing the demographics of respondents in this investigation in Table 4, only 6,25% of the respondents who have between 4 – 6 years' experience were registered as a professional engineer; the remainder of which are either registered as candidate engineers or are not registered at all.

5.4 Career relevance

The results pertaining to this framework relate to the second objective of the study to determine the key factors which drive the early career development ambitions of Generation Y engineers.

Crafford et al. [16] found that young engineers interviewed in their study prefer career paths to be clearly defined for them, conflicting with results highlighted in green in Table 7 which show that a strong majority of respondents believed their choice in career should offer multiple career paths and career progression opportunities [16]. This speaks to the desire for mobility in the early stages of Generation Y employees' careers as discussed by Cennamo & Gardner [24].

Generation Y engineers are noted to be a peer group which actively pursues opportunities for personal development and training [16], which has been identified as the preferred method of the Generation Y workforce as a collective to obtain the knowledge and skillset required to navigate multiple career paths [22]. This statement is supported by results shown in

Table 7, as close to all the respondents preferred a choice in career which avails formal training opportunities and opportunities to pursue further studies; speaking to Generation Y's desire to have careers which provide life-long learning [25]. Deterring the drive to produce more professional engineers, there is a changing scope of demand for engineers in roles outside of the traditional streams of engineering, in industries such as project management, management consulting and the financial services [26]. This change facilitates the desire of Generation Y engineers to pursue further learning and development opportunities and careers which offer multi-directional employment prospects more over than traditional engineering roles. Within the scope of traditional engineering roles, results relating to the Career relevance framework in Table 7 showed that the outcomes defined by ECSA are aligned with young engineers' current career paths. These typically progress to either senior management or specialisation roles within their field of engineering. However, there remains doubt on whether being registered as a professional engineer contributes to becoming a senior manager; whilst more confidence is given to registering as a professional engineer being necessary to become a specialist or subject matter expert. This has a direct effect on the talent management and recruitment processes within organisations like Company A, wherein barriers to sourcing ideal candidates for senior management and specialist positions will include a shortage of ECSA registered professionals.

5.5 Limitations of the study

The study was conducted at one organisation, due to a lack of accessibility to multiple organisations influenced by the COVID-19 pandemic in 2020, the scope of the study and the timeframe allocated to conduct the study. This limited the study to a small sample of the target demographic; engineers within the 20 – 29 age group employed in traditional engineering organisations where registration as a Professional Engineer is not mandated by their employer or necessitated by legislation. The study aimed to address this limitation by selecting Company A which employs engineers across multiple disciplines and industries in which engineering is practised. However, further studies could be conducted with participants from multiple organisations to improve the validity of the study. This would provide context on whether the influence of a participants' place of employment contributed to responses to the four aspects on which the study was based.

The study targeted the 20-29 age group to participate in the survey due to the presumed timeline to become a Professional Engineer being three years post undergraduate qualification as highlighted in section 1. Data on employees across age demographics within Company A who are currently registered with ECSA was not available from the organisation's human resources department, consequently restricting discussion on cross-generational professional registration statistics relevant to Company A specifically.

6 CONCLUSION 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.

Generation Y engineers pursue careers which provide them with training and development opportunities – in the form of formal training, further higher education and practical work aligned with ECSA's outcomes – as well as international work opportunities, and a wide scope of career paths which they can utilise and build on their past learnings.

Revisiting the relationship between ECSA and Generation Y engineers, it is indicative that this demographic is familiar with the role of ECSA and the process to become a professional engineer. However, the lack of engagement from the organisation reduces their ability to learn more about the benefits of being a professional engineer and the value-add the organisation offers young professionals.

6.1 Recommendations

The following recommendations to improve this study are to:

- Obtain more respondents across multiple industries and organisations, to evaluate if the type of work and industry the respondents work in, influences their sentiments to registering as professional engineers
- Engage directly with ECSA and their affiliated voluntary associations, to obtain databases of registered Candidate Engineers and Professional Engineers who work in the private sector to expand the sample of the study
- Engage with ECSA to evaluate their communication and engagement strategies planned for young professionals, focussing primarily on their online and digital presence.

- Engage directly with ECSA and their affiliated voluntary associations, to evaluate the efficacy of their communication channels with registered professional engineers, with focus on the reach of enrolment to training programmes and seminars.
- Engage with ECSA, government, private sector companies which employ engineers, and financial institutions to investigate the application of introducing salary premiums and or fringe benefits associated with being registered as a Professional Engineer in South Africa.

6.2 Possible Future Work

Possible future work which can be carried out relating to this study would be to investigate the existing competence levels of candidate engineers in South Africa, to evaluate what shortfalls young South African engineers need to address.

An investigation in collaboration with ECSA, government and the private sector can be conducted to identify the barriers experienced by young engineers hindering the process of registering with ECSA, for example insufficient development opportunities, financial constraints or lack of support from senior engineers by means of mentorship and coaching.

This is critical to ensuring the pipeline of registered Professional Engineers in South Africa is sustained, by developing strategies which address competency gaps, improve turnover rates of candidate engineers to professional engineers, and to create a long-term resource pool which is proven to be able to deliver on complex engineering solutions support.

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VALUE AND VALUES DYNAMICS IN SERVICE DELIVERY: A SYSTEMS APPROACH

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ABSTRACT

Governments across the world are faced with pressure from society to reduce the widening gap between rich and poor, and this pressure has taken the form of protests which often turn violent. In France, the yellow jackets revolution has gripped the country. South Africa has experienced its fair share of community protests to demand delivery of basic services enshrined in the Constitution of the Republic of South Africa. These protests very often turn violent as communities lose their patience due to not being heard. This paper aims to better comprehend the concept of value and value systems in the context of service delivery and a review of lean thinking, value engineering, design thinking, and systems thinking which are grounded on the concept of value. This research is envisaged to assist decision-makers at the coalface of service delivery to take cognizance of value and values dynamics when tackling service delivery challenges.

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1 INTRODUCTION AND BACKGROUND

Governments across the world have come under pressure from communities to respond with a sense of urgency to challenges facing communities and to offer value-based service delivery. In the South African contest, service delivery remains a prickly phenomenon since the dawn of democracy. This is characterized by service delivery protests which flash throughout the country as citizens demand access to services of which housing takes the pole position and followed by pertinent issues such as access to clean piped water and sanitation. These rights are enshrined in the Bill of Rights in the South African Constitution, albeit the slow pace of service delivery due to pipeline inefficiencies and sometimes maleficence; the rights of the citizens should still be upheld.

Antwerpen and Ferreira [1] propose that inadequate service delivery by government and in particular local government is incapacitating the South African economy and hindering economic growth and is characterized by a proliferation of service delivery protests, as repeatedly witnessed in the media [2] which disrupt communities and prospects of growth in the community at large.

This article aims to provide a holistic view of the concepts of value and values in the context of service delivery in South Africa which could be useful for policymakers and local government authorities to deal with discontent in communities. To accomplish this task, the paper will explore the concept of value and values (value systems) and their respective dynamics and also explore systems thinking, lean thinking, design thinking, and value engineering from a value perspective.

Pietersen [3] asserts that the South African government has put forward the "Batho Pele" principles policy which means "People first" which is meant to accelerate the provision of services to the citizens. These principles are (a) Consultation which means that citizens should be consulted level and quality of service they will receive (b) Setting of service standards in which citizens should be told what level and quality of public services they will receive so that they are aware of what to expect (c) Increasing access which relates to ensuring that all citizens have equal access to the services to which they are entitled (d) Ensuring courtesy which means that citizens should be treated with courtesy and consideration (e) Providing information which means citizens should be given full, accurate information about the public services they are entitled to receive (f) Openness and transparency which means citizens should be told how national and provincial departments are run, how much they cost, and who is in charge, (g) Redress which means If the promised standard of service is not delivered, citizens should be offered an apology, a full explanation and a speedy and effective remedy; and when complaints are made, citizens should receive a sympathetic, positive response; and (h) Value for money which means public service should be provided economically and efficiently in order to give citizens the best possible value for money.

These eight Batho Pele principles are values as in value systems that the State commits to and are a courageous stance that the State adopted to demonstrate their commitment to effective and efficient public service delivery. If these values are adhered to, public service will transform into effective and efficient machinery which "do" the right things and "do" them within cost, quality, performance, and safety.

The main research question is:

In delivering services to residents, what dimensions of value should decision-makers in local government take into consideration to ensure service delivered is of value?

The sub-research questions that underpin this study are:

1. What is service delivery?
2. What is value?
3. What are values (value systems)?
4. What are the dynamic interplays between value and values?

5. What dimensions of value are underpinned in value engineering, systems thinking, lean thinking, and design thinking?

2 LITERATURE REVIEW

2.1 The concept of service delivery

Kanyane [4] argues that it is a fact that municipalities depend on solid revenue bases to maintain their sustainability and capability to provide services to individual households. In situations where these revenue sources are depleted, communities will likely be plagued by high levels of abject poverty and unemployment and also have strong elements of rural and informal economies. This results in an increasing demand for subsidization and welfare, which are unsustainable. This is evidenced by the escalation of informal settlements which puts pressure on the municipalities to provide free basic services (FBS) such as water, electricity, and housing for the poor households [4].

Ngcamu [5] suggests that the South African government has been facing instability manifested in an array of protests that are exacerbating at the municipal level where service delivery issues are dominant. An upsurge in service delivery protests has been linked with economic decline, dual pressures of the declining environment, and mounting unemployment rate. Public Servants Association [6] argues that service delivery is a complex, grim task, and particularly so in South Africa. The infrastructure backbone of the country was not built to be inclusive, and the process of restructuring the entire system to meet the needs of the whole population is a daunting task for the government that is generally under-capacitated.

Public Servants Association [6] further argues that at the core of protests and sometimes violent protest, land and housing register as leading complaints which points to severe systemic problems associated with the RDP (Reconstruction and Development Programme) housing rollout and the slow pace of the land reform process. But core services such as electricity, water, sanitation, waste, infrastructure, and delivery broadly are leading complaints raised by communities, coupled with corruption and nepotism complaints which communities are of the view that they reinforce poor public service delivery.

2.2 The concept of value

Moeran [7] argues that three broad streams of investigation congregate on the current utilization of the word value(s). One is from an economic viewpoint which relates to a measurable degree to which people desire a good or service and to what length they will go to get it. The second is sociological in orientation and goes into what society perceives as good, appropriate, and acceptable ways of life. Last but not least is linguistic in orientation and relates to meaningful differences maintained in language. The second description as articulated by [7] is reinforced by Yamamoto and Gonca [8] who argue that values are internalized cognitive structures that steer choices by inducing a sense of simple principles of right and wrong, a sense of urgencies, and an inclination to make sense and see relationships; they are principles by which we live. Rosado [9] suggests that values are constitutive elements of the culture, defining meaning and significance within a social system they are complex coping systems [10].

Yamamoto [8] **proposes** that value is the difference between total customer value and total customer cost and argues that value is created when the views of benefits obtained from a transaction outstrip the costs of ownership. This proposition is reinforced by SAVE [11] and Rosado [9] who argue that value is defined as a fair return or equivalent in goods, services, or money for something exchanged.

2.3 Value systems

Dobbelstein and Krumm [10] argue that value systems theory presents the dynamics that are attributable to the development of people, groupings, and organizations. Value systems occasionally called psychological DNA, articulate attitudes, principles, intimate emotions, and organizational values. They are the fundamental beliefs, morals, and ideals of individuals and are manifested in attitudes and behaviors in society [12].

Whitehouse and Binderman [13] argue that an individual, organization, industry, or nation will cultivate its unique value system characteristics, based on its specific challenges for existence. They further suggest that each core value system has its style of managing, each manifesting specific thinking paradigms. The eight value systems are articulated by Whitehouse and Binderman [13] as follows:

- Beige value system: This expressive value system is at the bottom of the spiral and concerned with survival.
- Purple value system: This sacrificial value system is highly participative and relies on the inherently transparent dynamics of "the tribe".
- Red value system: This expressive meme is the most energetic of them all. The "red" manager has an extremely high self-image and will "call the shots". This value system is characterized by "power gods".
- Blue value system: This sacrificial value system relies on structure and rules. However, in its bright form, it is susceptible to bureaucracy or "blue-tape".
- Orange value system: This expressive value system focuses on "bottom line" improvements, personal as well as corporate. However, in its bright form, it is susceptible to corruption and self-enrichment.
- Green value system: This sacrificial value system has a core concern for other beings.
- Yellow value system: This expressive value system relies heavily on networking and systems thinking.
- Turquoise value system: This sacrificial meme is the most complex system currently known to man. Due to its advanced state of complexity, it is safe to assume that not many people would as yet be operating from this "turquoise" World.

The value systems articulated above are graphically represented below:

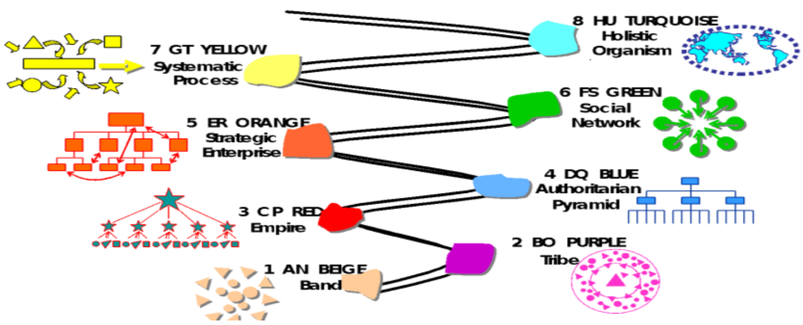

Figure 1: The eight value systems [13]

2.4 Lean thinking

Singh et al [14] postulate that the objective of lean thinking is to eliminate waste throughout an organizations business processes, this view is reinforced by Islam et al [15] who proposes that lean thinking is a systematic approach to identifying and eliminating waste through continuous improvement at the demand of the customer. Smith [16] argues that lean thinking is a system to specify the value, streamline value-creating activities, execute these value-creating activities without disruption whenever the customer demands them, and execute these activities effectively and efficiently. Smith [16] further articulates the five principles that underpin lean thinking as (a) Specify value from the customer point of view, (b) Identify the value streams, (c) Make the value flow, (d) Implement pull-based systems, and (e) Strive for perfection continuously.

Smith [16] postulates that the crux of the lean thinking principles is to create a perfect value stream by incessantly identifying, and eliminating activities that are deemed to be waste and focus on activities that create value while Bicheno and Holweg [17] suggest that waste is anything that a customer is not willing to pay for while value is something that a customer is willing to pay for. [17] further suggests that there are eight types of waste which the underlying philosophy is to avoid or reduce. An acronym DOWNTIME is used to describe these types of waste and are: (a) Defects, (b) Overproduction, (c) Waiting, (d) Non-utilized talent, (e) Transportation, (f) Inventory, (g) Motion, and (i) Extra-processing. These eight wastes erode value to a product, service, process, or system; and in the case of public service, these eight wastes are applicable.

2.5 Systems Thinking

Edson [18] postulates that systems thinking is the opinion that systems and problems cannot be resolved through reducing the systems to their constituent parts and that systems thinking is a methodical approach to comprehending problems and finding solutions to these problems. Edson [18] further asserts that one of the great challenges of systems thinking is comprehending "the system". Schumacher [19] proposes that systems thinking is a perspective seeing and comprehending systems as wholes rather than as collections of parts, this view is reinforced by Meadows [20] who postulates that a system is more than the sum of its parts; it (system) may display dynamic, oscillatory, goal-seeking, self-preserving and sometimes the evolutionary model of behavior.

Shaked and Schechter [21] argue that there are two key insights to derive from the definition of systems thinking which are: (a) Seeing the whole beyond the constituents, and (b) Seeing the constituents in the context of the whole.

Schumacher [19] proposes that systems thinking seeks to understand the connection among elements in a system and attempts to delve deep to understand: (a) What depends on what? (b) What is causing what? (c) Where is the information flows? (d) Where are control decisions made? (e) What information flows are critical? (f) How best to engage stakeholders? (g) How best to engage or intervene in the system for the desired action?

Jamshidi [22] suggests that Systems Thinking entails appreciation that in systems conceived by humans, recurring incidences or relations originate from systemic constructs which emanate from mental models. Jamshidi [22] further propose that the Iceberg Model (Illustrated in Figure 1), is a fundamental aspect of systems thinking. The Iceberg Model asserts that actions (events) and patterns (which can be observed) are prompted by universal (systemic) structures and mental models, which are usually not discernible. The iceberg model can provide deep insights as to why protests happen, what patterns emerge from the protests, what systemic structures drive these protests, and lastly what mental models are deeply rooted both in communities and in local government that cement the culture and values that are prevalent.

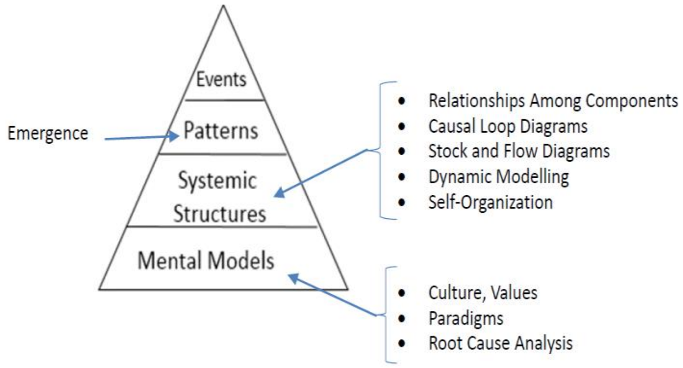

Figure 2: Integrated Model of Systems Thinking [22]

2.6 Value Engineering

Rad and Yamini [23] propose that value engineering is a systematic, creativity and collaborative-based method to solve a problem, decrease cost, and improves function, quality, and safety. This view is supported by Rane and Nitin [24] who assert that Value Engineering is a creative, organized effort, which examines the requirements of a project to achieve the essential functions at the lowest total costs over the life of the project. Value in the context of value engineering can be described as the lowest cost to reliably render a function with desired quality and safety. It can be defined as a fair return or equivalent in goods, services, or money for something exchanged [25]. SAVE [25] asserts that the value methodology is a systematic process that follows the Job Plan. A value methodology is applied by a multidisciplinary team to improve the value of a project through the analysis of functions.

Whitehouse and Binderman [13] propose that value, as defined in Value Engineering, is the ratio of Function to Cost while recognizing that ALL Functions incur a level of cost and their performance is a measurement of quality. They further propose that value as in value engineering is measured with a formula Value is a quotient of function and cost. They argue that the "Value Influence Curve" graph will show that 70% of all costs of a project, product, or process will be fixed by the end of the concept stage, 95% by the end of the design and development stage, with the remaining 5% during the construction and manufacturing stage. As a result, value engineering asserts that value can greatly be influenced at the beginning of the project. Municipalities are responsible for infrastructure development as in roads, stormwater, potable water, electricity, sanitation, wastewater, and other infrastructure that aids the local government to provide quality public service and as a result, it is key that during the planning phase municipalities deploy value engineering methodology. In the United States, it is mandatory as per the Presidential circular [26], for the Federal to consider and use VE as a management tool to ensure realistic budgets, identify and remove nonessential capital and operating costs, and improve and maintain acceptable quality in program and acquisition functions.

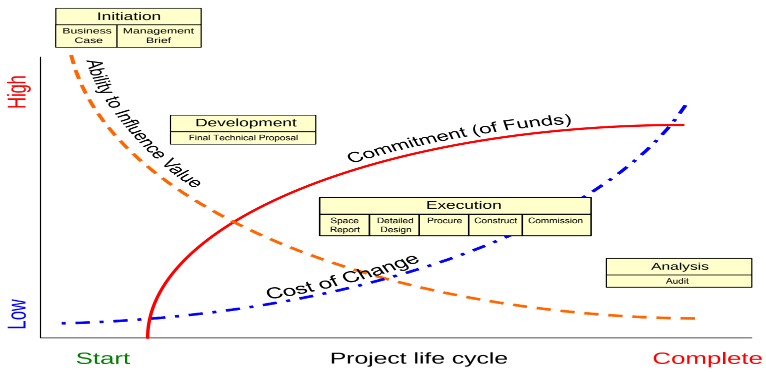

Figure 3: Project Lifecycle [13]

Rane [24] proposes that the value engineering methodology comprises six core phases which are the information phase, creative phase, evaluation phase, development phase, and presentation phase. This view is supported by [11] who articulates the same five phases. Whitehouse and Binderman [13] articulates the phases as information gathering phase, functional analysis phase, creativity phase, evaluation phase, and implementation phase. The phases articulated by [13] are depicted in the below graphical representation.

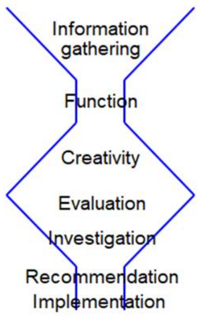

Figure 4: Value Engineering Methodology [13]

2.7 Design Thinking

Ambrose and Harris [27] assert that design is a process that transforms a brief or requirement into a finished product or design solution and design thinking is present in each stage of the journey from client brief to finished work. Hobcraft [28] asserts that Design Thinking is a methodology deployed to solve complex problems and uses systemic reasoning and intuition to explore an ideal future state. The end-user or customer is at the core of the design process [28]. Design thinking is a collaborative, creative, and human-centered approach to creating products and services that will achieve better results (value) [29]; and it is both a process and a mindset (way of thinking) [30].

Serrat [31] argues that design thinking revolves around three key phases: inspiration, ideation, and implementation while Müller-Roterberg [32] suggests that the design thinking process entails six process steps with iteration loops which are (a) understanding, (b) observing, (c) defining problems, (d) finding ideas, (e) developing prototypes and (f) testing. Müller-Roterberg [32] further argues that the first three of the six are described as “problem space” and describe the problem and its cause and answers what questions and why questions. The consequent three are described as "solution space" which describes which solutions there can be and how these can be implemented. The design thinking process is depicted in the double diamond model below which reinforces the assertions made by [32] about the problem space and solution space. This concept is depicted in Figure 5 which captures the underlying tenets of design thinking which are characterized by a problem space with divergence representing curiosity, convergence representing compassion. This part of the “first” diamond is meant to comprehend the problem in full. The second diamond which represents the solution space is characterized by divergence which seeks to find creative ways of resolving the problem at hand and lastly, convergence which seeks to “construct” the best possible solution.

Luka [30] postulates that design thinking is centered on three nine guiding principles which are (a) Ambiguity which recognizes that one phenomenon more than one perspective, meaning, or explanation exists. (b) Collaboration rather than cooperation. (c) Constructiveness refers to a solution-based approach that is seeking better outcomes (value). (d) Curiosity. (e) Empathy is at the foundation of the design thinking process (f) Holism which entails systems view rather than parts (g) Iteration which entails that design thinking is not a linear process (h) Non-judgemental. (i) Openness which entails transparency.

Figure 5 articulates the difference between cooperation and collaboration, design thinking is a collaborative effort that is characterized by iterative loops from beginning to end. It can better be described as a lateral process rather than a linear process which is also depicted in Figure 6 below which encapsulate the concept of a cooperative process.

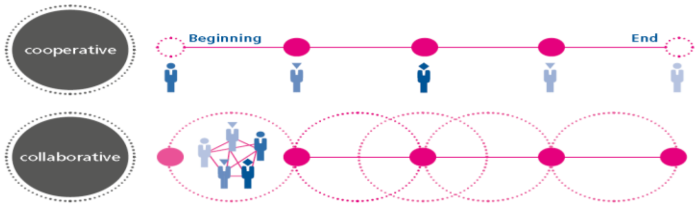

Figure 5: Projects based on collaboration vs cooperation [33]

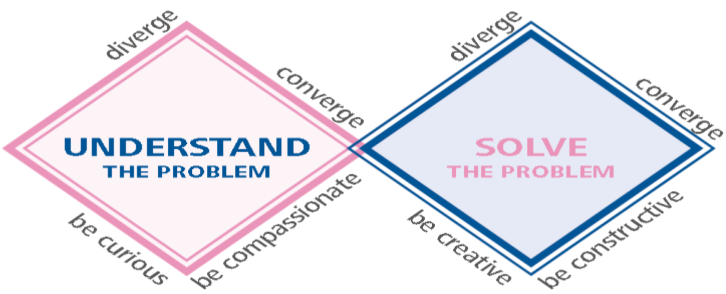

Figure 6: The double diamond with different thinking styles, tricks, and attitudes [33]

3 RESEARCH METHODOLOGY

Khothari [34] argues that research is a scientific and systematic exploration of relevant information on a specific topic. This research is a scientific and systematic exploration of literature relating to the concept of value, design thinking, value engineering, systems thinking, and lean thinking. This research adopted a pragmatic worldview which is based on the assertion of Saunders [35] who proposes that pragmatism contends that the most significant factor of the epistemology, ontology, and axiology adopted by the researcher; is the research question. The research question guides the way this study was approached. The research further adopted an inductive research approach in which follows a theory-building approach rather than a theory-testing approach and lastly adopted a research strategy that entails a critical review of relevant literature in the form of books, research articles, and research reports.

IBM Centre for Business of Government [36] postulates that by utilizing big picture, cross-agency thinking, New Zealand's experiences demonstrate one path towards "tilling the ground" for collaborative creativity, like design thinking. Through application of design thinking, New Zealand's policy makers have moved to merge system-wide desires for innovative solutions with bottom-up understanding of local problem-solving, by introducing policies aimed at encouraging collaborative creativity across traditional government silos and by balancing quantitative statistics with human stories. IBM Centre for Business of Government [36] further points to New Zealand Inland Revenue office when staffers shifted their emphasis from enforcing tax compliance and punishing evaders to figuring out how to make "doing the right thing easier. By focusing on understanding and empathizing with their taxpayers, tax staffers solved previously unforeseen practicalities around the process of paying taxes and generated more national income at less expense than prior punitive efforts. This action has spurred the New Zealand government's work to build design thinking and other innovative operations into state agencies

4 FINDINGS AND DISCUSSION

4.1 Service delivery factors

Literature reveals that there is an overabundance of factors that drive service delivery protests and sometimes violent protests. These factors include the ability of municipalities to collect revenue to ensure the ability to provide services to residents including those in poorer communities, capability, and capacity to deliver services, constraints in the RDP rollout, bottlenecks in the land reform process, systemic challenges in the provision of clean water and sanitation, electricity, waste management, frustrations of ignored grievances, poor and collapsing infrastructure, and corruption and nepotism in the municipal pipeline.

The issue of maleficence is dealt with clarity in the section below that deals with value and values.

4.2 Value and values

Literature review points that there is a fundamental variance between value in its singular form and values in its plural form. Value is often perceived as economic as in the value that someone places on pay; and values on the other hand are concerned with principles by which society lives and are often perceived in the cognitive sphere. There is a dialectical relationship between value and values and in this case value systems, as described in the literature, value systems (human dynamics) and value engineering are two sides of the same coin as they are interrelated.

Public service is plagued with inefficiencies and maleficence due to the inability to deliver value as demanded by multiple stakeholders with often conflicting interests, the second aspect is a value system that is not in the best interest of communities. As articulated in the literature review, the value system that should permeate all spheres of government including local government is the blue color value system where structure and rules reign supreme. However, maleficence in the public service strongly suggests a combination of red value system that is characterized by power-gods driven by the ego with no empathy and compassion to "the people" and a bright orange value system which is characterized by debauchery and "profiting" at the expense of "the people".

4.3 Lean thinking

Inefficiencies are a result of a lack of a systems approach to providing value for stakeholders in public service, examples are the Makhanda water crises, Hammanskraal water crises, Eskom blackouts, proliferation of squatter camps, and many more problems that have plagued the public service delivery systems. The literature points out that the essence of lean thinking is to specify a value from a customer point of view, optimize these value-creating activities, implement these value-creating activities without disruption whenever the customer demands them, and effect these activities effectively and efficiently. The service delivery protests which are more often violent point to the lack of a lean thinking mindset in public service, a casing point is the abundance of the 8 wastes (DOWNTIME) plaguing the business processes in the public service. Table 1 explains some of the common wastes that are typical in the public service that affect people daily.

Table 1: DOWNTIME wastes and examples in public service

Type of waste	Casing point
Defects	Breakdowns in plants resulting in rolling blackouts
Overproduction	Excess graduation of the 20th-century skills base
Waiting	Not attending to faults timeously
Non-utilization of talent	Poor maintenance of infrastructure
Transportation	Ambulances traveling long distances due to lack of healthcare facilities close to communities especially in villages
Inventory	Queues awaiting service (Hospitals, clinics)
Motion	Communal taps in villages and informal settlements, walking for hours to access services
Excess reprocessing	Fixing one thing many times

4.4 Systems Thinking, Design Thinking, and Value Engineering

The literature further points to the lack of a holistic view and iterative process when projects are conceived to provide value to stakeholders. This becomes clear when communities vent frustration and destroy infrastructure. This points to a systemic "design" failure because these communities do not perceive the value of public infrastructure, this failure points to a lack of system thinking which incorporates approaches understudy in particular value engineering and design thinking which are pertinent "design" tools to collaborate with communities from the beginning to end of projects. Design thinking and value engineering utilize the power of buy-in through a collaborative effort between "designers" and communities. Because the two approaches dig deep through the iceberg to understand problems in whole and in-depth, they could be characterized as tools of systems thinking.

4.5 Attributes underpinning the four system approaches

Table 2 depicts the attributes that are fundamental to the broad concept of value and values. Value as in stakeholder perceptions and values or value systems as in integrity, compassion, empathy, and the way "designers" in the form of public officials and public representatives conduct themselves and relate to stakeholders are extremely important. The table illustrates from a quantitative point of view that value engineering, design thinking, and system thinking share many attributes with design thinking trailing value engineering with a small margin. There is a respectable gap between value engineering and lean thinking which can be attributable to the fact that lean thinking is more linear in approach and perceive value from the customer perspective but fails to collaborate with the customer throughout the journey to realize value. Also, lean thinking is not "linked" to moral canons of value systems. Value systems can make or break projects, initiatives, organizations, governments, and communities. There is a symbiotic relationship between value and values (value system).

Table 2: Attributes vs approaches

Approaches → ↓Attributes		Systems Thinking	Value Engineering	Lean Thinking	Design Thinking
#	Attributes	1	2	3	4
1	Value focused	✓	✓	✓	✓
2	Definition of why assignment is undertaken	✓	✓		✓
3	Cooperative			✓	
4	Collaborative	✓	✓		✓
5	Agility	✓	✓	✓	✓
6	Quality of information gathering	✓	✓		✓
7	Focusing on the whole	✓	✓		
8	Identifying best practices and weaknesses	✓	✓	✓	
9	Sensitive to needs of clients		✓		✓
10	Ability to garner buy-in		✓		✓
11	Ability to mobilize stakeholders		✓		✓
12	Ability to align expectations of stakeholders		✓		✓
13	Quality of information	✓	✓	✓	✓
14	Compassion				✓
15	Futuristic thinking	✓	✓		✓
16	Creativity and innovation	✓	✓		✓
17	Value definition		✓	✓	
18	Ability to influence value	✓	✓		✓
19	Best design focus	✓	✓	✓	✓
20	Optimization of business processes	✓	✓	✓	
21	Elimination of waste		✓	✓	
22	Root Cause Analysis	✓	✓		
23	Multidisciplinary		✓		✓
24	Fuocused on improving fuction and reducing costs		✓		
25	Manages risks (consequences)		✓		
26	Rigour embedded in problem solving		✓		
27	Iterative (Lateral thinking)	✓	✓		✓
28	Divergance and convergence of ideas		✓		✓
29	Integrates value systems		✓		

4.6 The value-values dynamics

Service delivery is a complex system with ever-changing dynamics that underpin this complex phenomenon. The array of dynamics is characterized by factors such as the capability of the State to provide services which comprise of soft key issues such as corruption, nepotism, communities feeling unheard and their complaints ignored, constraints in the housing allocation process, land reform challenges, and the concept of values and value. In addition to soft key issues, there are hard key issues like ailing infrastructure, inability to deliver electricity, water, sanitation, and other services. This complex flux of dynamics is depicted in Figure 7 and the description and explanation of the loops are articulated in Table 3.

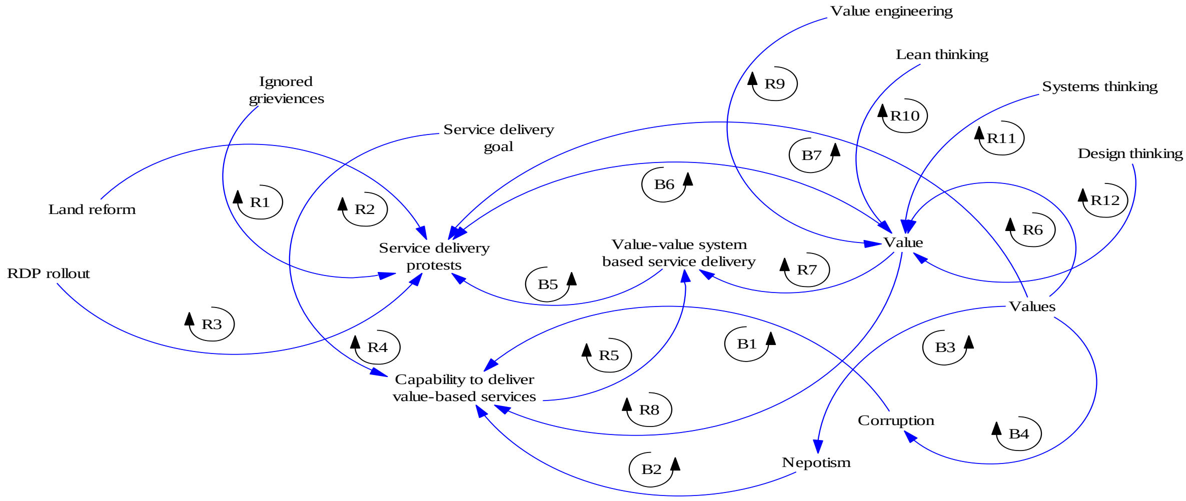

Figure 7: Value, values, and service delivery dynamics

Table 3: Description of value and values dynamics in service delivery

Loops	Explanations
B1: Corruption influence the capability to deliver a value-based services loop.	This loop reveals that corruption limits the ability of the State to deliver services. When corruption rises, the ability of the State to deliver plummets due to looting by corrupter and corrupted between the private sector and public sector leeches.
B2: Nepotism influence the capability to deliver a value-based services loop.	This loop reveals that nepotism limits the ability of the State to deliver services. As nepotism rises, the ability of the State to deliver plummets due to poor technical skills set.
B3: Values influence on nepotism loop.	This loop reveals that values decrease the pervasiveness of nepotism. The optimal the value system, the less prone it is to nepotism.
B4: Values influence on corruption loop.	This loop reveals that values decrease the pervasiveness of corruption. The optimal the value system, the less prone it is to corruption.
B5: Value-value system-based service delivery influence on service delivery protests loop.	This loop reveals that value-value systems-based service delivery reduces the likelihood of service delivery protests.
B6: Value influence on service delivery protests loop.	This loop reveals that value in the municipal pipeline reduces service delivery protests.
B7: Values influence on service delivery protests loop.	This loop reveals that values embedded in the municipal pipeline reduce service delivery protests.
R1: Ignored grievances influence on service delivery protests loop.	This loop reveals that ignored grievances reinforce service delivery protests by livid communities.

Loops	Explanations
R2: Land reform influence on service delivery protests loop.	This loop reveals that the slow pace of land reform reinforces service delivery protests by livid communities.
R3: RDP rollout influence on service delivery protests loop.	This loop reveals that the slow pace of RDP rollout reinforces service delivery protests by livid communities.
R4: Service delivery goals influence the capability to deliver value-based services loop.	This loop reveals that a service delivery goal that is value and values-based will reinforce the capability of the State to deliver services.
R5: Capability to deliver value-based services influence on value and value system-based service delivery loop.	This loop reveals that the capability to deliver value-based services reinforces value and value system-based service delivery.
R6: Values influence on value loop.	This loop reveals that values (value systems) reinforce value. The value increases when acceptable values are embedded in the system.
R7: Value influence on value system-based service delivery loop.	This loop reveals that value reinforces value-based service delivery.
R8: Value influence on the capability to deliver value-based services loop.	This loop reveals that value reinforces the capability to deliver services.
R9: Value engineering influence on value loop.	This loop reveals that value engineering positively reinforces the concept of value by innovatively and collaboratively looking for the lowest cost to reliably render a function within cost, performance, safety, and quality without sacrificing requirements.
R10: Lean thinking influence on value loop.	This loop reveals that lean thinking positively reinforces the concept of value by understanding value from a customer's perspective and eliminating waste throughout the value chain.
R11: Systems thinking influences on value loop.	This loop reveals that systems thinking positively reinforces the concept of value by understanding what drives behavior and mental models that reinforce the behavior.
R12: Design thinking influence on value loop.	This loop reveals that design thinking positively reinforces the concept of value by walking with the customer in the journey of co-creation.

5 RECOMMENDATIONS AND CONCLUSION

Service delivery protests which represent stakeholders' impatience with the provision of services to communities points to two-pronged trouble of (i) Poor provision or in some instances non-existent provision of services that communities can extract value from and, (ii) A value system that is compassionate about the needs of communities. There is great value in collaborating with stakeholders in the quest to find the best possible solutions to problems. Design thinking and value engineering as subsets of systems thinking as a broader phenomenon can take communities in confidence and "co-design" the best possible outcome for the complex challenge faced by communities. This removes the ego that is characterized by the red value system whereby power-gods run the show and are vessels of knowledge while communities are viewed as "children" who know nothing better and must get "marching orders" from power-gods.

Public service as an organizational system should transcend the red value system to a blue value system that is centered on good governance while its leaders should transcend the red value to a yellow value system that relies on systems thinking and networking. Systems thinking and its subsets; value engineering, and design thinking represent a yellow value system. A blue value system relies on structures, rules, and governance which are important to deal with maleficence, a yellow value system amongst the leadership is equally important to inculcate a system thinking mindset through the deployment of value engineering and design thinking methodologies to harmonize and streamline service delivery.

This paper presents a holistic view of value and values that decision-makers could take into consideration in the quest to build a capable state. This paper asserts that decision-makers should take a holistic view on the concept of value and values in the context of service delivery and should consider the four system approaches (Design thinking, value engineering, lean thinking, and systems thinking) when planning, commissioning, and operating service delivery projects and programs.

In conclusion, the concept of value and values was presented; followed by a thorough review of systems thinking, value engineering, lean thinking, and design thinking from a value and values point of view. A holistic view of value was synthesized and presented in Table 2 which articulates the attributes innate in the four systems approaches. The factors that interact in a dynamic setting in service delivery as a complex phenomenon were presented in Figure 7 and explained in Table 3. Further research in developing and implementing framework that incorporates the value-values approaches could be beneficial in truly living the Batho Pele principles as envisaged in the policy direction set by the State in order to provide effective and efficient public service with humility and dignity. This will restore the dignity the dispossed people of our country.

The implementation of the value-values approach will curtail maleficence that is characterized by a symbiotic relationship between dishonest public and private sector officials by creating a new culture and a new paradigm that puts people first.

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CORPORATE FAILURE PREDICTION OF JSE LISTED SOUTH AFRICAN FIRMS USING MACHINE LEARNING

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ABSTRACT

Corporate failure has increasingly become an area of interest to policy makers and lending institutions around the world. The aim of this paper is to analyse, improve and expand prior work in the prediction of bankruptcy in South Africa in order to develop a prediction model that can help predict bankruptcy and assist lending institutions to better manage credit risk. A sample of 381 companies listed on the JSE between 1997 and 2017 was used. This included 66 companies declared bankrupt during the period under investigation. Based on 72 financial variables, the results favour machine learning techniques over statistical models by an additional 9% in prediction accuracy. The random forest models showed the highest classification accuracy of 89%, followed by support vector machine at 87% and artificial neural network at 86%. Results of this study may be of interest for lending institutions and for academics in machine learning prediction algorithms.

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1 INTRODUCTION

Corporate failure prediction is a common problem investigated by researchers, credit institutions and banks [1]. The prediction of corporate bankruptcy has been addressed as an increasingly important financial problem and is extensively analysed in accounting literature. Successful prediction of this event can lead to robust preventative measures which can boost company revenues and encourage economic growth [2, 3]. One of the most important issues with predicting bankruptcy, is to employ an effective variable selection algorithm which will lead to an acceptable level of performance accuracy in the implementation stage. Applications of combined variable selection methods and classification models including machine learning techniques are topics that have been given significant attention in recent years [2, 4, 5].

Altman was the first to develop a multivariate logistic regression model to predict bankruptcy, called the Altman z-score model [6]. It became a popular tool to predict corporate failure. The model uses stepwise logistic regression to examine a combination of financial ratios from USA companies. The z-score, the output prediction value of the model, is calculated by a linear combination of several common financial ratios that are weighted by coefficients. The ratios cover aspects such as liquidity, profitability, operating efficiency, size and turnover of a firm [7].

Although the Altman z-score model is widely used, it was developed specifically for USA financial indicators. In this study, a new logistic regression model was developed to use financial indicators provided by JSE listed companies. In addition to the five variables used by Altman [6], this model introduced new variables including the enterprise value, operating margins, growth measures related to assets and sales, return on equity and others.

However, logistic regression models like the Altman z-score model, is limited due to assumptions such as linearity, normality and independence among predictor variables. The weakness in regression techniques causes limitations in obtaining effective and accurate results. Over recent years, several machine learning methods have been effectively applied to build accurate predictive models for detecting business failure with remarkable results. These have included artificial neural networks and ensemble methods and there is an ongoing debate about the superiority of machine learning methods over statistical methods [4, 8, 9].

The purpose of this research is to analyse, improve and expand forecasting models used for the prediction of corporate failure in South Africa in order to develop a bankruptcy prediction model that can help predict corporate failure to optimally manage credit risk.

2 COMPARED PREDICTION MODELS

Four different forecasting models were built and compared to determine the best model to use to predict corporate failure for JSE listed non-financial companies. The first model developed was a Logit logistic regression model. This model was used as the benchmark model for prediction accuracy. The predicted benchmark outcomes were then compared with variants of the following three machine learning models:

1. Artificial neural networks;
2. Random forests; and
3. SVM (Support vector machines).

For the machine learning models, supervised learning was chosen, because the desired outcomes are given for the sample dataset and the models were trained to create classifier models by example [10]. The four models are now discussed in further detail:

2.1 Logit logistic regression model

Logistic regression is a type of regression used to fit data on a regression equation to make future predictions. Various logistic regression techniques were investigated including the Univariate analysis model, Multivariate discriminant analysis model, the Probit model and Logit model [9].

The logit model uses the natural logarithm to transform a non-linear relationship between input variables x_i and the probability of event Y happening to a linear relationship [11]. A mathematical model of a set of explanatory variables was used to predict a logit transformation of the response variable Y using the following equation [11]:

$$Y = ln\left(\frac{p}{(1-p)}\right) = \alpha + \sum_{i=1}^{m} b_i x_i \;, \quad (1)$$

where p is the probability of corporate failure, m is the number of independent variables, α the constant or mean value, x_i is the explanatory variable of the feature attribute i and b_i is the coefficient of the independent variable x_i. Applying the antilog operator on Eq. (1) on both sides, one can infer the following equation [11]:

$$p = P.(Y = Y'|X = x)\,\frac{e^{\alpha+ b_1x_1+b_1x_2 \ldots\ldots\ldots b_m x_m}}{1+e^{\alpha+ b_1x_1+b_1x_2 \ldots\ldots\ldots b_m x_m}} = \frac{1}{1+e^{-(\alpha+ b_1x_1+b_1x_2 \ldots\ldots\ldots b_m x_m)}}, \quad (2)$$

where Y' is the outcome of interest for the response variable.

2.2 Artificial neural network (ANN)

An artificial neural network (ANN) consists of simple processing units called the neurons. These neurons are connected, where the strength of a connection between two neurons i and j is referred to as weights [12]. An ANN is defined as a sorted triple $(\boldsymbol{N},\boldsymbol{V},w)$ with two sets $\boldsymbol{N}$, $\boldsymbol{V}$ and a function w, where $\boldsymbol{N}$ is the set of neurons and $\boldsymbol{V}$ a set $\{(i,j)\,|\,i, j \in \mathrm{N}\}$ whose elements are called connections between neuron i and neuron j. The function w: $V \rightarrow \mathbb{R}$ defines the weights, where $w(i,j)$, the weight of the connection between neuron i and neuron$j$, is shortened to $\mathrm{w}_{\mathrm{i,j}}$.

Because the ANN models were trained using supervised learning, a multi-layer feed-forward propagation artificial neural network model was chosen [13]. Each neuron has a propagation function $s(x)$ which is the weighted sum of the inputs and weights associated with the input connections to the neuron. The propogation function is followed by an activation function which determines the output of the neuron.

The propagation function, $\mathrm{f_{pro}}$, is sometimes referred to as the network input function. It can be calculated as follows. Let $I = \{i_1,i_2, \ldots, i_n\ n\}$ be the set of neurons, such that $\forall z \in \{1,\ldots,n\}$: $\exists\ \mathrm{w_{i,zj}}$, then the network input of j, called $\mathrm{net_j}$ with [14]:

$$net_j = f_{pro}\ (o_{i1} . \ldots\ldots .o_{in,} . w_{i1} . \ldots . w_{in,j}) \quad (3)$$

The weighted sum of the above is the multiplication of the output of each neuron i by $\mathrm{w_{i,j}}$ gives the following equation:

$$net_j = \sum_{i=1}^{j} (o_i\ .w_{i,j}) \quad (4)$$

Before the training process begin, the set of weights need to be determined and assigned to the initial input values. Given a set of inputs $x_1,x_2, \ldots, x_m$ a weighted sum of the inputs is formed as follows:

$$C_j = \sum_{i=1}^{m} w_{i,j.} x_i + b_j \;, \quad (5)$$

where $w_{i,j}$is the network weights, x_i is the inputs and b_j the bias term. Here C_j is the activation and has the value of 1 if the neuron is activated and otherwise 0. From the weight activation, the output in the next hidden layer of the neural network process is computed by applying the activation function using the weighted inputs of the previous layer [12].

Different activation functions including linear and non-linear functions have been proposed in the literature. Until recently, the most used activation functions have been the sigmoid and hyperbolic functions [15]. In this study, the default rectified linear unit (ReLU) function from the Python sckit-learn library MLP function, was used [16]. This activation function was chosen because it is a fast learning activation function and has become the most widely used activation function for machine learning applications [17, 18].

There are different optimisation algorithms available to update the network connection weights. Three optimizer algortihms suggested by the Python sckit-learn library MLP function were tested, namely [16]:

- SGD - the Stochastic gradient descent algorithm updates parameters using the gradient of the loss function [19];
- Adam – a more advanced SGD solver algorithm that can automatically adjust the amount that parameters are updated [20]; and
- L-BFGS – the limited-memory Broyden-Fletcher-Goldfarb-Shanno algorithm that belongs to the family of quasi-Newton methods by approximating the Hessian matrix, representing a second-order partial derivative [21].

2.3 Random forest models

Decision tree models are another class of machine learning algorithms used widely in both regression and classification problems. In the decision tree model, data is divide based on a series of questions used to derive a treelike structure [8, 22]. A random forest model consists of an ensemble of decision trees, used to determine the best features to select for prediction [14]. Each decision tree then only contains a random subset of the features of the data and the ensemble votes for the best predicting features to be used, also referred to as "majority voting". It is sometimes also referred to as ensemble modeling.

The goal of each decision tree is to find the optimal way to split the data. There are three common splitting criteria listed in literature: Gini impurity, entropy, and the classification error [14]. The most frequently used criterion is to choose the split that maximizes the information gain by measuring the reduction of uncertainty after each split, or entropy [15]. Formally the entropy of a state s, $E(s)$, is defined as:

$$E(s) = -\sum_{i=1}^{m} p(i) log\ (p(i))\ , \qquad (6)$$

where m is the number of branches and $p(i)$ the probability of each branch i. The information gain, $G(S, A)$ of example set S on attribute A is defined as:

$$G(S, A) = E(s) - \left(\sum \frac{|S_V|}{(|S|)} E(S_V)\right), \qquad (7)$$

where S_V is a subset of S for which attribute A has value v. The attribute value that maximizes the information gain is chosen as the splitting attribute [23].

2.4 Support Vector Machine (SVM) models

Support vector machines (SVM) are supervised learning algorithms with kernel based support vector regression methods. These methods map the data from the original input dimension feature space to a lower dimension feature space (preferably to a linear problem) using a kernel function [24]. Various kernel functions were tested to determine the kernel function that will produce the most accurate prediction. These kernel functions included: the Radial Basis Function (RBF), linear, polynomial and sigmoid kernel functions, described by Müller and Sarah [13] and Raschka et al. [14].

The main aim of the SVM model is to devise a computationally efficient way of learning that effectively separates hyperplanes in a high dimensional feature space [25]. The RBF kernel, also called the Gaussian kernel, is a kernel that is in the form of a Gaussian function [24]. The RBF usually gets superior results than other kernel functions [26].

A RBF kernel which is defined as follows is used [24]:

$$K\ (x_i, x_j) = exp\ (-\gamma \|x_i - x_j\|^2), \qquad (8)$$

with $\gamma > 0$ and $\gamma = \frac{1}{2\sigma^2}$, where σ is a kernel parameter representing the standard deviation between two pairs of features: x_i and x_j .

3 METHODOLOGY

A sample of non-financial companies, listed on the JSE was extracted for the period 1997-2017. The dataset was used to build and compare the different prediction models. The logit logistic regression model, used as the benchmark, was built in MS Excel. In order to decrease the complexity of the model, only the most significant features were used in the regression model. These features were identified using the mean decrease impurity (MDI) index from the random forest technique. The ANN, random forest and SVM machine learning models were built using computational algorithms in Python with the scikit-learn library for machine learning [16]. Different variants of each machine learning model were tested to determine the most effective prediction for each variant.

3.1 Data

The dataset included financial indicators from companies listed on the Johannesburg stock exchange (JSE) between 1997 and 2017 and was sourced from IRESS Premium [27]. The investigation excluded financial institutions, including banks and insurance companies that use a different accounting reporting standard compared with non-financial institutions. In instances where data was missing, it was addressed by imputation, since deleting the record may impact the parameter estimate, as suggested by Smit [28]. The Imputation technique takes the average of the observed values for the variable with data gaps.

A total of 381 companies was used in the study and included 66 companies declared bankrupt during the period under investigation. IRESS Premium confirmed that once a company is delisted, its financial statements are not published again [27]. This means the latest financial statement available for a bankrupt company was the year bankruptcy was declared. The financial indicators in the 12 months before bankruptcy are normally important indicators to predict bankruptcy.

A total of 72 financial indicators, ranging from four categories including profitability, leverage, liquidity and activity, were used as input variables for the study. These indicators are listed in Table 1. Given that companies can enter into financial distress due to economic slowdown, periods when the global economy suffered a recession were excluded to avoid model bias. This included the Asian crises from 1997-1998 and the global financial crisis from 2007-2008.

Table 1: List of financial variables used in the study

Financial Variables	
Accounts Receivable / Turnover	Inflation Adjusted Profit / Share (c)
Adequacy Ratio	Inflation Adjusted Return On Assets %
Assets / Capital Employed	Inflation Adjusted Return On Average Equity %
Attributable Earnings	Inflation Adjusted Return On Average Total Assets %
Book Value / Share (c)	Inflation Adjusted Return On Equity %
Cash Flow (Cata Less Pref. Dividend) / Share	Interest Cover
Cash Flow (Cata) To Current Liabilities	Leverage Factor
Cash Flow (Cata) To Net Earnings After Tax	Long Term Loans % Total Debt
Cash Flow (Cata) To Total Debt	NAV / Share (c)
Cash Flow (Cata) To Turnover (Margin)	Net Profit Margin %
Cash Flow (Ncta) To All Investments	Net Turnover
Cash Flow (Ncta) To Capital Investments	Operating Profit / Employee

Cash Flow (Ncta) To Financial Investments	Operating Profit Margin %
Cash Flow (Ncta) To Return On Total Net Assets	Price / Book Value
Cash Flow / Share (c)	Price / Cash
Cash Flow Dividend Cover	Price / Cash Flow
Cash Flow Interest Cover	Price / Earnings
Cash Flow Less Interest Paid To Income Before Tax	Price / EBIT
Current Ratio	Price / EBITDA
Debt / Assets	Price / Inflation Adjusted Profit
Debt / Equity	Price / NAV
Directors Remuneration % Profit Before Tax	Price / Share (c)
Dividend / Share	Quick Ratio
Dividend / Share (c)	Retention Rate %
Dividend Cover	Return On Assets %
Dividend Yield %	Return On Average Assets %
Earning / Share (c)	Return On Average Equity %
Earnings / Share	Return On Average External Investments %
Earnings Yield %	Return On Capital Employed %
Enterprise Value	Return On Equity %
Enterprise Value / Cash	Return On External Investments %
Enterprise Value / EBIT	Total Assets
Enterprise Value / EBITDA	Total Assets Turnover
Enterprise Value / PAT	Total Debt / Cash Flow
Enterprise Value / Share	Total Shareholders Interest
Growth In Cash From Operating Activities	Turnover

3.2 Sampling and Assumptions

Companies delist from the JSE as a result of financial distress. The delisting could therefore be used to identify bankrupt companies on the JSE. An indicator was added to identify companies forced to delist from the JSE during the period 1997-2014 due to financial performance leading to liquidation.

IRESS was contacted to help identify the year which the company financial distress occurred. IRESS confirmed that once a company is delisted its financial statements stops to be published. This means that the latest financial statement available for a bankrupt company indicate the year of bankruptcy occurrence. This was important because the financial information 12 months before the occurrence will be used to predict bankruptcy in the next 12 months.

A sample of non-bankrupt companies was extracted for the same time period. As it is common with many other studies, the problem of missing data was present for this study. One can neglect the missing data or adjust for it on a case by case basis. The problem of missing data was addressed by imputation since deleting the record may impact the parameter estimate. This technique takes the average of the observed values for the variable with data gaps

After cleaning the records with missing data and nulls, the resulting training and test sample of non-bankrupt companies came to a total of 324, while the actual (out of sample) came to 242. The total number of bankrupt companies came to 66. The combined dataset of bankrupt and non-bankrupt companies for the training and test set came to a total of 366 companies, and 266 for the out of sample test.

3.3 Scope of data

The study only covers South African companies which are listed in the Johannesburg stock exchange (JSE). The investigation excludes financial companies such as banks and insurance because they have a different accounting reporting standard from non-financial companies and might contaminate the results.

3.4 Research strategy applied in building the models

Four different forecasting models were built and compared to determine the best model to use to predict corporate failure for JSE listed non-financial companies. The first model developed was a logit logistic regression model. This model was used as the benchmark model for prediction accuracy. The predicted benchmark outcomes were then compared to variants of the following three machine learning models:

1. ANN (Artificial neural network);
2. Random forests; and
3. SVM (Support vector machines).

For the machine learning models, supervised learning was chosen, because the desired outcomes are given for the sample dataset and the models were trained to create classifier models by example.

3.5 Statistical method used to build the benchmark model

The logistic regression model was built in MS Excel. The first task was to generate the parameters for the regression to be used in the final prediction model. The parameters were initially set at 0.1 across all factors. There were fourteen variables used in the logistic regression, this resulted in a total of sixteen parameters, one intercept coefficient and fourteen coefficients. These parameters are used to calculate the logit values which were optimised through the Maximum Log-Likelihood. The solver function was used to optimise the values.

3.6 Computational methods used to build machine learning models

Python is a recognised programming languages for data science and enjoys a significant number of useful add-on libraries developed by its great community in both academia and industry. For machine learning tasks, this study makes use of the available scikit-learn library. This library is one of the most common and accessible open source machine learning libraries.

The data was split into two sets, namely: the training/development set and test set; 70% of the data training was used to build the model and 30% of the data was used to test the accuracy of the training model. While there are many empirical studies and papers on the best way to split data, but according to Raschka et al. [14], the 70/30 split are the most widely recommended. Cross-validation was used for hyperparameter tuning of the training dataset.

4 RESULTS

The results from the four developed predictor models are given below:

4.1 Logit logistic regression model

Before creating the regression model using MS Excel Solver, the most significant financial indicators (variables) had to be identified. This was determined through the mean decrease impurity (MDI) index used in the random forest technique [29]. The 72 financial indicators from the original dataset were ranked from highest to lowest in significance and only the top fourteen highest scoring indicators were considered. These indicators are listed in Table 2 and were included in the final logit logistic regression model. The model yielded a performance of 80% with 76 misclassified companies on the data set of 381 observations.

Table 2: The top fourteen financial indicators used in the benchmark logistic regression model

Variable	MDI-index
Enterprise Value	0.101352081
Book Value / Share (c)	0.048777954
Cash Flow (Ncta) To All Investments	0.037518617
Price / Share (c)	0.037408592
Cash Flow / Share (c)	0.036042086
NAV / Share (c)	0.030834667
Inflation Adjusted Profit / Share (c)	0.030655472
Enterprise Value / Share	0.029656875
Price / Earnings	0.02333221
Retention Rate %	0.02028856
Earnings / Share (c)	0.019535247
Enterprise Value / PAT	0.018829024
Total Assets Turnover	0.017554885
Debt / Assets	0.017524244

4.2 Artificial neural network models

The ANN models were built using two layers and 150 neurons per layer. Three different optimizer solver algorithms, described in section 2.2, provided by the Python scikit-learn library were tested [16]. Table 3 lists the results for the three model variants for the training vs test sample data and the validation accuracy using the ReLU activation function. From the table, it is evident the L-BFGS optimizer algorithm calculated the best accuracy predictor model.

Table 3: Classification results of the ANN models using different optimizer solver algorithms-Training vs Testing Sample

Solver	Total Count	Training count	Validation accuracy %	Test count	Accuracy %	Misclassified samples
Adam	381	266	91%	115	83%	20
L-BFGS	381	266	91%	115	86%	16
SGD	381	266	91%	115	15%	98

4.3 The Random forest models

The percentages of the training vs testing split were varied during testing of the random forest model. The study trained a decision tree random forest classifier with six hyper-parameters, including the number of trees in the forest, data set split, the Gini function to measure the quality of a split (i.e. Gini impurity and “entropy” for the information gain), the maximum depth of the tree, minimum number of samples required to split an internal node and the minimum number of samples required to be at a leaf node, described by Goletsis et al. [8].

The results for the best combination of the six hyper-parameters for three of the percentage training vs testing split are listed in Table 4. The results confirmed the suggested 70/30 split from Raschka et al. [14] is more effective, because more data is used for training while avoiding overfitting.

Table 4: Classification results of random forest model using different data splits

Split Training	Split Test	Total Count	Training count	Test count	Accuracy%	Misclassified samples
70%	30%	381	266	115	89%	13
50%	50%	381	191	191	83%	32
20%	80%	381	76	305	75%	36

4.4 Support vector models

Four different kernel based functions, described in section 2.4, were tested. The results are given in Table 5. The RBF kernel based function provided an 87% accuracy rate and outperformed the other kernel based functions.

Table 5: Classification results of support vector machine model under different kernel types

Kernel function	Split Training	Split Test	Total Count	Training count	Test count	Accuracy%	Misclassified samples
RBF	70%	30%	381	266	115	87%	15
Linear	70%	30%	381	266	115	77%	26
Polynomial	70%	30%	381	266	115	83%	20
Sigmoid	70%	30%	381	266	115	77%	26

5 CONCLUSION

When considering machine learning techniques, it is clear machine learning methods outperform traditional statistical models like the benchmark logit logistic regression model. The machine learning models that were able to achieve the most accuracy was the Random forest model that provided an 89% prediction accuracy, followed by the RBF kernel based SVM model at 87% prediction accuracy. The Artificial neural network model is the least performing model with the optimal model being the L-BFGS optimizer algorithm at 86%. This is in line with the findings by Bjorn *et al*. [15] and Zi and Wang [30].

Not all machine learning models performed better than the benchmark logistic regression model. Therefore, it is clear that datasets need to be trained with multiple machine learning models and parameters to determine the best model variant to use for each specific one. The Random forest model had the most accurate prediction percentage and outperformed all the other models. This could be due to the random subset feature inclusion into each decision tree and the majority vote of the ensemble, compared to other models only relying on one set of calculations. Therefore, the other models explore a smaller possibility of feature combinations to determine the final prediction model.

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GENERIC SUSTAINABILITY DYNAMICS CONCEPTUAL MODELLING THROUGH CAUSAL LOOP DIAGRAMMING

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ABSTRACT

This paper addresses the concept of sustainability and the factors that are at play in a dynamic setting. This paper aimed to research sustainability dynamics through literature review and the extraction of insights that could be used to develop a conceptual model through causal loop diagramming. The paper reviewed the elusive concept of sustainability and further explored process-driven and market-driven motives for implementing sustainability initiatives in organizations. The paper revealed the intricacies of dynamics at play in the sustainability arena and articulated these intricacies through a causal loop diagram and further elaborated on the various balancing and reinforcing loops. The paper proposes a double-edged sword of fusing a strategic approach in the form of market-driven strategies and a tactical approach in the form of process-driven strategies, the inexhaustible circle that characterizes the combination of the two approaches will yield a sustainable future for organizations.

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1 INTRODUCTION AND BACKGROUND

Sustainability has become a leading topic in the agenda of governments, organizations, and society at large. The concept of sustainable development received traction when Gro **Harlem** Brundtland issued in 1987 her much anticipated report titled "Our Common Future" which was commissioned by the World Commission on Environment and Development as mandated by the United Nations General Assembly. Our Common Future was a clarion call for action to address developmental and environmental crises faced by humanity and was aimed at creating a just, equitable society environmentally responsible society.

Our Common Future articulated the proliferation of human economic activity driven by the industrial age which has increased environmental pollution to alarming levels, it further articulated the interlocking crises that are staring humanity and building up into a potential catastrophe if urgent action is not taken. This interlocking flux of crises is underpinned by environmental, developmental, and energy crises.

This work has evolved over the years since the release of the "Brundtland" report and more recently has culminated in the seventeen sustainable development goals commonly known as the SDGs. These SDGs are (1) No poverty (2) Zero hunger (3) Good health and wellbeing (4) Quality education (5) Gender equality (6) Clean water and sanitation (7) Affordable and clean energy (8) Decent work & economic growth (9) Industry, innovation and infrastructure (10) Reduced inequalities (11) Sustainable cities and communities (12) Responsible consumption and production (13) Climate action (14) Life below water (15) Life on land (16) Peace, justice and strong institutions and lastly (17) Partnerships for the goals.

Governments across the globe had set their national targets to achieve these SDGs and organizations around the world are not immune to sustainability pressures and a requirement to act and reduce its impact on the environment but also take part in sustainable development.

Several works and writings have been produced on sustainability and sustainable development over the years by various authors from academia as well as the private and public sectors. This paper is an attempt to articulate the insights organizations can explore and act on in their path towards a sustainable future.

The research questions that drive this research paper are:

(a) What is the elusive concept of sustainability?
(b) What are the sustainability dynamics that are prevalent in organizations?
(c) Can a conceptual model depicting insights from literature be developed illustrating sustainability dynamics?

2 LITERATURE REVIEW

2.1 Theory of sustainability

Goodland [1] argues that when the human economic subsystem was small, the regenerative and assimilative capacities of the environment appeared infinite. However, we are now learning that environmental sources and sinks are finite. While these capacities were originally very large, the scale of the human economy has exceeded them and as a result source and sink, capacities have now become limited [1]. As noted, sustainability is recognized as one of the most important challenges of our time [2]; in recent years, the natural environment has become a key strategic issue for stakeholders, and today many companies have accepted their responsibility to not harm the environment [3]. However, the first reality confronting businesses that are serious about sustainability is ambiguity, starting with the question: what do we mean by sustainability? The ambiguity inherent in sustainability has deep cultural roots [4].

Jenkins [5] postulates that theories of sustainability attempt to prioritize and integrate social responses to environmental and cultural problems. He argues that while the economic model looks to sustain natural and financial capital, the ecological model looks to biological diversity and ecological integrity and the political model looks to social systems that realize human dignity. Tibbs [6] suggests that the idea of sustainability is inspired by the widespread belief that the current pattern of human activity cannot be sustained for very much longer. At its simplest, sustainability is a rallying cry for hope. A major challenge for organizations is how to balance and incorporate competing interests, values, and constituencies [7]. Perhaps surprisingly, many improvements in environmental performance can pay for themselves and even generate profits [8] while evidence can be marshaled to support the view that reducing emissions increases efficiency and saves money, giving firms a cost advantage. This understanding is further reinforced by the view that sustainability should be driven through eco-innovation which entails a coordinated set of modifications or novel solutions to products (goods/services), processes, market approach, and organizational structure which leads to a company's enhanced performance [9].

Tibbs [6] further postulates that there could be a future design of society in which environmental degradation and extremes of social inequity are avoided continuously. As an agenda, it implicitly calls for a sense of responsibility and action, sincerely aimed at improving or changing our current way of living and averting what many feel is a looming social, ecological, and economic crisis.

Heinberg [10] suggests that the term "sustainability" gained widespread usage after 1987 when the Brundtland Report from the United Nations' World Commission on Environment and Development defined sustainable development as development that "meets the needs of the present generation without compromising the ability of future generations to meet their own needs." This definition of sustainability has proved extremely influential and is still widely used; nevertheless, it has been criticized for its failure to explicitly note the unsustainability of the use of non-renewable resources and for its general disregard of the problem of population growth. This view is supported by Tibbs [9] who asserts that the internationally recognized definition of sustainability is the use of resources to meet the needs of the present, without compromising the ability of future generations to meet their own needs.

Hart [11] argues that achieving sustainability will require stabilizing or reducing the environmental burden, and to effectively manage environmental issues requires finding a balance between economic success and ecological protection [12]. Mainstream thinking concerning sustainability evolved into three dimensions: environmental, social, and economic sustainability [9]. Adams [13] proposes that this view is supported by the program 2005-8 of the International Union for Conservation for Nature and Natural Resources which was adopted in 2005, which used the interlocking circles model to demonstrate that the three objectives need to be better integrated with action to redress the balance between dimensions of sustainability. Corporate Social Responsibility or CSR is a widely used term and various other terminologies have been used by practitioners to describe largely the same phenomenon. Terms include corporate citizenship, sustainable development, sustainability, and corporate responsibility [14].

2.2 Motives of firms for implementing sustainability strategies.

Lubin and Esty [15] argue that sustainability is an emerging megatrend, and thus its course is to some extent predictable. Understanding how firms succeeded in prior megatrends can help executives craft strategies and systems they will need to gain an advantage in this one because megatrends force fundamental and persistent shifts in how firms compete; such transformations arise from technological innovation or from new ways of doing business.

Baskin [14] postulates that scarcity of resources (such as energy and water), combined with regulations that bring in the 'polluter pays principle, and growing public awareness of sustainability problems, have placed pressure on companies to manage such. There are also cost-saving possibilities for companies where input use can be reduced, or other eco-efficiency gains achieved, and opportunities to create new products and services (such as carbon trading or new energy technologies). Hockerts [16] suggests that stakeholder concerns usually follow a life cycle of sorts; they start as weak signals voiced by arbitrary groups. Over time, the concerns gather speed as more powerful stakeholder groups pick up the issue. Finally, mass media and politics become aware of the topic as the issue matures.

Stead and Stead [3] contend that eco-enterprise strategy represents the idea that the Earth is the "trump-card" stakeholder in an organization's strategic thinking. This, they argue reflects the moral view of Aldo Leopold's (1949) "land ethic". Leopold argued that a land ethic brings the Earth's entire biotic pyramid into the sphere of human ethical consideration. Only when humans accept that the "land" has ethical rights will nature be elevated from mere property with economic value to an entity with aesthetic value, one to which the human community has an obligation.

Hart [11] contends that major sustainability challenges are motivating factors to implement sustainability strategies, where developed economies are faced with pollution problems (greenhouse gases, use of toxic materials, contaminated sites), depletion issues (scarcity of materials, insufficient reuse, and recycling) and poverty-related issues (urban and minority unemployment). Emerging economies' pollution-related challenges are high (industrial emissions, contaminated water, and lack of sewage treatment), depletion issues (overexploitation of non-renewable resources, over-use of water for irrigation), and poverty issues (migration to cities, lack of skilled workers, income inequality). Survivalist economies face pollution challenges which are characterized by dung and wood burning, lack of sanitation, eco-system destruction due to development; depletion issues relate to deforestation, overgrazing, and soil loss while poverty remains a huge challenge due to population growth, the low status of women and dislocation.

Hart [11] proposes that for companies, the initial sustainability strategic step to take is to make a shift from pollution control to pollution prevention. He contends that pollution control means cleaning up the waste after it has been created. Pollution prevention on the other side focuses on minimizing or eliminating waste before it is even created. He argues that much like total quality management, pollution prevention strategies depend on continuous improvement efforts to reduce waste and energy use. This transformation is driven by a compelling logic, that pollution prevention pays.

Hart [11] further proposes that companies adopt a product stewardship strategy that focuses on minimizing not only pollution from manufacturing but also all environmental impacts associated with the full life cycle of a product. As companies in Stage 1 move closer to zero emissions, reducing the use of materials and production of waste requires fundamental changes in underlying products and process designs. He argues that Design for Environment (DFE), a tool for creating products that are easier to recover, reuse, or recycle, is becoming increasingly important. With DFE, all the effects that a product could have on the environment are examined during its design phase. Cradle to grave analysis begins and ends outside the boundaries of a company's operations-it includes a full assessment of all inputs to the product and examines how customers use and dispose of it.

Hart [11] thirdly proposes that companies with their eye on the future can begin to plan for and invest in tomorrow's technologies. The simple fact is that existing technology bases in many industries are not environmentally sustainable. He gives an example of the chemical industry, which, while having made substantial headway over the past decade in pollution prevention and product stewardship, is still limited by its dependence on the chlorine molecule (many organo-chlorides are toxic or persistent, or bio-accumulative). As long as the industry relies on its historical competencies in chlorine chemistry, it will have trouble making major progress towards sustainability. Pollution prevention, product stewardship, and clean technology all move a company towards sustainability, but without a framework to give direction to those activities, their impact will dissipate. A vision of sustainability for an industry or a company is like a roadmap to the future, showing the way products and services must evolve and what new competencies will be needed to get there.

Braungart et al [17] pose a pertinent question "what would industrial systems that conform to natural principles look like?" Firstly, it is argued: industrial systems would be circular rather than linear, with significant reductions in all waste flows. This implies three specific waste reduction strategies: (1) resource productivity which reduces waste from production through eco-efficient production technologies and the design of production processes in which waste from one process becomes the nutrients for another process (2) Clean products reduce waste from goods in use through non-polluting product technologies (3) Remanufacturing and recycling and design of biodegradable products reduces waste from discard. Sustainability is a concept that embeds a healthy economic system into a healthy social system and ecosystem and can provide a framework for such strategies. Stead and Stead [3] suggests that by integrating sustainability strategies, firms can synergistically integrate long-run profitability with their efforts to protect the ecosystem, providing them with opportunities to achieve the traditional competitive advantages of cost-leadership and market differentiation via environmental responsibility.

Stead and Stead [3] further argue that two basic types of sustainability strategies are implied by these competitive advantages.

(a) The first type is market-driven sustainability strategies designed to provide firms with competitive advantages by environmentally differentiating their products and/or market from their competitors. Strategies include redesigning product packaging, advertising the environmental benefits of products, redesigning products to be more environmentally sensitive, developing new environmentally sensitive products, entering new environmentally sensitive markets, and selling or donating scrap once considered waste.

(b) The second type consists of process-driven sustainability strategies which are designed to provide firms with competitive advantages by reducing costs via the improvement of the environmental efficiencies of their production processes. Strategies include redesigning pollution control systems, waste disposal systems, and air and water treatment systems; using recycled resources derived from external sources, from scrap materials, or defective end products in production processes; redesigning production processes to be less polluting and more energy and resource-efficient; and using renewable energy sources in production processes.

Stead and Stead [3] in their final analysis postulate that various economic and green-stakeholder motives drive the decision to implement either process-driven sustainability strategies or market-driven sustainability strategies. They proposed the following propositions to capture these potential differences in motives:

- Proposition 1: Market-driven sustainability strategies, in comparison to process-driven strategies, are more likely to be initiated to enhance revenues.
- Proposition 2: Process-driven strategies, in comparison to market-driven strategies, are more likely to be initiated to reduce costs.
- Proposition 3: Market-driven sustainability strategies, in comparison to process-driven sustainability strategies, are more likely to be initiated due to green consumer pressures.
- Proposition 4: Process-driven strategies, in comparison to market-driven strategies, are more likely to be initiated due to legal/regulatory pressures.
- Proposition 5: Output-end ecological motives, in comparison to input-end ecological motives, have a greater influence on decisions to implement sustainability strategies.
- Proposition 6: Process-driven strategies, in comparison to market-driven strategies, are likely to be prominent in industries that produce and/or distribute commodities and or/ intermediate goods.
- Proposition 7: Market-driven strategies, in comparison to process-driven strategies, are likely to be more prominent in industries that produce and/or distribute consumer goods.
- Proposition 8: Market-driven sustainability strategies, in comparison to process-driven sustainability strategies, are more likely to positively influence firms' revenues.
- Proposition 9: Market-driven sustainability strategies, in comparison to process-driven sustainability strategies, are more likely to require lower initial capital investments.
- Proposition 10: Initial capital investments in market-driven sustainability strategies, in comparison to process-driven sustainability strategies, can be recouped in shorter periods.

These propositions offer insight into why certain organizations act the way they do and why they adopted specific sustainability strategies.

3 RESEARCH METHODOLOGY

Yin [18] argues that every research has a design, whether implicit or explicit. Klopper [19] suggests that research starts with a problem and is a precondition of any study; development of a research design follows logically from the research problem, implying that the research problem directs the choice of research design; a research design is a plan or blueprint of how research is intended to be conducted [20], it is the plan or blueprint that the researcher will use in conducting the research [19]. Lastly, Rowley [21] postulates that research design is the logic that links the data to be collected and the conclusions to be drawn to the initial questions of a study; and ensures coherence of the research.

Therefore, the research paper adopted a pragmatic philosophical worldview that relies on the research questions as the guiding ignot of the study, the research further adopted an inductive approach to build theory. The inductive approach in its nature is supported by a qualitative methodological choice which took the character of an exploratory study as the phenomenon under study is intricate and requires delving deep to understanding the dynamics at play. The exploratory study was conducted through the adoption of a review of archival documents as a research strategy and the utilization of a causal loop diagram to analyze the intricacies at play in a dynamic setting.

3 FINDINGS AND DISCUSSION

3.1 Sustainability concept

The literature review has undoubtedly pointed to how widespread sustainability definitions and practices are. Questions arise, such as “if one response to environmental and societal concerns, does that make the company sustainable?” This array of questions concerning what exactly sustainability stems from the lack of standardization; hence each company or organization has its point of view on what it means for it to be a sustainable organization.

Analysts agree that one reason for widespread acceptance of the idea of sustainable development and sustainability is precisely this looseness. Historian Thomas Berry said "We are in trouble just now because we do not have a good story"; we are in between stories. The old story, the account of how the world came to be and how we fit into it…sustained us for a long period [13]. It shaped our emotional attitudes, provided us with life purposes and energized our actions, consecrated our suffering, and integrated our knowledge. We awoke in the morning and knew where we were, we could answer the questions of our children. In a sense, sustainability requires letting go of the story of the supremacy of the human in nature, the story that the natural world exists as mere “resources” to serve human “progress” [4].

Senge and Carstedt [4] contends that most of us grew up with this story, it is still shared by a vast majority of modern society, and it is not easy to let it go, especially when we are uncertain about what the new story would be. Businesses seeking sustainability can easily feel like trapeze artists suspended in the air. They have to let go of a secure worldview without knowing what they can hang on to.

The latest science suggests that the majority of the planet's ecosystems and species cannot adapt quickly enough to the rate of warming predicted for the coming few decades under business-as-usual conditions (unchanged emission's growth). In other words, there is the real risk that the ecosystems that generate the oxygen we breathe and support the biodiversity that binds the intricate web of life on Earth may start to unravel and disappear: essentially, a geologically abrupt and widespread change in the biosphere of the planet, leading to the extinction of as many as half of the species on the planet today. The specter of abrupt and dangerous climate change is now examined as a matter of urgency. Hardisty [22] argues that the problem is that scientists have few ways of knowing how quickly this could happen or how startling the changes could be. The downside risk of climate change is almost certainly too frightening to allow.

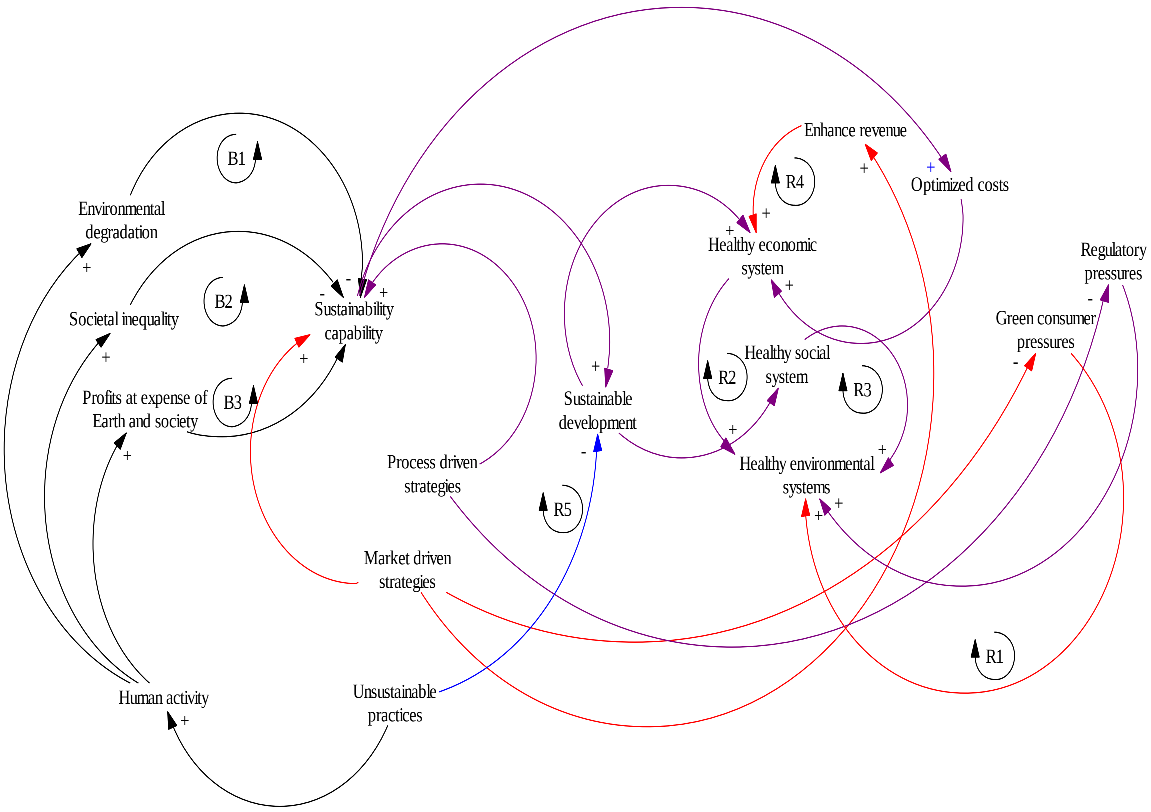
3.2 Sustainable development dynamics.

The literature points to a flux of dynamics and intricacies that are at play in the sustainability context in organizations. The literature points to the factors that drive or impede sustainability in its wholeness, wholeness in the context of healthy economic systems that are socially and ecologically (environmentally) responsible. These factors were extracted from the literature review and are presented in Table 1.

Table 1: Pertinent factors extracted from literature

Factors	Factors (Continues)
Market-driven strategies	Green consumers pressure
Unsustainable practices	sustainability development
Environmental degradation	Sustainability capability
Societal inequality	Human activity
Profits at expense of Earth	Sustainable development
Process-driven strategies	Healthy environmental system
Environmental degradation	Enhanced revenue
optimized costs	Regulatory pressures
Healthy economic system	Healthy social system

The factors that had been extracted from literature and tabled in Table 1 were further synthesized through VINSIM PLE to develop a sustainability dynamics conceptual model through a causal loop diagram as depicted in Figure 1.



B = Balancing (opposite direction) R = Reinforcing (Same direction)

Figure 1: Sustainability intricacies and dynamics

The causal loop diagram as depicted in Figure 1 provides deep insights on feedback behavior that emanates from the interaction of these factors in a dynamic setting. Three balancing loops (which are anti-clockwise) and five reinforcing loops (which are clockwise) emerged from the dynamic interaction of the factors or variables. B1 can be described as an increase in unsustainable practices increase human activity which increases environmental degradation which reduces the sustainability capability of the system. B2 can be articulated as unsustainable practices that increase human activity which increases societal inequality which reduces the sustainability capability of the system; and lastly, B3 can be described as unsustainable practices that increase human activity which increases profits at the expense of planet Earth and society which reduces sustainability capability of the system. B4 can best be explained as an opposite relationship between the two variables, an increase in unsustainable practices will reduce sustainable development goals.

R1 can be described as an increase in market-driven strategies that reduce green consumer pressures and ultimately leads to an increase in healthy environmental systems. R2 on the other hand could be ascribed to an increase in market-driven strategies which leads to an increase in enhanced revenue and leads to an increase in healthy economic systems.

R3 can best be articulated as an increase in sustainability capability triggers an increase in sustainable development which leads to an increase in a healthy economic system which further leads to an increase in a healthy environmental system. R4 represents an increase in sustainability capability triggers an increase in sustainable development which leads to an increase in a healthy social system which further triggers an increase in a healthy environmental system. R5 can best be articulated as an increase in process-driven strategies increases sustainability capability leading to an increase in cost optimization which results in an increase in healthy economic system triggering an increase in healthy environmental system. R6 can be explained as an increase in process-driven strategies result in a decrease in regulatory pressures which triggers an increase in a healthy environmental system. And lastly, R7 can be explained as a directly proportional relationship between the two variables, an increase in market-driven strategies leads to an increase in sustainability capability.

4 RECOMMENDATIONS AND CONCLUSION

Globally, governments are engrossed with the concept of sustainability with the sole objective of bringing a balance and synergy between societal, economic, and environmental considerations which are articulated as seventeen Sustainable Development Goals. These SDGs are important to ensure the prosperity of the planet and society while ensuring a sustainable economic system that protects the planet and empowers society.

This research outlines literature that provides insights on how organizations may transform and be on a sustainable path. The literature was presented and synthesized from which eighteen insights emerged; the eighteen insights were used to develop a conceptual model through a causal loop diagram which was presented and discussed at length.

Organizations should implement market-driven strategies to enhance revenue, manage green consumer pressures by becoming customer-centric and developing "green" products and services. Additionally, market-driven strategies increase the sustainability capability of organizations. Organizations should at the same time implement process-driven strategies to improve their sustainability capability, optimize cost, and reduce regulatory pressures. Both market-driven and process-driven strategies lead to a healthy economic system, healthy social system, and healthy environmental system. The implementation of both approaches provides organizations with many options which provides organizations with a competitive advantage and edge, it is the organization that possesses an arsenal of options that are ultimately successful and sustainable.

Proposed future research is to implement the conceptual model in an organization with the view to verify and validate the model with quantitative methods through stocks and flows and develop a system dynamic model to model the behavior of the variables over time. This will allow decision-makers and policymakers to anticipate the future and prepare for it accordingly based on scenarios presented by the system dynamics model.

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WORK-LIFE BALANCE: AN EXTRAORDINARY FEAT IN DIFFICULT TIMES

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ABSTRACT

The work environment is becoming increasingly challenging regularly. Employees are expected to be super-efficient, to do more with fewer resources, and work late hours. Employees often end up performing multiple roles, extracting every productive minute out of a workday. These same employees are expected to have normal fulfilling personal lives, be active parents, have engaged social lives, follow a healthy exercise routine and be less stressed. While all these are very possible, it is not realistic. Organizational leadership is required to recognize the risk of employees moving roles, becoming less productive or possibly disruptive to production, and experience work-related burnout. The study aims to identify the benefits of work-life balance to employers and employees through quantitative descriptive analysis in an organization.

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1 INTRODUCTION AND BACKGROUND

Metha and Kundnani [1] argue that the complexity of work is constantly changing in the evolving world. Prior studies have noted the importance of Work-Life Balance (WLB) issues play on the minds of the working class. This is unavoidable but maintaining a healthy balance proved to be challenging. Babin [2] proposes that the concept of WLB implies creating and maintaining supportive and healthy work environments that enable employees to improve productivity and strengthen employee loyalty by achieving a balance between work and personal responsibilities.

Babin [2] proposed that work-life conflict is a complex problem that impacts employees, employers, and their communities. Consistent with the literature, competing responsibilities like family, domestic responsibilities, partners and elderly parent care induces high levels of stress on individuals, their families, and the communities in which they reside.

2 LITERATURE REVIEW

Gragnano et al [3] maintained that work-life balance is an important aspect of a healthy work environment. Maintaining a work-life balance helps reduce stress, and assists in preventing burnout in the workplace. Chronic stress is one of the most common health is in the workplace, it could lead to stress-induced maladies such as hypertension, ulcers, chronic aches and pains; and cardio-vascular problems. Chronic stress could also negatively impact mental health as it is linked to the risk of depression, anxiety, and insomnia. Additionally, too much stress over a long period would lead to workplace burnout. Employees working extended hours are at a high risk of burnout which is manifested by fatigue, mood swings, irritability, and a decrease in work performance. The challenge for employers is the high cost of psychological and physical healthcare costs incurred by employees.

Jachens and Houdmont [4] suggest that antagonistic psychosocial employment conditions, such as job strain and effort promote imbalance. Additionally, poor WLB is another factor that has a work-related impact on employee health and wellbeing. To streamline WLB, [5] advised that as employees age, their responsibilities increase and as a result requires additional performance in the workplace and at their homes. This escalates signs of poor work-life balance manifesting with issues such as job dissatisfaction, absenteeism, and stress.

Ross et al [6] list the following signs that indicate an unhealthy WLB:

• Exhaustion: Employees that are frequently working long hours without clear boundaries between work and home life, and triggering physical and mental exhaustion. This manifests in the inability to rationalize, poor eye-hand coordination, reduction in productivity, increased mistakes which is the product of unsound minds, slower reflexes, which adds a risk of injury, liability, and potential reputational damage.

- Absence: The inability to maintain work-life boundaries leads to potentially "missing out" on important family events like unique moments, anniversaries, or birthdays. This absence can lead to irreparable damage to a loved one as the glue that holds the family together disintegrates.
- No friendships: In maintaining focus on careers, time for nurturing and growing friendships become non-existent. Solid friendships are essential elements of a good support system, providing positive support and preventing isolation. Support systems are key to maintaining WLB and essential for providing personal satisfaction in life. Friendships must be nurtured to prevent them from fading or losing meaning.
- Workload increase: Spending long hours at work is directly proportional to more workload and more added responsibilities. It seems like additional responsibilities are commensurate with potential career advancement with more money, on the contrary; the downside to more added responsibilities and long hours at work is the negative impact on other aspects of one's life, which could easily result in an endless cycle of work, concerns, and pressures.

Ross et al [6] warned that an unhealthy WLB results in high amounts of stress, leading to:

- cardiovascular disease
- erectile dysfunction
- weakened immune system
- migraines and headaches
- poor coping skills
- insecurities
- low self-esteem
- feeling a lack of control
- mental and physical fatigue

Abioro et al [7] discuss different WLB strategies that are friendly and can be applied at different organizations:

- Flexitime: This process allows employees to negotiate the working hours. Research has demonstrated that introducing flexible work options leads to a reduction in employee absenteeism thereby increasing the level of job satisfaction.
- Telecommuting or Telework: The process allows an employee to work from home, this intervention results in employees being able to structure family and personal life around work, thus reducing work-related expenses and work in less disruptive with limited stress impact.
- Compressed workweeks: This process allows employees to work longer shifts (or more hours per shift) to reduce the number of working days in a week.
- Part-time work: Allows employees the flexibility to study and work part-time, typically students. This arrangement could assist people to gain sufficient work experience
- Job Sharing: Allows two or more employees to engage in full-time work, sharing the work responsibilities amongst themselves.

Abioro et al [7] advised that WLB practices are well thought out strategies that are aimed at reducing work-life conflict and supporting employees to maintain a healthy WLB.

3 RESEARCH METHODOLOGY

The study was conducted using a quantitative approach as it is a formal, objective, systematic process to describe and test the awareness and understanding of the presented opportunities. Kothari [8]and Cresswell [9] posits that quantitative research gathered data that is ranked in order or measured in a numerical format provide useful insights into a phenomenon. The target population consisted of 90 employees at the organization in Gauteng. A sample of 70 employees was randomly selected that met the sample criteria. Respondents were asked to respond to 19 closed-ended questions anonymously, using a five-point Likert Scale of Strongly Agree, Agree, Neutral, Disagree, and Strongly Disagree. A total of 55 persons participated in the study. The questions were aligned to the objectives of the study that sought to identify the existing WLB at the organization, the impact WLB had on employee performance. Analysis of data was conducted to make recommendations to management.

4 RESULTS AND DISCUSSION

The questionnaire results are discussed per statement in this section of the paper, including tabulating and graphically depicting the frequency of the Likert scale responses.

Statement 1: I am aware that a work-life balance policy exists at work.

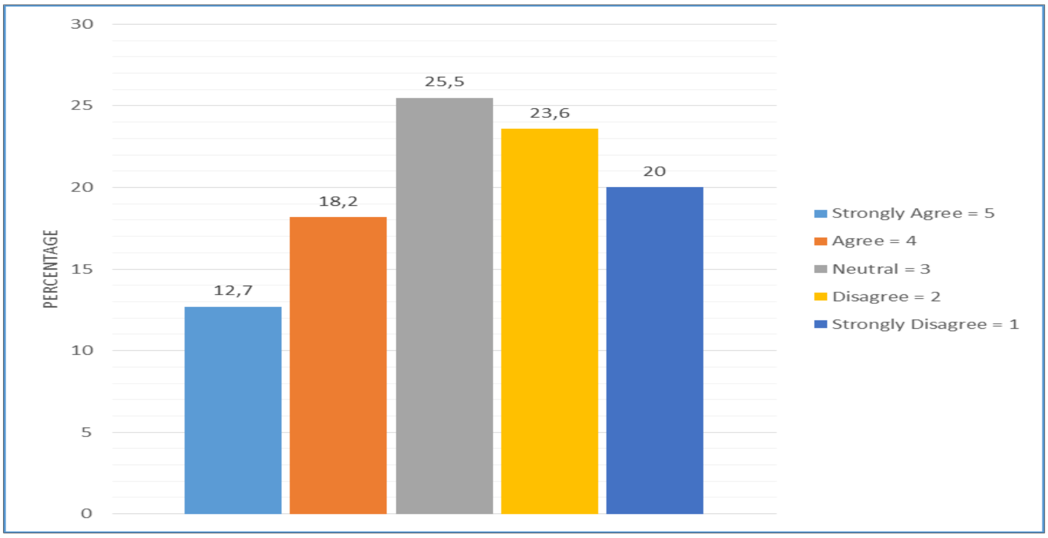

Figure 1: Work Life policy exists (n = 55)

Figure 1 presents the results for statement 1 and shows that 12.7% (n=7) of respondents strongly agree, 18.2% (n=10) agree, 25.5% (n=14) are neutral, 23.6% (n=13) disagree and 20.0% (n=11) strongly disagree with this statement. All respondents completed this question indicating a total of 55 responses. 43.8% of the respondents disagree and strongly disagree that a work-life policy existed at the organization, which may explain why 25.5% of the respondents selected Neutral, as they were not sure of the existence of the policy.

Statement 2: I am happy with the execution of the work-life policy.

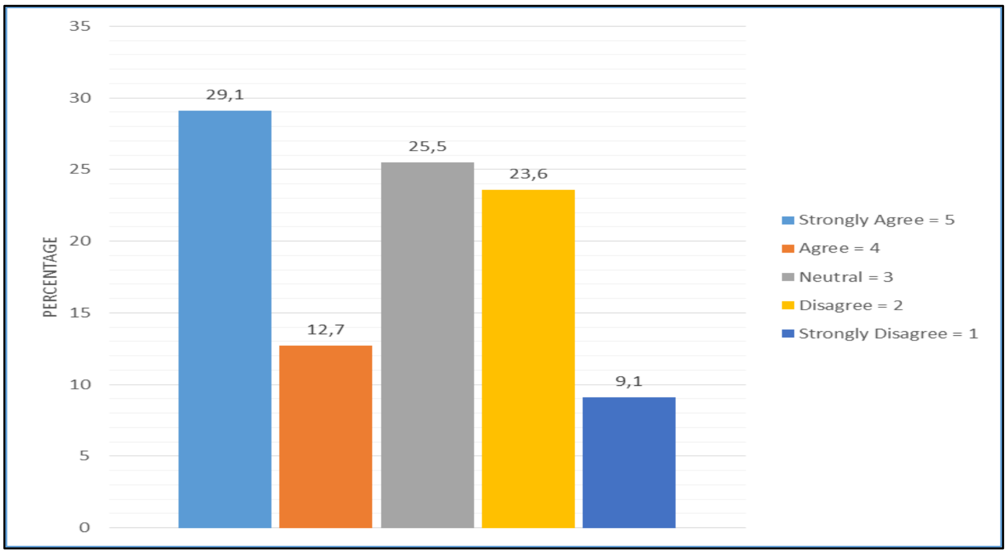

Figure 2: Execution of the WLB policy (n=55)

Figure 2 shows that 29.1% (n=16) of respondents strongly agree, 12.7% (n=7) agree, 25.5% (n=14) are neutral, 23.6% (n=13) disagree and 9.1% (n=5) strongly disagree with this statement. All respondents completed this question indicating a total of 55 responses. 32.7% of the respondents, disagree and strongly disagree that they were happy with the execution of the work-life policy at the organization. The number of respondents that selected neutral was 25.5%, implying that 41.8%

were happy with the execution of the WLB policy. This shows that the greater same was not pleased with the implementation of the policy.

Statement 3: I mostly do what I do because so many people depend on me for support.

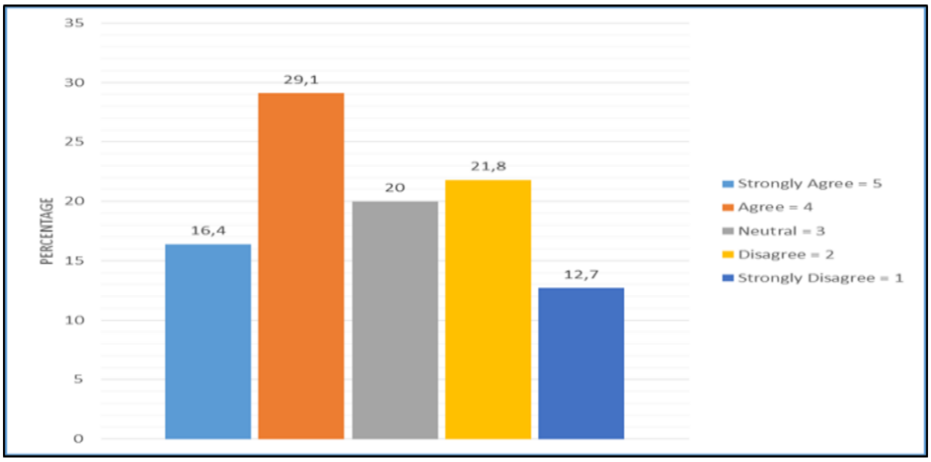

Figure 3: Comfortable doing what they do (n = 55)

Figure 3 presents the results for statement 4 and shows that 16.4% (n=9) of respondents strongly agree, 29.1% (n=16) agree, 20.0% (n=11) are neutral, 21.8% (n=12) disagree and 12.7% (n=7) strongly disagree with this statement. All respondents completed this question indicating a total of 55 responses. 45.5% of the respondents agree and strongly agree that they do what they do because a larger team depended on them for support at the organization. The number of respondents that selected neutral was 20%, implying that 34.5% of the respondents felt that they were not comfortable doing what they did.

Statement 4: I am constantly being pushed to deliver.

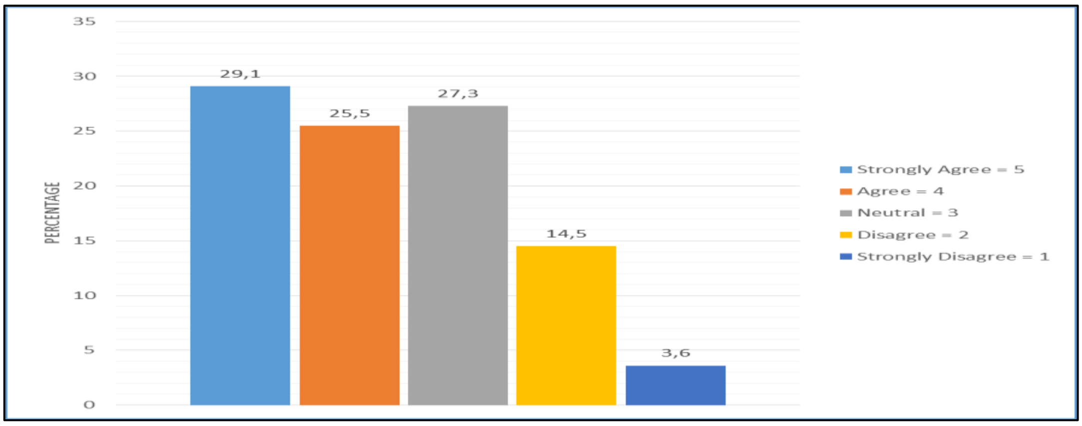

Figure 4: Constantly being pushed to deliver (n = 55)

Figure 4 presents the results for statement 5 and shows that 29.1% (n=16) of respondents strongly agree, 25.5% (n=14) agree, 27.3% (n=15) are neutral, 14.5% (n=8) disagree and 3.6% (n=2) strongly disagree with this statement. All respondents completed this question indicating a total of 55 responses. An overwhelming 54.6% of the respondents agree and strongly agree that they were constantly being pushed to deliver, while 27.3% chose to be neutral and 18.2% of respondents disagree and strongly disagree. As indicated in this question, the major component of the sample seems to be pushed to deliver.

Statement 5: No matter what I do, it seems that often every minute of every day is always scheduled for something.

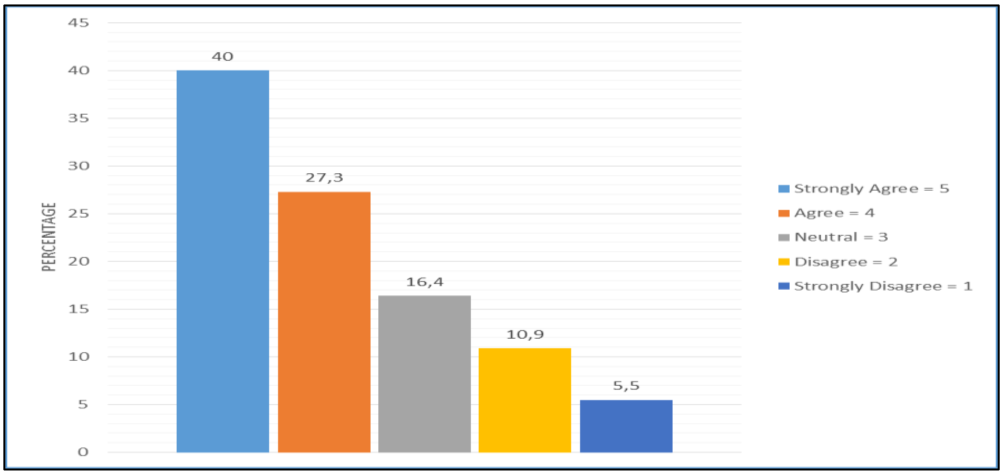

Figure 5: Fully scheduled days (n = 55)

Figure 5 shows that 40% (n=22) of respondents strongly agree, 27.3% (n=15) agree, 16.4% (n=9) are neutral, 10.9% (n=6) disagree and 5.5% (n=3) strongly disagree with this statement. All respondents completed this question indicating a total of 55 responses. An overwhelming 67.3% of the respondents agree and strongly agree that the workdays were fully scheduled with little or no time for much else. 16.4% chose to be neutral and 16.4% of respondents disagree and strongly disagree. This may be dependant on the type of work being performed and shows that there may be uneven balance in the workload of people.

Statement 6: I find myself spending more and more time on work-related projects.

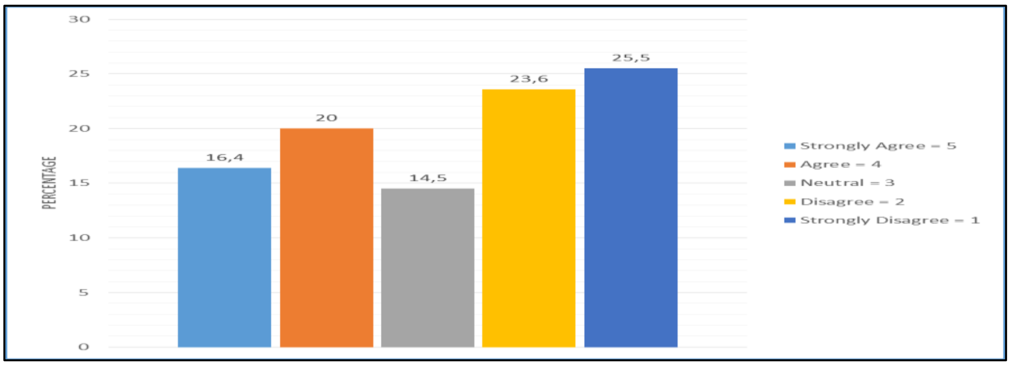

Figure 6: Spending more time on work projects (n = 55)

Figure 6 presents the results and shows that 16.4% (n=9) of respondents strongly agree, 20% (n=11) agree, 14.5% (n=8) are neutral, 23.6% (n=13) disagree and 25.5% (n=14) strongly disagree with this statement. All respondents completed this question indicating a total of 55 responses. 49.1% of the respondents disagree and strongly disagree that they were spending more time on work projects. 14.5% chose to be neutral and 36.4% of respondents agree and strongly agree. The discrepancy could be the difference in job functions as not all respondents work on projects.

Statement 7: I have missed many of my family's important events because of work-related time.

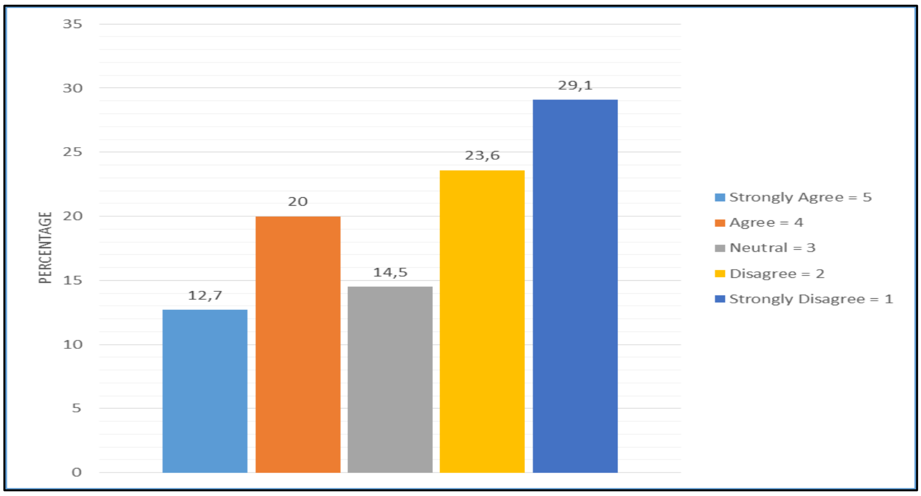

Figure 7: Missed family events due to work commitments (n = 55)

Figure 7 presents the results for statement 8 and shows that 12.7% (n=7) of respondents strongly agree, 20% (n=11) agree, 14.5% (n=8) are neutral, 23.6% (n=13) disagree and 29.1% (n=16) strongly disagree with this statement. All respondents completed this question indicating a total of 55 responses. 52.7% of the respondents disagree and strongly disagree that they missed family events due to work commitments or spending more time on work projects. 14.5% chose to be neutral and 32.7% of respondents agree and strongly agree. As per the nature of the organization of being closer to the clients, respondents could attend family events but needed to make up the hours at some point.

Statement 8: I can't remember the last time I was able to find the time to take a day off to do something fun, just for me.

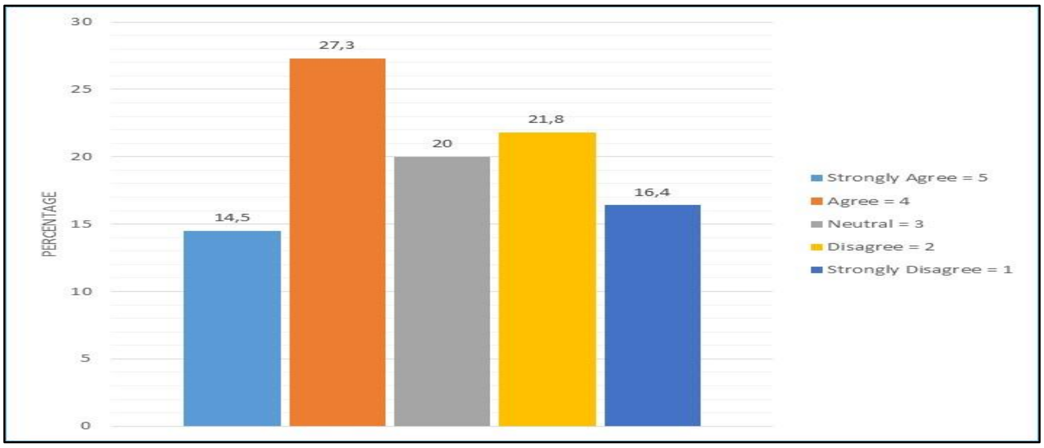

Figure 8:Time off from work for me (n = 55)

Figure 8 shows that 14.5% (n=8) of respondents strongly agree, 27.3% (n=15) agree, 20% (n=11) are neutral, 21.8% (n=12) disagree and 16.4% (n=9) strongly disagree with this statement. All respondents completed this question indicating a total of 55 responses. 38.2% of the respondents disagree and strongly disagree that they could take time off for a personal time. 20% chose to be neutral and 41.8% of respondents agree and strongly agree. Based on the respondent's feedback, the workforce seemed divided on this statement, this could be due to the varying job descriptions.

Statement 9: I am able to balance private time management with working activities.

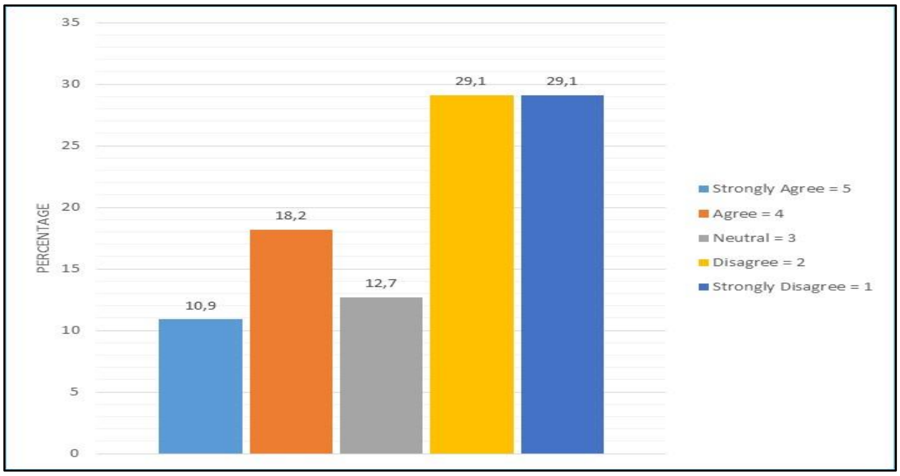

Figure 9: Private time management (n = 55)

Figure 9 shows that 10.9% (n=6) of respondents strongly agree, 18.2% (n=10) agree, 12.7% (n=7) are neutral, 29.1% (n=16) disagree and 29.1% (n=16) strongly disagree with this statement. All respondents completed this question indicating a total of 55 responses. 58.2% of the respondents disagree and strongly disagree that they could balance their private time. 12.7% chose to be neutral and 29.1% of respondents agree and strongly agree. Based on the respondent's feedback, it would imply that there was no real problem with private time management for the employees.

Statement 10: I am comfortable delivering as per my job description.

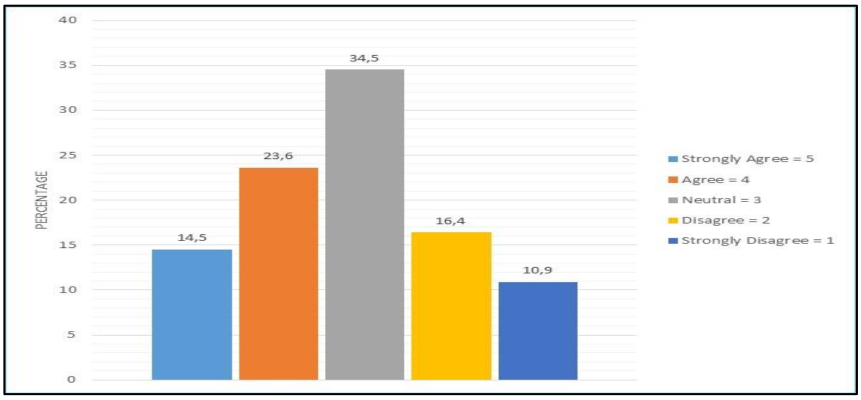

Figure 10: Deliver as per Job description (n = 55)

Figure 10 shows that 14.2% (n=8) of respondents strongly agree, 23.6% (n=13) agree, 34.5% (n=19) are neutral, 10.4% (n=9) disagree and 10.9% (n=6) strongly disagree with this statement. All respondents completed this question indicating a total of 55 responses. 27.3% of the respondents disagree and strongly disagree that they can deliver as per their job descriptions. 34.5% chose to be neutral, this could be explained as the organization did not provide a descriptive job description or no job description at all and 38.1% of respondents agree and strongly agree. This issue would need to be further investigated to understand the impact on employee performance.

Statement 11: Sometimes I feel like I just don't want to go to work.

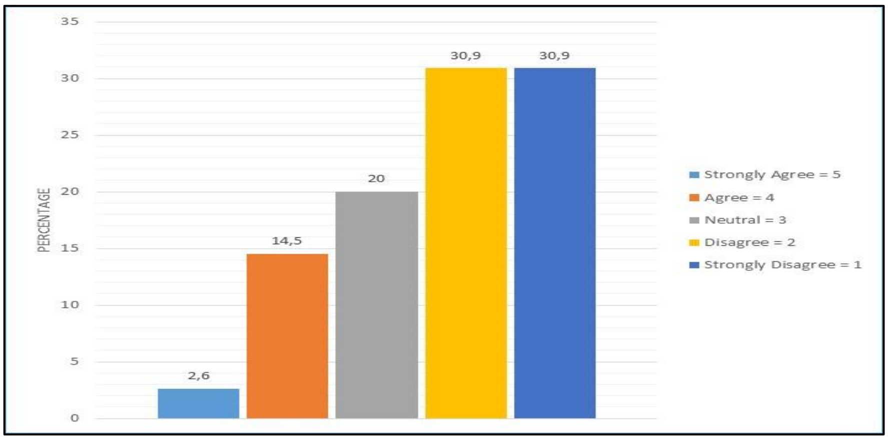

Figure 11: Don't want to go to work (n = 55)

Figure 11 shows that 2.6% (n=2) of respondents strongly agree, 14.5% (n=8) agree, 20% (n=11) are neutral, 30.9% (n=17) disagree and 30.9% (n=17) strongly disagree with this statement. All respondents completed this question indicating a total of 55 responses. 61.8% of the respondents disagree and strongly disagree that they don't want to go to work sometimes. 20% chose to be neutral and 17.1% of respondents agree and strongly agree. The results imply that the respondents chose to come to work every day, but this would need to be further unpacked to understand the policies it adopts in regards to the employee taking days off from work.

Statement 12: I almost always bring work home with me.

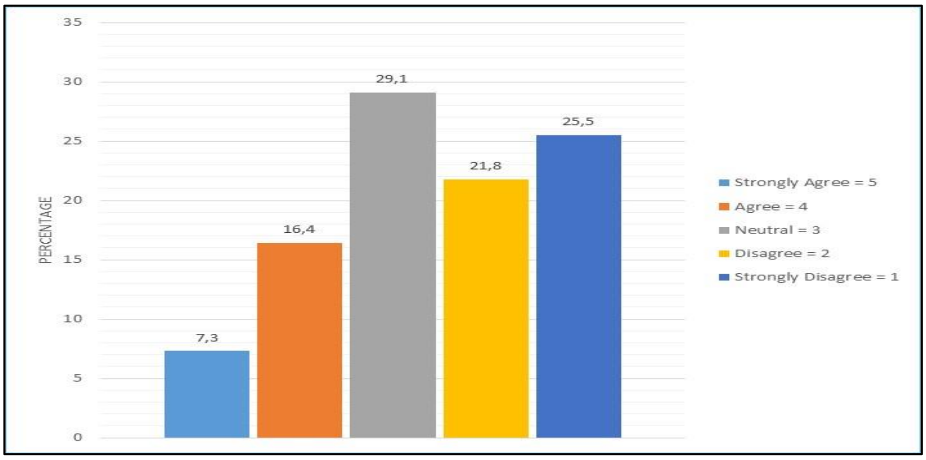

Figure 12: Taking work home (n = 55)

Figure 12 shows that 7.3% (n=4) of respondents strongly agree, 16.4% (n=9) agree, 29.1% (n=16) are neutral, 21.8% (n=12) disagree and 25.5% (n=14) strongly disagree with this statement. All respondents completed this question indicating a total of 55 responses. 47.3% of the respondents disagree and strongly disagree that they took work home. 29.1% chose to be neutral and 23.7% of respondents agree and strongly agree. The results imply that the respondents did not often take work home with them, again it could very well be related to the nature of the organization.

Statement 13: When I feel overworked it impacts my work performance.

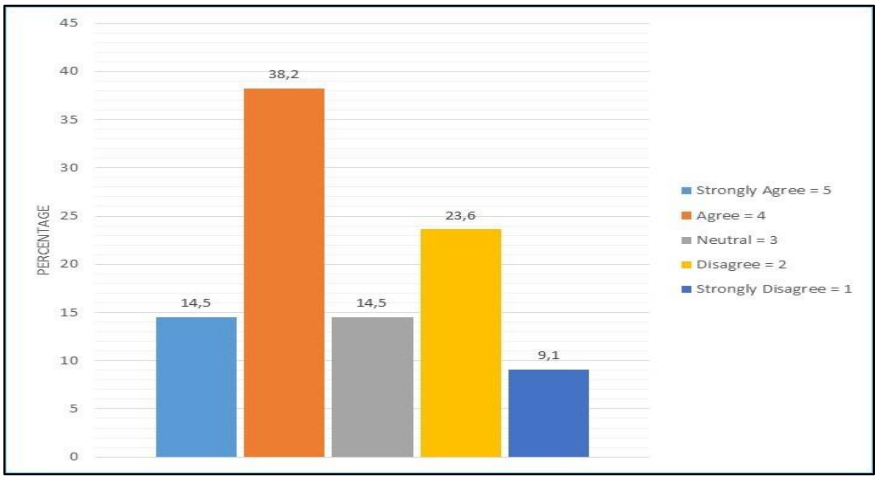

Figure 13: Impact on work performance (n = 55)

Figure 13 shows that 14.5% (n=8) of respondents strongly agree, 38.2% (n=21) agree, 14.5% (n=8) are neutral, 23.6% (n=13) disagree and 9.1% (n=5) strongly disagree with this statement. All respondents completed this question indicating a total of 55 responses. 52.7% of the respondents agree and strongly agree that overworking impacted their work performance. 14.5% chose to be neutral and 32.7% of respondents disagree and strongly disagree.

Statement 14: I feel that I perform better at work with balanced home life.

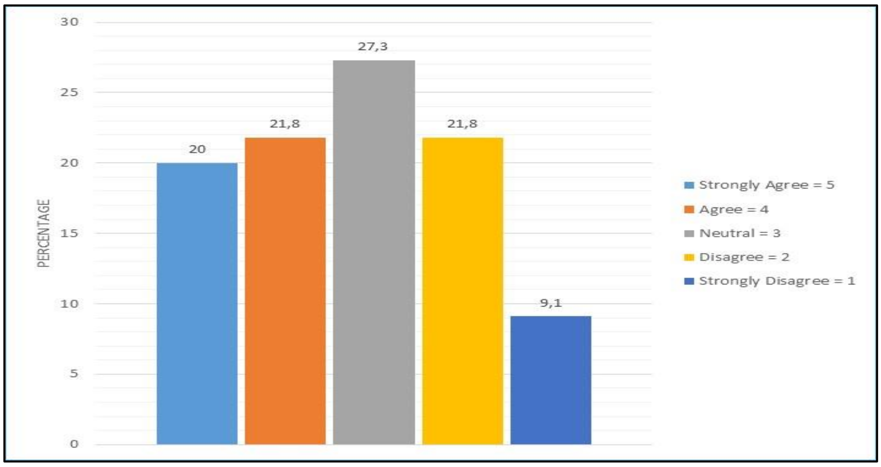

Figure 14: Better performance with balance home life (n = 55)

Figure 14 shows that 20% (n=11) of respondents strongly agree, 21.8% (n=12) agree, 27.3% (n=15) are neutral, 21.8% (n=12) disagree and 9.1% (n=5) strongly disagree with this statement. All respondents completed this question indicating a total of 55 responses. 41.8% of the respondents agree and strongly agree that they performed better at work with balanced home life, interestingly 27.3% chose to be neutral, this would require further investigation as to why these respondents didn't have an opinion on this statement and 30.9% of respondents disagree and strongly disagree.

Statement 15: I complete my tasks timeously.

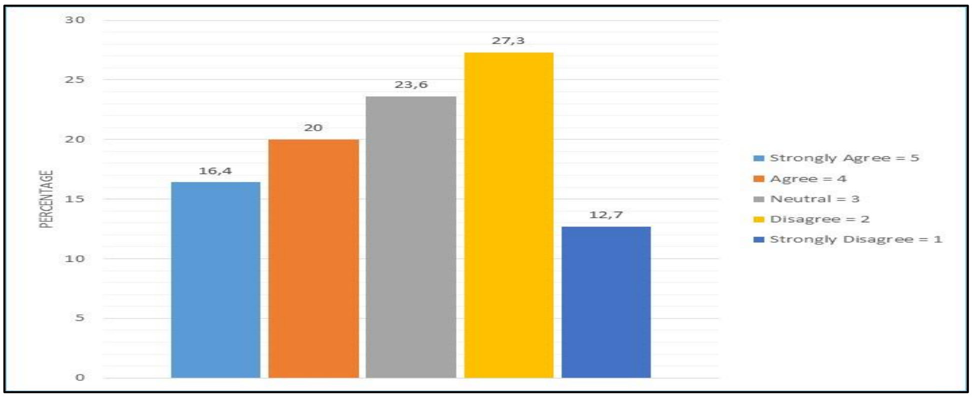

Figure 15: Complete daily tasks (n = 55)

Figure 15 shows that 16.4% (n=9) of respondents strongly agree, 20% (n=11) agree, 23.6% (n=13) are neutral, 27.3% (n=15) disagree and 12.7% (n=7) strongly disagree with this statement. All respondents completed this question indicating a total of 55 responses. 40% of the respondents disagree and strongly disagree that they complete their daily tasks timeously. 23.6% chose to be neutral and 36.4% of respondents agree and strongly agree. These results imply that there is a close correlation between those that did complete their daily tasks and those that didn't, the reasons for this would need to be further investigated.

Statement 16: I feel stressed out most of the time.

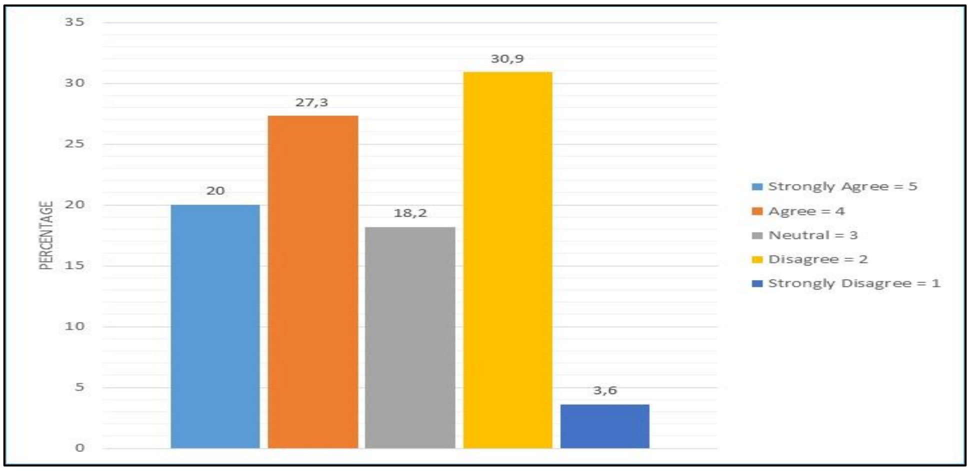

Figure 16: Stressed most of the time (n = 55)

Figure 16 shows that 20% (n=11) of respondents strongly agree, 27.3% (n=15) agree, 18.2% (n=10) are neutral, 30.9% (n=17) disagree and 3.6% (n=2) strongly disagree with this statement. All respondents completed this question indicating a total of 55 responses. 47.3% of the respondents agree and strongly agree that they felt stressed most of the time. 18.2% chose to be neutral and 34.5% of respondents disagree and strongly disagree. The factors that stressed the respondents out must be defined and understood and mitigation steps need to be investigated.

Statement 17: Work stress impacts my work and home life.

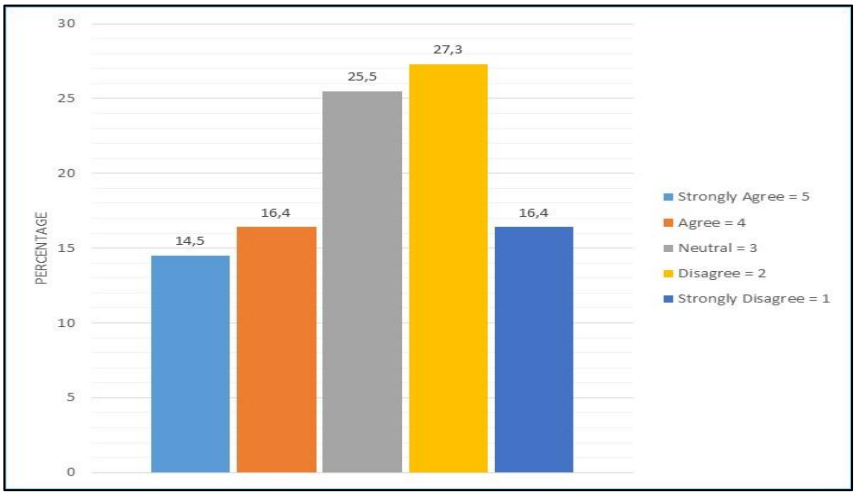

Figure 17: Work stress impacting life (n = 55)

Figure 17 presents the results for statement 20 and shows that 14.5% (n=8) of respondents strongly agree, 16.4% (n=9) agree, 25.5% (n=14) are neutral, 27.3% (n=15) disagree and 16.4% (n=9) strongly disagree with this statement. All respondents completed this question indicating a total of 55 responses. 43.6% of the respondents disagree and strongly disagree that work stress impacted their work life. 25.5% chose to be neutral and 30.9% of respondents agree and strongly agree.

4.1 Interpretation and Discussion

The overall Cronbach's Alpha coefficient resulted in a 0.890 score, according to the rule of thumb translates to an acceptable internal consistency. The Cronbach's Alpha coefficient per question result was acceptable in terms of the consistency of the reliability of the instrument.

Of the 55 questionnaires circulated 38.2% of the respondents were female and 61.8% were male. The participant's age analysis indicated that the majority of the respondents were between the ages of 30 and 40 years old, followed closely by 41 and 50 years old with 32.7%.

A high percentage of respondents were not aware that a formal WLB policy existed at the organization, contradicting the 52.7% of respondents that indicated that they were familiar with the contents of the policy. The majority of the respondents were happy with the execution of the WLB policy.

Most respondents felt that they had to perform duties simply for the sake of supporting other teams that depended on them. The majority of the respondents felt that they were pressurised to deliver on work responsibilities and the workdays were fully scheduled with little or no time for much else.

The majority of the respondents did not find that attending family events was an issue. The respondents seemed divided on taking time off for personal reasons, this could be related to the individual job descriptions, and additionally, there was no real problem with private time management for the employees.

A third of the respondents felt that they could deliver as per their job descriptions and the majority chose to come to work every day. Most of the respondents disagreed that they took work home, but more than half of them indicated that overworking impacted their work performance.

The respondents felt that they performed better at work with balanced home life, but a larger number felt that could not complete their daily tasks timeously. Stress seemed to play a major role with the respondents but the majority disagreed that it impacted their work life.

5 RECOMMENDATION AND CONCLUSION

Reviewing the findings from the study draws the inference that WLB has a deep impact on employee performance. Poor communication and understanding of the WLB policies further contribute to lowering employee performance. The respondents are committed to the organization and are committed to the support of their colleagues and customers. When organizations ensure that their employees are happy and can maintain a healthy WLB, it demonstrates that the organizations are committed to the employees. This commitment could be a major advantage in attracting and retaining top talent for the organization.

5.1. Communication within the organization

It is evident from the research that the employees were not clear on the existence of the WLB policy or what it entails or how it impacted the employees. Continuous internal communication is vital to ensure that all employees are aware of company policies and how they are applied.

5.2 Improving Employee Performance with effective Work-Life Balance

Organizations are required to formulate policies that apply to all employees equally. From the primary research, the evidence implied that the WLB policy in place did not suit all employees equally. Some employees always had to physically be at work due to the nature of their jobs, while others enjoyed the flexibility of a healthy WLB. Due consideration should be made so that all employees could have some level of flexibility in arranging working lives, as long as the assigned tasks are completed on time, within budget, and within desired quality.

5.3 Manage Stress to Maintain a Healthy Work-Life Balance

Fapohunda [11] argues that the current work environment became more stressful owing to globalization, varied role responsibilities, callous competition, and technological advancement. These changes have spawned several complications within the personal and professional facets of employees. Work pressure intensified, creating the sense amongst employees that work demands have started to control their lives. Today, the majority of employees experience the challenge of work and family life integration and it has become an everyday reality. Warren [12] argued that stress, in general, was a deviance from the regular functioning of body and mind. Organizations and individuals could experience stress due to several reasons for example managerial style or work control and that limited stress could prove beneficial to the employee and organization equally. Stress assists in achieving individual goals as well as the goals of the organization, however, excess stress impacts the mind, body, and employee psychology negatively.

Ross et al [6] suggested the following to reduce and maintain WLB:

- Allow employees to work 10-hour shifts instead of having a 5-day workweek, thereby creating a three day weekend
- Incorporate work-from-home policy
- Set up day-care facilities and offer discounted rates to employees
- Explore the possibility of onsite laundromats, gym or tax services
- Consideration of holiday packages for high-performing employees and or monetary bonuses.
- Set up concierge services to assist employees with errands
- Offer flexible hours allowing employees to select their preferred shift options
- Encourage employees to separate work and personal lives by avoiding tracking work e-mails after work or on weekends.

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EXPLORING THE ROLE OF TECHNOLOGY IN MANAGEMENT PRACTICE AND ITS IMPACT ON ORGANISATIONAL PERFORMANCE: A CASE STUDY

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ABSTRACT

With the development of Information Technology (IT), the world has become a global village and it has brought a digital revolution in the banking industry. The South African Banking industry is on a fast track for IT-based products and services. This study is centered on the role of technology in management practice, with a focus on the impact of technology on organizational performance. The findings of the study would assist bankers, bank managers, and relevant decision-makers to be aware of the role information technology plays in the performance of banks as it relates to management practice. A qualitative case study methodology was used as the primary instrument in the collection of data.

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1 INTRODUCTION AND BACKGROUND

The impact of information technology innovation on the customary duties of managers in the past ten years has been astonishing, specifically where these transformations relate to the global business environment. The study explores these effects by taking a closer look at the evolving nature of managerial functions in historic and present-day settings. The study provides literature on management functions that date back to the era of the Industrial Revolution and the Scientific Management era. Furthermore, the study also provides the transitions which took place from then up to present-day advanced and service-centered market economies whereby information technology (IT) and knowledge are becoming important weapons for growth, creating competitive advantage, endurance, and success in achieving organizational objectives. This study also scrutinizes the influence of information technology (IT) expansions on managerial roles using the four fundamental functions of management theory which include: planning, organizing, controlling, and leading. Lastly, an examination of the influence of IT on organizational performance will be provided in this study.

The importance of information technology as a considered and premeditated tool in an organization and as a main source of value-addition is familiar to everybody. Technology enhances the performance of business transactions and is considered a strategic imperative that enables a competitive edge. The importance of readily available and organized information in any organizational setup cannot be overemphasized.

The organization called ABC is among the leading financial services providers in South Africa and operates in 20 countries across the African continent and other crucial markets all over the world. Technology and Operations (T&O) delivers information technology and functional processing facilities to create a unique proficiency that exclusively controls a grouping of talented people, procedures, and information technologies to bring about sustainable productivity enhancements [1]. The organization has been able to decrease operational costs of leading-edge technology, and achieve lower unit costs, employment creation, and foreign currency earnings through the use of its technological strategy. This illustrates how information technology has widely been adopted as a core part of an organization's management and operational backbone in the modern business environment. The improvement to productivity is not only due to the technological application but rather due to its integration into the organization (Gagnon and Dragon 1998). Studies examining the relationship between information technology and organizational performance conflict on the way they theorize the fundamental constructs and their interactions [2].

The overall objective of the study is to come up with a structured scientific way of demonstrating how technology can be incorporated in the organization's management for the improvement of its management processes to have a technological competitive edge in its overall service offering.

In the modern competitive business environment, embracing and using information technology in banking management processes is not just an optional decision. It is believed that only banks that fix the totality of their employee relations, customer care, the distribution system, and related information technology to their processes are expected to endure and flourish in the contemporary business environment. Banks need to re-arrange their service and delivery system including management processes to cope up with the dynamism of information technology. Thus, senior managers of banks should adequately understand and be able to measure the influence of information technology on improving their performance in general and customer care facility quality and staff productivity. However, there are only a few studies that examined the role of technology on the management practice in the banking services in South Africa.

2 LITERATURE REVIEW

The current business atmosphere is very vibrant and concentrated due to the existence of technological advancement and the introduction of information technology as a competitive advantage of any organization. Ping-Ju Wu et al [3] argue that management functions in modern organizations have drastically changed because of worldwide rivalry, improvements in innovative information technologies (IT), and speedy expansions in e-commerce and e-business revolutions.

The literature review aims to justify that the shift resulting from these concurrent expansions in information technology and the globally competitive open market have affected decision-making responsibilities, roles, and organizational performance to some extent. The literature will explain how against the background of these factors, superior's obligation nowadays effectually entrench their classes of supervision into an all-inclusive and integrative approach, where IT deliberations and approaches are packaged for attaining organizational objectives.

2.1 What is Information Technology?

Agbolade [4] proposes that Information technology refers to the mechanization of progressions, gearshifts, and information construction by computers, telecommunications, software, and supplementary devices that warrant an even and well-organized running of undertakings. It is a term that includes the combination of electronic technology for the information requirements of a corporate at all heights.

2.2 Benefits of Information Technology in the Banking Industry

Currently, the exploitation of information technology has been superbly amplified in service organizations, mainly the banking industry, which uses information technology-associated services, including electronic payments, internet banking, information exchange, and security investments. This brings extraordinary service excellence to customers using a lesser amount of struggle [5]. The well-known quotation by Bill Gates says that "banking is vibrant to a strong economy, but banks themselves are not" shows the important landscape of electronic powers that are affecting banks. The transaction of business by banks has produced a new approach of action called e-banking. Web-centered banking facility or e-banking is the newest cohort of electronic banking operations that have unlocked innovative prospects to the existing banks. It authorizes a corporate method of re-engineering, the provision of an unlimited market to attain zero expectancies leading to expansions in customer service and improved risk management for the reason of real-time reimbursement.

2.3 Management functions in the settings of IT and e-commerce

According to Lauden and Traver [6] E-commerce refers to the process of procurement and retailing goods and services electronically including dealings using the Internet, networks, and other numerical technologies. Managers are required to efficiently use IT to advance e-managerial skills and approaches as they plan, organize, lead and control inside the framework of automated trade and the structural and business relationships, which are involved in computer-generated processes and dealings. Lauden and Traver [6] suggest that successfully managing such dynamics requires managers to perform their responsibilities and tasks using information movements in fresh and energetic means such as synchronizing resources and nursing their collaboration (both information and human resources) to generate and bring value to consumers internationally.

One could argue that the functions of planning, controlling, organizing, and leading are still central to management thoughts and theories regardless of the IT component and they continue to be instrumental in outlining and unfolding management functions, obligations, and accountabilities. The changeovers in managerial roles discussed in the literature review epitomize variations inside the utilities as superiors acclimate and answer to procedures such as globalization, industrialization, digitalization, innovativeness, and organizational conjunction and alterations interrelated to modern-day technical and socio-economic expansions.

2.4 The Effect of Information Technology on Organisational Performance

Agbolade [4] argues that in the last few decades, the application of information technology in business strategies has become a central point of the competitive process. As the economy moves from lower to higher stages of development, business processes are shifting from simpler to modern and complex techniques. In this regard, information technology has played a great role in changing the input-output relationship of business activities. Business organizations, particularly the banking sector are functioning in a multifaceted and modest environment characterized by fluctuating circumstances and a highly volatile economic environment with information technology being at the center of the change curve.

Moreover, the rapid diffusion of information technology in the current business environment during recent decades has affected many organization's business processes and organizational strategies. Studies have shown that world organizations have been motivated by the fast and persistent upgrading of expertise and systematic information. Rapid changes in computer and communication technologies have altered the way organizations do business and decision-making, which is reflected in their operational effectiveness. In this regard, technology has transformed all sectors across the world by interpreting quicker and cost-effective transfer of products and facilities to clients, who is a normal situation were not able to afford the same. It also enhanced producers of goods and services to remain viable and profitable.

3 RESEARCH METHODOLOGY

The study is quantitative and descriptive with a structured questionnaire using a Five-Point Likert. Convenience sampling is a non-probability sampling technique where subjects are selected because of their convenient accessibility and proximity to the researcher. Data was collected using a questionnaire through the technique of convenience sampling from a sample of 50 respondents out of a population of 103 from 3 branches of the bank in the Eastern Cape. The respondents range from tellers, front-line staff, to team leaders and supervisors. This will consist of questionnaires carrying cautiously planned predetermined questions meant for the targeted population. Some interviews will also be conducted to obtain additional information which would not be obtained through the questionnaires. Statistical software, SPSS (Statistical Programming for Social Sciences), was used for data analysis [7;8;9].

4 RESULTS AND DISCUSSION

Q 1 Committed to working because of the introduction of IT.

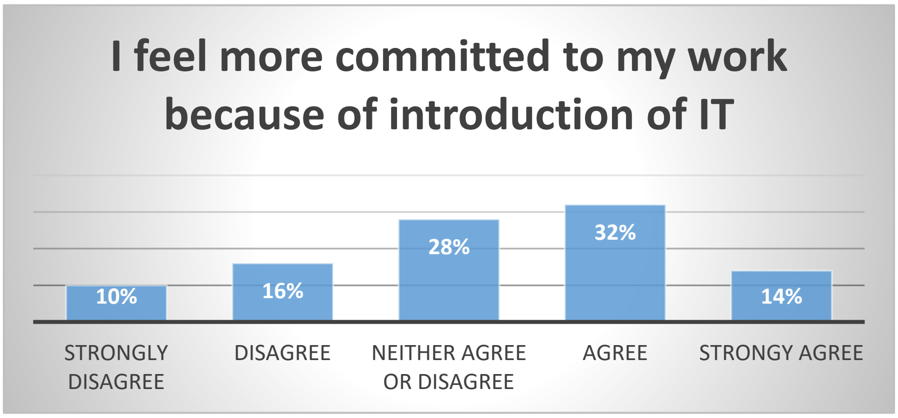

Figure 1: I feel more committed to my work because of the introduction of IT

As depicted in Figure 1, a considerable number of workers, 28%, were indifferent as to whether commitment was affected by the introduction of technology. About half of the workers were in support of this view as shown by the 32% who agreed and 14% who strongly agreed. However, 16% of the workers disagreed and 10% strongly disagreed that they feel committed due to the introduction of technology [10].

Q 2 With new technology, I can handle several responsibilities at one time.

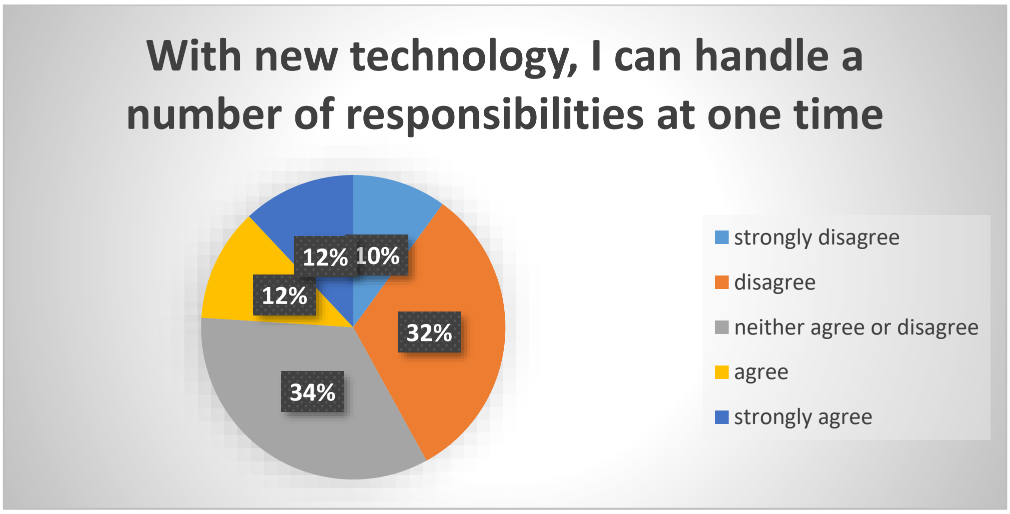

Figure 2: With new technology, I can handle several responsibilities at one time

Figure 2 indicates that several workers disagreed with the statement that they can carry out several responsibilities at one time because of technology. 32% disagreed whilst 10% strongly disagreed thus a total of 42% disagreed altogether. 34% neither agreed nor disagreed whereas 12% agreed and 12% strongly agreed. Cascio and Montealegre [11] supported this view by most workers that rather than helping in the responsibilities, technology is doing everything thus workers will in the end get retrenched. That is the reason why a substantial number of respondents neither agreed nor disagreed because this surely does not have one correct answer.

Q 3 My work is appreciated now.

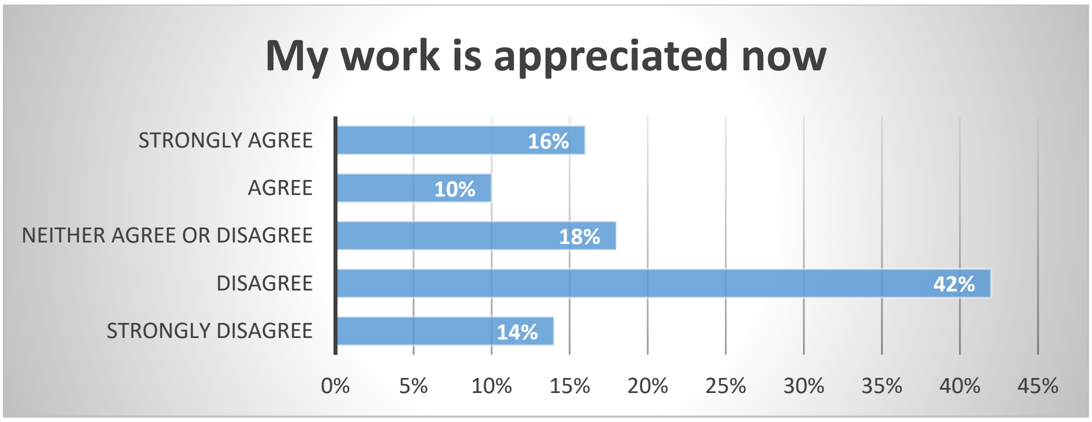

Figure 3: My work is appreciated now

As depicted in Figure 3 above, more than half of the workers, that is 56%, felt that their work is now unappreciated as depicted by the 42% who disagreed and the 14% who strongly disagreed. 10% agreed that their work is now appreciated while 16% strongly agreed. 18% neither agreed nor disagreed. With the introduction of technology, a lot of tasks are now automated thereby making manual labor obsolete thus most workers are retrenched [12].

Q4 I am provided with all the resources of work.

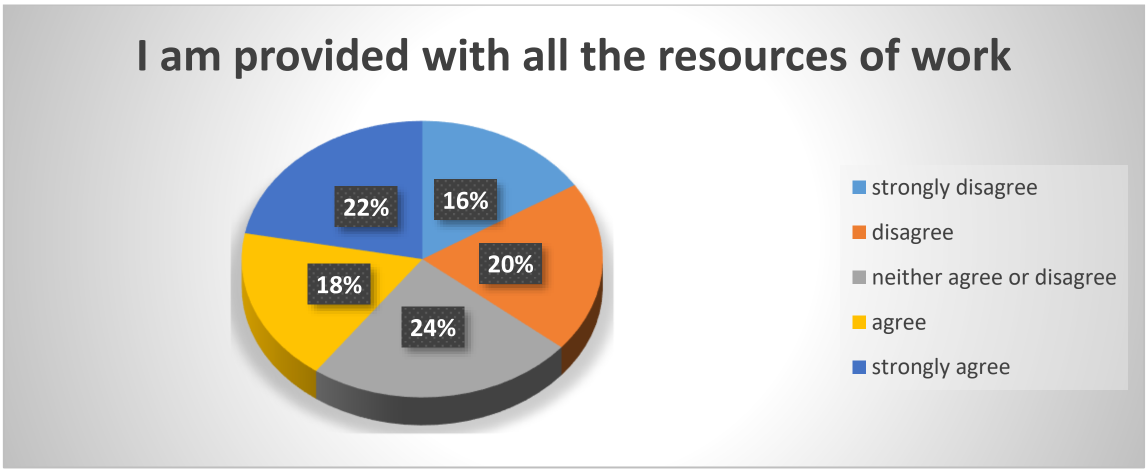

Figure 4: I am provided with all the resources of work

As depicted in Figure 3 above, 40% were in support that all the resources needed are provided whilst 36% of the workers were against that point of view. 22% strongly disagreed, 18% disagreed whilst 20% of the workers strongly agreed and 16% agreed. 34% neither agreed nor disagreed. These days, information is one of the most important power resources in every organization, and accordingly, acquiring information, especially central or strategic one can help organizations to build a power base and influence others [13].

Q5 Technology leads to greater opportunities for work.

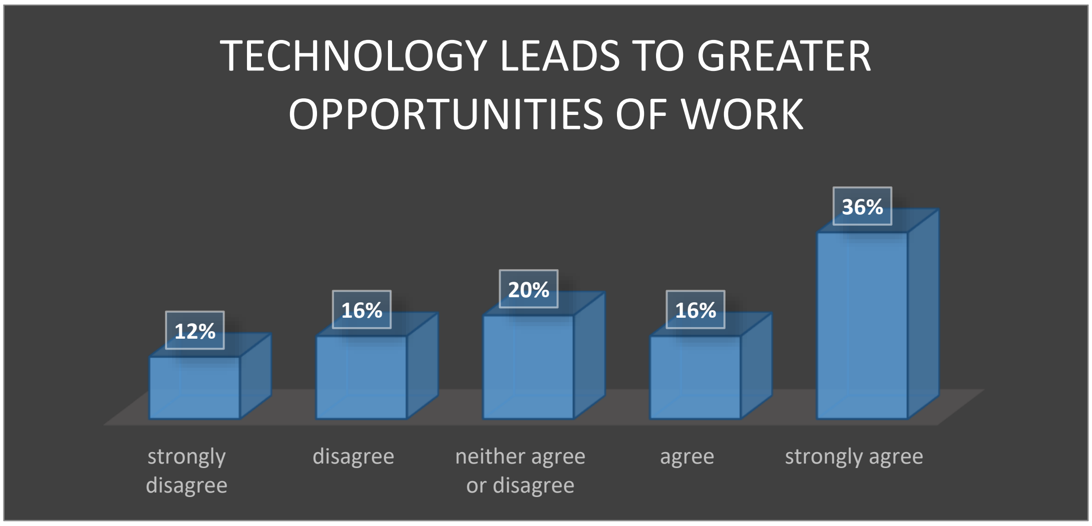

Figure 5: Technology leads to greater opportunities for work

Figure 5 depicts that most of the workers supported the view that technology leads to greater opportunities for work as shown by 52% of the workers. 36% strongly agreed whilst 16% agreed. 20% neither agreed nor disagreed whilst 28% did support the view. Respondents felt that there needs to be an increase in employees' job opportunities and this notion was highlighted by 52% of respondents who are supported by the World Bank Group who stated that there are huge opportunities for digital jobs and wider usage of digital tools [14].

Q6 The level of flexibility and integration at the bank has increased

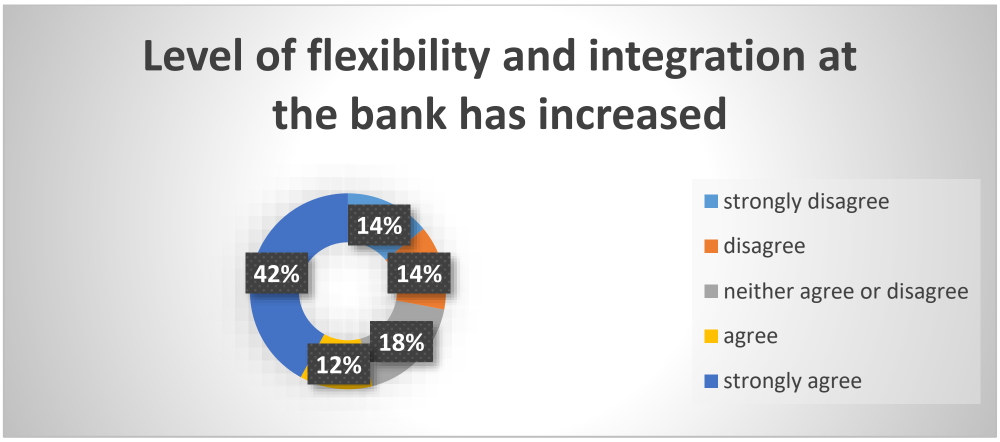

Figure 6: Level of flexibility and integration at the bank has increased

Figure 6 shows that more than half of the respondents accepted that the level of flexibility and integration at the bank has increased as revealed by the 42% who strongly agreed and 12% who agreed. 18% of the respondents were neutral while 14% disagreed and 14% also strongly disagreed.

Table 1: Issues on productivity due to new technology

	Strongly disagree	Disagree	Neither agree or disagree	Agree	Strongly agree
Now it takes less time to complete my work	10%	12%	28%	12%	34%
Productivity of my work has improved after the implementation of new technology	16%	12%	16%	12%	44%
With new technology, my task accomplishment has become easy and different	14%	20%	28%	18%	16%

Table 1 above shows that most of the respondents believe that it takes less time to complete work as shown by the 34% and the 12% who agree. 28% were indifferent whilst 10% strongly disagree and 12% disagree. One of the most obvious results in this area is observed in employees' faster and smoother access to required information which has been considered in research connected to information. Today, organizations can transfer orders and messages along with the organization without traditional management structures. This is possible through using information technology. This way, employees will have access to more information and do their duties effectively and efficiently [13].

Q7 Productivity of my work has improved after the implementation of new technology.

As revealed in Table 1, 56% of the respondents supported that their productivity was enhanced by new technology. 16% neither agreed nor disagreed. 12% disagreed and 16% strongly disagreed. Productivity is important when measuring the influence technology has on an organization. The application of information technology (IT) has expanded rapidly to increase efficiency and productivity in most areas [15].

Q8 With new technology my task accomplishment has become easy and different.

Table 1 indicates that most respondents believe that technology made work easier and different as shown by the 16% who strongly agreed and the 18% who agreed. 20% disagreed and 14% strongly disagreed. On the other hand, 28% were indifferent. One of the most obvious results in this area is observed in employees' faster and smoother access to required information which has been considered in most researches connected to information. Organizations can transfer orders and messages in the organization without traditional management structures. This is possible through the use of technology[10].

Q9 Working conditions have become good and safe.

As indicated in Figure 6, 20% strongly agreed and 24% agreed that working conditions have become good and safe. 20% disagreed, 14% strongly disagreed and 22% neither agreed nor disagreed. Working conditions have become good and safe thus minimize human errors in processing information and higher service provision which leads to client satisfaction due to the role of IT in employees' performance improvement [16].

Q10 Quality of work-life has improved.

Figure 6 below depicts that 20% of the respondents strongly agreed, 28% agreed, 18% disagreed and 10% strongly disagreed. 26% neither agreed nor disagreed with the notion that the quality of work-life has improved. Information communication technology can be used as a powerful tool to improve employees' quality and efficiency [10].

Q11 I do not feel stressed while working.

Figure 6 most of the respondents were not in support of the view that they do not feel stressed when they are working. 32% strongly disagreed, 20% disagreed, 26% were indifferent while 10% agreed and 12% strongly agreed. IT leads to a better performance accompanied by higher efficiency in service providing all of which will cause more satisfaction from fast and high-quality services [10].

Q12 My competencies and skills have improved now.

Figure 7 indicates that 18% strongly agreed, 20% agreed, 18% disagreed, and 18% also strongly disagreed with the viewpoint that workers' competencies and skills have improved. On the contrary, 26% of the respondents neither agreed nor disagreed. IT brought an increase in employees' independence and freedom. Furthermore, IT increased employees' knowledge and awareness [11].

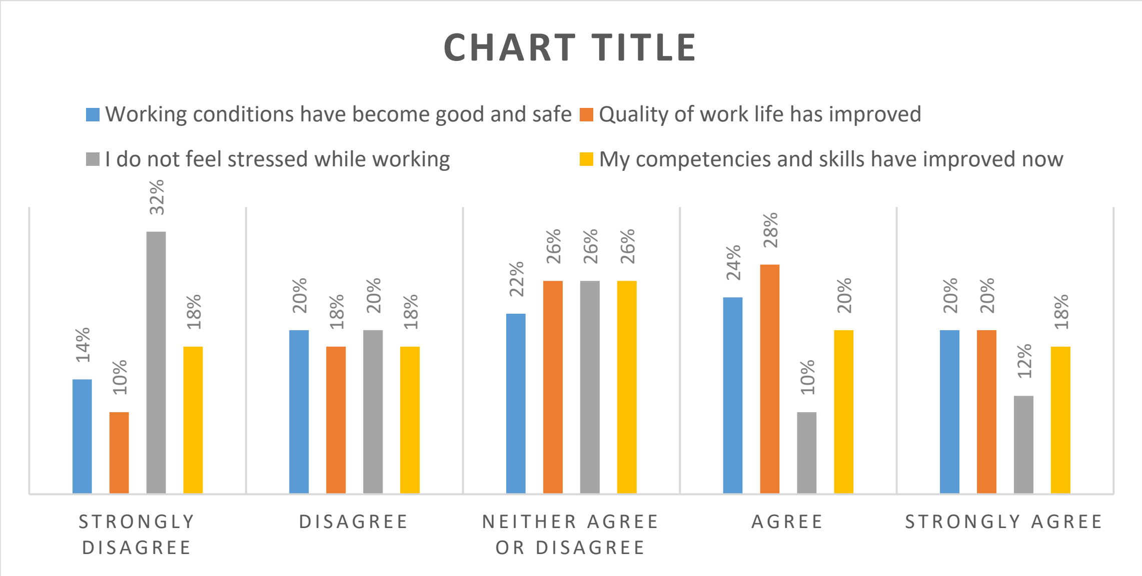

Figure 7: Quality of work with new technology

Q13 Technology improves motivation among operational management

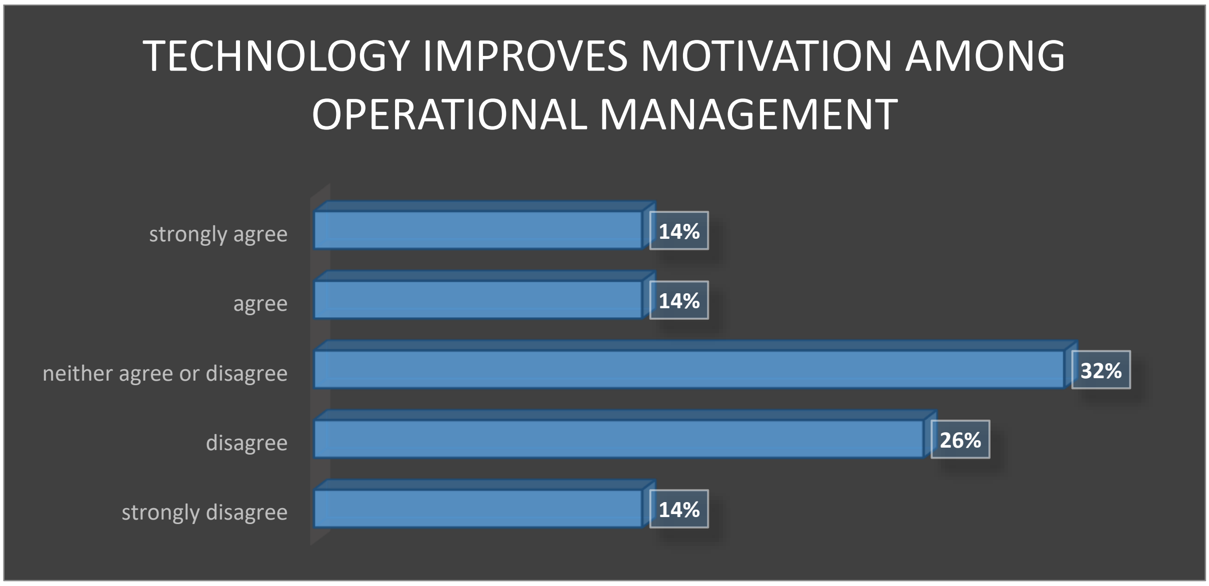

Figure 8: Technology improves motivation among operational management at standard

As highlighted in Figure 8, a considerable number of the respondents were indifferent that is 32%. 14% agreed, 14% strongly agreed while 26% disagreed, and 14% strongly disagreed with the view that technology improves motivation among operational management at ABC Bank. Information Technology is designed to make people and organizations more efficient and profitable. Cascio and Montealegre [11] argue that the benefits of the usage of technology include efficiency savings, greater volumes handled, at greater speeds, with fewer resources. Effectively introducing technology is not the only source of people becoming more motivated, but the management process turns out to be more naturally organized.

Q 14 Customer care is better because of technology at the bank.

Figure 9 below shows that more than half of the respondents support that customer care is now better because of technology. This is evident in the 30% of the respondents who agreed and 24% who strongly agreed. However, there were 10% who strongly disagreed and 14% who disagreed. 22% of the respondents neither agreed nor disagreed. Technology is a significant tool in the formation and management of customer relations because through technology banks can improve their connections with their customers and also shape improved customer relationships [12].

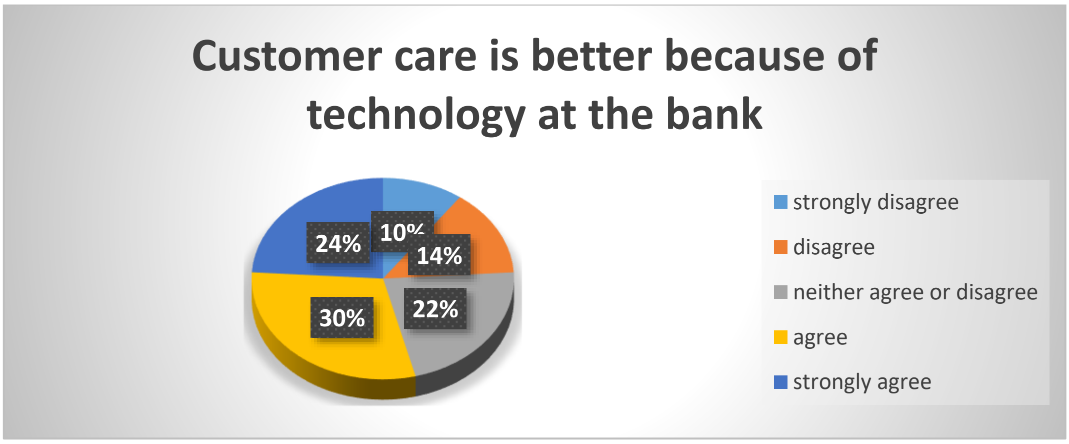

Figure 9: Customer care is better because of technology at the bank

Q15 The organization performs better because of technology.

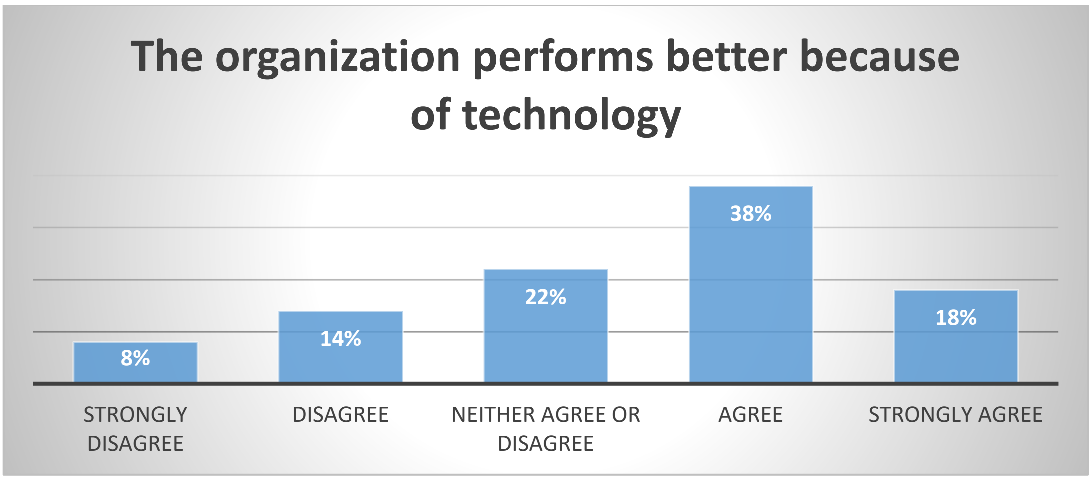

Figure 10: The organization performs better because of technology

Figure 10 reveals that 38% agree, 18% strongly agree, 22% neither agree nor disagree, 14% disagree and 8% strongly disagree that the organization performs better because of technology. Just as most of the respondents, Alraja and Alomian [13] concur that for an organization to run efficiently and to be competitive, technology has been used for the enhancement of performance.

Q16 Communication with teams is easier because of technology

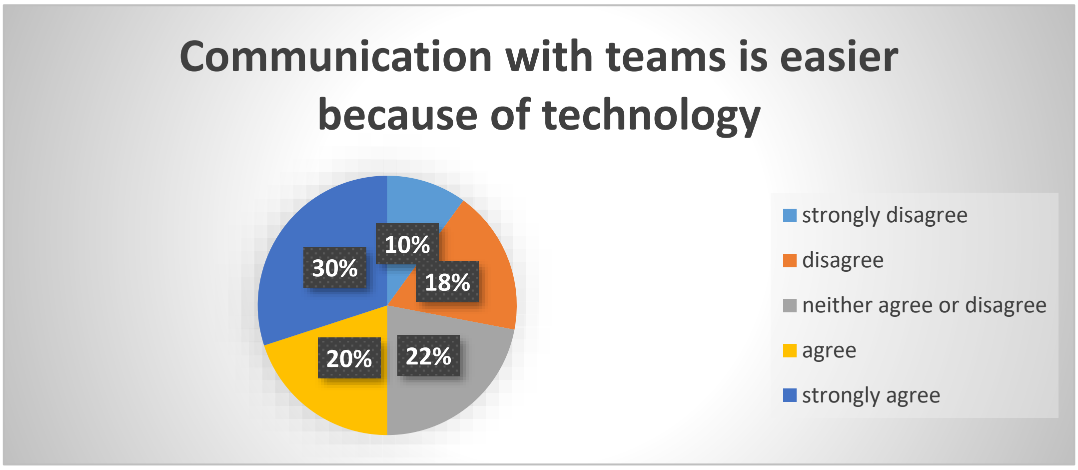

Figure 11: Communication with teams is easier because of technology

Figure 11 illustrates that half the respondents believe that communication with teams is easier because of technology. 30% strongly agreed and 20% agreed to this notion. However, 10% strongly disagreed, 18% disagreed, and 22% neither agreed nor disagreed. Teams are not fixed thus with the technology they form more easily due to the power of technology and the fast and reliable means of communication [14].

5 RECOMMENDATION AND CONCLUSION

Information technology and the communiqué networking schemes have transformed the operations of banks and financial bodies worldwide. The study aimed to determine the role of technology in management practice with a focus on the impact of technology on organizational performance. The findings show that new technology had an impact on employees' motivation. The results further showed that technology had an impact on the organizational performance at the bank. However, other factors showed that technology did not affect the way the bank employees do their work. Importantly, the role of planning, organizing, leading, and controlling diminished as most of these functions were done through technology. The formation of teams created an environment where people were required to working together, reducing the impact of conflict. Technology became the central focus, where performance management was controlled by a dashboard displaying performance. These would enable the banking sector to continuously manage its technology so that it keeps on increasing its employee motivation and the organization's performance [17].

In this time of Covid 19, the application of information technology is promoted to a large extent. The financial sector has transformed into a “paperless environment” through the utilization of information technology products which includes information transfer, microelectronic transfers, security investments, and internet banking to name a few changes.

The bank's administration is required to strengthen their venture into the application of information technology which would yield optimal performance in all departments of the bank. There is extreme rivalry in the financial sector and customers experience this regularly. The bank is looking for modest ways to retain customers and to enable a competitive edge over its opponents. Although banks are aiming at strengthening their relations with customers and shift to relationship banking, customers are now moving away from the boundaries of customary branch banking and looking for the accessibility of distant microelectronic banking.

With increasing global competition and the quick spreading of knowledge, the future of many businesses depends upon their ability to innovate. Information technology is one of the most important tools along with innovations in organizations and it plays a critical role in the development of new products and services. It provides new forms of customer services, new distribution channels, new information-based products, improved productivity, and can influence industry structure. The major impetus for innovation has been the globalization of the financial system, deregulation, and great advances in technology. Thus, with increasingly integrated financial systems facing higher volatilities, more competition, and wide varieties of risks, financial innovation has become essential to provide new products and strategies to better suit different circumstances of time and market and to meet different requirements of participants in the financial system.

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THE ASSIGNMENT OF BUSES TO PREDETERMINED ROUTES IN A PUBLIC TRANSPORT SYSTEM

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ABSTRACT

A mathematical model is proposed in this paper for the cost-effective assignment of the buses of a public transport provider to the routes that it services. The model takes the form of a binary programming problem in which the objective is either to minimise the total deadheading distance travelled or deadheading time expended by all the company's buses combined, the total number of buses utilised to service all routes, or the time spent on the road by the busiest bus in a bid to assign equitable driving schedules to drivers. The model is formulated and verified in the context of small, randomly generated problem instances. It is finally also validated by applying it to a case study involving real data of a well-known South African bus company with the purpose of comparing the efficacy of the model's recommended bus-to-route assignments with the company's bus-to-route assignents.

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1 INTRODUCTION

It has increasingly become important for companies in the highly competitive public transport sector to streamline their activities with a view to utilise their resources optimally. The effective use of resources enables companies to provide a high-quality service to passengers at a reduced cost. Decision support elements pertaining to the cost-effective utilisation of resources by a company providing a public transport service traditionally include the establishment of routes for transport vehicles [1], the setting of frequencies for vehicles along these routes [2], synchronised vehicle departure scheduling aimed at servicing the origin-destination demand of passengers by allowing for passenger transfers between routes [3,4], and the assignment of drivers to vehicles and vehicles to the routes serviced.

A case in point is the company *Golden Arrow Bus Services* (GABS), the employer of the first author. This company provides a passenger transport service to lower-income commuters in and around Cape Town along a fixed set of routes and according to fixed departure schedules for vehicles along these routes, as negotiated by government contract. Since these routes and their associated schedules cannot be changed, decisions by GABS related to improved cost-effective resource use revolve mainly around effective bus utilisation. Bus-to-route assignments are currently performed manually at GABS, based on considerable historical, but mainly anecdotal, scheduling experience at the company. The management of GABS is interested in assessing the degree of cost-effectiveness of their current bus-to-route assignments in terms of the following four criteria at each of its depots [5,6]:

- Minimising the total deadheading distance travelled by all its buses combined (deadheading occurs when a bus travels without passengers between routes),
- minimising the total deadheading time expended by all its buses combined,
- minimising the total number of buses utilised to service all routes, and
- minimising the time spent on the road by the busiest bus in a bid to assign equitable driving schedules to drivers.

The current paper is a first step in a larger research project launched by GABS to carry out the above assessments and has as objective the establishment of a first-order mathematical model in support of solving the *bus-to-route assignment problem* (BRAP) instances experienced at GABS in respect of the aforementioned four criteria. Related literature is discussed briefly in Section 2. The model is derived in Section 3 and then verified in Section 4. Section 5 is dedicated to a special validation case study involving those routes serviced from one of the depots of GABS. A few comments on the computational burden associated with solving the model follow in Section 6, before next steps in the greater over-arching BRAP research project at GABS are outlined in Section 7.

2 RELATED LITERATURE

There are several studies in the literature related to the BRAP. In particular, the BRAP is in essence an assignment problem of buses to pre-determined routes, similar to the classical assignment problem first suggested by Votow and Orden [7], but with additional side constraints. The BRAP is also easily confused with the class of *vehicle routing problems,* eloquently described by Toth and Vigo [8], since both problems involve the routing of vehicles through a transit system. In contrast to a vehicle routing problem, however, the BRAP does not require sub-tour elimination constraints because of the fact that bus routes in the BRAP have fixed departure times. This feature makes the BRAP significantly simpler to solve.

Ibarra-Rojas *et al.* [4] described the process of planning, operating and controlling a transit network, known as the transit network planning problem (TNP). The TNP consists of six different sub-poblems as illustrated in the central column of Figure 1.

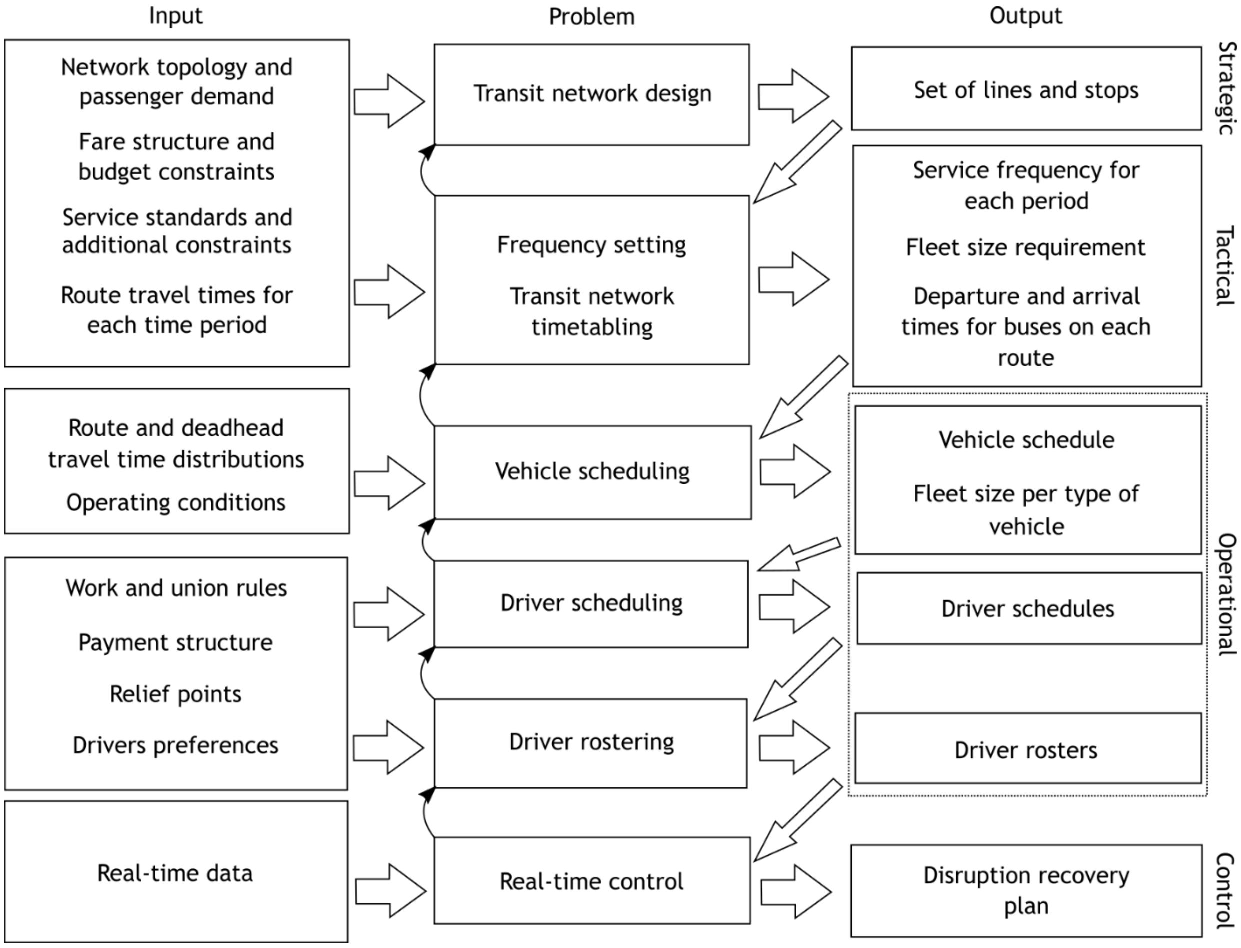

Figure 1: Phases of the TNP (adapted from Ibarra-Rojas *et al.*[4])

During the strategic phase of the TNP, the transit network design problem is solved, where the goal is to determine a set of routes in a transit network that will satisfy the network's passenger demand [2]. During the Tactical planning phase, the frequency setting problem and the transit network timetabling problem are solved. The frequency setting problem aims to assign frequencies at which buses should traverse each route as determined during the previous phase over a specified number of time periods in a day so as to meet passenger demand [2]. The timetabling problem involves the generation of timetables for the routes. The timetables consist of estimated bus arrival and departure times at all the stops along the routes determined during the strategic phase [2].

The operational planning phase is partitioned into the *vehicle scheduling problem* (VSP), the *driver scheduling problem* (DSP), and the *driver rostering problem* (DRP). The goal in the VSP is to assign the set of routes as determined during the strategic and tactical planning phases of the TNP to a set of homogeneous buses during a *scheduling period* (a scheduling period typically consists of one day) [9, 10]. The DSP aims to assign a set of available drivers to operate the vehicles (assigned to routes during the VSP), over some scheduling period [11, 12]. Finally, the aim in the DRP is to assign a set of routes to a set of available drivers over an entire rostering period (containing multiple scheduling periods) [13, 14]. The BRAP and the DSP differ significantly since the BRAP is solved over a single scheduling period while the DRP is solved over a collection of scheduling periods.

The VSP shares similar characteristics with the BRAP, since in both problems a set of routes is assigned to a set of available buses in both cases. The VSP typically aims to minimise a single cost function related to the operation of buses. In the BRAP, however, several objectives can be pursued that are not necessarily restricted to vehicle considerations, but also to driver considerations. The aim in the BRAP is therefore to solve a problem similar to the VSP, but while taking into account certain driver considerations typically only considered in the DSP.

During the control phase of the TNP, real time data are used to determine how the decisions made during the previous two phases should be adapted so as to better meet customer demand as well as how to better utilise a transport company's resources.

3 MATHEMATICAL MODEL

The mathematical model we propose for the BRAP takes the form of a binary programming problem. The model is derived in this section.

3.1 Model parameters

Let $R = \{1, \ldots, n\}$ be an ordered set of routes to which buses have to be assigned. The start and end time of route $i \in R$ are denoted by s_i and e_i, respectively, measured in minutes after some reference time, and it is assumed, without loss of generality, that the routes in R are indexed in order of non-decreasing starting time. Furthermore, consider two extra dummy routes indexed 0 and $n+1$, with time durations of zero, both starting and ending at the depot (therefore incurring zero travel distance), with start and end times $s_0 = e_0 = 0$ and $s_{n+1} = e_{n+1} = M$, respectively, where M denotes the end time of the scheduling cycle. These dummy routes fulfil the roles of vehicle departures from the depot and later vehicle returns to the depot.

Furthermore, define the set $P_i = \{0, \ldots, i-1\}$ of predecessor routes for each route $i \in R \cup \{n+1\}$ and similarly define the set $S_j = \{j+1, \ldots, n+1\}$ of successor routes for each route $j \in R \cup \{0\}$. Let t_{ij} denote the expected deadheading travel duration from the destination of route i to the origin of route j, taking into account the expected traffic conditions of the applicable time of day. Also, define the compatibility parameter

$$a_{ij} = \begin{cases} 1 & \text{if } e_i + t_{ij} < s_j, \text{or} \\ 0 & \text{otherwise} \end{cases} \quad (1)$$

for routes $i \in R \cup \{0\}$ and $j \in S_i$. The parameter a_{ij} therefore takes the value 1 if route $j \in S_i$ is serviceable directly after route $i \in R \cup \{0\}$ by the same bus, taking into account the scheduled start times of the two routes and the expected time it takes to travel from the destination of route i to the origin of route j. Finally, let the distance between the destination of route $i \in R \cup \{0\}$ and the origin of route $j \in S_i$ be d_{ij}, and index the set of all available buses for the BRAP instance by the set $B = \{1, \ldots, b\}$.

3.2 Model variables

A set of three-index flow variables,

$$x_{ijk} = \begin{cases} 1 & \text{if bus } k \in B \text{ is assigned to route } j \in S_i \text{ directly after route } i \in R \cup \{0\}, \text{or} \\ 0 & \text{otherwise} \end{cases}$$

is employed in the model.

3.3 Model formulation

One BRAP objective involves minimising

$$z = \sum_{k \in B} \sum_{i \in R \cup \{0\}} \sum_{j \in S_i} d_{ij} x_{ijk} \quad (2)$$

subject to the constraints

$$\sum_{k \in B} \sum_{j \in S_i} a_{ij}\, x_{ijk} = 1, \qquad i \in R, \quad (3)$$

$$\sum_{k \in B} \sum_{i \in P_i} a_{ij} x_{ijk} = 1, \qquad j \in R, \tag{4}$$

$$\sum_{j \in S_0} x_{0jk} = 1, \qquad k \in B, \tag{5}$$

$$\sum_{i \in P_{n+1}} x_{i,n+1,k} = 1, \qquad k \in B, \tag{6}$$

$$\sum_{i \in P_j} x_{ijk} - \sum_{l \in S_j} x_{jlk} = 0, \qquad j \in R, \qquad k \in B, \tag{7}$$

$$x_{ijk} \in \{0,1\}, \qquad i \in R \cup \{0\}, \qquad j \in S_i, \qquad k \in B. \tag{8}$$

The objective in (2) is to minimise the total deadheading distance travelled by all buses combined (*i.e.* the distance travelled by buses when not containing any passengers). Constraint set (3) ensures that each route $i \in R$ is assigned a unique successor route $j \in S_i$, as well as a unique bus $k \in B$, while constraint set (4) ensures that each route $j \in R$ is assigned a unique predecessor route $i \in P_j$ and bus $k \in B$. Moreover, constraint set (5) ensures that every bus is assigned to depart from the depot exactly once, while constraint set (6) ensures that every bus is assigned to return to the depot exactly once again. Constraint set (7) is a typical vehicle routing conservation-of-flow constraint set and ensures that, if a bus $k \in B$ is assigned to travel from the destination of a predecessor route $i \in P_j$ to the origin of route $j \in R$, it is also assigned to travel from the destination of route $j \in R$ to the origin of another successor route $l \in S_j$. Finally, constraint set (8) is a domain constraint set ensuring that the model variables are binary.

The constraints above are significantly simpler than those in models for well-known vehicle routing problems [8] because of the absence of subtour-breaking constraints, which cause the lion's share of the complexity associated with such problems. These subtour-breaking constraints typically have to be implemented as and when needed, in real time during the process of solving a vehicle routing model (because there are exponentially many of them). The reason why these constraints are superfluous in the BRAP is the fortuitous ordering of the routes in R. Since any route starting earlier than another one is not reachable by any bus from the later route in view of the compatibility parameters in (3)—(4), subtours cannot be formed (because buses cannot travel backwards in time), and so there is no need for BRAP model logic to prevent their formation.

3.4 Alternative model objectives

While keeping the constraints unchanged, an alternative to the objective in (2) is to minimise the total time spent by all buses while deadheading (*i.e.* the time expended by buses when not containing any passengers). That is, to minimise

$$z = \sum_{k \in B} \sum_{i \in R \cup 0} \sum_{j \in S_i} T_{ij} x_{ijk}, \tag{9}$$

where

$$T_{ij} = \begin{cases} t_{ij} & \text{if } i = 0 \text{ and } j \in R \\ s_j - e_i & \text{if } i \in \{1, \ldots, n-1\} \text{ and } j \in \{i+1, \ldots, n\}, \\ t_{ij} & \text{if } i \in R \text{ and } j = n+1. \end{cases} \tag{10}$$

Another alternative is to minimise the number of buses utilised to serve all routes. This objective involves maximising

$$z = \sum_{k \in B} x_{0,n+1,k} \tag{11}$$

in which case the model will attempt to maximise the number of buses assigned to "travel" from the initial depot-to-depot dummy route to the last depot-to-depot dummy route.

A fourth possible model objective is to minimise the longest time spent on the road by any bus. This may be achieved by introducing a new continuous variable W which serves the purpose of an upper bound on the longest time spent on the road by a bus $k \in B$ and then

$$\text{minimising } W. \tag{12}$$

In this case, the additional set of binary auxiliary variables

$$y_{jik} = \begin{cases} 1 & \text{if routes } i \in R \text{ and } j \in P_i \cup \{i\} \text{ are the last and first routes, respectively,} \\ & \text{assigned to bus } k \in B, \text{or} \\ 0 & \text{otherwise} \end{cases}$$

is required, and the following additional constraints also have to be included in the model:

$$x_{0jk} + x_{i,n+1,k} \leq y_{jik} + 1, \qquad k \in B, \quad i \in R, \quad j \in P_i \cup \{i\}, \tag{13}$$

$$(e_i + t_{i,n+1} - s_j - t_{0j})y_{jik} \leq W, \quad k \in B, \quad i \in R, \quad j \in P_i \cup \{i\}. \tag{14}$$

Constraint set (13) serves the purpose of linking the original decision variables and the newly introduced auxiliary variables by ensuring that the decision variable y_{jik} is assigned the value 1 if the decision variables x_{0jk} and $x_{i,n+1,k}$ both take the value 1 for some routes $i \in R$ and $j \in P_i \cup \{i\}$. Constraint set (14) finally ensures that W is indeed an upper bound on the longest time spent on the road by any bus.

4 MODEL VERIFICATION

This section is devoted to a verification of our implementation of the models in Section 3. This verification involves applying the four model implementations to a small hypothetical BRAP test instance and comparing the results returned by the models with those obtained when solving the test instance heuristically (by hand). These sets of solutions are further verified by executing an exhaustive search of all possible bus-ro-route assignments for the small hypothetical BRAP test instance and comparing all the optimal solutions thus found with the solutions returned by the models and that found heuristically.

Consider a small, hypothetical BRAP test instance in which $n = 8$ routes, together with two additional dummy routes (as described in Section 3.1), have to be assigned to $b = 4$ buses. The start and end times of the routes (measured in minutes after some reference time) are as listed in Table 1. As may be seen in the table, the scheduling period extends from time 0 to time 175 (both measured in minutes). Suppoe the values of d_{ij}, the distance (in kilometers) between the destination of route $i \in R \cup \{0\}$ and the origin of route $j \in S_i$, are as shown in Table 2. Similarly, suppose the values of t_{ij}, the anticipated driving time (in minutes) of a bus from the destination of route $i \in R \cup \{0\}$ to the origin of route $j \in S_i$, are as listed in Table 3.

Table 1: Routes that have to be serviced in the hypothetical model test instance. The start and end times of route 9 (*i.e.* one of the dummy routes), have been chosen large enough to ensure that all routes are compatible with the last route.

Route	Start	End	Origin	Destination
0	0	0	Depot	Depot
1	0	20	Observatory	Goodwood
2	0	30	Rondebosch	Philipi
3	20	50	Delft	Brackenfell
4	50	70	Kuilsrivier	Greenpoint
5	60	100	Observatory	Goodwood
6	90	140	Muizenberg	Rondebosch
7	120	130	Wynberg	Philipi
8	140	160	Milnerton	Rondebosch
9	175	175	Depot	Depot

Table 2: Travel distance (in km) from the destination of route i to the origin of route j.

d_{ij}	$j=0$	$j=1$	$j=2$	$j=3$	$j=4$	$j=5$	$j=6$	$j=7$	$j=8$	$j=9$
$i=0$	0	5	20	10	5	20	10	15	10	0
$i=1$		0	3	10	10	20	5	5	25	5
$i=2$			0	5	5	5	65	10	8	20
$i=3$				0	10	40	5	5	10	10
$i=4$					0	5	10	20	5	5
$i=5$						0	10	15	5	20
$i=6$							0	5	5	10
$i=7$								0	10	15
$i=8$									0	10
$i=9$										0

In order to construct a benchmark solution to the BRAP instance above, we applied an intuitive heuristic employed at GABS. The heuristic is initialised by assigning each of the first *b* routes to a different bus, so that each available bus is utilised (*i.e.* has at least one route assigned to it). Thereafter, the remaining routes are considered separately, in the order in which they are indexed. Each route is assigned to the first available bus with the least number of routes already assigned to it. A bus is considered available if it has no route already assigned to it which is incompatiable with the route being assigned. The heuristic terminates once all routes have thus been assigned to buses.

In the context of the small, hypothetical BRAP test instance above, the heuristic is initialised by assigning routes 1, 2, 3 and 4 to buses 1, 2, 3 and 4, respectively. This is achived by assigning these buses to depart from the depot (*i.e.* the destination of the dummy route 0) and to travel to the origins of routes 1, 2, 3 and 4, respectively (that is, the assignments $x_{011} = x_{022} = x_{033} = x_{044} = 1$ are made). These initial assignments add deadheading distances of 5, 20, 10 and 5 kilometres as well as deadheading times of 10, 25, 15 and 10 mintes to the tallies of buses 1, 2, 3 and 4, respectively.

Route 5 is considered next and the "first" bus considered to service this route is bus 1. Since $e_1 + t_{15} \leq s_5$ (*i.e.* $20 + 24 \leq 60$), route 1, which has already been assigned to bus 1, and route 5 are compatible, as described in (1). Bus 1 is therefore the first available bus to service route 5, and so bus 1 is assigned to travel from the destination of route 1 (already assigned to it) to the origin of route 5 (that is, the assignment $x_{151} = 1$ is made). This increases the deadheading distance objective function value in (2) by 20 kilometres, since $d_{15} = 20$, and the deadheading time objective function value in (9) by 40 minutes, since $s_5 - e_1 = 40$.

Table 3: Travel times (in min) from the destination of route i to the origin of route j

t_{ij}	$j=0$	$j=1$	$j=2$	$j=3$	$j=4$	$j=5$	$j=6$	$j=7$	$j=8$	$j=9$
$i=0$	0	10	25	15	10	25	15	20	15	0
$i=1$		0	7	14	14	24	9	9	29	9
$i=2$			0	12	12	12	72	17	15	27
$i=3$				0	12	42	7	7	12	12
$i=4$					0	9	14	24	9	9
$i=5$						0	16	21	11	26
$i=6$							0	8	8	13
$i=7$								0	14	19
$i=8$									0	12
$i=9$										0

Route 6 is considered next and the "first" bus considered to service this route is bus 2. It is, however, observed that $e_2 + t_{26} \nleq s_6$ $(i.e.\ 30 + 72 \nleq 90)$, showing that route 2, which has already been assigned to bus 2, and route 6 are incompatible. This means that bus 2 is not available to service route 6, and so the next bus considered to service route 6 is bus 3. Since $e_3 + t_{36} \leq s_6$ $(i.e.\ 50 + 5 \leq 90)$, it follows that bus 3 is indeed available to service route 6, and so bus 3 is assigned to travel from the destination of route 3 (already assigned to it) to the origin of route 6 (that is, the assignment $x_{363} = 1$ is made). This, in turn, increases the deadheading distance objective function value in (2) by a further 5km, since $d_{36} = 5$, and the deadheading time objective function value in (9) by another 40 minutes, since $s_6 - e_3 = 40$.

This iterative assignment process is continued until all the routes have been assigned to be serviced by buses and all of the buses have been assigned to return to the depot. The result returned by the heuristic is summarised in Table 4. This solution utilises all four buses by design and, as may be seen in the table, achieves a deadheading distance objective function value in (2) of 135 km as well as a deadheading time objective function value in (9) of 370 min. The time spent on the road by the busiest bus objective function value in (12) is 124 min. Although the solution is feasible, it is not expected to be optimal in terms of any of the BRAP model objectives in (2), (9), (11) or (12). The solution may, nevertheless, be considered as a benchmark solution against which other solutions may be compared.

Table 4: Feasible solution to the hypothetical BRAP test instance returned by an intuitive heuristic, along with the associated objective function values in (2), (9) and (12)

Bus	Routes assigned	Deadheading distance (km)	Deadheading time (min)	Time on the road (min)
1	0, 1, 5, 9	5 + 20 + 20	10 + 40 + 26	116
2	0, 2, 7, 9	20 + 10 + 15	25 + 90 + 19	124
3	0, 3, 6, 9	10 + 5 + 10	15 + 40 + 13	118
4	0, 4, 8, 9	5 + 5 + 10	10 + 70 + 12	112
	Total, Total, Max:	135	370	124

We implemented the model (2)—(8) in ILOG's well-known optimisation suite CPLEX, which utilises the celebrated branch-and-cut algorithm to solve mixed-integer programming models. The optimal solution returned by CPLEX for the small, hypothetical BRAP test instance above is summarised in Table 5. This solution achieves a deadheading time objective function value in (9) of 100 km, which is a 25.9% improvement over the solution returned by the heuristic. This shows that a potentially much higher-quality solution to an instance of the BRAP is achievable when solving the model of Section 3 exactly in the context of deadheading distance minimisation instead of doing so by following a structured heuristic approach, such as the one above, even for unrealistically small problem instances.

Table 5: Optimal solution to the hypothetical BRAP test instance when minimising the total deadheading distance, along with the associated deadheading distances

Bus	Routes assigned	Deadheading distance (km)
1	0, 1, 6, 9	5 + 5 + 10
2	0, 4, 9	5 + 5
3	0, 2, 5, 8, 9	20 + 5 + 5 +10
4	0, 3, 7, 9	10 + 5 + 15
	Total:	100

The optimal solution returned by CPLEX for the model (3)─(8) and (9) in the context of the small, hypothetical BRAP test instance above is similarly summarised in Table 6. This solution achieves a deadheading time objective function value in (9) of 246 min, which is a 35.5% improvement over the solution returned by the heuristic. Again it would seem that a much higher-quality solution to an instance of the BRAP is achievable when solving the model of Section 3 exactly in the context of deadheading time minimisation instead of doing so by means of a structured heuristic approach.

Table 6: Optimal solution to the hypothetical BRAP test instance when minimising the total deadheading time, along with the associated deadheading times

Bus	Routes assigned	Deadheading time (min)
1	0, 7, 9	20 + 19
2	0, 3, 9	15 + 12
3	0, 2, 4, 6, 9	25 + 20 + 20 + 13
4	0, 1, 5, 8, 9	10 + 40 + 40 + 12
	Total:	246

The optimal solution returned by CPLEX for the model (3)─(8) and (11) in the context of the small, hypothetical BRAP test instance above is summarised in Table 7. This solution achieves a number of unused buses objective function value in (11) of 1. The solution therefore utilises only three buses, which is a 25% improvement over the solution returned by the heuristic. This comparison would, however, seem to be unfair, because the heuristic utilises all available buses by design. Yet being able to save on the number of buses required at a depot constitutes a very significant saving on fixed cost and may hence be a very desirable objective.

Table 7: Optimal solution to the hypothetical BRAP test instance when minimising the number of buses utilised

Bus	Routes assigned
1	0, 1, 4, 6, 9
2	0, 9 (*i.e.* bus not used)
3	0, 2, 5, 8, 9
4	0, 3, 7, 9

The optimal solution returned by CPLEX for the model (3)—(8) and (12) in the context of the small, hypothetical BRAP test instance above is finally summarised in Table 8. This solution achieves a time spent on the road by the busiest bus objective function value in (12) of 124 min, which is on par with the the solution returned by the heuristic. The optimality reached in this respect by the heuristic is, however, only accidental and is due to the unrealistic small size of the hypothetical BRAP test instance. In general, we expect the model (3)—(8) and (12) to be able to outperform the heuristic in terms of the time spent by the busiest bus on the road.

Table 8: Optimal solution to the hypothetical BRAP test instance when minimising the time spent on the road by the busiest bus, along with the associated times spent on the road by all the buses

Bus	Routes assigned	Time on the road (min)
1	0, 1, 9	19
2	0, 3, 6, 9	118
3	0, 2, 7, 9	124
4	0, 5, 8, 9	87
	Max:	124

We finally also solved above small hypothetical BRAP test instance exhaustively by generating all feasible bus-to-route assignment combinations in Wolfram's Mathematica by brute force and recording the optimal combinations for each of the objective functions (2), (9), (11) and (12). In this way, we found that of a total of $4^8 = 65536$ possible bus-to-route assignment combinations, only $1\,536$ are feasible (in the sense of assigning compatible route combinations to each bus). Of these $1\,536$ feasible solutions, only 48 were found to be optimal in terms of minimising the total deadheading distance. All 48 of these optimal solutions achieved a deadheading distance objective function value in (2) of $z = 100\text{ km}$, thereby validating the optimal value of this objective returned by CPLEX in the solution of Table 5. The actual solution returned by CPLEX was indeed among these 48 optimal solutions. It was therefore verified that the model implementation of Section 3 was able to solve the BRAP test instance correctly and exactly. The same 48 optimal solutions alluded to above, each also yielded a deadheading time objective function value in (9) of $z = 246\text{ min}$, thereby validating the optimal value of this objective returned by CPLEX in the solution of Table 6.

The optimality of the solution in Table 7 returned by CPLEX when attempting to minimise the number of buses utilised was also confirmed by the brute force enumeration process. We found that of the 1 536 feasible solutions to the test instance, a total of 96 are optimal in terms of minimising the number of buses utilised in (11), and in each of these solutions, three buses were utilised.

The optimality of the solution in Table 8 returned by CPLEX when attempting to minimise the the time spent on the road by the busiest bus in (12) was similarly confirmed by the brute force enumeration process. We also found that 96 of the 1 536 feasible solutions are optimal in this sense, and in each of these solutions, the busiest bus spends exactly 124 minutes on the road.

A brute-force exhaustive search, such as the one carried out above for verification purposes, would, of course, not be feasible in the context of a large, real-world instance of the BRAP. In such cases one would have to rely solely on the (verified) branch-and-cut solution process launched by the CPLEX optimisation suite when solving the models of Section 3.

5 VALIDATION CASE STUDY

The mathematical models of Section 3 were also validated by applying them to a case study involving the routes serviced from one of GABS's depots, its Simon's Town Depot. This depot services a total of 115 routes (these routes and their attributes may be found in Appendix A). The route attributes include the *geographical positioning system* (GPS) coordinates of the origin and destination stops of each route, as well as its scheduled departure time from the route's origin stop and the arrival time at its destination stop.

A *subject matter expert* (SME) was consulted to validate whether the model posseses the required level of spohisitication to represent the real underlying system with reasonable accuracy. The SME selected to perform expert face validation was Mr Gideon Neethling [6]. He completed his Bachelor's degree in industrial engineering in 1989 at Stellenbosch University, and later obtained a Master's degree in Business Administration at Stellenbosch University's Business School. Mr Neethling was chosen as SME because he has extensive experience in business processes, especially with respect to cost minimisation efforts at GABS.

In order to evaluate the utilisation effectiveness of the twelve buses GABS currently has allocated to its Simon's Town Depot, the model objective of minimising the number of buses in (11) was selected. The minimum number of buses required for this particular instance of the BRAP was found to be eleven. This means that the strategic decision to allocate twelve buses to the Simon's Town Depot is perhaps good in view of the fact that there will be an extra bus available over and above the minimum number required, in the case of a breakdown.

When minimising the deadheading distance in (2) with eleven buses available, the minimum deadheading distance was found to be 476.87 km. When increasing the number of buses to twelve, however, the minimum deadheading distance decreased slightly to 473.62 km. This value remained constant thereafter as the number of buses was further increased from 12 to 25. It is therefore evident, from the perspective of minimising deadheading distance, that assigning twelve buses to the Simon's Town depot would seem appropriate. It was interesting to note that the assignment actually implemented at GABS achieved a total deadheading distance of 3 247 kilometres when twelve buses are utilised at the Simon's Town depot [5]. The model consequently showed that an 84.85% improvement on the current deadheading distance incurred at the Simon's Town depot is possible when assigning buses to routes more carefully. It would, however, be unfair to attempt to equate the improvement in the quality of the bus-to-route assignment achieved by the model (2)—(8) over the *status quo* at GABS to a potential annual saving of R 44 383 000 if implemented, based on a cost estimate by the SME. This is because the minimisation of the total deadheading distance was, in all likelihood, not the (sole) objective of the scheduler at the Simon's Town depot. Additional objectives and/or constraints may also have played a role in the bus-to-route assignment actually implemented at the depot, such as a requirement that a bus had to return to the depot after it had been on the road for a number of hours in order to avoid driver fatigue.

The high quality of the bus-to-route assignment returned by the model is nevertheless an indication of inefficiency of the *status quo* at the Simon's Town depot of GABS (in terms of total deadheading distance). The SME was impressed by the small deadheading distance that is achievable, viewing it as a benchmark against which future bus-to-route assignments can be measured, when pursuing other assignment goals in addition to the minimisation of total deadheading distance and/or adhering to upper limit constraints on the time that a bus can spend on the road. The SME also attested to the potential value that the model could add to bus-to-route assignment decisions that are made at the various other GABS depots.

Data on the deadheading time and the time spent on the road by the busiest bus were, unfortunately, not available. Similar comparisons between the *status quo* and the pursuit of the objectives in (9) and (12) were therefore not possible.

When minimising the total deadheading time if eleven buses were to be allocated to the Simon's Town depot, the smallest possible deadheading time was found to be 3 985.02 min. This value decreased by 12.72% to 3 478.07 min if twelve buses were instead allocated to the Simon's Town depot. The minimum deadheading time continued to decrease smoothly as the number of buses was further increased from 12 to 21. As may be seen in Figure 1, however, there is no significant subsequent decrease in the minimum total deadheading time when increasing the number of buses further from 21 onwards. It would therefore seem that if the objective were to minimise the total deadheading distance, twenty one buses would be an appropriate allocation to the Simon's Town Depot.

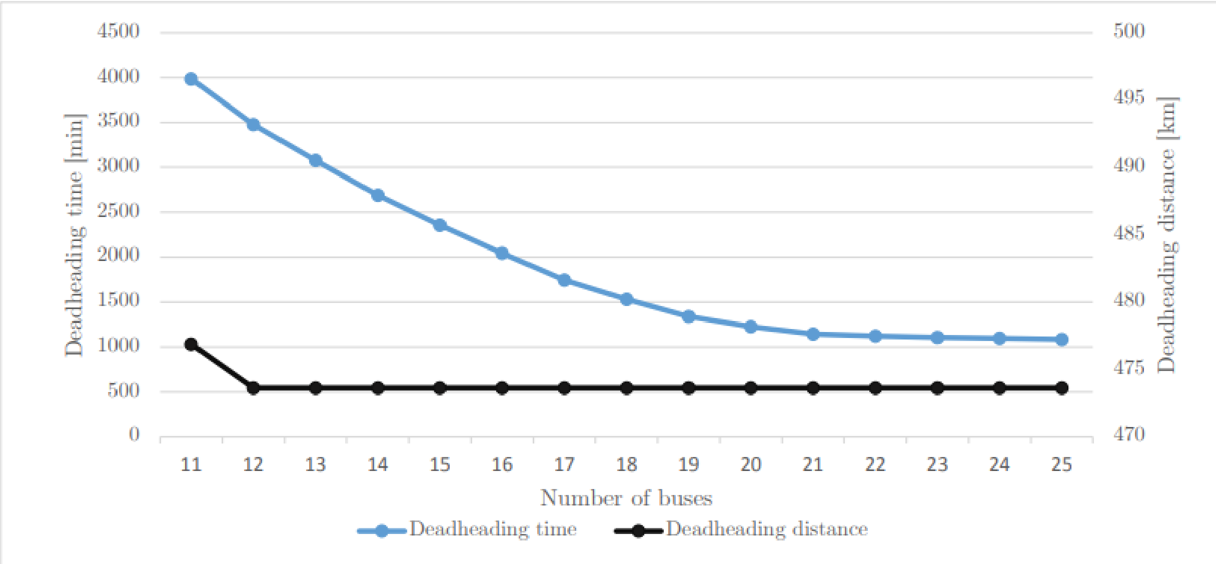

Figure 2: Pareto fronts obtained when minimising the deadheading distance as a function of the number of buses available for the case study instance of the BRAP

Finally, when minimising the time spent on the road by the busiest bus in (12), the smallest possible upper bound on the round-trip time of any bus was found to be 756.38 min (*i.e.* 12.61 hours) if eleven buses were to be allocated to the Simon's Town depot.

6 COMPUTATIONAL BURDEN OF THE BRAP

When attempting to minimise in the total deadheading distance in (2), the total deadheading time in (9), or the total number of buses utilised in (11) within the context of GABS's Simon's Town Depot instance of the BRAP, the optimal solutions presented in the previous section could each be computed by the branch-and-cut method (implemented in ILOG's CPlex 12.9) in less than ten minutes on an Intel Core i5 processor with 4Gb RAM running at a speed of 2.6 GHz in a Windows 10.1 operating system, executed in four parallel threads.

When minimising the time spent on the road by the busiest bus in (12), however, an optimal solution could only be computed in 11.62 hours (in the case of eleven buses being allocated to the Simon's Town Depot). When pursuing the same objective with twelve or more buses, optimal solutions could not be computed within a period of fifteen hours. It is therefore evident that the introduction of the additional variables y_{ijk} in (13)—(14) increases the model complexity by a significant margin.

7 CONCLUSION

A mathematical model was proposed in this paper for solving instances of the BRAP experienced at GABS when pursuing any of the four route-to-bus assignment objectives mentioned in the introduction. The utility of the model was showcased in the case study of Section 5 for one of the smaller depots of GABS. The model could be used to confirm that a sensible number of buses had indeed been assigned to the depot in question, while demonstrating that, when attempting to minimise the total deadheading distance or time, better than the current decision choices are available.

For a feasible number of buses assigned to a depot, the model can also be used to render bus-to-route assignments more equitable to drivers in terms of minimising the time spent on the road by the busiest bus. The computational cost of pursuing this bus-to-route assignment objective was, however, shown to be considerably more than when attempting to minimise deadheading distance/time or when minimising the total number of buses allocated to a depot. Given that the Simon's Town Depot, selected for this pilot study, is a relatively small GABS depot (the buses allocated to some of the company's other, larger depots number into the hundreds, while the routes serviced there number into the thousands), further investigation is warranted into whether the model will remain exactly solvable when pursuing any of the route-to-bus assignment objectives in the case of a large GABS depot. It may, in fact, be necessary rather to adopt a metaheuristic model solution approach for large BRAP instances.

Finally, a number of practical bus-to-route assignment constraints have yet to be included into the model in order to improve its realism, such as that:

1. Divers should not be required to service routes over a period of more than five hours consecutively, without being assigned a lunch break (drivers do not have to return to the depot in order to take such a break),
2. drivers should not be assigned routes that would take them on round-trips of more than eight hours in total duration away from the depot, and
3. it should be possible for buses to depart more than once from the depot per day (upon having experienced a change of drivers), thus introducing a driver-to-bus assignment element to the BRAP.

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APPENDIX

The routes serviced from the Simon's Town depot of GABS, along with their various attributes, can be found in Table 9. These routes were used to conduct the validation case study of Section 5.

Table 9: The attributes of routes serviced from the Simon's Town depot of GABS, as considered for the BRAP instance of the validation case study of Section 5

Route	Origin	Destination	Departure time	Arrival time	Kms	GPS Origin	GPS Destination
0	DEPOT	DEPOT	0	0	0	−34.1795,18.4250	−34.1795,18.4250
1	OCEAN VIEW S.A.P.	SIMONSTOWN DEPOT	240	300	32.8	−34.1442,18.3459	−34.1795,18.4250
2	OCEAN VIEW	FISH HOEK	285	305	13.7	−34.1429,18.3524	−34.1364,18.4324
3	FISH HOEK	OCEAN VIEW	305	370	13.7	−34.1364,18.4324	−34.1429,18.3524
4	OCEAN VIEW	FISH HOEK	320	345	13.7	−34.1429,18.3524	−34.1364,18.4324
5	OCEAN VIEW	JUBILEE SQUARE	330	330	16.7	−34.1429,18.3524	−34.1933,18.4330
6	OCEAN VIEW	CITY	345	455	40.2	−34.1429,18.3524	−33.9244,18.4254
7	FISH HOEK	MUIZENBERG	345	360	6.1	−34.1364,18.4324	−34.1164,18.4616
8	OCEAN VIEW	MURDOCH VALLEY	355	390	21.3	−34.1429,18.3524	−34.2076,18.4588
9	OCEAN VIEW	FISH HOEK	355	395	13.7	−34.1429,18.3524	−34.1364,18.4324
10	MUIZENBERG	FISH HOEK	360	370	5.5	−34.1164,18.4616	−34.1364,18.4324
11	OCEAN VIEW	MURDOCH VALLEY	370	400	21.3	−34.1429,18.3524	−34.2076,18.4588
12	PERDEKLOOF	DA GAMA PARK	370	390	7.2	−34.2054,18.4061	−34.1602,18.4289
13	FISH HOEK	OCEAN VIEW	370	385	13.7	−34.1364,18.4324	−34.1429,18.3524
14	OCEAN VIEW	FISH HOEK	375	400	13.7	−34.1429,18.3524	−34.1364,18.4324
15	OCEAN VIEW	MURDOCH VALLEY	385	425	21.3	−34.1429,18.3524	−34.2076,18.4588
16	OCEAN VIEW	MURDOCH VALLEY	385	425	21.3	−34.1429,18.3524	−34.2076,18.4588
17	MURDOCH VALLEY	OCEAN VIEW	390	420	19.5	−34.2076,18.4588	−34.1429,18.3524
18	DA GAMA PARK	MURDOCH VALLEY	390	490	13.5	−34.1602,18.4289	−34.2076,18.4588
19	FISH HOEK	NOORDHOEK	395	420	9.5	−34.1364,18.4324	−34.1171,18.3876
20	MURDOCH VALLEY	OCEAN VIEW	400	425	19.5	−34.2076,18.4588	−34.1429,18.3524
21	FISH HOEK	KOMMETJIE	400	425	15	−34.1364,18.4324	−34.1403,18.3286
22	OCEAN VIEW	MURDOCH VALLEY	400	440	21.3	−34.1429,18.3524	−34.2076,18.4588
23	OCEAN VIEW	FISH HOEK	410	450	13.7	−34.1429,18.3524	−34.1364,18.4324
24	OCEAN VIEW	SEA FORTH SCH	420	465	19	−34.1429,18.3524	−34.1975,18.4464
25	NOORDHOEK	FISH HOEK	420	445	10.6	−34.1171,18.3876	−34.1364,18.4324
26	OCEAN VIEW	SEA FORTH	425	470	33.6	−34.1429,18.3524	−34.1959,18.4455
27	MURDOCH VALLEY	OCEAN VIEW	425	450	19.9	−34.2076,18.4588	−34.1429,18.3524
28	MURDOCH VALLEY	FISH HOEK	425	475	19.4	−34.2076,18.4588	−34.1364,18.4324
29	KOMMETJIE	SEA FORTH	425	490	20.5	−34.1403,18.3286	−34.1959,18.4455
30	MURDOCH VALLEY	OCEAN VIEW	440	480	26.1	−34.2076,18.4588	−34.1429,18.3524
31	FISH HOEK	NOORDHOEK	445	510	12.8	−34.1364,18.4324	−34.1171,18.3876
32	OCEAN VIEW	FISH HOEK	450	495	17.8	−34.1429,18.3524	−34.1364,18.4324
33	SEA FORTH SCH	MURDOCH VALLEY	465	475	2.4	−34.1975,18.4464	−34.2076,18.4588
34	MURDOCH VALLEY	FISH HOEK	475	490	7.5	−34.2076,18.4588	−34.1364,18.4324
35	OCEAN VIEW	MURDOCH VALLEY	480	535	19.7	−34.1429,18.3524	−34.2076,18.4588
36	OCEAN VIEW	FISH HOEK	490	525	17.8	−34.1429,18.3524	−34.1364,18.4324
37	FISH HOEK	OCEAN VIEW	490	515	10.4	−34.1364,18.4324	−34.1429,18.3524
38	OCEAN VIEW	NOORDHOEK	490	555	13.7	−34.1429,18.3524	−34.1171,18.3876
39	FISH HOEK	NOORDHOEK	500	530	9.5	−34.1364,18.4324	−34.1171,18.3876
40	OCEAN VIEW	MURDOCH VALLEY	515	575	23.2	−34.1429,18.3524	−34.2076,18.4588
41	FISH HOEK	OCEAN VIEW	525	555	17.8	−34.1364,18.4324	−34.1429,18.3524
42	FISH HOEK	KOMMETJIE	535	580	22.2	−34.1364,18.4324	−34.1403,18.3286
43	OCEAN VIEW	FISH HOEK	555	585	17.8	−34.1429,18.3524	−34.1364,18.4324
44	KOMMETJIE	FISH HOEK	580	620	15.9	−34.1403,18.3286	−34.1364,18.4324
45	FISH HOEK	OCEAN VIEW	585	615	17.8	−34.1364,18.4324	−34.1429,18.3524

Table 9 (continued): The attributes of routes serviced from the Simon's Town depot of GABS, as considered for the BRAP instance of the validation case study of Section 5

Route	Origin	Destination	Departure time	Arrival time	Kms	GPS Origin	GPS Destination
46	OCEAN VIEW	FISH HOEK	615	645	17.8	−34.1429,18.3524	−34.1364,18.4324
47	FISH HOEK	OCEAN VIEW	645	670	17.8	−34.1364,18.4324	−34.1429,18.3524
48	OCEAN VIEW	FISH HOEK	670	695	17.8	−34.1429,18.3524	−34.1364,18.4324
49	FISH HOEK	OCEAN VIEW	705	735	17.8	−34.1364,18.4324	−34.1429,18.3524
50	OCEAN VIEW	FISH HOEK	735	765	7.8	−34.1429,18.3524	−34.1364,18.4324
51	JUBILEE SQUARE	FISH HOEK	750	765	6.7	−34.1933,18.4330	−34.1364,18.4324
52	FISH HOEK	OCEAN VIEW	765	795	17.8	−34.1364,18.4324	−34.1429,18.3524
53	FISH HOEK	NOORDHOEK	790	810	10.7	−34.1364,18.4324	−34.1171,18.3876
54	FISH HOEK SCH	OCEAN VIEW	790	840	34.2	−34.1975,18.4464	−34.1429,18.3524
55	FALSE BAY COLLEGE	MURDOCH VALLEY	790	860	19.5	−34.1084,18.4678	−34.2076,18.4588
56	KOMMETJIE	FISH HOEK	800	825	13.5	−34.1403,18.3286	−34.1364,18.4324
57	NOORDHOEK	FISH HOEK	810	830	6.5	−34.1171,18.3876	−34.1364,18.4324
58	FISH HOEK	OCEAN VIEW	825	855	17.8	−34.1364,18.4324	−34.1429,18.3524
59	FISH HOEK SCH	NOORDHOEK	845	930	16.5	−34.1975,18.4464	−34.1171,18.3876
60	OCEAN VIEW	FISH HOEK	855	885	17.8	−34.1429,18.3524	−34.1364,18.4324
61	SEA FORTH SCH	SITE 5 CROSSRDS	855	900	30.9	−34.1975,18.4464	−34.1326,18.3826
62	FISH HOEK	NOORDHOEK	860	880	10.7	−34.1364,18.4324	−34.1171,18.3876
63	SEA FORTH SCH	DA GAMA PARK	860	880	7.6	−34.1975,18.4464	−34.1602,18.4289
64	SEA FORTH SCH	OCEAN VIEW	860	900	21.3	−34.1975,18.4464	−34.1429,18.3524
65	NOORDHOEK	FISH HOEK	880	915	6.5	−34.1171,18.3876	−34.1364,18.4324
66	DA GAMA PARK	SIMONSTOWN	880	890	8.5	−34.1602,18.4289	−34.1865,18.4250
67	FISH HOEK	OCEAN VIEW	885	915	17.8	−34.1364,18.4324	−34.1429,18.3524
68	FISH HOEK SCH	KOMMETJIE	885	920	15.2	−34.1975,18.4464	−34.1403,18.3286
69	SIMONSTOWN	MURDOCH VALLEY	890	900	5.2	−34.1865,18.4250	−34.2076,18.4588
70	FISH HOEK SCH	DA GAMA PARK	890	930	8.8	−34.1975,18.4464	−34.1602,18.4289
71	FISH HOEK SCH	OCEAN VIEW	900	920	17.7	−34.1975,18.4464	−34.1429,18.3524
72	MURDOCH VALLEY	OCEAN VIEW	900	945	19.5	−34.2076,18.4588	−34.1429,18.3524
73	OCEAN VIEW	SEA FORTH SCH	900	930	19	−34.1429,18.3524	−34.1975,18.4464
74	FISH HOEK	KOMMETJIE	915	960	15	−34.1364,18.4324	−34.1403,18.3286
75	OCEAN VIEW	FISH HOEK	915	945	7.4	−34.1429,18.3524	−34.1364,18.4324
76	OCEAN VIEW	NOORDHOEK	920	940	13.7	−34.1429,18.3524	−34.1171,18.3876
77	SEA FORTH SCH	OCEAN VIEW	930	975	26.8	−34.1975,18.4464	−34.1429,18.3524
78	NOORDHOEK	FISH HOEK	930	955	6.5	−34.1171,18.3876	−34.1364,18.4324
79	SIMONSTOWN	MURDOCH VALLEY	940	960	5.2	−34.1865,18.4250	−34.2076,18.4588
80	FISH HOEK	OCEAN VIEW	940	960	10.4	−34.1364,18.4324	−34.1429,18.3524
81	FISH HOEK	MURDOCH VALLEY	955	960	11.4	−34.1364,18.4324	−34.2076,18.4588
82	KOMMETJIE	FISH HOEK	960	1000	13.9	−34.1403,18.3286	−34.1364,18.4324
83	MURDOCH VALLEY	OCEAN VIEW	960	995	26.6	−34.2076,18.4588	−34.1429,18.3524
84	OCEAN VIEW	JUBILEE SQUARE	960	1000	16.7	−34.1429,18.3524	−34.1933,18.4330
85	FISH HOEK	NOORDHOEK	965	985	10.7	−34.1364,18.4324	−34.1171,18.3876
86	NOORDHOEK	OCEAN VIEW	970	1005	13.6	−34.1171,18.3876	−34.1429,18.3524
87	FISH HOEK	OCEAN VIEW	975	1035	17.8	−34.1364,18.4324	−34.1429,18.3524
88	OCEAN VIEW	TOP STONES FACTORY	980	1015	13.8	−34.1429,18.3524	−34.1711,18.4261
89	NOORDHOEK	FISH HOEK	985	1015	6.5	−34.1171,18.3876	−34.1364,18.4324
90	OCEAN VIEW	PICK 'N PAY	995	1030	7.2	−34.1429,18.3524	−34.1229,18.3907
91	MURDOCH VALLEY	OCEAN VIEW	995	1030	26.1	−34.2076,18.4588	−34.1429,18.3524
92	FISH HOEK	OCEAN VIEW	1000	1025	17.5	−34.1364,18.4324	−34.1429,18.3524

Table 9 (continued): The attributes of routes serviced from the Simon's Town depot of GABS, as considered for the BRAP instance of the validation case study of Section 5

Route	Origin	Destination	Departure time	Arrival time	Kms	GPS Origin	GPS Destination
93	JUBILEE SQUARE	OCEAN VIEW	1000	1030	16.7	−34.1933,18.4330	−34.1429,18.3524
94	MURDOCH VALLEY	DA GAMA PARK	1000	1040	10.1	−34.2076,18.4588	−34.1602,18.4289
95	TOP STONES FACTORY	OCEAN VIEW	1015	1045	12.6	−34.1711,18.4261	−34.1429,18.3524
96	OCEAN VIEW	SEA FORTH	1025	1045	23.6	−34.1429,18.3524	−34.1959,18.4455
97	PICK 'N PAY	OCEAN VIEW	1030	1090	7.1	−34.1229,18.3907	−34.1429,18.3524
98	OCEAN VIEW	FISH HOEK	1030	1055	7.4	−34.1429,18.3524	−34.1364,18.4324
99	FISH HOEK	OCEAN VIEW	1035	1095	17.8	−34.1364,18.4324	−34.1429,18.3524
100	CITY GOLDEN ACRE D LANE	OCEAN VIEW	1040	1135	40.2	−33.9244,18.4254	−34.1429,18.3524
101	DA GAMA PARK	FISH HOEK	1040	1060	8.9	−34.1602,18.4289	−34.1364,18.4324
102	SEA FORTH	SIMONSTOWN	1045	1055	3.1	−34.1959,18.4455	−34.1865,18.4250
103	OCEAN VIEW	JUBILEE SQUARE	1045	1075	16.7	−34.1429,18.3524	−34.1933,18.4330
104	SUN VALLEY MALL (PNP)	FISH HOEK	1050	1070	7.7	−34.1229,18.3907	−34.1364,18.4324
105	SIMONSTOWN	OCEAN VIEW	1055	1080	15.7	−34.1865,18.4250	−34.1429,18.3524
106	FISH HOEK	OCEAN VIEW	1055	1080	10.4	−34.1364,18.4324	−34.1429,18.3524
107	FISH HOEK	NOORDHOEK	1065	1080	10.7	−34.1364,18.4324	−34.1171,18.3876
108	FISH HOEK	OCEAN VIEW	1070	1090	10.4	−34.1364,18.4324	−34.1429,18.3524
109	JUBILEE SQUARE	SIMONSTOWN	1075	1080	1.2	−34.1933,18.4330	−34.1865,18.4250
110	SIMONSTOWN	PERDEKLOOF	1080	1110	9.2	−34.1865,18.4250	−34.2054,18.4061
111	OCEAN VIEW	FISH HOEK	1080	1105	7.4	−34.1429,18.3524	−34.1364,18.4324
112	PICK 'N PAY	OCEAN VIEW	1090	1115	7.1	−34.1229,18.3907	−34.1429,18.3524
113	FISH HOEK	OCEAN VIEW	1095	1195	17.8	−34.1364,18.4324	−34.1429,18.3524
114	FISH HOEK	OCEAN VIEW	1105	1125	10.4	−34.1364,18.4324	−34.1429,18.3524
115	FISH HOEK	OCEAN VIEW	1120	1145	10.4	−34.1364,18.4324	−34.1429,18.3524
116	DEPOT	DEPOT	1440	1440	0	−34.1795,18.4250	−34.1795,18.4250

LEAN MANUFACTURING IN ADDITIVE MANUFACTURING

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ABSTRACT

The papers main focus was to find out the extent which lean principles are applied in additive manufacturing. The research question was to find out the extent which lean principles are applied in Additive Manufacturing. The literature review revealed that there is little done on the application of lean. Within the publications available it was found that many articles only highlighted the similarities between Lean Manufacturing principles and the additive manufacturing technology. It was revealed that additive manufacturing is still a developing technology and more work needs to be done to improve its efficiency. The research also revealed that more research still needs to be done the on application of lean principles in additive manufacturing. The application of lean principles in additive manufacturing is vital in ensuring the technology is efficient.

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1 INTRODUCTION

Lean manufacturing was derived from Toyota and the term was coined by John Krafcik in 1988. Today lean manufacturing is implemented in the manufacturing industry. Lean manufacturing is manufacturing with the intent to eliminate waste [1] [2]. The research paper sought to assess the extent which it has been adopted though a systematic literature review. The systematic literature review critically analyses the adaptation of lean manufacturing from 2017 to 2021. Lean manufacturing is a continuous process in manufacturing and can be applied in additive manufacturing [3]. Additive manufacturing techniques are rapidly improving and in some cases change and thus a methodology to ensure that waste is eliminated while the technology is improving is needed. Materials in additive manufacturing are expensive to manufacture and extract and thus eliminating their waste is important in ensuring the economic sustainability of additive manufacturing.

The initial purpose of the research was to find out the extent of application of lean principles in spheroidisation of titanium alloy. The initial searches yielded no results and thus the research was adjusted to include additive manufacturing. The purpose of the paper is to identify the possible gaps in additive manufacturing specifically spheroidisation of titanium alloy. Spheroidisation falls within the value stream of additive manufacturing and thus by knowing the extent which lean has been applied in additive manufacturing the researchers will have a bench mark to start from in conducting future research in the additive manufacturing sector. Spheroidisation is an integral part of additive manufacturing which ensures that additive manufacturing produces little wasted powder. Spheroidisation is a reconditioning technique that reconditions used metal powder by reshaping and removing impurities so that the powder can be reused [4]. The search for lean manufacturing in spheroidisation of metal powder yielded no results and that is the reason why the focus was shifted towards additive manufacturing. Lean manufacturing can greatly improve the additive manufacturing process though it was found that many of the article only highlight the similarities between lean and additive manufacturing which are also discussed in the article [5].

2 METHODOLOGY FOR THE REVIEW

A systematic literature review was used to conduct the research. A systematic literature review is a research method which seeks to answer a formulated research question systematically. The aim is to find relevant research on a particular research question [6]. The steps taken to conduct the review are:

1. Develop the research question
2. Develop search strategies.
3. Develop an inclusion and exclusion criteria
4. Select the studies to be review
5. Extract the data
6. Analyse the data
7. Interpret the results

The researchers had a goal to find out the extent to which lean manufacturing was applied in additive manufacturing. Lean manufacturing is the topic to be researched on. Within additive manufacturing lean principles care also found but the research also sought to find out how manufacturing are applying lean manufacturing directly in additive manufacturing.

To what extent is lean manufacturing applied in additive manufacturing?

A search was done on Scopus to find out the extent to which lean has been applied in additive manufacturing. Scopus is the preferred data base as it one of the biggest data bases worldwide. It also has a wide availability of journals and research articles with more than 80 million records and 30000 journals to date. Table 1 shows the results from Scopus. A case study was also used to highlight the similarities between lean manufacturing and additive manufacturing. A case study is an in-depth examination of a particular scenario or events in a real world context [7]. The case study analysed data from real world scenarios in additive manufacturing and the case selected was the optimisation of an aircraft bracket. This was done to further elaborate the finding in the systematic literature review.

2.1 Selection of journals

The journals selected had to include an additive manufacturing related topic. The abstract were also read to ensure that the article was related to additive manufacturing. From the additive manufacturing related articles only the ones related to lean manufacturing were selected. The specific terms searched for were

- Additive manufacturing
- 3D printing

From the articles with additive manufacturing related topics in their titles and abstracts, the ones with lean manufacturing related keywords were selected for analyses. The primary search term is additive manufacturing 3D printing, and selective laser melting. The secondary term was lean manufacturing. Only articles from 2017 to 2021 were used for the research.

Table 1: Search Terms and Topics

Topic	Search term	Filters	Number of Articles	Relevant Papers
Lean Manufacturing in Additive Manufacturing	Additive Manufacturing AND Lean Manufacturing	Year 2017 -2021	335	13

From the Scopus search only relevant 14 journals where found of which only 5 were related to lean manufacturing and additive manufacturing. Most of the journals were literature reviews. There is still much research to be done with regard to lean manufacturing in additive manufacturing. Additive manufacturing is still a growing technology and there is still room for improvement and thus there is need to keep researching on how it can be improved. Though many of the articles include lean within additive manufacturing they only highlight the similarities between lean manufacturing and additive manufacturing.

2.2 Findings in the literature

From literature and observation there is an overlap between lean manufacturing principles and the additive manufacturing technique [5] [8] [9] [10]. There is little reference within the literature to industry applying lean in additive manufacturing. Many articles highlight the similarities between lean manufacturing and additive manufacturing [11] [12] [13]. It was found that additive technology produces less waste than conventional manufacturing though it’s layer by layer manufacturing technique. Literature reviews that highlight the similarities between additive manufacturing and lean manufacturing have been done. From the articles each lean principle was compared to additive manufacturing and the extent which it was similar to additive manufacturing [8] [9] [10] [14] [15].

2.3 Overview of Lean manufacturing and additive manufacturing

As highlighted lean manufacturing and additive manufacturing are similar and this section aims to give an understanding of the similarities [11] [12]. Each lean principle is discussed in relation to additive manufacturing.

2.3.1 Five principles of lean manufacturing

Lean manufacturing follows principles that give a guide in its implementation which are:

1. Identify what the customer perceives as value. The customer defines the value which the producer must thrive to produce. This can help the producer focus on activities that add value for the customer and also determine what the customer is paying for. The business can eliminate the activities that do not add value for the customer [16].

2. The second phase is to map the value stream, which means analysing the flow of information and materials. This involves mapping the products life from extraction to end user and disposal. Each stage of the lifecycle of the product must be evaluated and analysed[17].

3. The third stage is to establish flow which entails eliminating disturbances and interruptions to flow [18].

4. Establish a pull system by ensuring work is done when it is needed. This is called just in time.

5. Ensure continuity by continuously improving the process [19].

2.3.2 The seven wastes of lean production

Seven wastes were highlighted by the Toyota production system which are:

1. unnecessary transportation;
2. excess inventory;
3. unnecessary motion of people, equipment or machinery;
4. waiting, whether it is people waiting or idle equipment;
5. over-production of a product;
6. over-processing or putting more time into a product than a customer needs, such as designs that require high-tech machinery for unnecessary features; and
7. defects, which require effort and cost for corrections [20].

2.3.3 Seven lean manufacturing tools and concepts

Other important concepts and processes lean relies on include:

1. Heijunka is production levelling or smoothing that allows for continuous flow of production, releasing work to a station at the required rate and avoiding disruptions [21].
2. 5S is a set of practices for organising environments to create efficient, effective and safe workspaces for workers preventing wasted effort and time. 5S emphasizes workspace organization and cleanliness [22].
3. Kanbanis a signal used to streamline processes.Kanban also facilitates creation of just-in-time delivery. The signals are either physical, such as a tag or empty bin, can be electronically sent through a system[23].
4. Jidoka is a method that defines an outline for detecting abnormalities within the system.When the abnormalities are detected the work is stopped until they are detected then the root causes are detected [19].
5. Andonisa visual aid that alerts workers to a problem. This can be in the form of a flash light. [2].
6. Poka-yoke isa mechanism for safeguarding against human error which can be in the form of an indicator light that turns on if an important step is missed. The system may block a preceding step until a previous step is completed [24].
7. Cycle time is the time it takes to produce a part or complete a task [2].

2.4 Similarities in lean manufactruing and additive manufacturing

Table 2 summarises the overlap and similaritites between lean manufactruing and additive manufactruing.

Table 2: Comparison of lean manufacturing and Additive Manufacturing benefits[25]

Category of waste	Lean Manufacturing			Additive Manufacturing		
	Jobbing	**Batch**	**Mass**	**Jobbing**	**Batch**	**Mass**
Defects	Minimal	Low	High	High	High	Low/Medium
Unnecessary inventory	Minimal	Low	High	High	High	Low/Medium
Waiting	Minimal	Low	High	High	High	Low/Medium
Transportation	Minimal	Low	High	High	High	Low/Medium
Inappropriate processing	Minimal	Low	High	High	High	Low/Medium
Over production	Minimal	Low	Medium	High	High	Low/Medium
Unnecessary motions	Minimal	Low	High	High	High	Low/Medium
Physical environment externality	Minimal	Low	Low/Medium	Medium	Medium	Low
Sustainability	Minimal	Low	Low/Medium	Medium	Medium	Low

From Table 2 there is an overlap between lean manufacturing and additive manufacturing. Additive manufacturing on its own produces less waste compared to subtractive manufacturing [5]. Table 1 show the comparisons of the impacts of lean manufacturing and additive manufacturing [25].The studies available are not conclusive on weather additive manufacturing can be improved to reduce waste and thus more studies need to be conducted. Additive manufacturing reuses powder from previous runs which makes it an efficient and economic process in terms of material usage [26] [27]. This trait of additive manufacturing makes it more efficient than subtractive manufacturing when it comes to material useage. Additive Manufacturing as an advanced manufacturing technique reduces the following waste as indicated:

- unnecessary transportation

With additive manufacturing, production can be decentralised and thus minimising transportation [11] [5].

- excess inventory

It can apply just in time manufacturing. With additive manufacturing only the parts needed are manufactured and thus inventory is reduced [28].

- unnecessary motion of people, equipment or machinery

With additive manufacturing the only action required is designing the part and setting the printer thus minimising human action. The motion that can be involved are loading raw material and calibrating machinery [24] [25].

- waiting, whether it is people waiting or idle equipment

Additve manufacturing can be done with no tool change over meaning waiting between processes is minimised [29].

- over-production of a product

As additive manufacturing is not suited for mass production the chances of over production are minimal [12].

- Overprocessing

In additive manufacturing the cost of over processing is not high because the cost making a part more complex in structure will not increase its cost of production [30].

- Defect
  Additive manufactruing still produces defects thus lean manufacturing principles still need to be applied to reduce defects in additive manufacturing [20].

Defects can still occur in additive manufacturing and this is where much work is to be done. Lean manufacturing can be applied in order to reduce defects in the printing process through constantly calibrating the process parameters to avoid deviation from required quality level [31]. Additive manucatuirng also has te potential to apply lean principles.

Table 3 shows how lean princles are applied in additive manufacturing with conventioanal manufatruing as a reference for comparison. From studies metal additive manufacturing can still be made more afficient through spheroidisation of the metal powder [32]. Spheroidisation is a reconditioning process that sprays powder through a plasma at high temperature typically 3000k – 10000k [30] [33].

Table 3: Lean Principles in Conventional Manufacturing and Additive manufacturing

Lean Principle	Conventional manufacturing	Additive manufacturing
Identifying customer needs [34] [22]	Identifies customer needs however customising for individual customers brings about additional costs.	Can meet customers' needs quicker and more accurately without additional costs [35] [36].
Mapping value stream [24] [21] [17]	In conventional manufacturing mapping the value stream is not easy as each time there is a need to make adjustments tooling is required.	Additive manufacturing is flexible and can make parts that are lighter and more complex than conventional manufacturing techniques and thus can ensure the product serves the customer more efficiently during its lifetime. This may include lighter parts on an aircraft thus saving fuel. Making adjustments during a product's life-cycle is easier in additive manufacturing as the cost is minimal [37].
Eliminating disturbances [19]	Interruptions to flow are high in conventional manufacturing especially in subtracting manufacturing.	Interruptions to flow are minimal as printing is a single process. The only disturbances that can occur are due to software errors and issues arising due to printer settings [19].
Just in time [24] [17]	In conventional manufacturing just in time manufacturing depends on the product made and the size of the batch. Making small batches in conventional manufacturing is costly thus there is a risk of overproduction and having excess products .	Can meet customer needs on a need basis. Additive manufacturing is suited for smaller batches thus goods can be made when they are needed [29].
Continuous improvement [19]	CNC, Casting and injection moulding take longer than additive manufacturing and thus can lengthen the product development process.	Additive Manufacturing allows for faster product development [38].

2.5 Decentralising manufacturing as a Lean principle

It was also observed that decentralisation of manufacturing was highlited in the articles found. Decentralisation of manufacturing can minimise transportation cost in production. The reduction of transport and movement is a fuction of lean manufacturing [11] [5]. With the need to produce highly customised products in the global market, manufacturing strategies to get the products closer to the customer at a fast pace is needed. The emergence of additive manufacturing has enabled decentralisation of manufacturing in the production of customised product [39]. Decentralising manufacturing has the advantages of high flexibility, close proximity to customers, better services on meeting customer demands which are all functions of lean manufacturing [26]. In decentralising manufacturing, information can be exchanged between manufacturer and customer faster which improves the ability of additive manufacturing to meet customer needs [38]. The lead time between the manufacturing and customer is also shortened and thus bringing better customer satisfaction. Communication is also easier and more efficient when manufacturing plants are bought closer to the consumer [40]. Employees also have freedom to impacts on the design of the product without need to seek approval from a centralised organisation thus can make improvements according to customers within a specific area [41]. Decentralisation is easy with additive manufacturing and thus can help bring about lean manufacturing. The decentralisation aspect of additive manufacturing also makes the manufacturing technology similar to lean manufacturing. To apply lean manufacturing in industry manufacturing technology must also meet customer demands as well and decentralisation allows for companies to meet customer needs in different regions of the world.

2.6 Minimising Material waste through spheroidisation

Powder from selective laser sintering eventually becomes unusable and thus needs to be reconditioned to prolong its use and reduce waste and thus can be done by spheroidisation. Spheroidisation is a valuable waste in additive manufacturing thus spheroidisation can be technique to apply lean manufacturing. significantly reduce waste in additive manufacturing [42]. The economic sustainability of the spheroidisation process has not yet been measured and thus needs to be validated . Spheroidisation is an integral part in lean manufacturing within additive manufacturing. Of the 7 wastes in manufacturing the waste of material is the main waste targeted by the process.

Additive manufacturing can cut out wear housing because in additive manufacturing there is little need to store the products [28]. The products can be made on demand and to the specifications of the customer without adding extra tooling cost [43] [44] [45]. Additive manufacturing can also disrupt the supply chain. In subtractive manufacturing there are multiple work stations, whereas in additive manufacturing there is only one work station which eliminates transportation costs [43]. Unnecessary motions are minimal in additive manufacturing because there is minimal physical labour. Defects can be minimal in additive manufacturing for small batches, but in mass production the technology may fail and produce multiple defects [12]. In small batches, additive manufacturing reduces time wasting because the technology is designed for customisation thus, can make different designs within a single job [44] [46] [47].

Additive manufacturing eliminates overproduction as the products can made on demand. This entails lean manufacturing techniques are within additive manufacturing thus lean is already applied within the technology [48]. The affect of over-processing is also minimised in additive manufacturing in that the machine is pre-programmed and in many cases high tolerances do not add significant cost to the product with the exception of more processing time [25].

With the overlaps identified the potential impact of lean manufacturing on additive manufacturing can be measured [9]. Lean manufacturing applied in additive manufacturing lifecycle can improve the profitability of additive manufacturing. Few studies have been conducted that apply lean manufacturing and additive manufacturing and thus there is need to conduct more studies [14].

2.6.1 *Case study : Selective Laser melting for a bracket*

Selective laser melting is an additive manufacturing technique which manufactures metal parts through layer-by-layer building of components. Selective laser melting is suitable for manufacturing small quantities of parts which can include spares on demand and parts with complex geometries . Selective laser melting can also make lighter parts which can save on material and reduce weight of parts [49] [50]. This is suitable in aerospace industry where reduction of weight is critical for reducing fuel consumption.

Figure 1 shows a bracket design stages of a bracket. Through additive manufacturing the volume of the part can be reduced to 37% [51]. With additive manufacturing the bracket can be made with a single printing process.

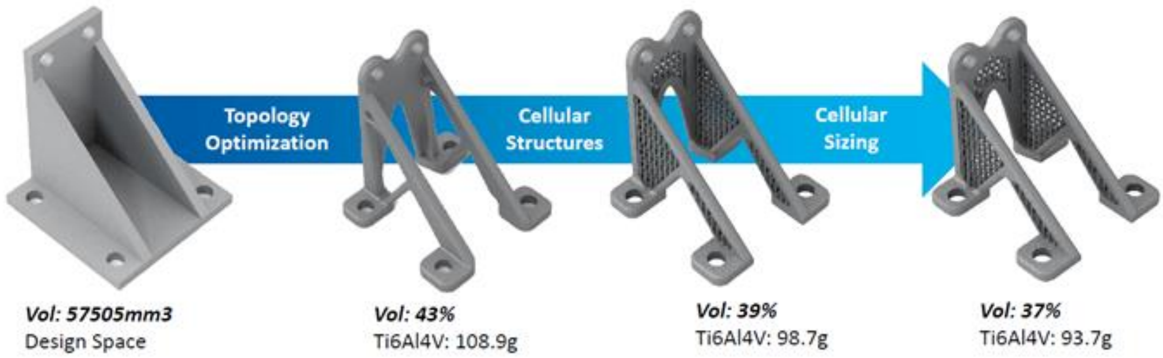

Figure 1: Part optimisation using additive manufacturing [51]

Additive manufacturing highlights its lean capabilities in the manufacture of the bracket in that:

- With additive manufacturing there is no drilling, milling, cutting, skilled, labour and minimum welding [5] [52] [30]. The drilling of the 6 holes is eliminated and there is no welding of the plates together.
- Material waste when making a part through CNC is high as 95% of the material is scrap and needs to be sent for re-melting [53] [54]. The coolants that are used in machining make the metal powder more difficult to extract.
- Some of the material in conventional manufacturing is difficult to recycle thus making it extremely wasteful. Additive manufacturing reduces this waste by a large margin due to its ability to reuse [27] material . Material waste is also eliminated by additive manufacturing through reducing the weight of the part.
- Transportation, of parts in conventional manufacturing need to be moved from machine to machine for different processes which is also time consuming but in additive manufacturing there is only one process even for complex parts [55].
- For machining, waiting is common especially when there are multiple machining processes and tool changes for different features in a part. With machining bottlenecks can occur if parts are produced in batches especially if there are processes that take longer than others [55].
- Unnecessary motion is common in machining, but is minimal in additive manufacturing as it is a single process for each part. Multiple parts can be made using additive manufacturing thus reducing multiple set up times [5].
- Over-production is not desirable as it can increase cost unnecessarily. Overproduction has the potential to produce parts that can end up obsolete as technology and designs keep changing. This entails only parts that are required are to be produced in additive manufacturing. Overproduction of parts can lead to inventory which is costly thus a method to minimise the inventory is needed. Excess inventory is minimised in additive manufacturing as the part is produced as customers order them.

2.7 Short comings of lean manufacturing in additive manufacturing

Additive manufacturing still has short comings in that it cannot be used for mass production and the size of the parts made is limited [41]. In selective laser melting the parts are not as strong as the parts made from conventional manufacturing and thus cannot be used in working conditions that require high fatigue strength [12] [46] [14]. Additive manufacturing is also expensive and thus is still not yet fully trusted in many industries [56] [36] [57]. The additive manufacturing technology is fairly new and in the future there is hope that the technology will produce parts of low cost and high quality. If lean principles are applied in additive manufctruing the potential to improve additive manufacturing efficiency is high. Litrearture has identified the similarities between additive manufacturing andlean manufacturing. More studies need to be focused on application of lean manufacturing in additive manufacturing.

Another disadvantage with additive manufacturing is that corrections to the product cannot be made once the printing has started. All measures and actions to ensure quality and accuracy should be made at the design stage and at the setting up of the printer [54]. For high volume production additive manufacturing is costly and thus it is not feasible for mass production [58] [54]. It also takes up a lot of time if multiple parts are to be printed as the technology cannot accommodate a large number of parts at the same time [58]. Dimensional accuracy is still not always guaranteed and in many cases parts require post processing to increase dimensional accuracy [54]. Lean manufactruing needs to be implemented in additive manufacturing as a manufacturing technique to improve on its consistency. Additive manufacturing can be a tool for lean manufacturing but more focus needs to be placed on implementing lean manufacturing techniques on the additive mnaufacturig technology. The spheroidisation technology can also be another tool for implementing lean manufacturing within additive manufacturing [4].

3 CONCLUSION

The researchers sought to find out the extent which lean manufacturing was applied in additive manufacturing. It was founfd that there was little done in application of lean principles in additive manufacturing. The researchers found that many articles just highlight the similarities in lean manufacturing and additive manufacturing. The main similarities are the fact that both additive manufacturing and lean manufacturing them reduce waste in their execution. It is clear that additive manufacturing reduces material waste which is a lean manufacturing goal. For small batches additive manufacturing also eliminates inventory, transportation and overproduction. In the case of over processing additive manufacturing is hardly affected because the cost does not increase significantly with complexity of parts. Meeting customer demands is a lean principle which additive manufacturing technologies can do without increasing cost and processing times. The literature has shown that the additive manufacturing technology in itself eliminates wastes and unnecessary costs for small batches but there is still more work to be done to improve the efficiency for larger batches. Implementing lean manufacturing within additive manufacturing can reduce the additive manufacturing operating costs.

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THE IMPLEMENTATION OF OPERATIONAL EQUIPMENT EFFECTIVENESS IN A BEARING REMANUFACTURING COMPANY

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ABSTRACT

In the bearing remanufacturing sector, competition is intense between the companies that compete against each other, vying for lucrative contracts and tenders. The lowest price often rules and these companies have to be at the top of their game in terms of innovation, productivity and efficiency. They are required to be innovative in employing the latest technologies and lean manufacturing techniques in order to keep their operational costs at a minimum so as to maximise profitability. This paper presents the implementation of Overall Equipment Effectiveness (OEE) within one such organisation using the Define, Measure, Analyse, Implement and Control (DMAIC) process. From the implementation, a 14% decrease in downtime was realised through time studies and root cause analysis. This in turn improved the company's OEE index by at least 13%. In addition, the decrease in downtime translated to a decrease in direct labour costs, thereby improving the company's financial competitive position. The discussion on each phase of the process is undertaken with particular emphasis on the measurement and analysis phases. Included in these discussions, are the investigations and analysis on OEE metrics namely: availability, performance and quality. The availability percentage of 81% indicates there is a need for improvement as 90% would be the ideal percentage for continuous productivity. Further analyses showed that a focus in these areas does result in improved performance.

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1 INTRODUCTION

Companies are required to be innovative in employing the latest technologies and lean manufacturing techniques in order to reduce and eliminate production losses thus keeping their operational costs at a minimum in order to maximise profitability.

In 2007 a bearing remanufacturing company, situated in the KZN North Coast, entered into a joint venture agreement with a well-known international organisation specialising in rail undercarriage component manufacturing. The objective of this joint venture was to enable the local company to expand their skills base in the refurbishment and assembly of used and new specialised bearings for the rail industry. This enabled the local business to compete for and secure tenders related to the refurbishment of bearings for the local rail industry. However, in order to maintain these contracts in an increasingly competitive market, the business had to look at various techniques in order to minimise production losses and improve overall productivity. One such project undertaken to reduce production losses and to improve productivity was the implementation of Overall Equipment Effectiveness (OEE). For the implementation of OEE, and with the lack of substantial and accurate historical data, the DMAIC (Define, Measure, Analyse, Improve and Control) problem solving process was adopted. This data driven process is a proven strategy in implementing process improvement.

The process is structured and sequential which increases the chances of a successful project. During the course of the project, emphasis was placed on the measurement and analysis phases in order to realise the quantitative data to track improvements in the production process. One such technique used during the project was root cause analysis which is further described below.

2 LITERATURE REVIEW

OEE can be defined as a tool for evaluating the future performance of manufacturing resources and comparing them with the initial situation by considering alternative operational scenarios This is considered essential in processes that require high standards of quality as well as good product throughput [1]. It has been suggested that after years of use and misuse and given the lack of agreement between OEE experts, there is no conclusive definition for OEE. It is for this reason that it is possible to find inconsistencies in the different aspects of OEE that include: its interpretation; the calculations; the definition of losses; the treatment of planned downtime; minor stoppages as well as the definition of an optimum overall value [2]. OEE is not only used as an operational measure, but it also serves as an indicator of process improvement activities within the manufacturing environment [3]. There is emphasis on the need for measurement accuracy in determining OEE values [2]. Implementing OEE provides “visibility” into an organisation and it can be seen that the improvement effort is universal in nature i.e. the application is not necessarily limited to a particular industry or industry sector [4].

DMAIC is applied in practice as a generic problem solving and improvement approach. Although commonly associated with Six Sigma, DMAIC is similar in function to its predecessors such as the Plan-Do-Check-Act (PDCA) and the Seven Step Method. It is considered as being a metaroutine: changing established routines or for designing new one. DMAIC can be considered as applicable to: empirical problems ranging from well-structured to semi-structured; rather extensive problem-solving tasks requiring all components of problem definition, diagnosis and the design of remedies [5]. Figure 1 below illustrates the comparison between the DMAIC and the PDCA processes. From this it can be seen that the DMAIC process is more quantitative in nature [6].

Define, Measure, and Analyze	**Plan**
1. Select appropriate metrics Key process output variables	1. Recognize a problem exists
2. Determine how these metrics will be tracked over time	2. Form a quality improvement team
3. Determine the current baseline performance of project/process	3. Develop performance measures
4. Determine key process input variables that drive the key process output variables	4. Clearly define the problem
5. Determine what changes need to be made to the key process input variables in order to positively affect the key process output variables	5. Document and analyze problem/process
	6. Determine possible causes
Improve	**Do**
6. Make the changes	7. Identify, select, and implement the solution
Control	**Study and Act**
7. Determine whether the changes have positively affected the key process output variables	8. Evaluate the solution
	9. Ensure permanence
8. If the changes made result in performance improvements, establish control of the key process input variables at the new levels	10. Continuous improvement

Figure 1: Comparison of DMAIC with PDSA [6]

Applications of OEE in combination with the DMAIC process were presented in three studies. The industries where the applications were conducted included the semiconductor industry as well as the automotive industries. In both instances, the OEE DMAIC approach yielded positive results with an increase in the OEE values [7] [8] [9] [10].

Production losses are defined as the Six big losses. Six big losses are six categories of losses that must be avoided by every company because those losses can reduce the level of process effectiveness. Six big losses are categorised into three main categories based on the characteristics of their losses, namely downtime, speed losses, and defects [11]. Losses need to be kept at a minimum in order to reduce operational costs and maximise profitability. Focused improvement in these areas result in improved efficiencies and productivity.

3 METHODOLOGY

The data collection methods included direct observation, interviews, method and time studies. Using the DMAIC process outlined [5] in Figure 1, each of the five phases were followed. Phase 1 focussed on the clarity of the problem and the need to identify the suitable metrics for measure. Phase 2 focussed on the need to identify the performance of the existing process and to identify the levers that could be used for performance improvement. Phase 3 focussed on feasible improvements to that would enable improved targets. Phase 4 focussed on identifying and implementing sustainable practices to ensure improvements were maintained over time. It was envisaged that the project would uncover root causes that affected Availability, Performance and Quality. By using the identified groups under the six big losses (Table 1), one could then relate this back to the OEE factors and then perform the relevant calculations in order to determine the OEE for the business [3].

Table 1: Six Big Losses

OEE FACTORS	LOSS CATEGORIES	SIX BIG LOSS CATEGORIES
Availability	Down time loss	Breakdowns Set up and adjustments
Performance	Speed loss	Small stops Reduced stops
Quality	Quality loss	Start-up rejects Production rejects

3.1 Define

Through an analysis of past production performance data (Figure 2), it was established that there was a decrease in productivity in the preceding months. This related to production losses arising from low efficiencies, reduced throughput and increased operational costs. Accurate data was not available to calculate the exact causes and impact of these production losses due to the sources of data (namely log sheets) that were incorrectly completed, inaccurate and therefore unreliable. Therefore, the first phase of the study was to define which data needed to be collected and how it was to be done.

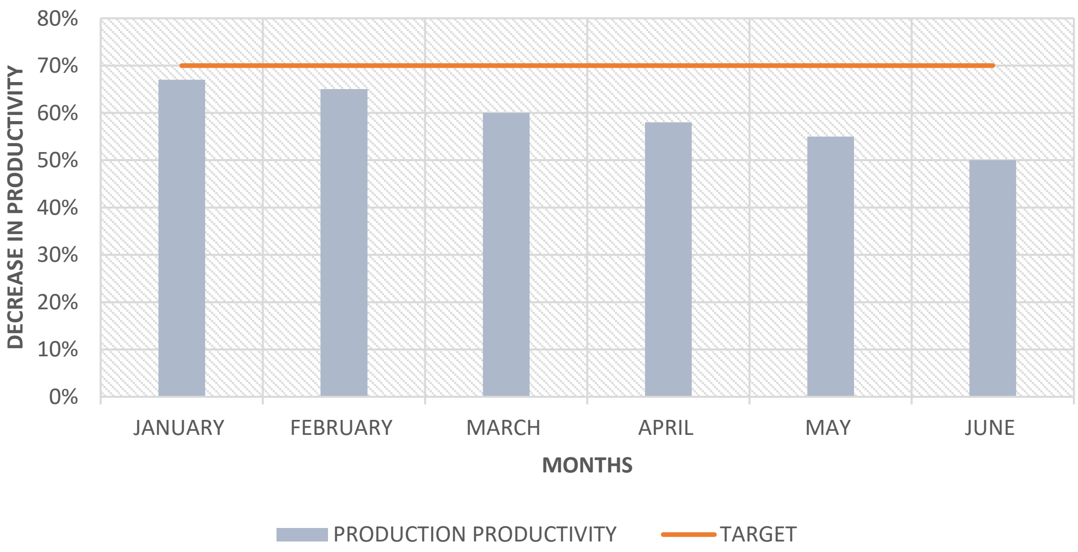

Figure 2: Production productivity in 2019

From what was existing, the challenge for management was to make an informed decision on where to focus their improvement efforts. With this it was also determined that the subsequent phase would include a data analyse and tracking tool that could be easily developed using spreadsheet software. The aim was to provide visibility to the needs of the organisation and direction for continuous improvement. Based on this it was envisaged to use the use the historical data to establish a baseline from which to track the implementation of the OEE program to see if it results in an improvement of the OEE index for the organisation.

In earlier statements, prior to the implementation of OEE project, capturing of data was challenging. A further analysis of the key performance indicators (KPI's) revealed that production losses were the main cause of the decrease in productivity and high operational costs. The decline in productivity identified a need for possible interventions to increase available time. As the OEE factors relied on allocated time for operational processes, the need to improve productivity was essential. The root causes of the production losses were unknown as there were no tools or processes in place to adequately record the data and the subsequent impact on productivity. Through analysis of historical data and with buy in from management, it was agreed to use the existing data for 2019 as the benchmark for the OEE calculations.

Process mapping

OEE measurement could be manual or automated depending on the processes involved. The processes were mapped out to determine the areas that need improvement, identify bottlenecks and losses.

Figure 3 shows the mapping of the process followed in the plant. Marked on the diagram is also the identified bottleneck processes which had an impact on the line in terms of the three OEE measurements. This would have also affected the throughput of the system as well.

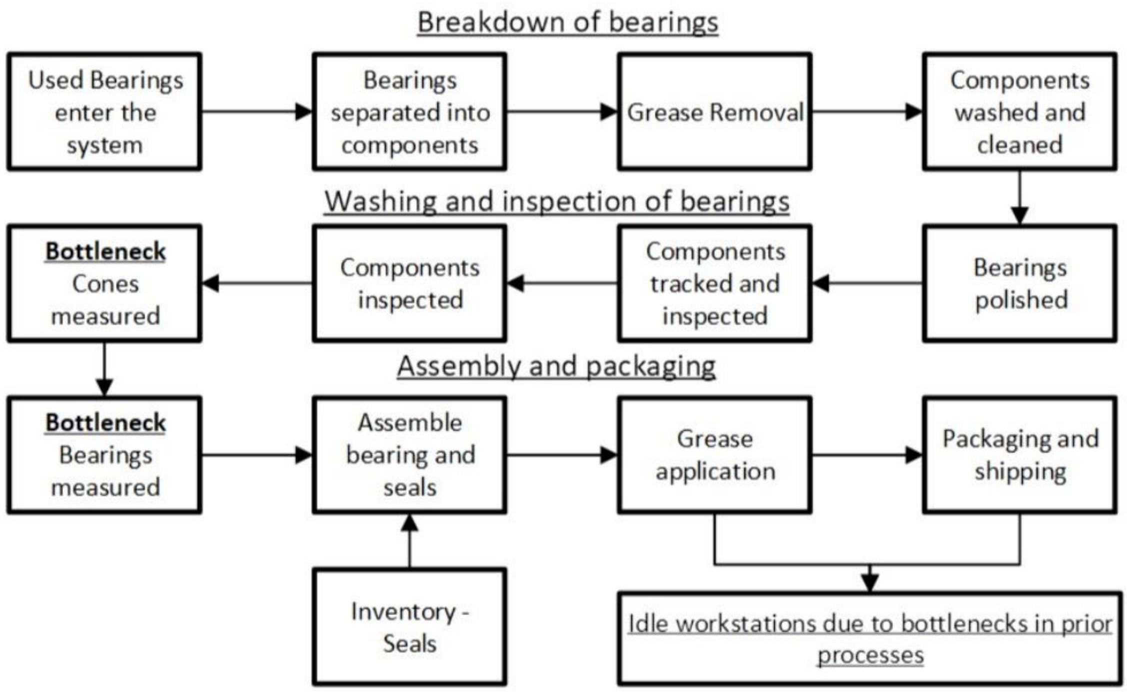

Figure 3: Mapping of relationship between departmental operations

From Figure 3, it was noted that the inspection operations were the bottleneck operations in the system. This indicates losses in the Washing and Inspection department that would have contributed to the lower levels of productivity. This prompted the investigation into the possible causes of the losses that were incurred.

3.2 Measure

Data collection consists of gathering those symbols in order to have a good basis for evaluation of studies on a subject to assess current and future predictions. Accurate data collection is essential for OEE as to maintaining the integrity of research, make informed business decisions and ensuring quality assurance. Qualitative and quantitative data collection methods were used through DMAIC.

OEE can be measured using [11]:

$$OEE = A \times P \times Q \quad (1)$$

(1)

$$\text{Availability}(\%) = \frac{\text{Actual production time}}{\text{Scheduled time}} \times 100\% \quad (2)$$

$$\text{Performance}(\%) = \frac{\text{Actual output}}{\text{Theoretical output}} \times 100\% \quad (3)$$

$$\text{Quality}(\%) = \frac{\text{Actual output}}{\text{Predicted output}} \times 100\% \quad (4)$$

Time studies were done on the entire manufacturing plant through direct stopwatch timing. This timing was done in order to obtain factual real time data to validate the current OEE efficiency standard in the analysis phase. Table 2 represents the standard minutes required to produce a product in each department.

Table 2: Time studies

TIME STUDIES (STANDARD MINUTES)		
DEPARTMENTS	**CLASS D**	**CLASS F**
Breakdown and Wash Department	0.4 Minutes	0.7 Minutes
Inspection Department	2.4 Minutes	3.02 Minutes
Assembly Department	0.58 Minutes	0.75 Minutes

Standards times were collected for two different classes of bearings namely class D and class F. Since the mass of class F bearings is greater than the mass of class D bearings, it is shown that the standard time for the former is higher. From this and other data sources, the OEE data shown in Table 3 was developed using the formula shown earlier.

Table 3: OEE data

OEE 2020								
DEPARTMENTS	**CLASS D**				**CLASS F**			
	A	P	Q	OEE	A	P	Q	OEE
Breakdown and Wash Department	71.94%	82.99%	99.71%	59.53%	81.87%	81.71%	100%	66.84%
Inspection Department	92.9%	60.8%	100%	56.32%	88.34%	63.76%	100%	56.21%
Assembly Department	84.32%	66.15%	100%	56.94%	67.84%	73.85%	100%	50%
Average %	83.1%	70%	99.9%	57.6%	79.4%	73.1%	100%	57.7%

To determine the organisation's production loss impact, the OEE factor was used. Central to this was the keeping of accurate records. During this exercise, operators were trained to keep detailed records onto log sheets designed specifically for each department. Data was collected manually using relevant forms and then fed into the OEE program implemented for the formulation of the historical and current OEE factors.

Table 3 indicates a loss in the availability percentage at an average of 81.2%, significantly lower than the ideal availability of 90%. The data generated was further analysed using the following tools: Ishikawa diagram (fish bone or cause and effect diagram), pareto analysis and through visual observation. This was done in order to determine an appropriate strategy to reduce downtime.

3.3 Analysis

Through analysis of the historical OEE versus the current OEE, an improvement was evident. The Ishikawa or cause effect diagram was the tool used to identify the areas that that required improvement. This made the allocation of resources easier to manage as they could be focussed in specific areas to address the problems highlighted. In the past the organisation lost volumes of product and time due to issues that were unknown to management. This was addressed through the implementation of OEE, as the formula work required visibility from the organisation in terms of their performance metrics.

A root cause analysis was done to determine and categorise the related causes to the low production availability identified during the earlier process. This is presented in Figure 4.

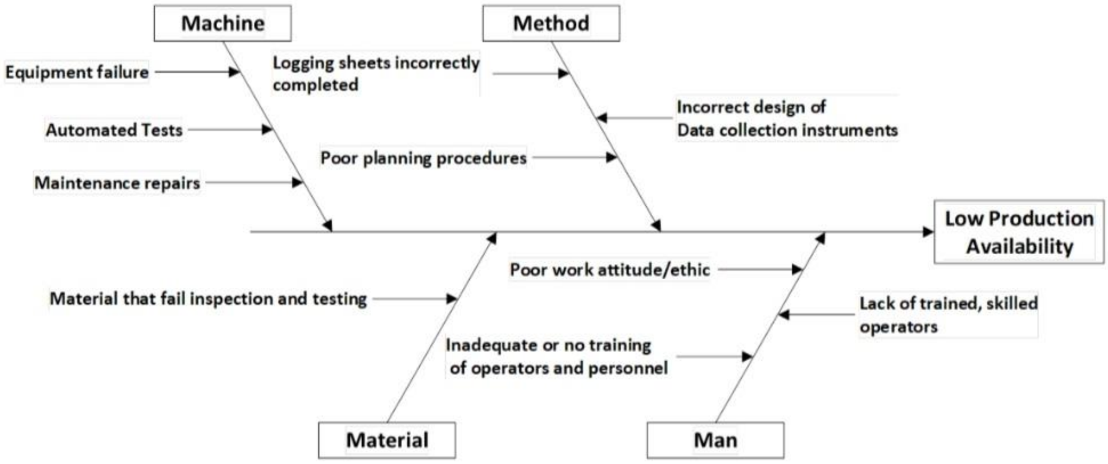

Figure 4: Ishikawa Diagram

From the diagram the common theme running through the majority of the causes that resulted on production losses was related to downtime. This was further explored by the use of check sheets that the operators completed each time a downtime event occurred. Further to this the following measures were implemented as well such:

1. A simple production tracking system was developed using Excel, with the OEE formula integrated into the spreadsheet
2. Monthly reports on production downtime and other production losses were made available to management and operators at all levels
3. A visual management system was implemented making the reporting visible so that quick action could be taken when issues arose
4. This was then categorised into the loss areas as identified earlier as the "Six big losses". The comparative analysis between 2019 and 2020 is shown in Table 4.

With these measures in place and with the data collection activities under way, a comparative analysis was done for the years 2019 and 2020. Table 4 illustrates the outcome.

Table 4: The comparative analysis of downtime between 2019 and 2020

Loss factor	Downtime in minutes 2019	Downtime in minutes 2020
Start ups	5475	4850
Changeovers	12 775	10585
Maintenance	10950	8300
Equipment failure/breakdowns	18000	16800
Reduced speed	7300	6305
Total	54500	46840

From this tabulated comparison, the downtime percentage was then calculated as follows:

Down time percentage:

$$Downtime\ (\%) = \frac{Downtime\ 2019}{Downtime\ 2020} \times 100 \tag{5}$$

$$= \frac{46840}{54500} \times 100$$

$= 14\%$ *downtime reduction*

The calculation indicated a 14% reduction in production downtime, which indicated that the measures implemented using the OEE system served to improve the system.

3.4 Improvement / Control

Section 3.3 indicated a significant reduction of downtime by 14%. The downtime reduction directly affects the OEE index of an organisation therefore an improvement in the reduction of downtime would improve an organisation's OEE [2]. World class companies control an OEE standard of between 80% - 90% and. An OEE score of 60% is fairly typical for discrete manufacturers, but indicates there is considerable room for improvement [12]. Figure 5 represents the Historical OEE versus the current state OEE after implementation.

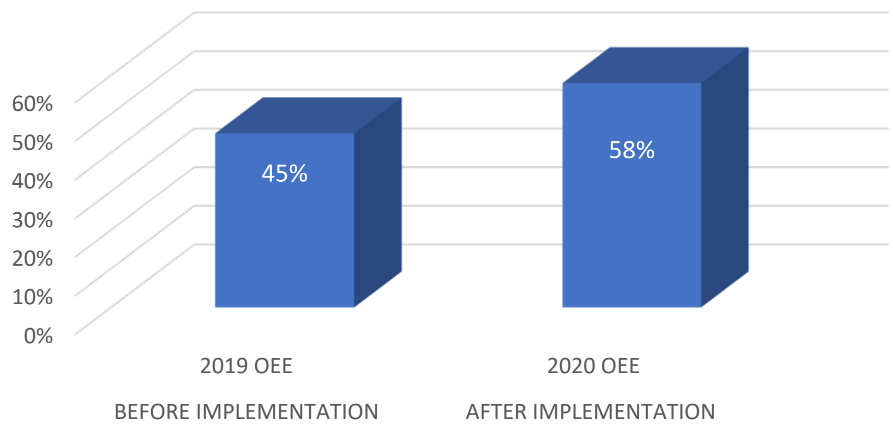

Figure 4: Actual OEE versus Historical OEE

The data shows a direct relationship between production losses and the OEE percentage. The implementation of a data collection/analysis tool enabled a 13% increase in OEE and a data system to use as a benchmark for future analysis of the organisation. In the control stage, the best practices were shared with each department in the organisation.

The data indicated that most processes cycle time did not comply with the theoretical cycle time as there were frequent unplanned stop events. The unplanned stops usually resulted from idle time, breakdowns and minor stops. The organisation decided to place more focus on continuous improvement as this is vital in any organisation, therefore projects will be discussed with staff to improve the OEE index.

New standard operating procedures (SOPs) were developed and operators and staff were trained as per the quality management and production systems. In this case twenty-five shop floor operators were trained on the new OEE system that was implemented. Benefits to the organisation and staff were presented through various training seminars as well as regular meetings.

4 CONCLUSION

This case study carried out in a medium sized bearing reconditioning plant demonstrated that implementation of an OEE system does reduce downtime and improve overall efficiency of the organisation. The project had been carried out in accordance with the DMAIC process using tools such as check sheets, cause and effect analysis, production tracking and visual management. These tools assisted in quantifying and visualising the data so that the analysis is known and can be acted upon. This has resulted in a reduction in downtime for the benefit of the organisation and a positive effect on the OEE index. It is clear that good problem definition as well as identifying the correct variables to collect data on is essential for a successful implementation. Production losses were identified and corrective actions taken that has resulted in an improvement on the OEE index. The results obtained from this study reinforces the notion that the OEE/DMAIC combination does indeed result in process improvements.

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AN ANALYSIS OF ORDER PICKING PERFORMANCE TRADE-OFFS USING A DESIGN OF EXPERIMENTS APPROACH

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ABSTRACT

In this paper, the redesign of an order picking process was investigated by analysing operating strategies such as batching, routing and storage location. This research study was conducted to improve the performance of a company's warehouse process, focusing on the order pickingprocess. The design of experiment (DOE) was applied to determine the relationship between factors that have an impact on the process (inputs) and its output. The Design-Expert softwarewas used to conduct the analysis, with the results represented in the form of graphs and Box-Cox plots. A retail distributor was considered as a case study to illustrate the approach proposed in this study. This study provides an insight into the influence of operating strategieson the important performance measure of the entire order picking such as Total Picking Timeand Order Maturity Time. This analysis contributes meaningfully to the management of processinputs to maximize output.

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1 INTRODUCTION

1.1 Supply chain management

There are certain value-adding activities or processes that need to be performed from the time items reach manufacturer's shelves to the moment it is in the possession of the end-user.Those activities or processes consist of raw materials procurement, goods production, marketing of products and delivery to end-user. Nowadays, different companies and organizations are responsible for these different activities. It is very important for those companies or organizations to properly manage the above-mentioned activities or processes and establish a good relationship among them as they all constitute the cornerstone for the strategic function known as supply chain management. To maintain competitiveness in today's economy, companies need to have an excellent management of processes and activities and maintain a good relationship with all stakeholders [1].

The term" supply chain management" appeared in the industry's lexicon in the 1990s for thefirst time [2]. It is delineated as an array of business entities that work in collaboration towardpurchasing raw materials and transforming them into a finished good, then distributing themto retailers [3]. The different business organizations from which all processes or activities stem are suppliers, manufacturers, distributors and resellers. Supply chain activities consist of product development, material procurement, manufacture, logistics and the information system required to manage those activities [4].

1.1 Warehousing

Warehousing is considered one of the most dominant entities in supply chains. It is defined asa building or facility used to stock products before they are shipped or delivered to the customers [5]. Its importance is attributed to its ability to dispense a buffer area for goods that facilitate a match between supply and demand. It also enables products consolidation, which is the action of combining into single shipments different orders coming from multiple suppliers and then shipped or delivered to individual resellers. Its ability or function of buildingup stocks is beneficial for especially periodic products. For example, stocks are built up in a season where sales drop in preparation for the picking season [6]. Lin [7], identified several crucial tasks within warehouses. Those tasks are goods receiving, put away, storing, order picking, sorting, cross-docking, packing, and shipping.

1.1.1 Warehouse layout

The layout and size of a warehouse plays a significant role in its performance. It is importantto consider some details when designing a warehouse picking strategy.

One of the crucial points is the warehouse structure, we distinguish between conventional andnon-conventional structures. The conventional warehouse which is characterised by a rectangular layout consists of parallel and non-conventional aisles. Pickers find products thatare ready to be picked on parallel aisles while being perpendicular to front and back cross- aisles. Its main advantage is that it helps pickers to be quick in changing lanes. The non- conventional warehouse structure, on the other hand, has more innovation and complexity while being effective. An example of a non-conventional warehouse structure is the fishbonelayout that was introduced by Meller & Gue in 2019 [22].

The proper layout implementation associated with the proper routing strategy could influencea good performance of order picking [2]. The wrong decision on the warehouse layout and routing strategy will generate negative outcome on customer service and profitability that willtake a while to be changed.

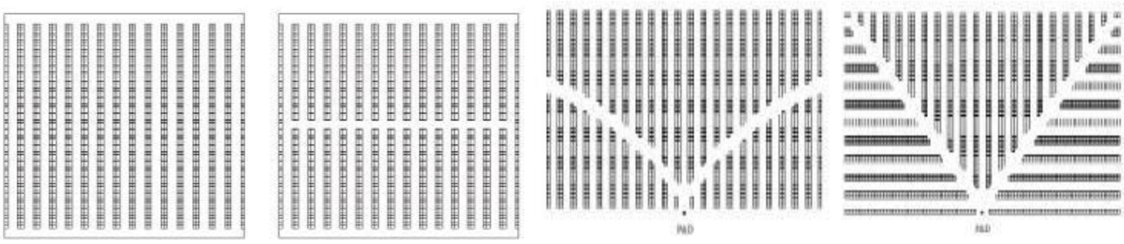


Figure 1- (a). Traditional warehouse layout (b). Flying- V and (c). Fishbone warehouse layout [22]

1.1.2 Storage policies/Item allocation

The proper allocation of products to the storage location will facilitate order pickingefficiency. The storage policies govern the storage allocation in a warehouse. The non- theoretical method of storage mainly concentrates on criteria like stock location and the arrangement in the warehouse [24].

The different types of storage allocations are:

- Random storage: items are randomly allocated to an unoccupied storage area. Its simplicity makes it easy to adopt and implement [29].
- Closest open location: products are allocated to the first available location. It entails that the depot out of all the remaining section of the warehouse is the most used.
- Dedicated storage: space is reserved for specific items. Every item has its own assigned location that cannot be used by other items. These results, in pickers, getting familiarwith items and their locations, except when there are thousand and more products. [28]
- Class-based storage: this policy mixes some of the above-discussed method [6]. It groups items in classes (between two to five) and those classes are assigned specific locations. Each class has its name according to the frequency at which they are ordered. Class A is for fast-moving items, class B for the next fast-moving, etc. Pickingperformance is better in class-based storage compared to random storage, but it requires more space to accommodate this strategy compared to the random storage,and travel time is reduced.
- Family grouping: similar items are stored close to each other. It enables the combination of precedent discussed policies.

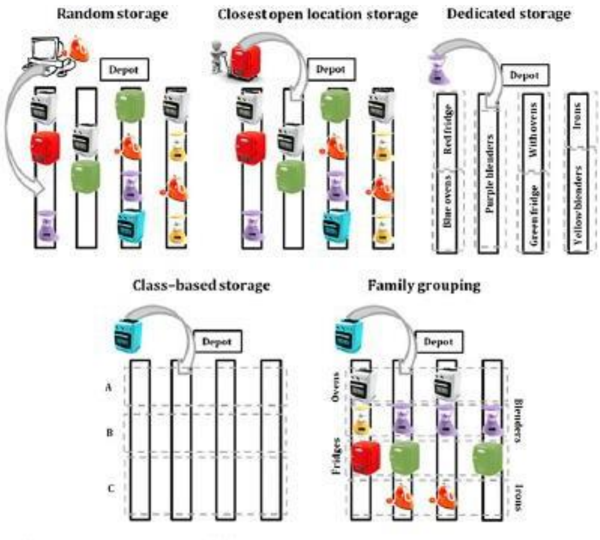


Figure 2- Different types of storage location [28]

1.1.3 Routing strategy

Routing strategy determines the trajectory that pickers need to follow in the warehouse. These are:

- S-SHAPE STRATEGY: the trajectory of the picker takes the form of the letter S. The journey begins at the left hand of the warehouse and start from one end and finishes in the other. The picker goes through every aisle containing a pick. It is known as a traversal [30].
- RETURN STRATEGY: The picker makes use of one particular point to enter and exit.
- MIDPOINT STRATEGY: the warehouse is divided into two sections. Picker is only permitted to access an aisle as far as the midpoint.
- LARGEST GAP STRATEGY: like the midpoint strategy, but in this strategy, the midpointis replaced by the largest gap between aisles. Meaning that the picker starts from oneend and can only reach the largest gap within an aisle [31].
- COMPOSITE STRATEGY: characterised for its complexity in implementation as it mixesthe best features of the return and S-shape strategy. It was introduced by Petersen, Siu and Heiser in 1995 [32].
- OPTIMAL ROUTING: it combines the different heuristic strategies (S-shape, Return, Midpoint, Largest gap and Composite), and minimizes the travel distance. Its introduction was in 1983 by Ratliff and Rosenthall. Ratliff, H. D., and A. S. Rosenthal.1983 [33].

1.2 Cost and labor

From the overall Warehouse annual operating costs, 55% is attributable to order picking, thusit is the most significant cost element [9]. A study by Tompskins et al. shows that order pickingis the most labor-intensive activity and the most capital-intensive to automate [10]. Surely, the order picking process is the most important of all processes as it has such a great impacton the capital and operating cost of a warehouse design [10]. The order picking process focuses on the selection (pick) and collection of a desired amount of stock responding to an order. The different activities involved in the process are picking, lifting, moving, packing [1][11].

1.3 Pickering

Order picking is said to be the most important activity. It is described as the process of searching, finding, and drawing out goods from a warehouse to meet customers need [8].

1.4 Picking Process

When considering improving the warehousing, it is necessary to consider order picking. Pickingareas are characterized by the presence of several aisles where products are kept, either on shelves, racks, pallets or on the ground. The number of aisles depends on the space available,and the overall quantity of items forecasted to be stored. For the ordered product collection,the picker has a choice/alternative of either walking or driving through toward the designatedarea of pick in the warehouse. The conventional itinerary in warehouses for order picking entails: the picker departs from the depot holding a picking list, he directs himself toward thestorage location, he picks the requested product and retraces his way back to the depot and hands over the picked item(s) [2].

1.5 Types of Order Picking Strategies

The order picking process can be performed in multiple ways depending on the type of business. The choice of type of order picking is dictated by multiple factors, which include: the size of the facility, manpower availability, and the daily quantity of items ordered [3].

Batch picking is a picking strategy, the order picker on a single trip picks more than one order,either manually or automatically. In a manual scenario, the order picker picks Stock keeping units (SKUs) required for multiple orders in one cycle. In the automated scenario, the picker must remain at one place meanwhile carousels brings to him the requested SKUs. This approach is more efficient than single order picking as it reduces travel time [4] [5] [6].

The study of Malmbor and Al-tassan show that the operating strategies that significantly impact the order picking performance in a warehouse include: routing strategies, batching strategy and the storage allocation strategy [11]. Kee proposed a class-based storage locationstrategy as a means of reducing picking time and increasing the productive capacity of the system [12]. Manzini, Gamberi and Regattieri [13] believe that ordered items that are pickedin a group or batch in a single trip, could result in an amelioration of picking throughput [6]. Bottani, Volpi and Montanari [14] identified certain critical factors that affect the travel distance in order picking. The factors incude:

a. Warehouse structure specifically layout and dimensions [15].

b. The operational strategies, for example, zone picking vs. batch picking [8].

c. The use of low-level vs, high-level picking in the manual order picking [16].

d. The routing strategy [17].

e. The storage assignment policy [18].

The common ground on processes in both manual and automated order picking are storing, picking and material handling. Order pickers perform those tasks to deliver the ordered products to customers. The goal is to satisfy customers and by consequence order pickers needto efficiently follow the process [1]. Figure 1 shows travelling in the order picking process takes longer compared to the other activities. Therefore, it is of high importance for warehouses to work toward the minimization of the travel activity, which will simultaneouslyreduce the order picking time. To attain that objective, warehouse should work toward identifying the significant factors that influence the long travel of pickers and identify the shortest route to minimize the order picking process time [12].

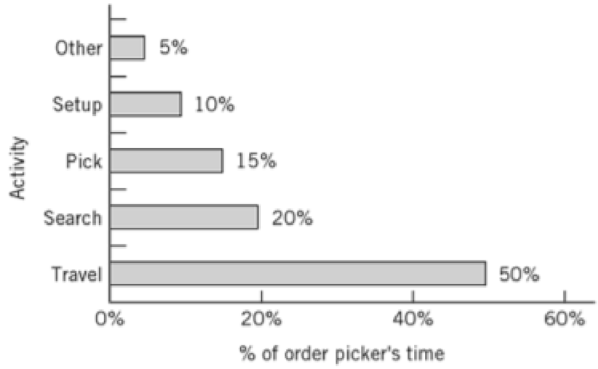


Figure 3-Order picking time vs activities [1]

Warehouses want to optimize overall performance in order to remain competitive. Order picking is one of the most significant process of a warehouse, that plays a big role in its performance. It is thus important to properly design the order picking process taking into considerations the different activities and configurations it can incorporate. Thus the use of aproper tool is crucial in order to perform simulations and analysis in order to get a good idea of what could be expected.

This study aims to explore the order picking process by looking at factors that could contributeto a better performance of the warehouse. This study focuses on three objectives namely 1. The identification of tools that could help the warehouse to evaluate order picking performance; 2. The determination of significant factors that play a major role in the overallperformance of order picking and 3. The evaluation of the existent relationship or trade-offs between factors and an analysis of their impact on order picking.

2 METHODOLOGY

2.1 Data gathering

2.1.1 Source of data

In order to illustrate the analysis proposed in this study, a quantitative approach has been adopted to evaluate the performance of the warehouse under study. Numerical data were analysed statistically by the use of Design Expert software (DoE) [34]. The secondary data were extracted from an existing study related to the warehouse [35]. They were a result of multiple experiments performed in that warehouse. The different experiments involved the different configurations of order picking and simulation was used to facilitate it. The study from which the data was collected used another software Minitab to perform their performance analysis.

2.1.2 Length and range of data

The length and data range were determined by the tool used to resolve this problem. In the DoE, a full factorial design with two as the number of level's factor (2k) is a very efficient wayto experiment [49]. In this case, since we have five factors, it means that K can be equated to 5 thus giving us thirty-two different experiments [37].

2.1.3 Input and output

The input were the numerical values corresponding to the five factors differently combined ineach experiment. This study considers five factors namely the batching, the order commonality, the routing, the lines per order, and the storage strategy in a typical warehouse.

The Output were the responses or the impacts of these factors on Order Maturity Time (OMS) response and the Total Picking Time (TPT) after being analysed. This approach has been implemented by the software design expert.

2.2 Model development

2.2.1 DoE

To evaluate the impact of input parameters on output results, a design of experiment approach has been adopted in this study. This approach provides clarity about the effect of possible changes of input parameters on the response variable [36]. The approach used to analyse the data was Design of experiment (DoE) with Design Expert as its tool. DoE is a systematic method that evaluates the impact of inputs over the output. Multiples tests or experiments are conducted in which the inputs are liberally changed to detect the possible changes in the output response [36].

2.2.2 The method /Modelling procedure

Design Expert generated multiple combinations as experiments (inputs), with empty responses (output). The response column will be filled either by practically experimenting or by using Simulation tools. Simulation is increasingly popular as it is fast and does not interrupt work during experiments. It is safe and does not consume a lot of time. And for this study simulationwas used to perform the experiments.

2.2.3 Analysis of developed model

A full factorial design with two as the number of levels factor (2k) is a very efficient way to experiment [49]. In this case, since we have five factors, it means that K is equated to 5 thus giving us thirty-two different experiments [37]. For the performance assessment, the Analysisof Variance (ANOVA) was performed to verify that the experiment or survey results are significant. In other terms, the ANOVA results reveal the null hypothesis must be rejected or if the alternate hypothesis must be accepted [38].

In this paper, the following Anova plots are used:

Main effect plot: it compares the relative strength of the effects of various factors.

Interaction plot: this plot presents all different factors on a single graph and shows the relationship between them. The interpretation of this plot is subject to an evaluation of line to comprehend how the interactions affect the relationship between factors and responses. Therefore, when two lines are parallel, it indicates that there is no interaction between factors. When the lines are nonparallel, it indicates that there is an interaction between factors and the strength of the interaction is determined by how many lines are nonparallel. The more nonparallel lines there are, the stronger the interaction is [39].

initial results were similar to the results generated in this case study using the new software.

3 FINDING AND DISCUSSION

Table 1 shows the factors and corresponding levels of a case study describing a typical warehouse facility X.

Table 1: Factors used for DoE (adapted from reference [28])

Factor	No of Levels	Low (-1)	High(1)
A: line per order	2	< 25 lines per order (Ftl)	>25 lines per order (Tml)
B: Order commonality	2	< 3 common references per order line ((ftc)	>3 common references per order line (Tmc)
C: Routing	2	S-shape(Ssh)	Return (Ret)
D: Storage	2	Closest location (Cl)	ABC class-based (Cb)
E: Batching	2	By order (Bo)	By article (Ba)

The table shows the different factors considered for the analysis of order picking performanceof facility X. The five factors are critical as they impact the OMT and TPT. As said above the 5 factors will correspond to a total of 32 different combination of experiment for a full factorial design. The 32 configurations of experiments were automatically generated within Design Expert software.

A= line per order. For facility X The lines per order were classified into 25 or more lines per order(Tml) and fewer than 25 lines per order (Ftl), equally dividing the number of orders available in their database.

B= Order commonality. For facility X, Using the same criterion, order commonality was dividedinto two, three or more common references per order line (Tmc), and fewer than three common references per order line (Ftc).

C= Routing. Facility X considered the S-shape (Ssh) and the Return routing strategy (Ret).

D= Storage. Facility X considered the closest location (Ci) and the class-based storage allocation (Cb).

E= Batching. Facility X considering the batching pick-by-order (Bo) or pick-by-article (Ba)

3.2 Analysis of OMT plot

Figure 4 shows the trends of responses (OMT and TPT) as a result of factors being changed among levels. This plot determines the positive effect (orange box) and negative effect (blue box). Positive effect signifies that the response will be incremented when that factor is increased. The negative effect signifies that the response will be reduced when the factor is decreased.

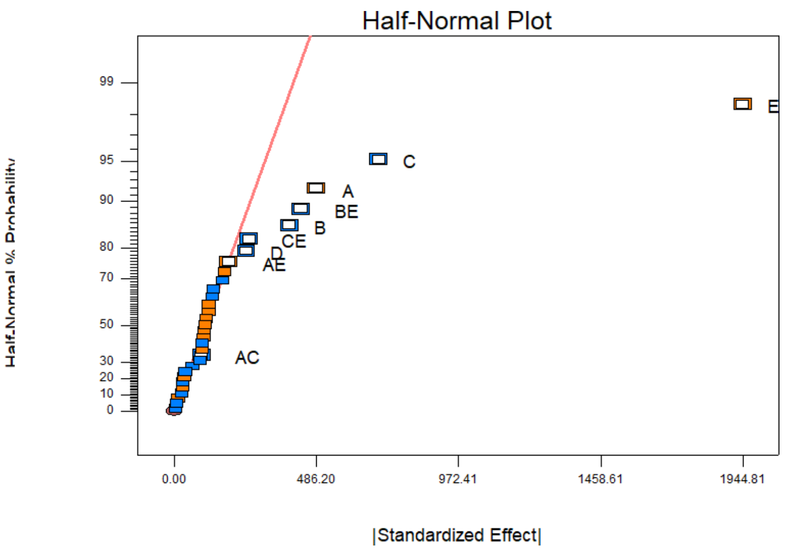


Figure 4: OMT plot

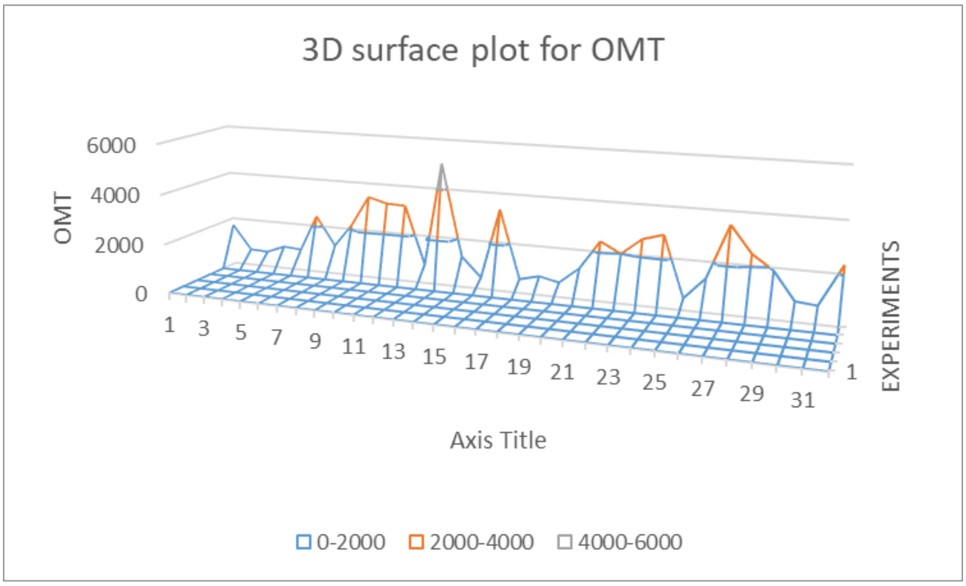


Figure 5: 3D surface plot of OMT

The factor effect plot reveals that E, C and A are the most significant factors with a great impact on the model. It means that batching, routing and lines per order influences the OMTmore than the other ones. Similarly, BE, B, CE and D are significant. From the half-normal plotthe level of significance of factors is determined by their positions on the plot. Factors level decreases from right to left of the plot. E is on the furthest right on the plot meaning it is themost significant, then followed by C, then A etc.

3.1.1 OMT analysis of variance

The first response, in this case, the OMT has been analysed separately using ANOVA calculations. The F-value equals 61,38 indicates the significance of the model. Values of "Prob>F" less than 0.0500 implies that model terms are significant. In our case, A, B, C, D, E,BE, CE have been identified as the most important factors for OMT analysis.

Table 2: ANOVA for OMT (Design Expert)

OMT						
ANOVA for selected factorial model(Partial sum of squares- Type III)						
Source	Sum of Squares	df	Mean Square	F Value	p-value Prob>F	
Model	4.015E+007	9	4.461E+006	61.38	< 0.0001	significant
A-Lines per order	1.884E+006	1	1.884E+006	25.92	< 0.0001	
B-Order commonality	1.238E+006	1	1.238E+006	17.04	0.0004	
C-Routing	3.919E+006	1	3.919E+006	53.92	< 0.0001	
D-Storage	4.839E+005	1	4.839E+005	6.66	0.0171	
E-Batching	3.026E+007	1	3.026E+007	416.31	< 0.0001	
AC	69844.53	1	69844.53	0.96	0.3376	
AE	2.770E+005	1	2.770E+005	3.81	0.0638	
BE	1.496E+006	1	1.496E+006	20.58	0.0002	
CE	5.240E+005	1	5.240E+005	7.21	0.0135	
Residual	1.599E+006	22	72682.25			
Cor Total	4.175E+007	31				

The relationship between factor B (order commonality) and E (Batching) is very important since they affect OMT. There is a reduction in OMT when orders are picked by order (Bo). Meanwhile, on the order commonality, the common references per order line or batches increases (Tmc) (refer to table 1). The reduction in OMT is explained by picking products fromdifferent orders on a single trip which results in a reduction of the travel distance. Please notethat on the plot the horizontal axis represents factor B and the value -1 correspond to Ftc and the value +1 correspond to Tmc (Please refer to table 1). The two lines represent factorE with the red corresponding to +1 which is the Ba and the black corresponding to -1 which isBo (refer to table 1).

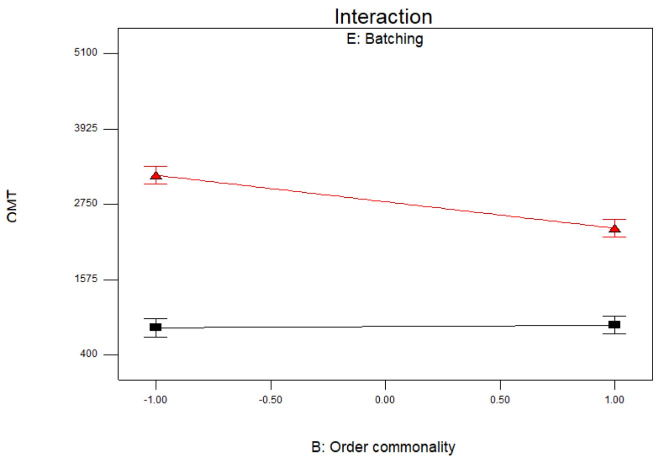


Figure 6: Interaction for B and E factors on OMT. (Design Expert)

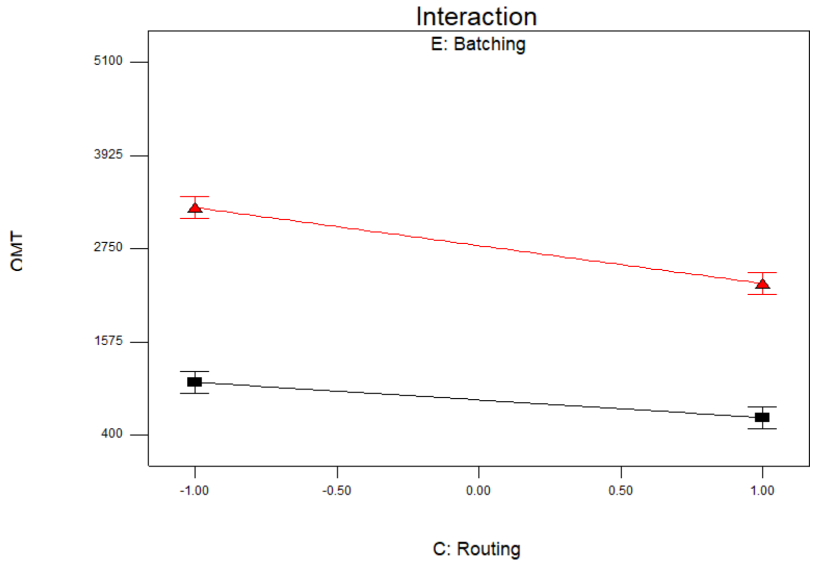


Figure 7: interaction for C and E factors on OMT

From figure 7, the Interaction between C(routing) and batching (E) has a moderate effect. By setting a return method for routing (C=Ret) and picking-by-article strategy (E=ba) OMT is significantly reduced.

3.1.2 OMT Box-Cox Plot

sS the lambda value is a one it means that transformation is not appropriate for this case. The recommended transformation is at lambda = 0

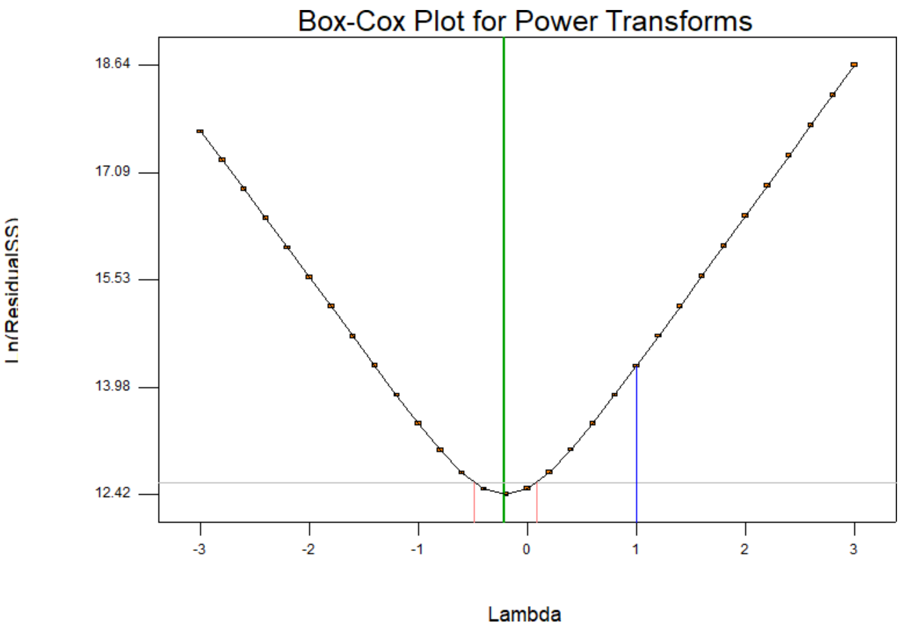


Figure 8: Box-Cox Plot for OMT

3.3 Total Picking Time (TPT)

3.3.1 TPT plot

The same analysis and evaluation done on OMT have been done with TPT. The factor effect plot shows that C, E A have the greatest influence on TPT. Similarly, CE, BE, AE, AC also impacts the TPT (refer to table 1). It means that those factors whether taken individually or associated, have a significant impact on the TPT. Figure 8 shows the relevant factors on the level per order. Their significance decreases as we move down to the bottom left.

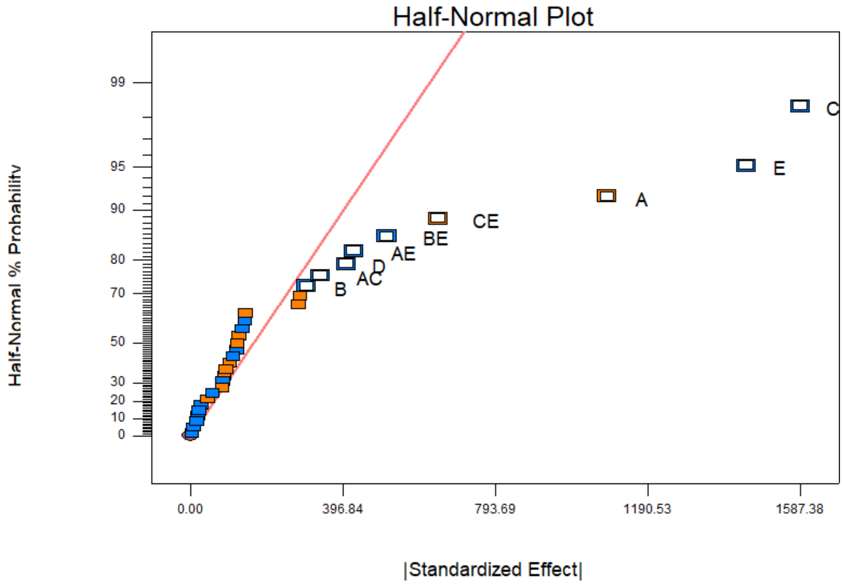


Figure 9: Factor effect plot for TPT

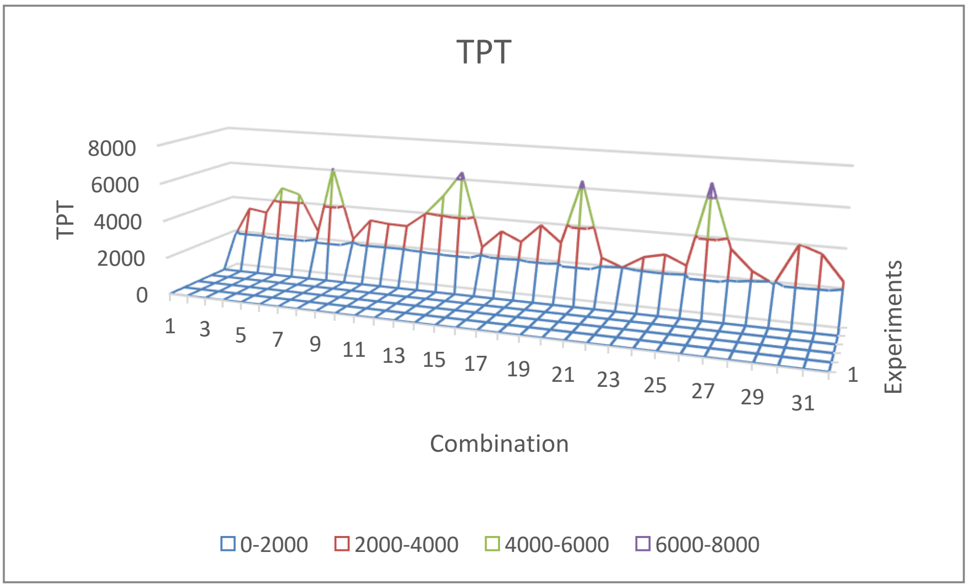


Figure 10: 3D surface plot TPT

3.3.2 TPT Analysis of Variance

For the TPT, the f-value calculated by the Design Expert is equal to 52,41 which indicates the significance of the model. Values of "Prob > F" less than 0.0500 implies that model terms are

[142]-12

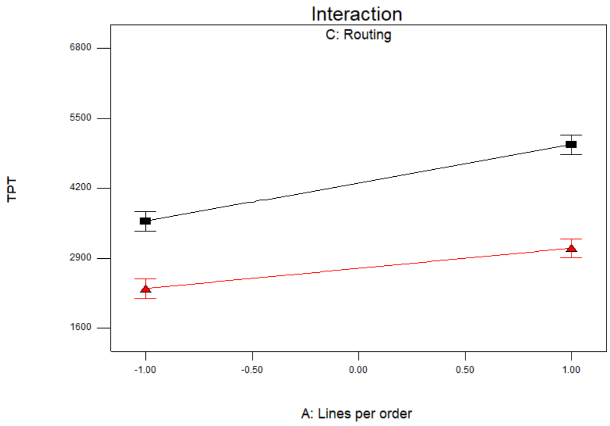
significant. In our case, A, B, C, D, E, AC, AE, BE, CE are significant model terms as they exceed 0.0500 (refer to table 1). And for the p-value, values greater than 0.1000 indicate themodel terms are not significant.

Table 3- Anova calculation for TPT (Design Expert)

TPT						
Analysis of variance table [Partial sum of squares-Type III]						
Source	Sum of Square	df	Mean Square	F Value	p-value Prob>F	
Model	5.612E+007	9	6.235E+006	52.41	< 0.0001	significant
A-Lines per order	9.409E+006	1	9.409E+006	79.09	< 0.0001	
B-Order commonality	7.314E+005	1	7.314E+005	6.15	0.0213	
C-Routing	2.016E+007	1	2.016E+007	169.45	< 0.0001	
D-Storage	1.309E+006	1	1.309E+006	11.00	0.0031	
E-Batching	1.674E+007	1	1.674E+007	140.70	< 0.0001	
AC	9.153E+005	1	9.153E+005	7.69	0.0111	
AE	1.449E+006	1	1.449E+006	12.18	0.0021	
BE	2.089E+006	1	2.089E+006	17.56	0.0004	
CE	3.318E+006	1	3.318E+006	27.89	< 0.0001	
Residual	2.617E+006	22	1.190E+005			
Cor Total	5.874E+007	31				

3.3.3 TPT interaction plot

Lines per order and routing as well contribute to the diminution of TPT. The smaller the number of lines per order is picked, the probability of reducing TPT when using a return strategy is greater. TPT is significantly reduced when order picking is made of many lines andpicking is done by article. This is justified because it is faster to retrieve orders from the same batch, thus eliminating unnecessary travel distance.



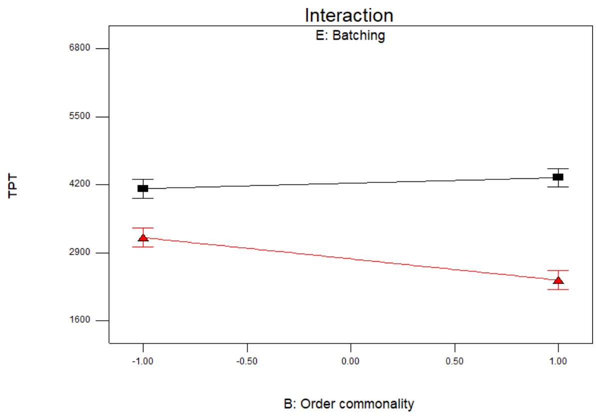


Figure 11: a) Interaction plot for C and A b) interaction plot for E and B factors on TPT

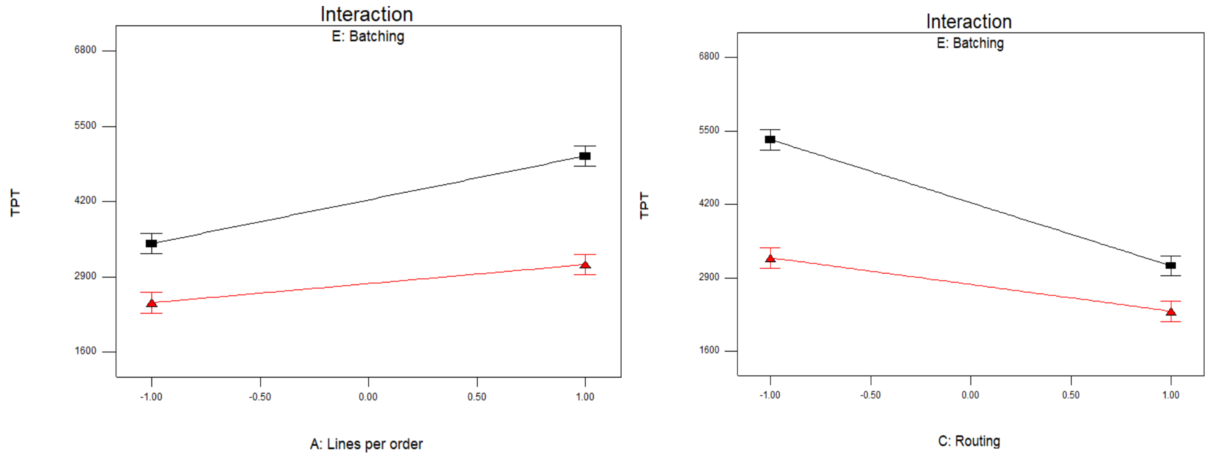


Figure 12: a) Interaction plot for A and E b) Interaction plot for E and C factors on TPT

3.3.4 TPT Box-Cox Plot

AS the lambda value is a one it means that transformation is not appropriate for this case. The recommended transformation will be at lambda= 0.5 (inverse square root)

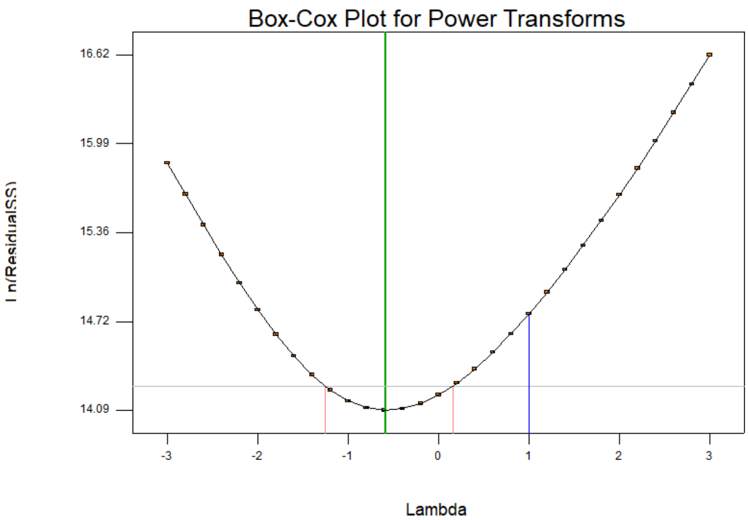


Figure 13: Box-Cox Plot for TPT (Design Expert)

4 CONCLUSION AND RECOMMENDATION

Order picking is indeed a very crucial process in warehouses as it influences its performance.The first objective established for this study was the identification of tools that could help evaluate picking performance. We have developed a Design of Experiment technique that assisted in the generation of multiple experiments to be analysed. The proposed approach wasimplemented within the software Design Expert for further analysis using ANOVA. The secondobjective was to determine the important factors that influence the order picking overall performance. From the information gathered and the analysis performed, this study reveals that routing(C), batching(E) and lines per order (A) have a significant impact on the performance based on how they affected the two responses OMT and TPT. Contrarily as said in the literature above, a previous study [11] revealed that the most significant factors observed in their studies were: Routing strategies, batching strategies and the storage allocation. This study and the [11] identify common factors being routing and batching. We can therefore conclude by affirming the great impact routing and batching have on the overallperformance of order picking. The third objective, which was the evaluation of the existenceof a relationship or trade-offs between the various factors. We identified six significant interactions in total, with BE (order commonality and batching) and CE (Routing and Batching)for OMT and AC (Line per order and routing), AE (Line per order and batching), BE (Order commonality and Batching), CE (Routing and batching) for TPT. We have seen for example that the TPT is decreased when order picking is made of more than 25 lines and picking is done by article. The study also reveal that OMT and TPT have as common significant interaction BE (Order commonality and batching).This study demonstrates a design of experiment approach is potentially suitable for the analysis and the improvement of order picking in a warehouse.

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DEVELOPING A FRAMEWORK FOR A CONFIGURATION OF AN IRRIGATION SYSTEMS FOR SMALL-SCALE FARMERS

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ABSTRACT

Globalization and the increase in demand for goods and services have resulted in businesses needing to satisfy these higher demands with increased efficiency and accuracy. The agricultural industry is no exception, and the emergence of precision farming has increased the potential to meet high food demands and increase potential economic growth. Irrigation systems enable farmers to achieve this. Small-scale farmers, however, experience barriers to implementing irrigation systems.

The main barriers are the investment costs, unclear irrigation system and component benefits to the farm, and not having or being unsure of the knowledge and skills required for irrigation systems.

In this paper, a framework is proposed with a system configurator that is developed based on the Reference Architecture Model for Industry 4.0. The configurator enables the small-scale farmer to address the barriers by integrating them to develop an irrigation system based on their site-specific requirements.

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1 INTRODUCTION

Industry 4.0 is widely known for the disruption it causes in industries by providing technologies that enable, or to an extend force, businesses to create new business models and value offerings. The agricultural industry is no exception, as Precision Farming (PF) technologies have increased the potential for economic growth of participants in the sector. The PA technologies includes all those agricultural production practices that use information technology either to tailor input to achieve desired outcomes, or to monitor the outcomes. [2]

Small-scale and subsidiary farmers face several challenges to applying the irrigation systems to their farming practices. These problems include the high cost of acquiring such a system, the knowledge and skill level demand in operating the system and the benefits of such systems are not clearly articulated or known. [3] The thesis provides a framework for the configuration of an irrigation systems for small-scale and subsidiary farmers to address these problems. The framework is designed by using the Reference architecture model for Industry 4.0 (RAMI 4.0). The three-dimensional model acts as a map providing a structured approach to defining an Industry 4.0 concept ensuring a common understanding on what it entails, the functions of each component and the interfaces that exists between them. [5]. The framework allows the small-scale farmer to configure an irrigation systems to address his/her specific capabilities and site requirements. The aim is to therefore empower the small-scale and subsidiary farming community to apply irrigation systems and contribute to their growth and sustainability.

2 THEORY AND LITERATURE ANALYSIS

In this section literature aspects surrounding about the topic is discussed. Supplementary research is analysed, and areas of weakness are identified. Precision farming, Industry 4.0 and barriers to applying precision farming are discussed in detail. These topics aid in the development to a solution of the problem statement.

2.1 Precision Farming

Precision Farming (PF) has come to fruition in recent years along with Industry 4.0 as a tool that obtains more accurate data from an increased utilization of resources to potentially yield increased profits [16]. PF, as a management practice, first found its widespread acceptance in the Midwest of the United States of America. There in the corn belt, it was applied to increase the yields of corn, wheat, and soybeans and to reduce the production costs at the same time. PF management principles and technologies can be applied to almost any agricultural commodity [16].

2.2 Industry 4.0

The term Industry 4.0 refers to intelligent machine and process networking and involves the control of the entire stream along the life cycle of a product. It was brought along due to the increase in customer individualization needs and the increasing variation in the order, development, production, and delivery to the end customer. A uniform and methodological structure is required to develop standard descriptions and specifications of system architectures for the new industrial revolution, Industry 4.0. This can be achieved through a reference architecture.[15]

2.2.1 Reference Architecture Model for Industry 4.0 (RAMI 4.0)

RAMI 4.0 is a three-dimensional map detailing the structured approach to develop Industry 4.0 products and services. The model ensures all participants involved in Industry 4.0 discussions understand each other. It is a Service-Orientated Architecture and combines all elements and IT components in a layer and life cycle model. [15]

2.2.2 RAMI 4.0 Structure

When developing RAMI 4.0 product, the architecture provides functionalities that enables the guidance of products in production system. It requires dividing the architecture in layers and components.[12] The first layer is the Asset Layer, which describes all the physical devices and resources. The second is the Integration Layer, which contains the objects that are responsible for the interaction between the product ID and device and to manage operations. The Communication Layer consists of stable protocols and standardised data transmissions to support the communication of the virtual services. The Information Layer consists of the databases about products that needs to be processed and data of equipment that needs to perform operations. The Functional Layer is where a service and components are provided to enable information exchange between the real and virtual worlds.

Hierarchy levels describe the breakdown structure of assembled components. Devices, motors, and machines are controlled and operated by workers. The hierarchy levels indicate the interlinked nature of stakeholders and information flow. The levels describe the assembled components in a breakdown of their structure. The levels are divided into the Connected World, Enterprise, Work Centre, Station, Control Device, Field Device and Product. To operate a system within the above mentioned structure, certain competencies, knowledge and skills are required.

2.3 Competencies, Knowledge and Skills

Industry 4.0 will bring a higher level of automation and connectivity. Technology, tools, and machines are expected to differ from present ones. Smart machines will coordinate themselves with other devices and their environment. Smart devices and system will be used to gain and analyse real time information. New machines and tools will collect the data in real time and be able to analyse it. Machines will be able to calibrate themselves based on quality parameters and historical data. Industries will become more flexible and changeable. Workers will be required to be capable of handling data using IT and be able to perform cross functional tasks. Pinzone [14] conducted a focused-group survey to identify sets of technical skills for Industry 4.0 in 5 subsections of an organization. Small-scale farmers will have to operate within these areas, namely Supply Chain, Data Science, Operation, IT Integration and Product Service Innovation.

2.4 Barriers to Applying Precision Farming

There is a lack of methodology or guidance towards identifying the barriers to apply Industry 4.0 and a lack of knowledge on how to apply it. [7]

Applying PF is not an immediate activity and depends on various variables. In many studies, it is agreed that young, well-educated farmers with large farms are more likely to apply PF. Widely agreed upon barriers are the learnings curve and costs.[17]

To address the barriers to applying PF, such as an irrigation system, by small-scale farmers, a Pareto Analysis was performed. This was done to identify the top barriers to applying PF technologies by analyzing literature sources. After extracting data from 426 different sources that fall into the inclusion criteria, the Pareto Chart was constructed. The inclusion criteria are:

- Type of publication: Website Article, Study, Question and Answer Blog
- Date: The source of data should not be conducted prior to 2000.
- Participant: There are no restrictions on the participants involved in the data source
- Key words: Precision Farming / Precision Farming/ Smart Farming / Digital Farming; Challenges / Limitations / Obstacles / Problems; Small-scale Farming / Small-scale Farming / Small-Scale Farmer / Small-scale Farmer

The top barriers that were identified are Too Expensive, Benefits Uncertain and Too Complex. A framework will be presented in order to provide a solution to the three barriers.

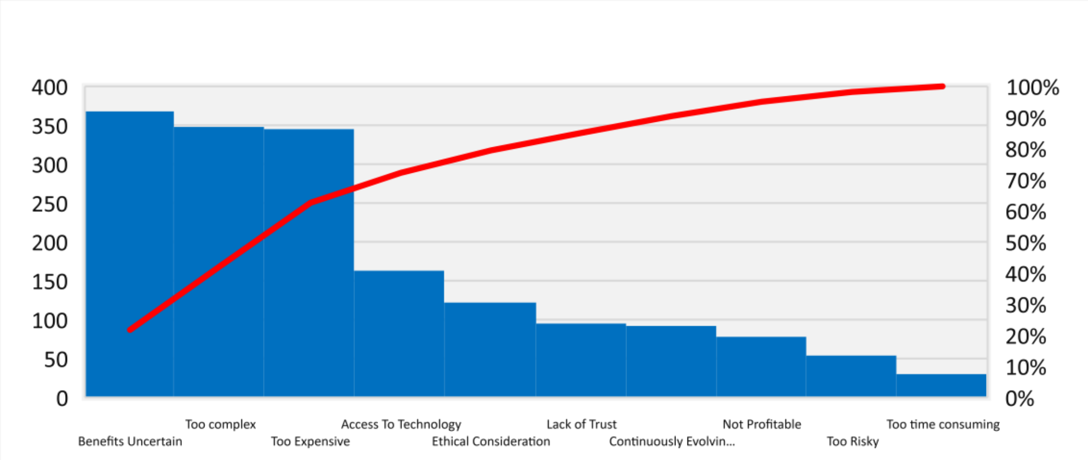

Figure 1: Barriers to Adopting Precision Farming (Pareto Analysis)

3 FRAMEWORK DEVELOPMENT

The system configuration will be developed on RAMI 4.0 as it presents the most complete architecture due to it allowing a representation of a physical object in the information world. It also determines what is required to manage, operate and apply the physical object. [6]

The framework was developed in three different parts. First to identify the preconditions for the framework perspectives, each one addressing one of the barriers. It sets the entry level requirements and eliminates largescale and complex systems. The second identifies the existing technologies and the benefits, costs and requirements of the technologies and their components. The third part develops pathways via a system configurator for using the framework.

3.1 Deriving Framework Perspectives

The pre-conditions for the framework set the criteria for each framework perspective. It therefore underlines the entry level and optimal requirements to operate, finance and understand the irrigation system. The pre-conditions therefore aim to eliminate largescale and complex irrigation systems.

3.1.1 Too Expensive

A potential budget split in needed to determine the budget allocation towards irrigation. The institute for sustainable food system provides an enterprise budget for the small-scale farmer regarding various crops and products. The following allocation percentages is derived from the allocation for potato production constructed by the Institute for Sustainable Food Systems from the Kwantlen Polytechnic University [1].

$$Total\ Costs: 100\%\ ;\ Total\ variable\ Costs: 50{,}23\% \quad \textbf{(1)}$$

I. $Irrigation\ variable\ Cost: 1{,}21\%\ \ \therefore \%\ of\ Total\ cost: 0{,}608\%\ per\ hectare$

$$Total\ Fixed\ Costs: 49{,}77\% \quad \textbf{(2)}$$

II. $Irrigation: 4{,}67\%\ ; Equipment\ and\ Tools: 6{,}99\%\ ;\ \therefore \%\ of\ Total\ Costs: 5{,}8\%$

Lass in CSA [11] provide a model for the expected expenditure of agricultural production. The reported cost per share listed various expenses for operations. Utilities (1,8%) and Farm supplies and hand tools (4,1%) are potential budget allocations towards new irrigation management technologies. The Land Redistribution for Agricultural Development programme provides grants for individuals that were previously disadvantaged in acquiring farming land and ranges from R20000 to R400000 depending on the land being distributed per applicant. MAFISA also grants loans up to R100 000. Grants The grants were limited to South African grants as variance worldwide could disqualify too many farmers.

Therefore, the pre-condition for the acquisition of new irrigation management equipment is calculated as follows:

$Both\ [3] and\ [11])\ agree\ upon\ a\ \approx 6\%\ allocation\ of\ total\ budget.$

$The\ min\ investment\ capability\ through\ LRAD\ Grant\ is\ , (R20000\ +\ R5000) * 0.06\ =\ R1500\ \approx\ \$91$ **(3)**

$The\ max\ LRAD\ grant\ investment\ capability: (R100000 + R400000) * 0.06\ =\ R3000\ \approx\ \$1820$ **(4)**

$The\ MAFISA\ Loan\ enables\ a\ \ med\ capital\ investment\ of\ (R100\ 000) * 0.06\ \approx\ \$364$ **(5)**

3.1.2 Too Complex

The second perspective, the knowledge and skills requirement aim to address the complexity of the system. Determining a farmer's knowledge based on their academic qualifications alone is difficult due to the knowledge they gain through experience and general knowledge on their environment. Therefore, the pre-conditions for the perspective can be expressed as a qualification or skill and knowledge level. Clay et al. [4], performed an industry survey to determine the knowledge, skills and abilities required in the Precision Farming workforce. The two workforce categories that the system configuration is interested in are equipment operator and the precision equipment technician.

The academic requirements for the roles vary over having a high school diploma, 1 year or 2 year community college degree, bachelor's and master's degree. Clay [4] related key knowledge, skills and abilities (KSAs) to each workforce role. The general knowledge of precision farming technology and the ability to install, calibrate, troubleshoot, and repair precision farming hardware and equipment were the most prominent for the two roles.

Therefore, the perspectives precondition is set as that of the equipment operator and technician. The knowledge, skills, and abilities acquisition for PF technologies follows an orderly learning process. It is ordered as learning and understanding the concept spatial data, learning to fully utilize sensors, learning to use computer software, improved crop production decisions through assessing yield variation and narrowing potential cases and lastly, interpreting, summarizing, and collecting information. {9]

3.1.3 Benefit Articulation

When considering the benefits that the system configuration will provide the farmer, breaking down the system into its various components and stating the benefits each component each component will provide and the available technologies for each component, was determined.

From the various architectures shown and discussed in the literature review, the main components of an irrigation systems can be identified. The main components present across the studies are Microcontrollers/Microcomputers & the processor; Sensors; Drivers/Receivers; Display; Analog to Digital Converter; GSM Module; Wi-Fi Modules; Relay Modules; Application (Smartphone/Computer).

3.2 Visual Representation of the System Configurator

The next step involves developing a system configuration on RAMI 4.0. The visual representation of the requirements for the architecture layers are given in Figure 2. They include the hardware concept of the irrigation system in the asset layer, the integration with the network in the integration layer, communication via cloud computing in the communication layer, the soil moisture and rainfall information database controlling and monitoring in the information layer, the physical configuration in the functional layer and the business model and pricing in the business layer.

The main tasks of an irrigation systems enable the population of these layers. They are to monitor and collect soil and weather information and patterns, controlling the irrigation process in real time, and performing decision making on the irrigation system. The tasks determine the essential components of the irrigation system configuration. [10]

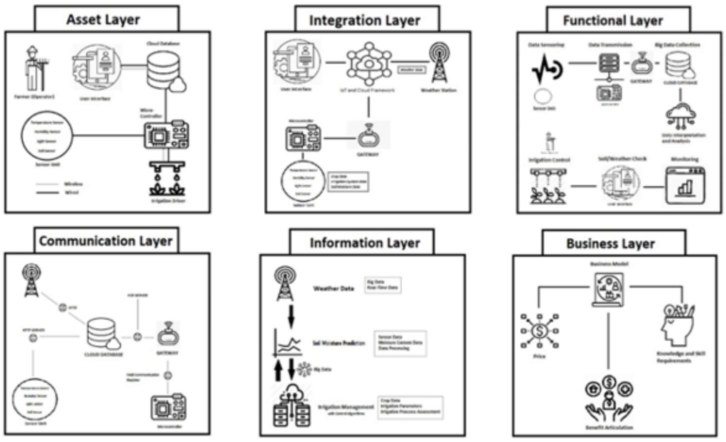

Figure 2: Visual Representation of the System Configuration Layers

3.3 System Configurator on RAMI 4.0

Moghaddamet al. [13] proposes dividing fundamental architectural elements into three architectures namely, the functional architecture that describes the system functional requirements, the physical architecture that describes the components of the system and an architecture that integrates the two. The elements are modelled into a platform with an Industry 4.0 component allocated to each aspect of RAMI 4.0 to describe the configuration.

The system configuration is designed at the product level. The system is designed based on the platform architecture and modelling thereof. The usage of the system can thus be described with Industry 4.0. The proposed RAMI 4.0 led irrigation systems configuration identifies the main components and enabling Industry 4.0 technologies. The system configuration on the layers is given in Figure 3.

Each layer, hierarchy level and lifecycle phase in the configuration is represented. The layers consist of the technology functions, the component arranged on the platform such as the hardware, data collection and connection, information processing and operating and control strategy. The hierarchy levels indicate the required components that support the proposed approach concept. The Product Level is the irrigation controller placed in the irrigatable field among crops. The Field Device refers to the sensors and actuators of the Irrigation Systems. Lastly, the Control Device refers to the irrigation system controller in a machine and/or application. The required components on the RAMI 4.0 layers are given in Figure 4.

4 APPLICATION OF THE FRAMEWORK TO DESIGN AN IRRIGATION SYSTEM

From RAMI 4.0 and the pre-conditions, a system configurator with required Industry 4.0. components are presented. The core components of the system should enable the functionality of an irrigation systems. The blue components indicate the necessary components the configuration requires to qualify as an Industry 4.0 product and the yellow components are not necessary for that purpose but are needed as enablers of an irrigation system. From the literature study performed, the core components were identified and shown in the following Figure 5:

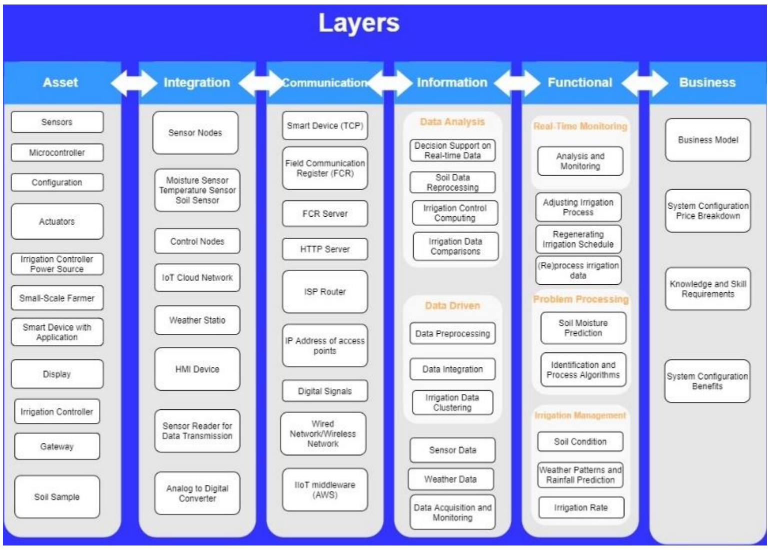

Figure 3: System Configuration Mapped on Layers Axis

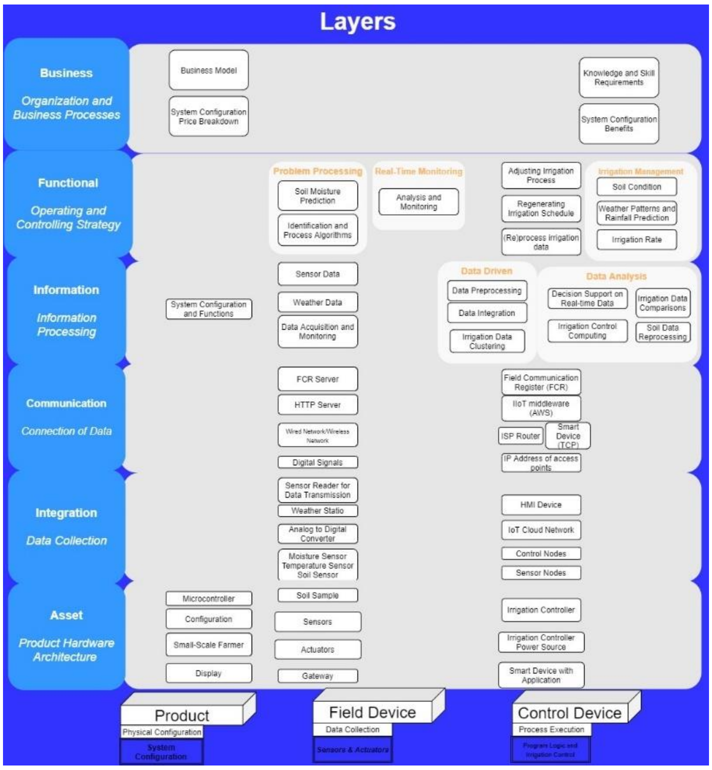

Figure 4: Components at Hierarchy Levels of the System Configuration

To use the framework, the small-scale farmer should first establish their starting position before using the configurator. This will allow them to determine what they can achieve and require them to take stock of farming related factors. The factors include site-specific requirements, goals, and constraints. The pre-conditions are defined and categorized in detail in the full text article.

4.1 Site-Specific Requirements

The site-specific requirements prompt the small-scale farmer to evaluate what his farming conditions are and under what conditions the irrigation system will operate. This allows the farmer to choose irrigation systems and components based on the farm's characteristics. The requirements are categorized under sensor type, connectivity, automation level, capacity, smart connectivity, component, application and geography.

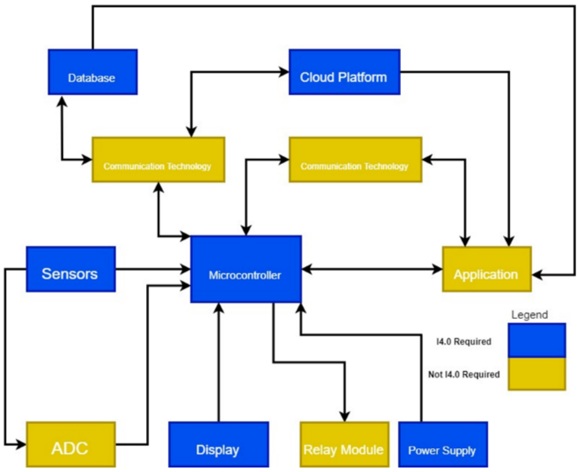

Figure 5: System Configurator

4.2 Constraints

The constraints determine what the limits are to the farmer when using the framework. The constraints should be defined with reference to the barriers identified. Therefore, the first constraint needed for identifying is the financial constraint. This requires the farmer to determine how much capital they can allocate towards an irrigation system. As previously stated, a good measure would be to allocate 6% of their yearly farming budget towards irrigation.

The second constraint would be to determine which knowledge and skills they have available through the framework. Defining this constraint would help determine which components and available irrigation system will be of use to them. Also to what the system has to and can achieve, in other words what the benefits can be.

4.3 Goals

Small-scale farmers are encouraged before they start using the framework to determine what they want the irrigation to achieve for them. Common goals for employing an irrigation system are to:

- Improve yields.
- Reduce water usage and irrigation operating costs.
- Reduce labour costs.
- Improve irrigation efficiency and preserve the environment.

4.4 Design of the Site-Specific Irrigation System

4.4.1 Perspective 1: Financial Capability

Description: The perspective addresses the barrier where the high capital cost and initial implementation and investment cost are deemed too high to apply the irrigation systems. The perspective defines the irrigation systems and components according to the capital requirements to implement the system.

Small-scale farming characteristics: Farmers who approach the framework for the system configuration from this perspective are risk adverse and have certain financial capabilities that the system needs to satisfy. They are either limited by their financial capabilities or is already aware of the other requirements and is only interested in choosing the configuration that matches their financial plan.

The first iteration of the perspective requires the farmer to develop their own system configuration based on the component requirement and availability outlined in Figure 5. To choose the amount the small-scale farmer wishes to invest in each component or the system as a whole, the study provides tables capturing financial information regarding both scenarios.

Figure 6 is an extract of the financial requirements in the full text version of the article, that is used in the following equation to determine a system comprising of a Raspberry Pi Zero W microcontroller, FC37 Rain Sensor, Geekcreit 3.2 Inch MEGA2560 display, MCP4725 ADC, 50-meter Ethernet Communication Technology, HiLetgo 2pcs 5V relay module, 4 Battery Power Supply and the Raspberry Pi Cloud Platform:

Microcontrollers		Sensors		Display		ADC		Communication Technologies		Relay Modules		Application		Cloud Platform		Database		Power Supply	
ESP8266 Microcontroller Board	3 USD	Rain Sensor		Arducam 1602	6 USD	MCP3008 / MCP3004	2 USD	Ethernet	0.19 USD	HiLetgo 2pcs 5V	6 USD	Spruce	≈ 180 dollars for the controller and application	Raspberry Pi	Free	SQLite	Free	Batteries	1 USD
		FC37	< 2 USD																
		YL83	< 2 USD																
WEMOS MINI D1	8 USD	Rain Sensor Module - Microcircuits	4 USD	Geekcreit 3.2 Inch MEGA2560 Display Module	9 USD	MCP4725	5 USD	Bluetooth	9 USD	KNACRO 1-Channel	8 USD	Rachio	≈ 200 US Dollars for the controller and application	NETPIE	Free	NoSQL	Free	USB Port	2.6 USD
		HALJIA	6 USD																
		Leaf Wetness 12V DC Rain Sensor Module	10 USD																
Raspberry Pi Zero W	10 USD	AZDelivery 5 x Rain Sensor Module	11 USD (5pcs)	Geekcreit® UNO R3	10 USD	LTC2499	6 USD	GSM	Price dependant on	JBTek	8 USD	GreenIQ	≈ 249 US Dollars for	Firebase	Free	JSON	Dependant on service database	Solar Cell	2.91 USD

Figure 6: Extract from the financial capabilities in the framework

$$(Raspberry\ Pi\ Zero\ W\ )10 + (\text{FC37})2 + (Geekcreit\ 3.2\ Inch\ MEGA2560)9\ + (Ethernet)(50)(0.19) + (HiLetgo\ 2pcs\ 5V)6 + (MCP4725)5 + (Batteries)(4)(1) + (Raspberry\ Pi\ Cloud)(0) = 45.5\ USD \quad (6)$$

The second iteration of the perspective provides industry ready irrigation systems that perform set functions and are provided by third party companies. Small-scale farmers can evaluate if the system configuration they develop would better suite heir financial capabilities compared to Available Irrigation Systems. These financial requirements are summarised in the study.

4.4.2 Perspective 2: Benefit Articulation for Farming Requirements

Description: Benefit articulation for farming requirements aims to describe the benefits that the system configuration will have for their individual needs. This addresses the barrier of farmers being uncertain of the advantages, benefits, and improvements that irrigation systems will bring their farming operations. Therefore, they lack information that would justify implementing the system.

Small-scale farming characteristics: Farmers approaching the framework from this perspective are uncertain about new irrigation systems and their functionalities, capabilities, components, legality, and limitations. They also have specific requirements that the system should perform for them to adopt the system.

In the first iteration of the perspective the small-scale farmer refers to the configurator when developing their own system configuration to ensure it adheres to the required components for an Industry 4.0 product and adding additional components. After the components are selected, the benefits and functions of the specific product of each component are provided. The small-scale farmer can choose the components based on the benefit they would provide him/her and can develop a system configuration that serves his/her personal, professional, or crop-specific needs.

The second iteration of the perspective enables the farmer to evaluate if the benefits and functions of an Available Irrigation Systems would suit their personal and/or professional farming requirements. The functionality of each product in a category provides the information needed to determine if the product will serve the professional and/or personal farming requirements of the farmer.

A thorough literature review of available technologies was conducted, and various market ready, available Irrigation systems were identified. The variety of product benefits are vast and are tested across a large variety of soil conditions, landscapes, rainfall patterns and site-specific requirements. The benefits of the available systems and components are outlined in the full text version of the article.

If the small-scale farmer requires more technical specifications for each available irrigation systems, summaries of these specifications which the farmer can use to supplement their decision. In the supporting documents of the full text article, specifications of the core irrigation systems components regarding their benefits, drawbacks and description if the farmer wants to develop the system to the furthest level of detail.

4.4.3 Perspective 3: Knowledge and Skill Capability

Description: Most studies listed that there is a perception (justified or not) that PA and irrigation systems are too complex to implement on their farm. This perspective identifies the knowledge and skill requirements needed to operate the developed system.

Small-scale farming characteristics: This farmer is concerned about the complexity of the system and level of technology literacy required to operate the irrigation systems. The farmer and/or his labor force has a certain knowledge and skill level available to operate a system and wants to ensure the system is within this level in order to properly operate the system.

From the results of the extensive literature review, in the first iteration of the perspective, it is possible determine the knowledge and skills required from the small-scale farmer to develop, operate, implement, and maintain their irrigation systems. The knowledge and skills requirement are identified through the logic framework in Figure 7.

Competencies, knowledge, and skills needed in irrigation systems and Industry 4.0 are identified through a thematic analysis. They are categorized by defining a competency domain (represented by letters A-D), populating that competency domains with a subset of competencies (represented by letters A-D), followed by listing the knowledge and skills that are part of that competency subset. For example, the competency domain “Professional Competence” (represented by the letter C), is populated with the subset competency “Technical Competence” (represented by C.A.) and has the knowledge and skill requirement “Ability to operate precision farming equipment” (represented by C.A.1.).

The competencies, knowledge and skills are then related to each component to serve as a comprehensive reference in the full text version of the article. An extract of this full reference is given in Table 1. The table reads from left to right. The small-scale farmer identifies the component they want to add to their system, then the next column is the subsect of that component. It must be noted that it cannot be expected to master each skill in the knowledge area, but it serves as a starting point to identify which skills they have of those listed and to identify gaps where training and education can be provided.

Table 1: Knowledge and Skills Required for a Temperature Sensor

Smart Irrigation System Component	Description	Competencies	Knowledge & Skills
Sensor	Temperature Sensor	A	A.A.1 & A.A.2.; A.B.2.; A.C.1.
		B	B.B.1.
		C	C.A.1; C.C.1; C.D.1.; C.D.2 & C.D.3.
		D	D.A.3. & D.A.4

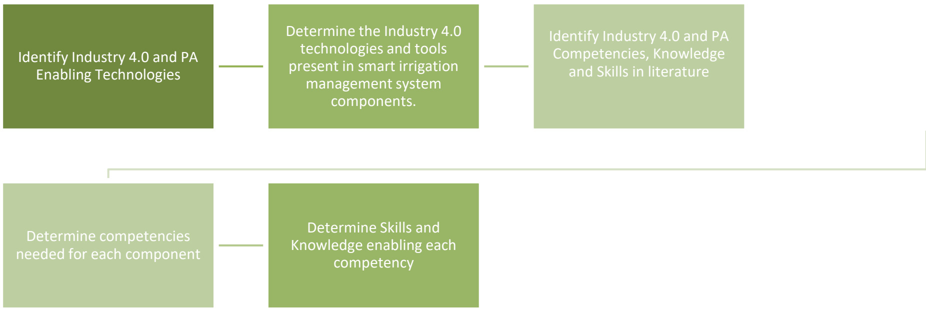

Figure 7: Framework for Determining Knowledge and Skill Requirement

The second iteration of the perspective allows the farmer to evaluate Available Irrigation Systems based on the knowledge and skills required to use the products. If a farmer wishes to acquire the competencies, skills and knowledge required to operate different components of an irrigation systems, different levels of education are provided that provide the opportunity to acquire them. The education levels are provided in full with all the skills attained through them in the full text version of the article.

4.4.4 Integrating Perspectives to Achieve Goals

To integrate the perspectives, the framework looks at the three perspectives. The framework is initiated when the farmer identifies the requirements, constraints, and goals. For this example, the small-scale farmer provides the following constraints:

- Having capital of less than $100 to allocate to the system.

Goals:

- Goals of improving water savings up to 30%

And requirements:

- Requirements of having a soil-based sensor.
- The small-scale farmer would want the benefit of his soil-moisture sensor to have low power consumption and have analog to digital output potential.
- The small-scale farmer would want the benefit of having a display that needs no extra wiring or soldering and low power consumption.
- Requires WIFI or ethernet connectivity and
- Being able to operate in more than 10 zones.

4.4.4.1 Perspective 1: Financial Capability

For the first perspective, the system configurator in Figure 5 along with the financial requirements for components in the full text article are used to construct an irrigation system that is under $100, has a soil-based sensor and can operate in more than ten zones. One iteration of such as system is shown above in designing the financial capability perspective. The iteration equates to

45.5 USD. The system configurator is used to determine which components are necessary to achieve the system that will adhere to site-specific requirements, constraints, and goals.

When choosing an available irrigation system there are various products available. Orbit B-Hyve 12 Zone Smart Indoor/Outdoor Controller retails under $100.It should be noted that the price of the available irrigation system can vary depending on the provider, the source of the system and the location it is purchased from.

4.4.4.2 Perspective 2: Benefit Articulation

For the benefit requirements set out by the farmer, The FC37 soil moisture sensor has an analog to digital output potential and a low power consumption. The Geekcreit 3.2 Inch MEGA2560 display requires no additional wiring or soldering and has a low power consumption. The Orbit B-Hye claims to save up to 50% of water compared to traditional irrigation systems. The Orbit B-Hyve also can functions at more than 10 zones and comes with WIFI connectivity and requires no additional wiring and soldering for its display.

4.4.4.3 Perspective 3: Knowledge and Skills Requirements

From the knowledge and skills perspective, the requirements are captured to operate each individual component. Orbit B-Hyve systems are according to the product, easy to install and operate. Wiring and connecting a controller to an irrigation technology is made easy through manuals and clear instructions. Therefore, additional knowledge and skills mentioned above are not necessary. Table 2 is a representation of the framework, based on the site -specific requirements, goals, and constraints, in matrix form. The table reads from left to right. The first two columns represent the irrigation system. The first column includes the components selected by the farmer using the system configurator. The second column is the available irrigation system from the market that is selected by the farmer based on their site-specific requirements. The following columns each represents one of the perspectives. Each perspective provides the necessary information for each component and the available irrigation system from the market. For example, the financial capability perspective provides the financial requirement for each component selected and the market available irrigation system.

5 SMALL-SCALE FARMER SURVEY

The overall objective of the Irrigation system configuration is to address the challenges faced by small scale farmers to implement the relevant precision agriculture irrigation technologies at their farms. The outcome of the system configuration should provide small-scale farmers with the knowledge and ability to negate the challenges to implement the technology and elevate their farming practices.

5.1 Objectives

The general objective of this survey is to determine if the developed framework is understandable, usable, and applicable to the small-scale farmer. It is also used to determine whether a small-scale farmer would desire such a framework, or if they identify with the need to have such a framework.

5.1.1 Specific Objectives

Breaking down the general objective, entails:

- Determine if small-scale farmers experience the barriers identified.
- Determine if small-scale farmers are knowledgeable on irrigation systems and precision farming.
- Determine whether the use of the framework is understandable.

- Would Small-scale farmers be able to identify their site-specific requirements and goals?
- Is the outcome of the framework sufficient for their site-specific requirements and goals?
- Establish the level of difficulty to use the framework.
- Is the information provided of interest to the small-scale farmer?
- Would they use the framework to apply an irrigation system to their site-specific requirements and goals?
- What the small-scale farmer would like the framework to provide them?

5.2 Discussion of Results

The survey reinforced findings in literature and underlined the need for support to be provided to the small-scale farming industry. The results from the survey indicate that most of the farmers experience the barriers that are identified in literature. The barrier that received the most entries is being too expensive, which corresponds to the findings in literature. One of the participants indicated that the barrier that keeps them from applying irrigation systems is:

> *"Low income for the purchase of farm inputs"*

This is in line with the barrier of being too expensive. It does raise a different issue. A farmer might want to apply an irrigation system that could increase their income, by reducing irrigation costs and improving yields. They can only do so if they have the initial capital to acquire a system. Survey respondents indicated that they could determine their site-specific goals mostly in a qualitative manner. "Cost Reduction" was the only category in which farmers indicated that they could not indicate any qualitative or qualitative goal.

The framework's useability is based on the system configurator. Survey respondents indicated that they mostly agree with the statement that they would be able to develop a system using the configurator. The financial capability perspective proved to be the most positively received perspective. Meaning, that it would be most applicable to the farmers. It was however indicated that the first perspective with the system configurator would not be enough to develop a system and additional resources would be required. When considering the benefits of the irrigation system, reducing costs, and saving water are the most desired benefits for the farmer. The benefit of least interest came out to be increasing overall yields. Farmers indicated that they would mostly be interested in the benefits of an entire system or available irrigation systems.

Even though the farmers indicated that component level benefits are inferior to entire systems, they responded that component-level benefits would be beneficial and could help them develop their own system Farmers indicated that the level of difficulty of the framework was either being mostly of a medium difficulty. The farmers however mostly indicated that they would not refer to the framework to aid them in developing their own irrigation system. Expectation around this was that the time it would take may not be of interest or that the informational load may be too high. Farmers indicated the following:

> *"Use currently available system components instead of trying to develop new ones."*

The farmer refers to the benefits of developing their own system not outweighing the already available systems on the market. It indicates the need to rely on the established products. This corresponds to the farmers indication that the systems may not be profitable. Having a proven system with case study findings indicating water savings, increased yields and other indicators can prove to be a more motivating factor to acquire such a system even if it could cost more than developing their own system.

> *"Explain clearer what knowledge and skills are needed. Ex. Need to solder on board, be able to set up cloud data base, etc."*

The farmer expresses that the knowledge and skills requirement should be less general and more focused on what exactly is needed to perform tasks in the developing process. The farmers indicated that they are mostly satisfied with the results and the outcome of the framework. It is noted that only 3 farmers completed the survey. The reluctance from farmers to complete the survey was a limitation to the outcome of the survey. This could be due to the number of questions in the survey deterring potential participants, or it indicates an unwillingness to participate in the study. The unwillingness can be attributed to the uninterested in applying irrigation systems and precision agriculture in general.

6 CONCLUSION AND FUTURE RECOMMENDATIONS

6.1 Conclusion

This study aims to address the barriers small-scale farmers are confronted with when applying irrigation systems to their farming operations. It was proposed to develop a configuration for an irrigation system that a small-scale farmer can use to apply a system to their site-specific requirements, goals and accompanied constraints. In the study it was found that there is a general lack of existing guide, references, and frameworks for small-scale farmers to improve their farming practices. Due to majority of small-scale farmers not having access to vast number of resources and not having prior educational training, there is a need to provide these resources to empower them and improve their farming operations. The framework provides the ability for the farmer to configure their own irrigation system or choose an existing one to satisfy their site-specific requirements, constraints, and goals.

The framework succeeds in communicating the financial requirements for the development of a system and that of available products. The framework provides an easily understandable configurator and provides sufficient resources in choosing system components. Constraints for applying these systems cannot simply be overcome by a framework, but external resources and support may be needed for a farmer to be able to either afford the system or gain knowledge and skills to develop and operate a system. Financial requirements of available systems can be source and location sensitive.

The benefit articulation of the system is crucial for the success of the framework, as small-scale farmers are reliant on traditional methods and techniques, they are familiar with. Having access to the requirements and benefits for applying irrigation system may prove to be a sufficient motivator to acquire them. Small-scale farmers are noted to have vast knowledge about their own crops, resources, and environment they operate in. The survey also indicated that farmers could identify what goals they want to achieve if they are to apply an irrigation system to their farm. If they can combine that with the technology that Industry 4.0 and precision farming brings, it can elevate their farming practice.

Table 2: Integrated Perspectives Matrix

Irrigation System			Financial Requirement ($)		Benefit Articulation		Knowledge and Skill Requirement			
Component		Available Systems	Component	Available Systems	Component	Available Systems	Component		Available Systems	
Microcontroller	Raspberry Pi Zero W	Orbit B-Hyve 12 Zone Smart Indoor/Outdoor Controller	10	83	1.Various I/O pins which can interface to other boards and circuits. 2.USB port, 14 I/O pins, ICSP header, power supply and reset press. 3.Compatible with computers 4.Low cost with online libraries available	The Orbit B-Hye claims to save up to 50% of water compared to traditional irrigation systems. The Orbit B-Hyve also can functions at more than 10 zones and comes with WIFI connectivity and requires no additional wiring and soldering for its display.	A	A.A.1 A.A.2; A.C.1.	A	A.A.1 A.A.2; A.C.1.
							B	B.A.1.	B	B.A.1.
							C	C.A.1. C.A.2.; C.B.1. C.B.2.; C.C.1.; C.D.1. C.D.2. C.D.3.	C	C.A.1. C.A.2.; C.B.1. C.B.2.; C.C.1.; C.D.1. C.D.2. C.D.3.
							D	D.A.1. & D.A.3. & D.A.4.	D	D.A.1. & D.A.3. & D.A.4.
Sensor	FC37		2		1.Analog and digital output potential 2.Easy installation features 3.Low power consumption 4.Adjustable digital output threshold with potentiometer	Orbit B-Hyve systems are according to the product, easy to install and operate. Wiring and connecting a controller to an irrigation technology is made easy through manuals and clear instructions. Therefore, additional knowledge and skills mentioned above are not necessary.	A	A.A.1 A.A.2.; A.B.2.; A.C.1.	A	A.A.1 A.A.2.; A.B.2.; A.C.1.
							B	B.B.1.	B	B.B.1.
							C	C.A.1; C.C.1; C.D.1.; C.D.2 C.D.3.	C	C.A.1; C.C.1; C.D.1.; C.D.2 C.D.3.
							D	D.A.3. D.A.4	D	D.A.3. D.A.4
Display	Geekcreit 3.2 Inch MEGA2560		9		1.High image quality and fast response. 2.Module can be inserted directly into a Mega board. 3.Low power consumption 4.Easy installation.		A	A.A.2.		
							B	B.B.1.		
						Up to 12 zone capacity.	C	C.A.1. C.A.2.; C.C.1.; C.D.1 C.D.2. C.D.3.		
						Any Biome.	D	D.A.1. D.A.2. D.A.3.		
Power Supply	Batteries		(4) x (1)		1.Batteries are low-cost devices. 2.Small size 3.Can be inserted on device. 4.Does not require external components and provides the irrigation systems with freedom to be placed wherever it is needed.		A	A.A.2.; A.C.2		
							B	B.B.1.		
							C	C.A.1. C.A.2.; C.B.1. C.B.2.; C.C.1.; C.D.1 C.D.2. C.D.3.		
							D	D.A.1.		
ADC	MCP4725		5		1.Lower Power consumption 2.Ease of use and fast setting time. 3.6-pin package suitable for applications requiring power		A	A.A.2.; A.C.2		
							B	B.B.1.		
							C	C.A.1. C.A.2.; C.B.1.		

					saving during off times.			C.B.2.; C.C.1.; C.D.1 C.D.2. C.D.3.		
Database	*On Microcontroller*		0						A	A.A.1 A.A.2; A.C.1. A.C.2. A.C.3.
									B	B.B.1 B.B.2.B.A.1. B.A.2.
									C	C.A.1. C.A.2.C.B.1. C.B.2.C.C.1.C.D.1. C.D.2. C.D.3.
									D	D.A.1. & D.A.3. D.A.4.
Relay Modules	HiLetgo 2pcs 5V		6		1.Enables user to set high and low trigger threshold 2.Very convenient interface through direct connection. 3.High quality relay		A	A.A.2.; A.C.2		
							B	B.B.1.		
							C	C.A.1. C.A.2.; C.B.1. C.B.2.; C.C.1.; C.D.1 C.D.2. C.D.3.		
							D	D.A.1. D.A.3. D.A.4.		
Application	-		0							
Communication Technology	WIFI & Ethernet		(50m) x (0.19)		WIFI: 1.Wireless communication of data. 2.High internet speeds. 3.Wi-Fi strengths can be increased through mesh and extenders. 4.Remote monitoring and control capabilities. Ethernet: 1.Enables communication between devices. 2.Can carry information over long distances up to 10,000 meters. 3.Cable's bypass obstacles that can interfere with transmission. 4.Fast speeds, low latency. 5.Greater security and reliable connections.		A	A.A.1 A.A.2; A.B.1; A.C.1. A.C.2	A	A.A.1 & A.A.2; A.B.1; A.C.1. & A.C.2
							B	B.A.1.; B.B.1 B.B.2.	B	B.A.1.; B.B.1 & B.B.2.
							C	C.A.1. C.A.2.; C.B.2. C.C.1.; C.D.1 C.D.2. C.D.3.	C	C.A.1. & C.A.2.; C.B.2.; C.C.1.; C.D.1. & C.D.2.
							D	D.A.1. D.A.2. D.A.3. D.A.4.	D	D.A.1. & D.A.2. & D.A.3. & D.A.4.
Cloud Platform	Raspberry Pi Cloud		0		1.No costs 2.Allows user to customize data, share and store incoming data. 3. It uses PHP scripts to access SQLite and MySQL databases installed on the		A	A.A.1 A.A.2; A.C.2. A.C.3.	A	A.A.1 A.A.2; A.C.2. A.C.3.
							B	B.B.1 B.B.2.	B	B.B.1 B.B.2.
							C	C.A.1. C.A.2.; C.B.1. C.B.2.;	C	C.A.1. C.A.2.; C.B.1. C.B.2.;

					server and runs on Windows and Linux systems. 4.Easy usage and implementation.			C.C.1.; C.D.1. C.D.2. C.D.3.		C.C.1.; C.D.1. C.D.2. C.D.3.
							D	D.A.1. D.A.2. D.A.3. D.A.4.	D	D.A.1. D.A.2. D.A.3. D.A.4.

6.2 Future Recommendations

The framework proposed in this thesis would serve as a reference on how to construct the tools the solution for the other technologies. It can be simplified or compressed to contain less information to reduce the informational strain in real time applications.

Government agencies, learning centres, small-scale farmer organizations and groups can use the framework as an educational tool or resource. The framework can be used in learning programs deployed by these stakeholders to supplement their education of small-scale farmers on precision farming and irrigation systems. They need to decide on irrigation systems or aim to develop their own system for their farm. The framework can be transformed into a roadmap to achieve the same objective. The roadmap can stipulate a stepwise path to achieve a certain goal, rather than providing the information and guide to address all three barriers.

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THE IMPACT OF 100% RENEWABLE TECHNOLOGIES FOR HOUSEHOLD DEMANDS OVER FOSSIL-FUELED BASED ELECTRICITY: A REVIEW

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ABSTRACT

Strategies to alleviate poverty often seem to stand in opposition to environmental and social sustainability, particularly in the realm of energy provision. The challenge of reforming entire economies is immense; even more so if a country is a fossil fuel-based and emissions-intensive as South Africa. In an increasingly carbon-restricted environment and already facing climate change impact, however, South Africa must rapidly and decisively reduce the intensity of greenhouse gas emissions. The main aim of this paper was too assess the use of renewable energy in the household sector and more specially for an isolated home by providing 100% of the needed energy from renewables. Wind energy, photovoltaic, biofuel, and batteries are the renewable that will be evaluated. The end goal is to find suitable technologies that can solve the challenges of shortage of energy experienced in South Africa.

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1 INTRODUCTION

Strategies to alleviate poverty often seem to stand in opposition to environmental and social sustainability, particularly in the field of energy provision [1] . The challenge of reforming entire economy is immense even more so if a country is fossil fuel-based and emissions-intensive as South Africa. Climate change is already causing significant impact in South Africa (SA). To avoid this, the country must urgently reduce its greenhouse gas emissions. The electricity sector in SA is a critical part of economy and, at the sometime, contribution much to the issue of pollution. Figure 1 presents an example from one of the coal fired power stations available in SA where large amounts of smoke is allowed into the atmosphere.

Figure 1: Power Station Plant that generate electricity while causing air pollution [2]

SA is in southernmost nation on the African continent, with latitude between 22° and 35° S and longitude between 17° and 33° E as presented in fig. 2 [3].

Figure 2: Republic of South African Map [3]

There are a significant number of coal reserves in SA; most of the recognized coal reserves are located in Mpumalanga, Free State, and Gauteng and Northwestern province of Limpopo. SA has historically been dependent on fossil fuels, such as coal and natural gas. Eskom, the state-owned utility of South Africa, has been the sole primary producer of 95% of its electricity in South Africa and 45% in Africa currently generating up to 37, 868 MW of the country's output from its coal-fired power plants [4-6]. Eskom is an acronym for Electricity Supply Commission which was founded by the South African government in 1923 [7].

Although the national utility Eskom, high levels of household coal use, especially in areas close to coalmines and areas experiencing cold winter, uses the majority of coal in electricity generation are prevalent. The worst incidents of poor air quality in South Africa occur with the burning of wood, dung, or coal and multiple fuel consumers have millions of low-income homes, prioritizing other energy sources such as paraffin, wood, and coal over electricity, resulting in related problems such as air pollution, respiratory disease, and shack fires [8]. When these fuels are used in poorly ventilated households, particularly in informal settlements and rural villages, this situation is particularly problematic. However, despite households having access to electricity, it is recognized that coal it's still used continually.

Research has shown that electrified low-income households continue to use a range of fuels because electricity is found to be less cost-effective (Department of Minerals and Energy, 1998)'. However, it is not just the low cost of fuel that makes coal appealing to households with low incomes. Coal simultaneously provides thermal energy for space heating and cooking, killing two birds with one stone, so to say, one fuel and one appliance provide energy for two end-uses. It is because of this dual utility that other energy forms find it difficult to compete with coal [9]. However, energy access is not the only concern; energy supply should also be sustainable, avoiding emissions, noise, high fuel costs and supply insecurities. This call for sustainable energy access for development is further underlined by the declaration of the decade 2014 – 2024 as the decade of Sustainable Energy for All by the United Nations General Assembly [10].

The initiative promotes renewable energy sources as a key technology to reach the energy poor, providing clean electricity, heating, cooking and lighting solutions to people and communities that currently rely on conventional energy sources and/or costly fossil fuels. Renewable energy technologies are regarded as especially suitable because they can provide small-scale solution and decentralized energy supply that meet the needs of the population. The cost reduction over the last decade have rendered renewable energies more economically efficient in comparison to conventional fuels [11, 12].

Nevertheless, these technologies still face a range of social, economic and structural challenges, requiring not only further technological development but also a deeper understanding of both the success factors and the barriers to accomplish widespread dissemination. A study by Bhattacharyya [13] on financing energy access and off-grid electrification, showed that despite recent progress and the support of the international community only limited funding is available for small-scale community projects, most funds are allocated to larger energy generation projects that barely address the energy needs of the poor. Yet small-scale projects can play a key role in supporting the transition towards more sustainable energy systems [10].

2 ENERGY CONSUMPTION PER HOUSEHOLD IN SA - AVERAGE

South Africa's access to energy, as well as access to other basic services such as shelter, education, and water, is associated with a high level of poverty and socio-economic disparity. Until 1994, approximately one-third of the population was connected to the grid [14]. During the transition to democracy, access to affordable electricity became 'a basic need and basic right' with high political and cultural significance and central to the post-apartheid government's Reconstruction and Development Programme (RDP) [15]. Consequently, low-income households have typically aspired to a grid connection rather than off-grid alternatives such as solar homes system solar water heaters [1]. The state's free basic electricity (FBE) allowance, introduced in 2004 to provide 'electricity to all' through the provision of 50 KWh per month of free electricity to low-income households, is one measure to address electricity access and affordability, for basic lighting, media access, and water heating, such an amount is considered adequate, but critics charge it is inadequate for basic household needs, even as a result of the degradation of infrastructure and service quality [4]. Meanwhile, after the country's electricity, tariffs began to grow, illegal electricity connections in townships and informal settlements have increased. Illegal links, for which households sometimes pay an agent to circumvent the meters of the municipality or Eskom, have resulted in live cable electrocutions and have led to unplanned power outages [14].

After intensive research by scientists to find alternatives, renewable energy has emerged. These technologies include hydro, wind, wave, tidal, geothermal, biomass, biofuel, and solar energy. Due to the dependence on nature, most renewable sources cannot be used as a baseload for energy supply. However, introducing these sources would help ease the pressure on the use of fossil fuels thus reducing greenhouse gases that are released into the atmosphere are nuclear-based energy supply.

South Africa's low-income household's energy consumption per daily power rating (Watt) as shown in Table 1.

Table 1: Average energy consumption per household in SA

Household items	Power Rating (Watts)	Power Consumption, Watt per hour per day	
	Watts per rating	Per hour	Watt Power Rating
Energy saver globes	8 W - 20 W	5	100
Stove (Hotplate)	1500 W – 2000 W	3	6000
kettle	1850 W	1	1850
Fridge	80 W	24	1920
Iron	1600 W	1	1600
Cellphone charger	10 W – 15.03 W	2	30.06
Microwave	600 W	1	600
Television	100 W	6	600
Laptop / computer	65 W	6	390
Bluetooth speaker	15.03 W	4	60.12
Total kW/h rating in a 24 hour period			13.150 kW/h

This energy consumption covers the basic needs of a standard living even less compared informal settlement household. There are still households in South Africa that rely heavily on candles. Just over 5% of South Africa's households use candles as a main source of lighting, according to the

General Household Survey (GHS) 2016 report [16]. As a result, South Africa has been experiencing load shedding for quite a while since first initiation year 2008 till to date. It has been observed that renewable energies are leading in the implementation to sustainable energy for all. It is a matter of urgency to come up with a solution now and for future generations to maintain a balanced ecological system, by promoting 100% renewable energy technologies. The principal use of energy in the household, is the area of concern, for space heating and cooling, water heating, cooking, lighting, and electrical appliances. After considering how energy is used and the scale of its use, resulting in various environmental challenges, renewable sources are the focus primary sector to assess the use of renewable energy in the household sector and more specifically for an isolated home by promoting 100% of the needed energy from renewables.

Hydrogen production and fuel cell technology can be classified as alternative energy producers. Although the first applications of renewable energy sources such as wind, bio products, and photovoltaics are likely to involve the direct production and use of electricity, the potential for using renewables for electricity is limited by the intermittent nature of solar radiation, biomass, and wind energy, and the difficulty of using electricity when the extraction of energy from such technologies is limited. Renewable energy's significance in the global economy may be considerably expanded if they could be turned into conveniently stored energy carriers. Even while this problem can now be solved by using batteries, there are still some environmental issues that hinder the system from being widely accepted. However, because this new technology for creating hydrogen and using it in fuel cells is still in its early stages of development, it is currently impossible to replace existing batteries with a hydrogen-fuel cell combination. Before the aforesaid application can be implemented, more research and development must be completed.

3 ENERGY AVAILABILITY - INTERNATIONALLY

The International Energy Agency (IEA) report on key electricity trends in the world's developing economies, shows renewable energy overtaking coal as a source of electricity generation for the first time in 2019. In Europe and America, overall fossil fuels dropped, while renewable production rose [17]. U.S. Energy Information Administration's report that United States renewable energy consumption beats coal for the first time in 130 years as well as other developing countries [18]. German town disconnect from the grid goes 100% renewable for an hour, as the result of the transition to 100% zero-emission energy, the research suggests the transition will lead to the creation of more paying jobs. As an innovation, the biogas technology was introduced in Indonesia around 1970 and had largely been disseminated since 1980 by the Minister of Agriculture. In Indonesia, The implementation of mixed crop and livestock farming was extremely essential for smallholder farm households as about two thirds of the world's rural poor farmers rely on this practice as the backbone of the farming system, the study showed that the adaptation of the biogas technology significantly reduced firewood consumption among smallholder famers and contributed to behavioral changes of the women in the households especially with respect to firewood collection and cooking activities.

4 ENERGY AVAILABILITY - LOCALLY

Local small renewable energy projects (<1 MW) in South Africa, such as Bethlehem Hydro, eThekwini Landfill Gas, Darling Wind farm, PetroSA Biogas Power projects, Hessequa Water purification and George Airport Solar Plant, have proven that successful renewable energy implementation is possible [Ref]. A case study of an excellent programmed prototype energy-efficient solar house that was designed and built at the University of Fort Hare [19]. The Energy Efficient Building Integrated Photovoltaic house was built at the University, which is located 32.8°S and 26.8°E in South Africa. Measures to reduce ghg emissions from the EEBIPV house can be classified in two: reducing energy consumption and demand through energy efficient measures and replacing fossil fuel generated grid supply with BIPV decentralized power. The results shown that using renewable energy technologies and reducing demand through energy efficiency measures in the residential sector does not only take pressure off Eskom's loaded coal-fired station but also help South Africa to meet its commitments to reduce high carbon emissions and mitigate climate change [19].

Hessequa Municipality, situated in the Western Cape Province of South Africa, is one of 226 local municipalities in South Africa. An estimated population of 54, 237 in 2016 [stats] consisted of 17, 371 households (3.3 residents per household) Saw this potential benefit of energy autarky when a decision was taken to include renewable energy solutions as part of its long-term vision and strategy during an Energy Summit that was held in June 2015 [2]. Potential renewable energy solutions became evident through the discussions of the five strategic themes, namely to 1) plan for sustainable infrastructure and innovative services delivery, 2) provide a space for personal and social cohesion, 3) plan for sustainable economic development, 4) plan for environmental conservation, and 5) keep municipal tariffs affordable [20].

uMhlabuyalingana Local Municipality is one of the five municipalities in uMkhanyakude District, situated in the North-Eastern part of KwaZulu-Natal Province of South Africa and lies on 27°1' S 32° 44' E coordinates. Implemented renewable energy sources micro grid electricity access compared to grid extension. It was discovered that a Stand-alone micro grids are an excellent way to carry power to rural areas, and for Umhlabuyalingana, the best choice for generating all of the energy supply was found to be a PV/Battery micro grid. Its 100% renewable penetration translates to 0 kg/person CO_2 emissions, compared to South Africa's overall average of 8.9 kg/person CO_2 emissions [2]. South Africa is a signatory of the Kyoto Protocol and the United Nations Framework Convention on climate Change and, as such, has an obligation to mitigate climate change. Policy landscape enables the implementation of renewable energy technologies and promotes ecologically sustainable development and the use of natural resources [20].

The Kuyasa Low-Income Urban Housing Energy Upgrade Project, which began in 2002, has being subsidized by the City of Cape Town. The goal of this project is to show how energy-efficient technologies such as solar water heaters, insulated ceilings, and compact fluorescent light bulbs can reduce carbon dioxide emissions and other greenhouse gasses while also being cost-effective, improving quality of life, and improving health standards [21].

5 DISCUSSION

Globally, renewable energy has shown a booming rise in terms of producing power to sustain the balance of economy. Table 2 below provides the evidence and confirms these claims. The rise in wind and solar production coincides with a steady decrease in global coal production. Countries across the world are noticeably moving away from the fossil fuel, however not all kinds of renewable energy are suitable for use in all parts of the world, and indeed, suitability of technologies can range widely even within the different regions of a particular country. The South African government appears to be evading the realities of the energy situation, owing to its focus on large-scale energy provision, which does not necessarily result in the required level of energy supply. Furthermore, because these investments are so expensive, macro-level energy creation offers energy that the poor cannot purchase [new]. Small-scale projects, on the other hand, can help promote the transition to a more sustainable energy system [22]. Appropriate technologies that are applicable to South Africa:

Solar Energy Potential For South Africa

Photovoltaic solar panels produce electricity using radiant (light and heat) energy which is converted into electrical energy using semiconducting materials [23]. South Africa has a high level of sunshine, with rainfall that is about half that of the rest of the world. The majority of locations receive an average of 8-10 hours of sunlight per day, with a nationwide average of 2500 hours per year and a radiation level of 4.5 to 6.6 kWh/m^2[24]. The new solar panels are comprised of a special low-cost metal alloy that turns light into electricity. This alloy is thin, light, and flexible, and it may one day be able to cover roof tiles and be installed during the house's roofing stage.

Wind Energy

Wind resources cover almost 80% of South Africa's geographical area, allowing for the creation of cost-effective wind farms with annual load factors more than 30% and a total wind power potential of 67000 GW, which is comparable to solar potential [25]. With the start of the demonstration Darling wind farm in 2008, wind energy began to gain traction in South Africa. Wind power generation, on the other hand, took off after the introduction of REIPPPP, which is currently in its second bidding round with projects under development and the fourth bidding window closed. There are 19 wind energy developments in South Africa, with over 600 wind turbines totaling 1,471MW [26].

Biomass

Biomass produces biofuel from waste: solid waste is usually burned in incinerators liquid waste, such as sewage sludge, manure, food waste, slaughterhouse waste, etc, can be digested into biogas leaking gas from waste dumps that can be collected [27]. South Africa does not currently use its waste for the generation of flammable gas, but there are many sites all over the country that are suitable for this application.

Table 2: Different types of renewable energy across the globe

Renewable Energy Technologies	Objective	Region	Accessibility	Efficiency in Supplying Energy	Current Market Share
PV Panels	Solar power	Global	Sunny days	21,3%	USD 18.0 billion in 2019
Bio-mass	Bio-energy	Global	Waste product	52%	USD 344.90 Billion in 2019
Wind Energy	Wind power	Global	Windy days	50%	650.54 GW in 2019
Batteries	Power (kva)	Global	When charged	92 - 96%	USD 88.49 billion in 2019
Fossil Electricity	kwh	Global	Eskom / municipality	96%	23,398 TWh global consumption

Due to loadshedding in many cities across South Africa, fossil-fueled electricity is no longer a reliable source of power. Without scholarly simulations, environmental and weather effect consultations, wealthy individual civilizations are gradually deploying renewable solar technology. Since the method is a more natural way to generate the same amount of watt power per day as fossil-fueled electricity, Renewable energy is becoming more affordable as technology progresses. Renewable energy is now cheaper than coal-fired electricity, according to a CSIR study [28].

6 CONCLUSION

One of the most important findings of this study is the need for a smooth and effective transition of environmental policy to housing development practice, particularly in South Africa, where the pressing need for low-cost housing delivery often leads to the negligence of the equally important renewable energy agenda. The possibility of using energy efficient and renewable energy technology to help South Africa reduce greenhouse gas emissions has been considered. In the study, renewable household technologies are being compared to Eskom fossil fuel-based energy, with the goal of harnessing natural resources in a spectacular and sustainable way. Wind, sunlight, large mass, and batteries all have a good chance of transforming humanity. Small-scale projects can help facilitate the transition to a more sustainable energy system by providing a thorough understanding of both the success criteria and the impediments to broader adoption. This article suggests that reducing demand in the residential sector with renewable energy technologies and energy efficiency measures not only relieves strain on Eskom's overburdened coal-fired power plants, but also helps South Africa meet its promises to lower high carbon content.

Through daily and most adaptable convenient circumstances, the South African public must slowly adopt and adjust to what is also a reliable alternative source of energy. Renewable energy has proven to be a reliable source of everyday sustainable energy in both international and domestic studies. As an alternate type of advancement and incentive, adopting and embracing adaptable impacts to what renewable energy can purely transform. Improving the nation's health through the reduction of hazardous emissions, the relief of energy poverty, the creation of long-term jobs, and the strengthening of energy security.

For low income homes to prioritize other energy source such as renewable energy, it requires decentralizing energy supply that fulfils the demands of the community. Coal offers thermal energy for both space heating and cooking. In addition to fossil fuel power, renewable energy can be used as a full-capacity alternate source of energy. The majority of civilisations worth their salt have adopted renewable technologies to power their homes. When compared to wealthy person society energy use, low-income homes' average daily power consumption is significantly lower. It is possible, but it will take time to provide a sufficient amount of renewable energy knowledge and acceptance to source human societies.

The project's success highlighted South Africa's ability to integrate and execute new technology in order to accelerate the country's adoption of renewable energy initiatives.

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ANALYSIS OF ENERGY USE AT KING SHAKA INTERNATIONAL AIRPORT

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ABSTRACT

This paper is an analysis of energy use at King Shaka International Airport (KSIA). The paper presents a discussion of cost reduction initiatives the airport must put in place through a roadmap for electricity consumption reduction due to high cost of tariffs and a requirement of carbon footprint reduction. The paper outlines the results of interventions done by Infrastructure Asset Management for Financial Year 2019-2020. Analysis was done with an assumption of 9% increase on tariffs by National Energy Regulator of South Africa and 15% increase taken from eThekwini Municipality's proposed electricity tariffs for 2020-2021. Furthermore, peak months in KZN were taken into consideration. The challenge is high costs and carbon footprint since KSIA is 100% dependent on the municipality for electricity there is no clean energy produced. This paper aims to analyze different innovations to mitigate the issue and create roadmaps to neutrality as well as energy mix, benchmarking with international airports, and the results has shown a lot of development that South Africa may use in the market.

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1 INTRODUCTION

1.1 Background

Airports Company South Africa (ACSA) was established through the Airports Company Act of 1993. ACSA is an independent statutory and regulation committee which oversee the economic regulation of airports authority. South Africa has three (3) International airports (OR Tambo Airport in Johannesburg, Cape Town International Airport in Cape Town, and King Shaka International Airport in Durban). In addition, the country has 6 regional/domestic airports (at Bram Fisher, Port Elizabeth, Upington, East London, George, and Kimberly). There are, therefore, a total of 9 airports, Figure 2, operated by the state government owned Airports Company South Africa (ACSA) [1].

The cost of electricity from the Eskom national grid for the airport operations across the ACSA group is approximately R350 million per annum which is a significant cost on the company's annual operating budget. As Eskom is going through some challenges in terms of power generation and inflation since 2008, it is anticipated that annual increase in Eskom's electricity tariffs as well as promulgation of the carbon tax bill with the use of coal will lead to a further 10% increase in OPerational EXpenditure (OPEX) on electricity. This is equivalent to a further R 34 million in one financial year - 2019 to 2020 [2]. This is due to Eskom tariffs which is 356% since 2007-2017 and inflation of 74% during the same period, Figure 1 [3].

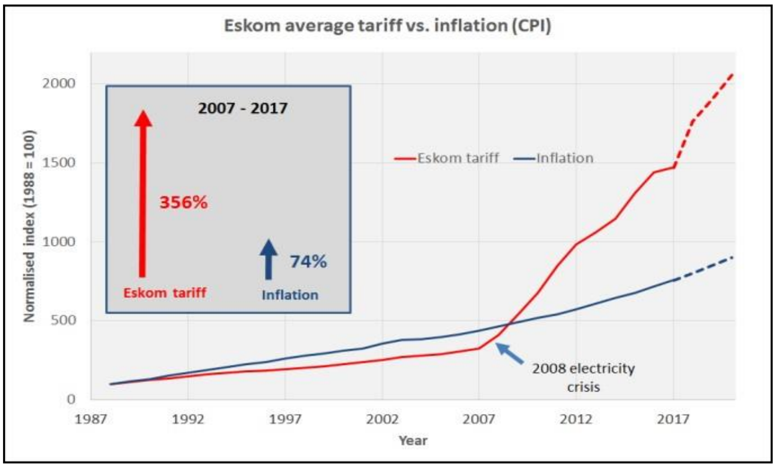

Figure 1: Eskom Average Tariffs vs Inflation (CPI) [3]

Electricity is the most important part of the airport for it to stay in operation and South Africa has not been doing well when it comes to meeting the demands due to failures at power stations owned by the state utility, Eskom. Although consumers are paying high prices on tariffs as electricity has become more and more expensive in the past few years and continue climbing with the estimation of more than 15% increase for year 2020 which has been approved by National Energy Regulator of South Africa (NERSA), yet it is not enough to keep the country's power supply stable. For the first time in history South Africa has had the airport (OR Tambo International airport) switch off to darkness which paused a very high risk on national security as it is the gate way of the African continent (International Boarder) to the country [4].

Figure 2: 9 South African Airports [1]

According to census in the year 1995, the percentage of household use per municipality that use electricity as their main energy source for lighting kept on climbing until to the current year which is 100%. Figure 3 is a graphical representation of those percentages per municipality [3].

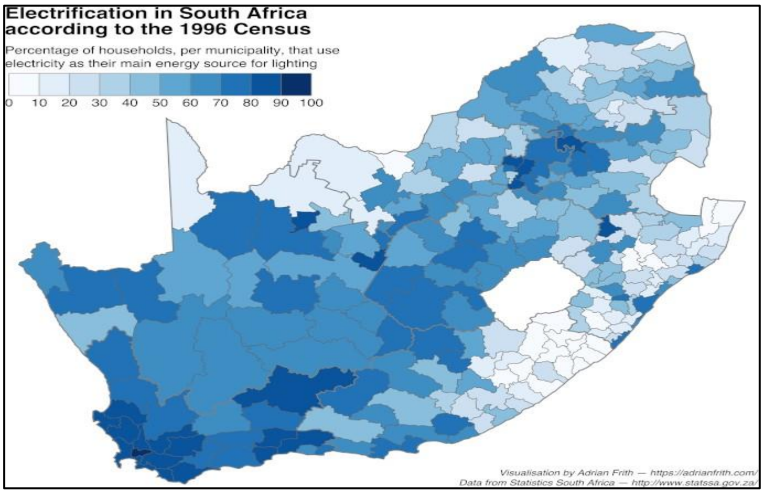

Figure 3:Census percentage for energy us by households per municipality [3]

Electrical energy at the airport is distributed according to Figure 4, about 25% is HVAC consumption, 20% is lighting, 18% is information and communication, 12% is tenants (external Companies) and the rest includes airfield lighting, radio navigation systems, and electromechanical facilities.

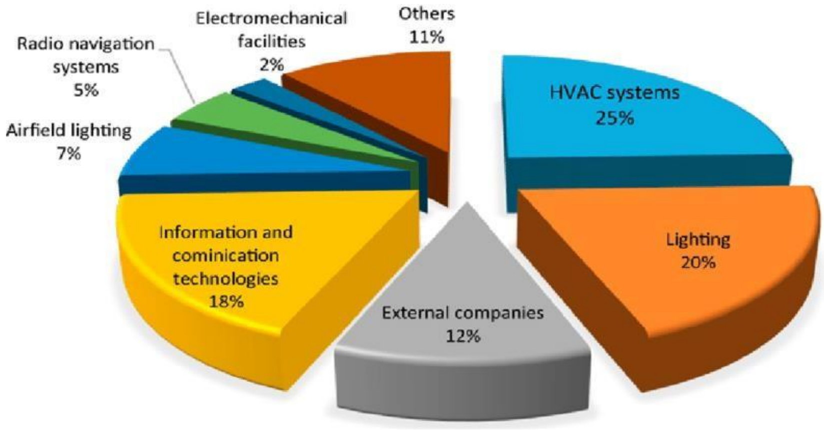

Figure 4: How Electricity is distributed at the Airport [5]

1.2 Airport Company South Africa energy reality and impact

What contributes to cost of energy at the airport apart from the existing infrastructure are aeronautical passenger movements, Infrastructure growth and Aerotropolis. To create an energy balance there are few aspects to take into considerations those are energy mix initiatives, green building accreditations and a new culture of Energy Management System (EMS). 3 Strategic pillars were developed which are reduction of energy consumption, which takes into considerations percentage of energy reduction as well as carbon footprint reduction, introduction of energy mix where new percentage internal energy mix to grid supplied energy is initiated and culture of energy pillar which involves green star accreditation and percentage movement to standard operating practices is introduced. 3 innovations were initiated those are luminaires replacements, HVAC system & Controls and solar plants installations mostly for regional airports [5].

1.3 Taking ACSA Energy into the Future

Looking at the future of energy after the strategic pillars were developed estimations were considered looking at roadmaps to carbon neutrality which can be a reality, solar PV technology, gas to power technology, vertical axis wind turbines which will all be fed to micro grid concepts [5].

The micro-grid concept is the optimization of power generation technologies to satisfy demand requirements. Operation can be within and/or independent from the grid after all has been implemented. Shown in figure 5 is a microgrid concept where everything is integrated together for management and monitoring [5].

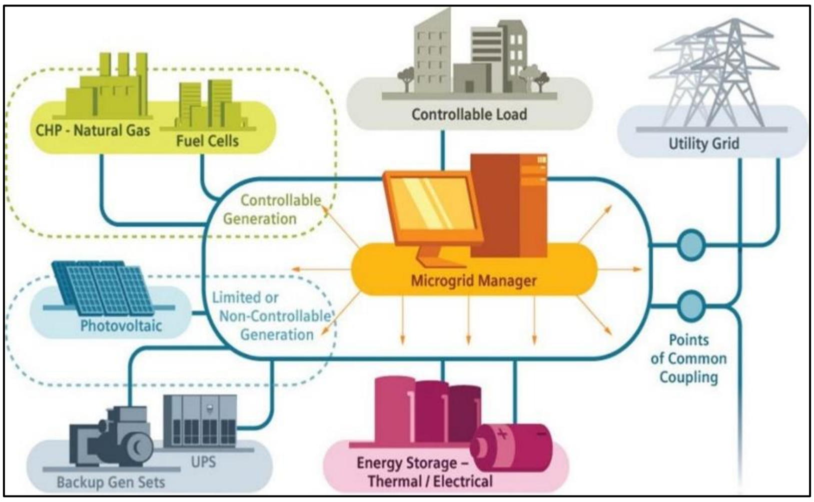

Figure 5:Micro-Grid Concept [5].

2 CURRENT STATE

2.1 Billing According to History

This is the tracking done per month using bills from municipality which shows savings per month on demand in kVa each month for FY19-20 (April 2019 -April 2020), which shows some declines. Figure 6 shows energy savings obtained monthly which is discussed in further sections as well as Figure 7 which gives a view in different peaks. The information used is before COVID-19 national lockdown for clear indication when the airport was operating fully as it can be noted that energy savings started to escalate during March 2020 (12%) and April 2020(42%) going forward. Table 1 is the capturing done from bills and includes the recoveries from the tenant's calculation. Using the metering system tenants are billed first than what remains falls under ACSA's cost. The metering system plays an important role as it determines the percentage difference in kWh between what ACSA and tenants.

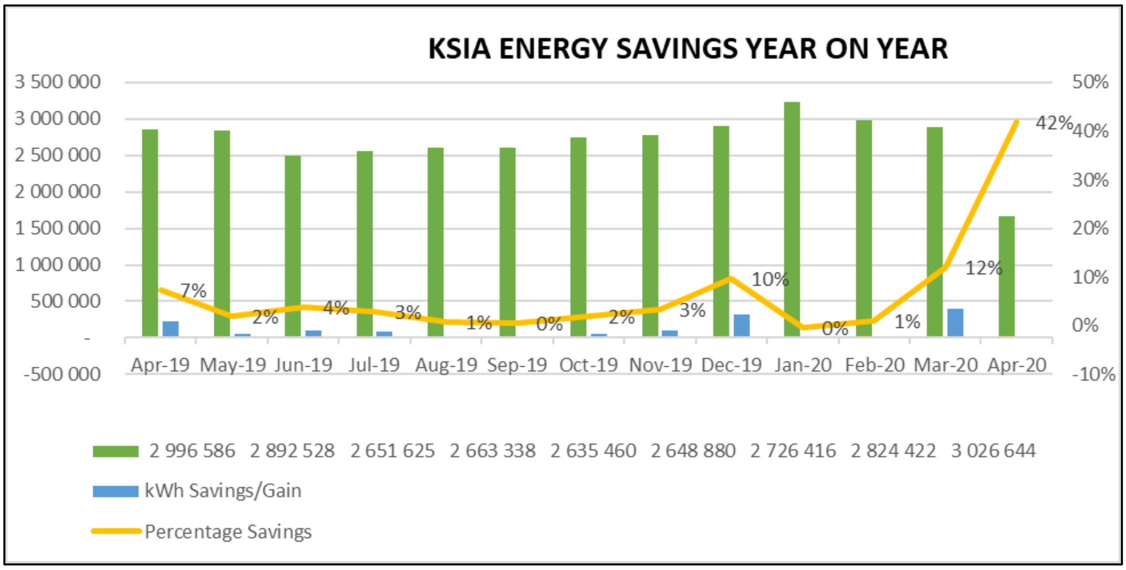

Figure 6: KSIA energy saving year on year in kWh. [6]

In Figure 6, the chart shows fluctuations on savings on monthly basis, around April there is mostly more savings simply because of the winter season that starts which ultimately reduces the use of HVAC in KZN. In winter season for KZN weather conditions are cooler and does not necessarily need heaters so mostly office staff and building need to use less energy for HVAC for cooling and it takes less for the airport chillers to make the environment of the airport temperature comfortable as compared to summer seasons. Ultimately on the months of August and September it is a hot season and HVAC in KZN is a need so the percentage of saving on energy declines and December season it picks up as more staff are mostly on leave. Another contributor is the tariff increase which happens every year by NERSA in June and effect will start to show in the months of July going forward.

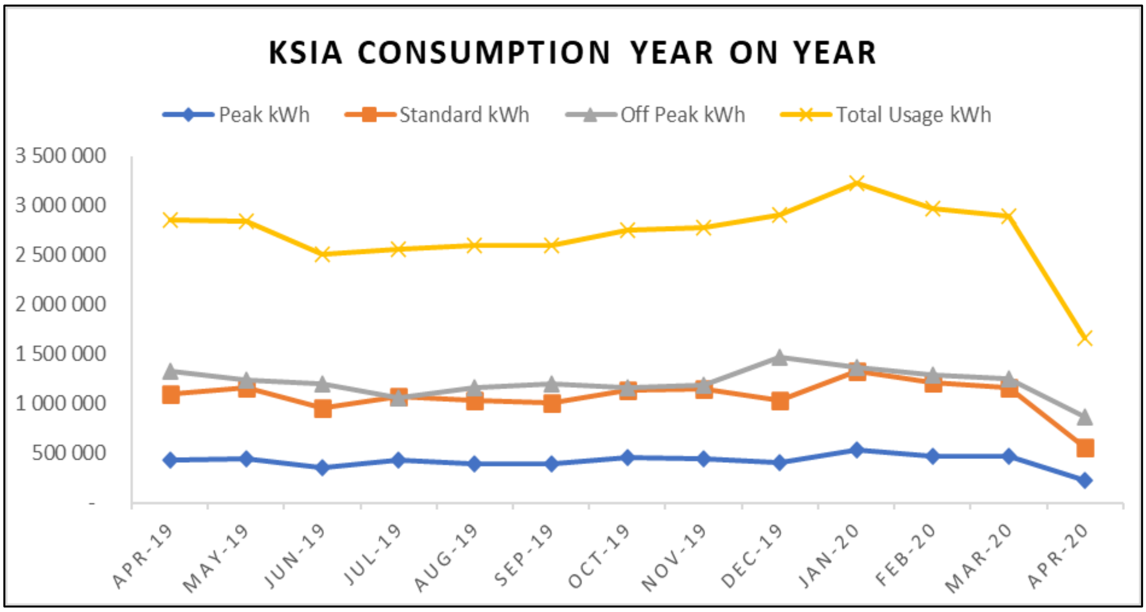

Figure 7: Year on year KSIA consumption showing different peaks [6]

Table 1: Tracking table from the bills FY19-FY20 with recoveries [6]

	Peak kWh	Standard kWh	Off Peak kWh	Total Usage kWh	Cost (ex vat)	Avg Cost per kWh	Electricity recovery	% Recovery	Notified Max Demand kVA	Maximum Demand kVA
Apr-19	430 964	1 100 259	1 328 403	2 859 626,0 kWh	R 2 816 960,14	R 0,99	2 177 855,8 kWh	76%	8 721	5 492
May-19	447 874	1 164 530	1 234 422	2 846 825,2 kWh	R 2 849 532,29	R 1,00	2 166 174,0 kWh	76%	8 721	5 632
Jun-19	353 822	953 779	1 193 926	2 501 527,2 kWh	R 3 507 957,07	R 1,40	1 796 264,7 kWh	72%	8 721	4 812
Jul-19	425 496	1 070 158	1 064 211	2 559 865,6 kWh	R 4 299 336,14	R 1,68	1 850 475,0 kWh	72%	8 721	4 843
Aug-19	392 289	1 039 316	1 167 717	2 599 322,0 kWh	R 4 218 174,31	R 1,62	1 946 164,2 kWh	75%	8 721	4 878
Sep-19	389 773	1 005 868	1 205 508	2 601 149,0 kWh	R 2 962 251,40	R 1,14	1 768 786,5 kWh	68%	8 721	5 323
Oct-19	458 236	1 138 178	1 155 974	2 752 388,0 kWh	R 3 105 393,40	R 1,13	1 753 093,1 kWh	64%	8 721	5 057
Nov-19	446 920	1 150 288	1 181 247	2 778 456,0 kWh	R 3 175 728,83	R 1,14	1 814 152,1 kWh	65%	8 721	5 606
Dec-19	403 860	1 035 020	1 463 500	2 902 380,0 kWh	R 3 883 970,70	R 1,34	1 913 886,8 kWh	66%	8 721	5 364
Jan-20	529 020	1 325 953	1 372 726	3 227 699,0 kWh	R 3 883 970,70	R 1,20	2 143 662,4 kWh	66%	8 721	6 038
Feb-20	469 356	1 218 607	1 286 315	2 974 278,0 kWh	R 3 340 898,66	R 1,12	1 979 330,7 kWh	67%	8 721	5 745
Mar-20	473 016	1 165 992	1 250 281	2 889 289,0 kWh	R 3 248 448,37	R 1,12	1 928 863,6 kWh	67%	8 721	5 472
Apr-20	228 231	564 321	871 292	1 663 844,0 kWh	R 1 979 136,00	R 1,19	1 203 027,6 kWh	72%	8 721	3 484
	21 894 048	**56 496 098**	**62 085 590**	**140 703 969**	**R 105 832 844,78**	**R 37,55**	**21 309 845,5 kWh**	**15%**	**0%**	**0%**
	Peak kWh	**Standard kWh**	**Off Peak kWh**							
	21 894 048	**56 496 098**	**62 085 590**							

2.2 Cost Increase by NERSA Estimates taking into considerations impact of COVID-19

Analysis was done with assumption of 9% increase in tariffs which gave more than R30 000 000 and 15% increase in tariffs which gave more than R32 000 000 to be spent per year taken from eThekwini Municipality's proposed electricity tariffs 2020-2021 [7]. Further assumptions were energy used as base which is April and May 2020. Assuming load Increase of 20%, from the month of June 2020 for level 3 lockdown going forward, as well as for peak months in KZN which are Jan, Feb, March 2020 an average was taken from the previous years to assume what will be the increase in % demand and applied. Tables 2 and 3 are the breakdown calculations for 9% increase on tariffs same thing was done for 15%.

Table 2: Utility savings calculations considering tariff increase (Apr 2020-Oct 2020). Developed by the Authors

	Tarrif %	Load Increa	Apr-20	May-20	Jun-20	Jul-20	Aug-20	Sep-20	Oct-20
Peak	9%	20%	228 231,2 kWh	228 231,2 kWh	273 877,44 kWh	298 526,41 kWh	298 526,41 kWh	298 526,41 kWh	298 526,41 kWh
off Peak	9%	20%	871 292,8 kWh	871 292,8 kWh	1 045 551,36 kWh	1 139 650,98 kWh	1 139 650,98 kWh	1 139 650,98 kWh	1 139 650,98 kWh
Standard	9%	20%	564 321,6 kWh	564 321,6 kWh	677 185,92 kWh	738 132,65 kWh	738 132,65 kWh	738 132,65 kWh	738 132,65 kWh
Total Demand			**1 663 845,6 kWh**	**1 663 845,6 kWh**	**1 996 614,72 kWh**	**2 176 310,04 kWh**	**2 176 310,04 kWh**	**2 176 310,04 kWh**	**2 176 310,04 kWh**
Average NMD			**4 000,00**	**4 000,00**	**4 000,00**	**4 000,00**	**4 000,00**	**4 000,00**	**4 000,00**
NMD			**8 721,00**	**8 721,00**	**8 721,00**	**8 721,00**	**8 721,00**	**8 721,00**	**8 721,00**
	Current Tar	**New Tarrif**							
Peak	1,1167	1,217203	R254 865,78	R254 865,78	R305 838,94	R363 367,24	R363 367,24	R363 367,24	R363 367,24
Off Peak	0,5381	0,586529	R468 842,66	R468 842,66	R562 611,19	R668 438,35	R668 438,35	R668 438,35	R668 438,35
Standard	0,7967	0,868403	R449 595,02	R449 595,02	R539 514,02	R640 996,61	R640 996,61	R640 996,61	R640 996,61
Network Demand Charge	96,65	105,3485	R386 600,00	R386 600,00	R386 600,00	R421 394,00	R421 394,00	R421 394,00	R421 394,00
Network Access Charge	31,75	34,6075	R276 891,75	R276 891,75	R276 891,75	R301 812,01	R301 812,01	R301 812,01	R301 812,01
Total (Voltage Surge Charge)		R -	**R1 836 795,21**	**R1 836 795,21**	**R2 071 455,90**	**R2 396 008,21**	**R2 396 008,21**	**R2 396 008,21**	**R2 396 008,21**
% Voltage Surge Charge	11%	11%	**R192 863,50**	**R192 863,50**	**R217 502,87**	**R274 223,14**	**R274 223,14**	**R274 223,14**	**R274 223,14**
Service Charge	4500	R4 905,00	R4 500,00	R4 500,00	R4 500,00	R4 905,00	R4 500,00	R4 500,00	R4 500,00
Grand Total			**R2 034 158,70**	**R2 034 158,70**	**R2 293 458,77**	**R2 675 136,35**	**R2 674 731,35**	**R2 674 731,35**	**R2 674 731,35**

Table 3: Utility savings calculations considering tariff increase (Nov 2020-Mar 2021). Developed by the Authors

		Peak seasons			
Nov-20	**Dec-20**	**Jan-21**	**Feb-21**	**Mar-21**	
298 526,41 kWh	298 526,41 kWh	336 172,03 kWh	314562,5811	345701,3346	
1 139 650,98 kWh	1 139 650,98 kWh	1 200 870,49 kWh	1319745,433	1139650,982	
738 132,65 kWh	738 132,65 kWh	854 776,78 kWh	738132,6528	738132,6528	
2 176 310,04 kWh	**2 176 310,04 kWh**	**2 391 819,29 kWh**	**2 372 440,67 kWh**	**2 223 484,97 kWh**	
4 000,00	**4 000,00**	**4 000,00**	**4 000,00**	**4 000,00**	
8 721,00	**8 721,00**	**8 721,00**	**8 721,00**	**8 721,00**	
R363 367,24	R363 367,24	R409 189,60	R382 886,52	R420 788,70	
R668 438,35	R668 438,35	R704 345,37	R774 068,97	R668 438,35	
R640 996,61	R640 996,61	R742 290,72	R640 996,61	R640 996,61	
R421 394,00	R421 394,00	R421 394,00	R421 394,00	R421 394,00	
R301 812,01	R301 812,01	R301 812,01	R301 812,01	R301 812,01	
R2 396 008,21	**R2 396 008,21**	**R2 579 031,69**	**R2 521 158,10**	**R2 453 429,67**	
R274 223,14	**R274 223,14**	**R295 170,18**	**R288 546,54**	**R280 795,03**	
R4 905,00	R4 500,00	R4 500,00	R4 500,00	R4 905,00	
R2 675 136,35	**R2 674 731,35**	**R2 878 701,87**	**R2 814 204,65**	**R2 739 129,70**	**R30 843 010,48**

3 DISCUSSION

Energy consumption was used as base during April and May 2020, assuming load Increase of 20%, from the month of June 2020 for level 3 going forward. Into considerations 15% and 9% tariff increase was applied from June 2020 until March 2021. For Peak months in KZN which is Jan, Feb, March 2020 an average was taken from previous years to assume what will be the increase in % demand and applied. Due to the results calculated which show a definite increase of cost and demand, a strategy must be in place which takes into consideration renewable energy and alternative sources of energy for the airport to move away from 100% use of energy from municipality, as the government has announced that they permit private sectors to produce their own electricity.

The target was to reduce electricity consumption by 2% year-on-year. A strategy is in place for energy and demand projects to commence although some of them have been started by electrical department e.g. (LED lights, sensors etc.) and to continue further. Table 4 outlines the results of interventions done by infrastructure Asset Management (IAM) in terms of controlling maintenance for FY 19-FY20.

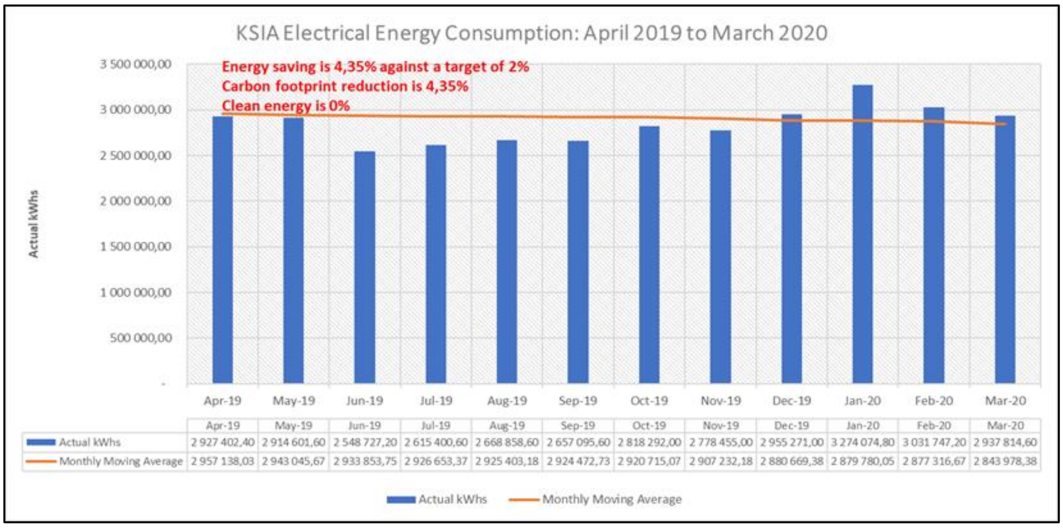

Figure 8: Chart showing carbon footprint reduction [6]

Figure 8 is the overall consumption at which KSIA archived 4,35% energy savings against a target of 2%. This also equates to 4.35% carbon footprint reduction by KSIA, which earned KSIA accreditation level 2 (Reduction) before end of FY19. Since KSIA is 100% dependent on Municipality for electricity there is no clean energy produced like renewable energy [8]. However, the next step is included on the roadmap to neutrality which consists of innovations that will move KSIA to clean energy which is expected to materialise in few years to come, refer to Table 4 with projects.

Table 4: IAM projects to meet strategy with their anticipated dates

Assets Projects	Year
Lighting Change to LED Technology	FY24
Thermal Deflection Innovation	FY24
Geyser Sleeve Technology	FY23
Terminal and Office Building Green Star Rating	FY25
Lighting Control: Occupancy Sensors, BMS Control, Dimming Functions	FY25
Carbon Offsetting Solar PV Plant	FY29

Table 4 shows some of the projects in the pipeline for cost savings, carbon neutrality as well as to move away from depending 100% on the grid from the municipality since they are faced with challenges.

4 CONCLUSION

This paper has presented an analysis of energy usage at King Shaka International Airport of Republic of South Africa. It has been found that more than 2% reduction in a financial year is possible for as long as interventions are done and monitored correctly. The target of 4.35% reduction obtained for FY 19-FY 20 proves that if more gaps are found more can be saved as well as a possibility of generating own energy should be in the pipeline [8].

Improved tenant recovery system can also yield a positive change towards cost for ACSA if all uses are metered and managed on Building Management System (BMS) not only monitor tenants, but that can also enable troubleshooting where high usage in kWh is. The projects like Solar PV plants and energy mix trigeneration gas plant will take the pressure off, on depending entirely to the municipality. If KSIA can implement those projects and have an energy management system which can internally monitor bills, it can ultimately save on cost as well as control carbon footprint reduction and move closer to the goal of 2030 commitment towards carbon neutrality.

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ENERGY DEMAND INTERVENTIONS AT KING SHAKA INTERNATIONAL AIRPORT TO MITIGATE THE EFFECT OF COVID-19 ON AIRPORTS OPERATIONS

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ABSTRACT

This paper outlines interventions done by KSIA airport due to COVID-19 pandemic effect in the year 2020. Airports Company South Africa (ACSA) had challenges of load shedding as well as high cost on tariffs long before COVID-19 emerged. During the lockdown imposed in 2020, energy demand was reduced before interventions which were outlined in the airport roadmaps were implemented that was during lockdown levels 5 and 4, (March-July 2020), adjustments were made to consider a gradual increase on capacity which was assumed to be 20%, from the month of July 2020 for level 3 lockdown. The tracking of savings per month on demand for financial Year 2019 to 2020 showed some decline of more than 40% due to initiatives done by management. As lockdown eased that meant energy demand and costs to company increased again. The conclusion drawn from this research is that a more permanent cost saving mechanisms is required to cater for full capacity operation of the airport.

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1 INTRODUCTION

1.1 Background

King Shaka International Airport (KSIA) was built and stated operating in 2010, it is in the northern side of Durban in KwaZulu Natal province along the coast in La Mercy. The airport services 24% of international traffic with 7.5 million passengers per annum in its 3.7 km runway which carries airbus and Boeing to land and take off, with a possible provision of additional runway in the future. Durban is rated as the event city of South Africa, as a result KSIA works closely with strategic partners which included the eThekwini Municipality, Convention Bureau, ICC Durban, Durban Chamber of Commerce and Industry, Tourism KZN, Durban Tourism, Dube Trade Port, Trade, and Investment KZN and others to ensure our airport is always ready to welcome tourists, business, and conference delegates [1]. KSIA contribute to the growth of business and trade for the province of KwaZulu Natal by insuring the growth of local exports with international cargo throughput volumes. Figure 1 is the overview of King Shaka International Airport terminal building.

Figure 1: King Shaka International Airport (KSIA) Precinct

Airports Company South Africa is currently facing challenges due to power generation in South Africa with it being too expensive to use. In addition to the problem of COVID-19 pandemic, it has become even more imperative for the company to do cost savings as much as possible in all departments and one of these departments is energy, demand, and consumption which operations needs to be designed and optimised as matter of emergency. This will help cost savings, monitor as well as manage areas and equipment to detect and troubleshoot faults automatically and for the airport to stop depending on municipality bills for but instead have their own system to validate the municipality bills.

1.2 Bulk electrical 11 kv systems and service connection at KSIA

According to the original design of the airport the basement serves as the main intake substation, this section gives a breakdown of the design for electrical distribution which was done before South Africa had issues of electricity back in year 2010.

1.2.1 Load Estimates

There are 2 main substations A1 and A2 (incomers) with connected load in kVa, both consists of non-essentials and essential loads. They are separated into different locations those are passenger terminal Connected on main substation A1 whereas airside corrido is connected to main substation A2. Table 1 and 2 shows different loads in their respective locations.

The main intake substation for the KSIA is located next to substation A1. The main intake station is fed by means of a ring supply from the municipal substation A on the site boundary. The main intake station distributes to all KSIA substations, including Passenger terminal, Multi-Storey Parkade (MSP), Apron services, Runway Systems, ATNS Control Tower, Fire & Rescue building, Fuel Farm, Ground Services buildings.

Table 1: Load Estimates on Connected Load Passenger Terminal

Location	**Connected Load in kVa**	
	Non - Essential	Essentials
Passenger Terminal	9 295	1 450
Total Estimated Load	9 295	1 450
Substation A1 Capacity	10 000	2400
Spare Capacity	705	840
[n +1] Redundancy		

Table 2: Load Estimates on Connected Load Airside Corrido and Apron Services

Location	**Connected Load in kVa**	
	Non - Essential	**essential**
Airside Corrido	2 420	540
Apron Services	800	180
Total Estimated Load	3 220	760
Substation A2 Capacity	4 000	1600
Spare	780	840
[n + 1] Redundancy		

1.2.2 Load Centres

The main load centres will be the following:

- Air conditioning plant at basement level (essential & non-essential)
- Baggage handling equipment in the basement (essential).
- Retail (non-essential)
- Electronic Communications Systems (essential)
- Electronic Security Systems (essential)
- Joint Operations Centre (JOC) (essential)

1.2.3 Capacity

Substation A1 is designed in the basement services area. The substation consists of ten (10) switchgear panels each and spare space for another four panels. Five 2000kVA transformers are installed with spare space for another one transformer. Substations are designed to be extendable from 10 000 kVA to 12 000 kVA.

Substation A2 is designed on the apron level of the airside corridor. The substation consists of Five 11kV switchgear panels each and spare space for another six (6) panels. Two 2000kVA transformers are installed with spare space for another two transformers. Substation A2 can be extendable from 4 000 kVA to 8 000 kVA.

1.2.4 Main intake Station Layout

Substation A1 (Passenger Terminal) is fed from the main intake station by means of 4 x 185mm x 3 core PILC 11 kV cables as per Table 19 of SABS 97 in a ring configuration. Transformers at substations A1 and A2 are fed from the local MV switchboard by means of 185mm x 3 core XLPE 11 kV cables.

1.2.5 Substation Finishes Detail

Substation floors are accurately levelled, strong enough to withstand the physical loads of the equipment and be finished off with epoxy paint. Walls are plastered and painted white. Ceilings are painted white. Doors will be made of steel substation doors of adequate size for the equipment. All doors will be protected with steel burglar bar doors. A master key system for all doors will be implemented.

1.2.6 Specifications

The system parameters are as follows:

- Nominal voltage 11 kV
- Frequency 50Hz
- Phase rotation R-Y-B anticlockwise
- Fault capacity 350MVA

11 kV ring feeder cables is paper insulated (PILC) specified to Table 19 of SABS 97.11 kV transformer feeder cables are made of cross-linked polyethylene (XLPE) specified to SABS 1339: Type A. The 11 kV switchgear is rated at 800 A and the breaker mechanism is motorized. The transformers are 50Hz, three-phase, 11 kV (nominal) primary and three-phase four-wire 420V (nominal) secondary systems. The transformers will comply with SABS 780.

1.2.7 Building Maintenance system

All Major electrical & mechanical equipment are provided with required facilities to interface with the BMS system. Equipment Monitored ae as follows:

- Electrical switchgear
- Diesel generators
- Escalators & lifts
- Air conditioning
- Pump stations
- Control of light switching
- UPS units
- Electrical metering

2 COVID-19 INTERVENTIONS AT KING SHAKA INTERNATIONAL AIRPORT DURING LOCKDOWN

Due to the airports changes because of not operating at full capacity an advantage was taken as most places could be either reduced or switched off for energy savings. Interventions were put in place and tracking was done starting from March 2020.

2.1 Interventions During COVID-19 Lockdown

From the month of March 2020, the government announced a total lockdown for south Africa level 5 due to pandemic, that meant shutting down all business including the airport hence there were no passenger movements, no tenants to recover any electricity from and that meant no revenue as Airport Company South Africa is a profit-making entity. Due to that the airport had to put initiative in place to make sure there is no energy waste during that time because the organisation will be billed by the municipality as usual. For the beginning of lockdown which was last week of March 2020 interventions were implemented and all tenants and stakeholders were shut down as follows:

- Lighting in the terminal, Multi-Story Offices (MSO) reduced.
- HVAC switched OFF.
- Escalators switched OFF.
- ACSA systems idling switched OFF.

More was done in the month of April as the lockdown continued.

- Terminal lighting further reduced to 35% throughout in the terminal via Building Maintenance system (BMS)
- Apron Lighting reduced to 50% via remote monitoring.
- MSP lighting reduced to 35%
- MSO Lighting switched OFF except 1st and Ground Floor. First floor occupied by SAPS, and Ground Floor DB locked in within Bid Air Offices, no access.
- All MSO Split units isolated from the DB Board.
- F&R Building common lighting areas switched OFF.

For the month of May 2020

- Terminal lighting circuits in the Essential Board (Red) has been switched OFF to leave only lighting circuits in Dedicated Boards (Blue) ON
- The attempt to switch OFF completely the international portion of the terminal i.e., Normal DB, Essential DB and Dedicated DB lighting circuits will be switched OFF.
- AGL Circuits will be remotely switched OFF by ATC, and can only be switched back ON, on request, and to be switch OFF on completion.

Table 3: Summary Table for 3 months of Lockdown intervention for KSIA

Area Circuit	Area Description	Circuit/ System Status	Control Kiosk/DB
Apron Lighting	Delta Apron Lighting	All Masts OFF, All Obstruction lights OFF	Main LV DB Kiosk next to Cargo Fence
	Charlie Apron Lighting	All Masts OFF, except: All obstruction lights ON	Individual DB on each Mast
	Bravo Apron Lighting	All Masts OFF, except: 1 x Mast ON (aircraft parked) & All obstruction lights ON	Individual DB on each Mast
	Alpha Apron Lighting	All Masts OFF, except: 1 x Mast ON (aircraft parked) & All obstruction lights ON	Individual DB on each Mast
MSO Building	4th Floor	All lighting OFF except emergency lighting & Air-conditioning (No Access) ON	Via BMS
	3rd Floor	All lighting & Air-conditioning OFF except emergency lighting ON	Via BMS
	2nd Floor	All lighting & Air-conditioning OFF except emergency lighting ON	Via BMS
	1st Floor	All lighting & Air-conditioning ON except some offices on Eastern side. BMS schedule in place. Area occupied by Police	Via BMS – current BMS schedule is OFF @ 18h00 ON @ 07h00
	Ground Floor	All lighting OFF except emergency lighting & Air-conditioning ON	Via BMS
MSP Parking	1st Floor	All Normal circuit lights OFF except Essential circuit lights ON	Via BMS
	Ground (-) Floor	All Normal circuits lights OFF except Essential circuit lights ON	Via BMS
	Basement (-1) Floor	All Normal circuit lights OFF except Essential circuit lights ON	Via BMS
Advertising Bill Boards	Terminal advertising	All plugs switched OFF	Individual plugs
	Landside advertising	Main Breaker OFF	Mounted DB on Individual Billboard
Staff Parking	Southern side	50% Lighting switched OFF	Control Kiosk
	Northern side	All lights ON	
Car Rental Parking	From Southside to Northside	70% lighting switched OFF	Control LV Kiosk

2.2 Results from Interventions

March Maximum Demand is lower compared to previous years (Curtailment request for load shedding) In March 2020 67% of total maximum demand in consumption was recovered at KSIA. There is a more gain in terms of saving compared to March 2019 of about 12% with saving of 395 699 in kWh. In April Maximum Demand went further down compared to previous years due to Lockdown. In April 2020 72% of total consumption was recovered. There was also more gain in terms of savings compared to April 2019 of about 42% with saving of 1 195 782kWh.Figure 2 is the information obtained using the municipality bills for the past 5 years (from 2016-2021).it can be noted that for the month of May 2021 the maximum demand was the lowest in history that was because all the results from interventions were giving results for the interventions started in March 2021.

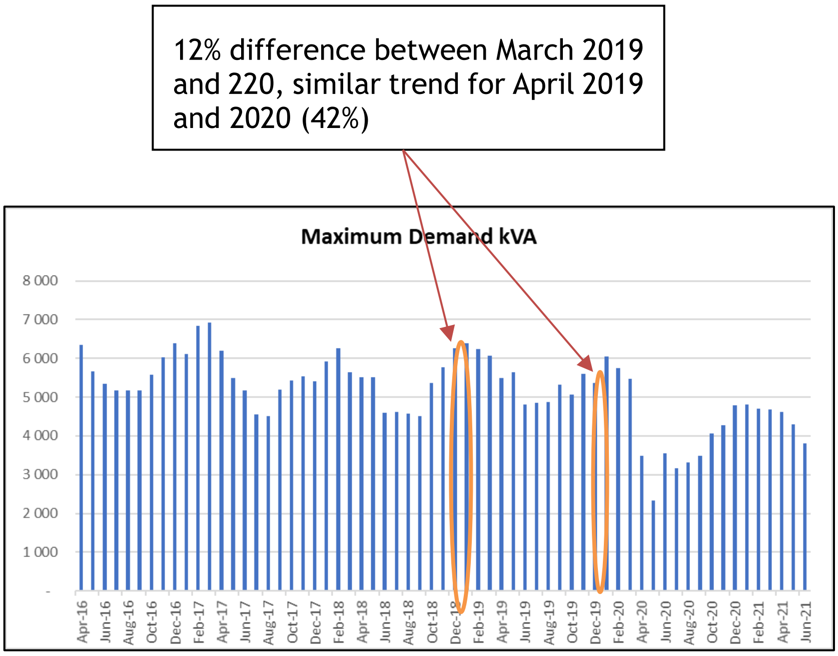

Figure 2: Maximum Demand Trends (2019-2020)

2.3 Current State

Although all the above gave positive results in terms of saving energy, the challenge faced is that when all this happened the Airport was not operating at full capacity, now since it does than the organisation is seen going back to high cost and demand on energy which paused a challenge because we cannot switch off areas like when the airport was almost non-operational. This means the Airport is back to innovations and finding ways to implement the strategy which was established before COVID-19 pandemic, but now with challenges like cutter budgets which was done during lockdown.

3 CHANGES ON ENERGY BY OTHER ENTITIES (CAPE TOWN AIRPORT AND NEDBANK) DURING COVID 19 PANDEMIC

3.1 Cape Town International Airport interventions

This is an analysis of electricity consumption at Cape Town International Airports CTIA. The power consumption can be clearly distinguished as follows in Figure 2:

- The Eskom Airport Substation supplies the airport operations.
- The Air franc Substation supplies the external stakeholders (e.g., Massmart, Clover, Bidvest, DHL etc) [7]

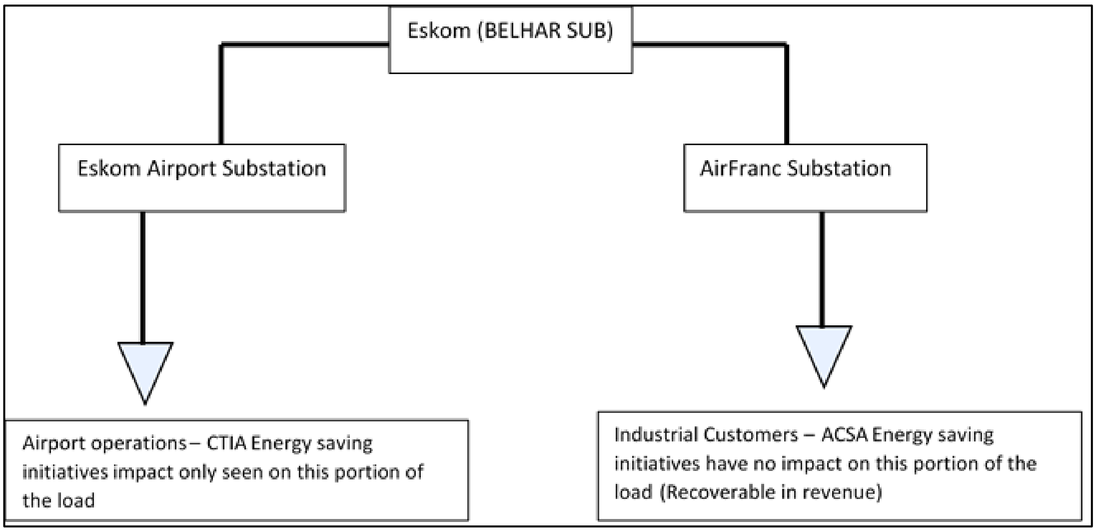

Figure 3: CTIA Power Distribution [7]

25% (319529kWh/week) of the total (1298754 kWh/week) energy consumed at CTIA is consumed by the industrial customers via Air Franc Substation as can be seen in Figure 3. Therefore, any energy saving initiatives done at CTIA only impact the 75% (979225kWh/week) portion which is due to airport operations and supplied from Eskom Airport Substation. The analysis can thus be done for each of the distinct load portions exclusively.

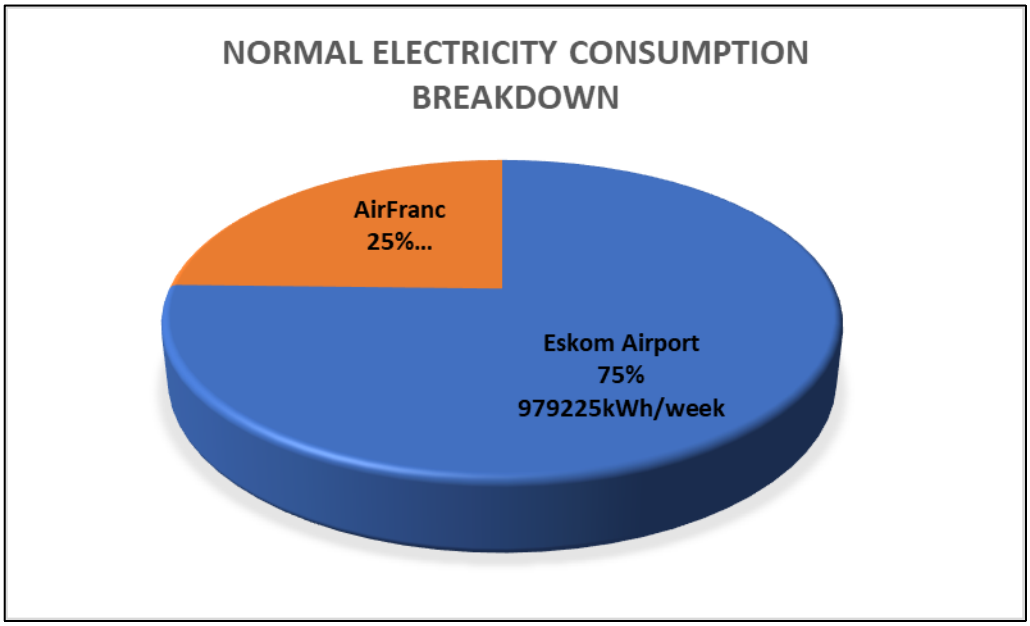

Figure 4: CTIA Power Analysis

Over and above the stakeholders at Terminal Building being forced to close shop at the start of lockdown, the following energy consumption reduction initiatives were undertaken by CTIA Maintenance Engineering:

- Mechanical significantly reduced consumption on HVAC, Lifts, Escalators etc (during Weeks of 27th March-3rd April)
- Lighting was significantly reduced at Terminal buildings, ACSA Offices, Aprons and Parkades, with just enough lighting left on for security reasons.
- All advertising boards were switched off.

3.2 Downstream analysis

For an airport that is almost completely non-operational, not much saving seemed to be achieved. An investigation as to why this is so led to conducting an analysis downstream to develop an understanding of where energy is still being consumed. Weekly data was drawn for loads at the substations downstream from Eskom Airport Sub.

The cumulative percentage reduction in consumption was calculated using the weeks before the lockdown data as the base for each substation, respectively. Figure 3 displays these reductions as of 10th April 2020.

The chart in Figure 4 shows the weekly energy consumption for the substations feeding from Eskom Airport Substation from the 13th of March 2020 to 10th April 2020. This indicates a significant reduction in consumption in some stations and not so much in others. For example, the lumped load AGL (for Sub 01 and Sub 19) can be expected to remain unchanged since the airfield ground lights are still fully operational.

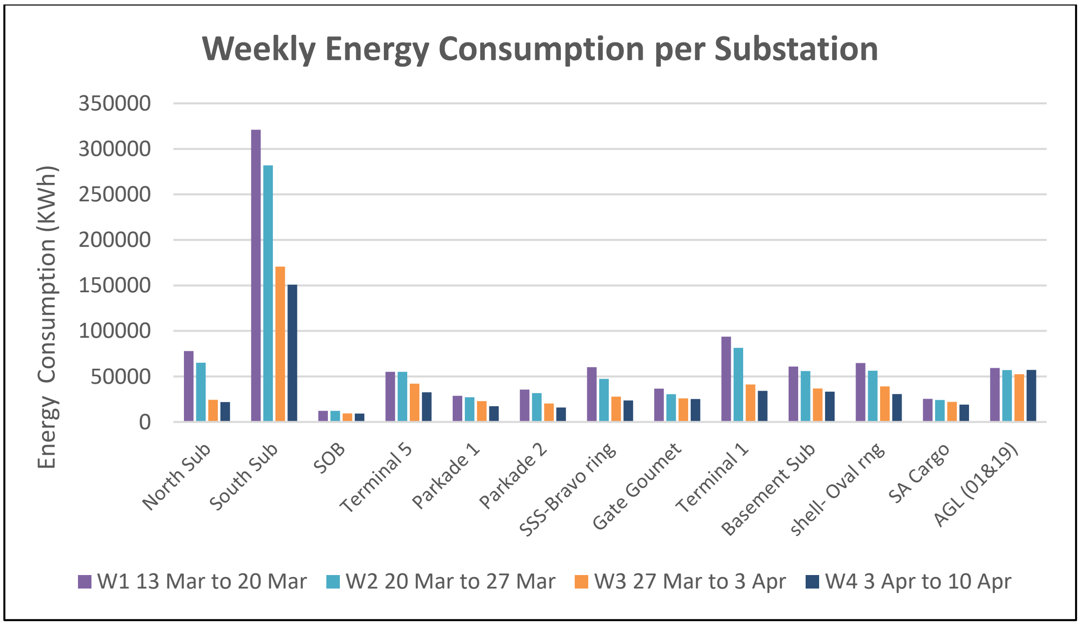

Figure 5: Weekly Energy Consumption per Substation downstream

Figure 5 displays the cumulative percentage reduction in consumption calculated using the week before the lockdown data as the base for each substation, respectively. From the graph, for North Sub, for instance, during the week of 20th March to 27th March (the week of the lockdown), the consumption reduced by 17% of the load before the lockdown. Further reduction was realised, resulting in a total reduction of 69% of the consumption of the week before lockdown. As of 10th April, the total energy consumption was reduced by 72% since before lockdown.

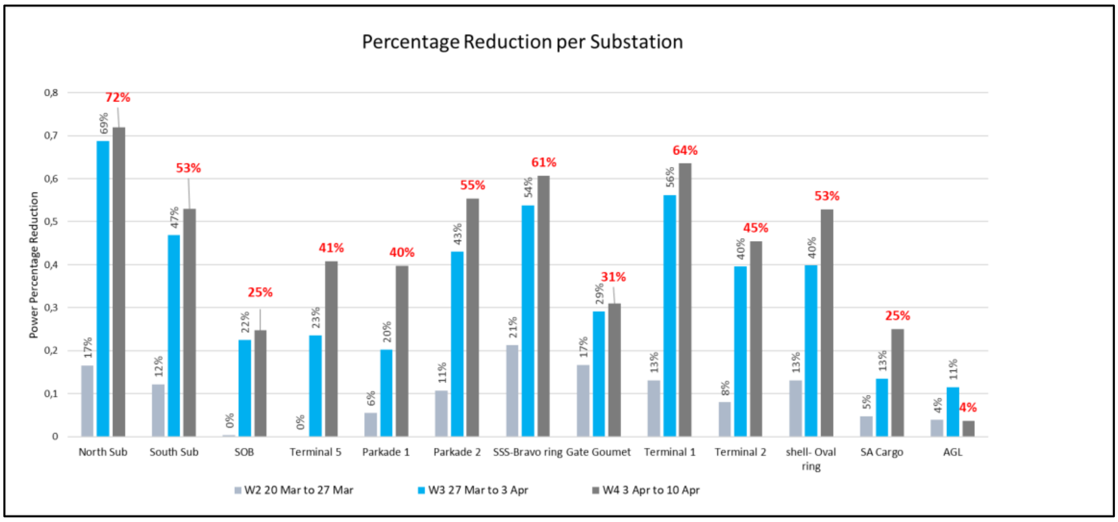

Figure 6: Cumulative Percentage Reduction in Energy Consumption downstream

3.3 Nedbank

Nedbank is one of the financial institutions which has realised an energy policy where they outline their commitment to align their business strategy with the Paris climate change agreement. The policy focuses on financing activities related to energy which was realised in April 2020 during Covid 19 pandemic period where most companies are facing challenges financially to even produce new energy as the government permit. Their policy scope includes but not limited to fossil fuel (Thermal Coal, oil, Gas, Power Generation), renewable and embedded energy solutions. This is aimed to support socio-economic development while driving the transition to zero carbon energy systems. The commitment is more than R 50 billion to support South African Renewable energy independent power producing procurement programme [8].

3.4 The Government and Regulations in South Africa

The President of South Africa made some announcement during his yearly SONA address with the Department of Minerals Resource and energy (DMRE) which will soon be acquiring 2,000 megawatts of emergency power to assist ESKOM, in the address focused on the Covid-19 pandemic, accelerating economic recovery. This will include natural gas, battery storage and coal in line with the integrated resource plan 2019. The Electricity Regulation Act will be amended going forward to increase the licensing threshold for embedded generation. This will include consultation with key stakeholders on the level at which the new threshold should be set and the finalisation of the necessary enabling frameworks [9] and state-owned companies like ACSA are encouraged to leverage on this framework.

4 CONCLUSIONS

The expectation was that during lockdown an almost 80% saving on energy can be possible, but the organisation could not reach at least 80% energy savings a maximum of 42% saving for KSIA and CTIA 72% was achieved, this meant more needed to be done or investigated as the expectation was higher but only amounted to just 43% on average as it is shown on figure 2. This also points out that there is energy that the airport is not accounting for and too much estimation on billing from the municipality side, hence ACSA ends up paying almost the same while it was not on full operation.

What is drawn from the above analysis is that more permanent intervention needs to be done or revisited which were included on the strategy before COVID-19 pandemic and Lockdown. The challenges of high cost, carbon footprint reduction needs to be looked at closely as the Airport is back to normal operation. More engagement in terms of how the airport is being billed by the municipality also becomes crucial that is getting rid of estimations calculation they use to bill King Shaka International Airport.

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THE STATUS QUO OF SUSTAINABILITY IN HEALTHCARE

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ABSTRACT

Increasing the social-, environmental and economic sustainability of global and local healthcare systems is expected to contribute significantly towards the attainment of various sustainable development goals. A significant body of literature has focused on the development of sustainable health and care systems, however, significant challenges in terms of economic-, social, and environmental challenges remain evident in healthcare systems across the world.

In this paper, we aim to asses the extent to which sustainable transitions have been incorporated into healthcare as a sociotechnical system. This will aid in the lack of research in transitions of healthcare systems into more sustainable states. Our analysis illustrates the role of inter-institutional collaboration in ensuring sustainability in healthcare systems and based on an analysis and visualization of content analysis, we also contextualize how the various sustainability paradigms are integrated into healthcare literature as well as healthcare systems. This paper presents a bibliometric analysis of literature that considers the combination of the concepts sustainability, sustainable development, and sociotechnical systems and transitions within the healthcare industry.

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1 INTRODUCTION

Sustainability is not a new concept, but it continues to become increasingly popular as time passed due to the increase in the need to understand and acknowledge resource scarcity. This concept has originated from movements such as social justice, conservationism, internationalism, etc. which by the end of the 20th century came together as a collective to be called 'sustainable development'. In 1987, the Brundtland Commission released a famous definition for 'sustainable development: "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" [1].

Sustainability as a movement approach is deemed a holistic approach in which social, economic, and environmental aspects must all be considered together to find a lasting existence of prosperity [2]. Social sustainability is defined as the universal human rights and basic needs of all people are being satisfied, through means of being able to access enough resources to keep communities healthy, secure, and functioning. Healthy communities consist of developments where personal, labor, and cultural rights are considered and all individuals are safe from discrimination. Economic sustainability is defined as the ability of communities to be able to maintain independence while having access to their required resources in order to meet needs. Environmental sustainability is defined as the ecological integrity which is maintained by ensuring that all the environmental systems that are on earth, is kept in balance. This means that natural resources are able to replenish themselves at a natural rate after it has been consumed by humans [1], [3].

Sustainable healthcare systems are the gateway to providing higher quality healthcare at lower costs, while being able to reach large populations in a certain area and being able to effectively manage diseases [4]. Cost efficiency and the effectiveness of a healthcare system cannot be achieved simultaneously. It has also been proven by researchers that there is an evident compromise between the increases that occurs between effectiveness and efficiency. The effectiveness is an indication of the potential of the healthcare system to be able to achieve its maximum possible output [5].

Sustainability and sustainable development are concepts that are directly related to sociotechnical systems, which is defined as the combination of technologies, infrastructure, industries, supply chain and organizational responsibility to deliver a societal function [6]. Sociotechnical systems have been analyzed in the dimensions of environmental protection and affordability. Sustainability issues pertaining to the environmental and financial aspects have increased the focus on reducing waste and emissions, the development of new technologies, and the "greening" of industrial ecosystems [7], [8].

The way we reach sustainability is through the transitioning of socio-technical systems towards sustainability: i.e. socio-technical transitions / sustainability transitions. Sociotechnical transitions operate at a societal level or functions which include transport, energy, housing, agriculture, communication, and healthcare. [9] Sociotechnical also refers to co-evolution of social and technological relationships, while transitions refer to the dynamics by which the change in these specific relationships occur. [10] It has become the focal point of many analyses to focus on innovation and environmental studies within sociotechnical regimes. This recognizes that there is a need for drastic change to happen in the form of sociotechnical transitions to deliver more sustainable development. [11]

This paper aims to present the analysis of the extent to which sociotechnical transitions have been incorporated into healthcare. This study also aims to highlight opportunities for further research regarding sociotechnical systems in the advent of sustainability or sustainable development within healthcare. This paper is structured in the form of a bibliometric analysis. Section 1 consists of the introduction of the paper. Section 2 discusses the research approach/ methodology, while section 3 presents the results. Finally, section 4 discusses the observed gaps in literature and the implications of possible future research.

Table 1: Applied search terms used in SCOPUS

Key Term	Variations
Healthcare	Healthcare; health care
Sociotechnical	Sociotechnical; socio technical; socio-technical
Transition	Transition; transitions

Specific searches were conducted by using combinations of the search terms. This led to four search combinations that were labelled, as indicated by Table 2.

2 RESEARCH APPROACH/ METHODOLOGY

Literature pertaining to sustainability or sustainable development, sustainable transitions, healthcare, sociotechnical systems was collected using SCOPUS. Specific search key terms were selected that relate to the aforementioned concepts; the set of selected terms was further expanded to include variations of the key terms to ensure an accurate search. Table 1 indicates the key terms and the variations of the terms used.

Table 2: Search combinations

Searches	1	2	3	4
Sociotechnical systems		x	x	
Sustainability transition(s)			x	
Sociotechnical transition(s)				x
AND				
Sustainability OR sustainable OR sustainable development	x	x	x	x
Healthcare	x	x	x	x
Search combination (SC) label	**SC1**	**SC2**	**SC3**	**SC4**

1.1 Research protocol

This section will elaborate on the outlines for the planning of this research. This plan is designed to fit the aim of the paper while providing a description of the objectives and methodology used.

An in depth literature analysis will be conducted pertaining to the search combinations as mentioned in table 2. The literature that will be included in this paper will contribute to the understanding of the paper aim. This will supply the author with the necessary theory to come to valid conclusions and ensure that relevant, meaningful, and applicable research outcomes will be reached. To ensure that the theory in this literature review will still be relevant, published articles and other theoretical sources will be used that have been published within the past five years. The literature sources that will be used will be retrieved from trusted sources, such as SCOPUS and other accredited sources, which also means that the quality of these published sources will be of high.

3 RESULTS

The results that were obtained with the aid of SCOPUS are discussed in this section. To conduct a comprehensive analysis, no exclusions were made as to ensure that access is gained to as much literature as possible. The following section, discusses the overall results of the searches that were conducted, including the analysis and inferences. The section that follows thereafter, focuses on the literature within the focus areas of this research being, sustainability, healthcare, and sociotechnical systems and transitions. This method is used determine whether sufficient amounts of research has been done in the areas pertaining to the aim of this paper.

3.1 Overall research results

The specific combination of search terms, as illustrated in Table 2, resulted in a number of documents that were obtained. These numbers as well as the corresponding SCOPUS algorithm is displayed by Table 3.

Table 3: Document results

Search Combination Label	Scopus Algorithm	Number of documents obtained
SC1	(TITLE-ABS-KEY ("sustainability" OR "sustainable" OR "sustainable development") AND TITLE-ABS-KEY ("healthcare" OR "health care"))	26 111
SC2	(TITLE-ABS-KEY ("sustainability" OR "sustainable" OR "sustainable development") AND TITLE-ABS-KEY ("healthcare" OR "health care") AND TITLE-ABS-KEY ("sociotechnical system*" OR "socio technical system*" OR "socio-technical system*"))	21
SC3	(TITLE-ABS-KEY ("sustainability" OR "sustainable" OR "sustainable development") AND TITLE-ABS-KEY ("healthcare" OR "health care") AND TITLE-ABS-KEY ("sociotechnical system*" OR "socio-technical system*" OR "socio technical system*") AND TITLE-ABS-KEY ("sustainability" AND "transition*"))	3
SC4	(TITLE-ABS-KEY ("sustainability" OR "sustainable" OR "sustainable development") AND TITLE-ABS-KEY ("healthcare" OR "health care") AND TITLE-ABS-KEY ("sociotechnical transition*" OR "socio-technical transition*" OR "socio technical transition"))	1

It is evident that there is a substantial amount of literature pertaining to sustainability or sustainable development within the context of healthcare. However, upon further investigation, less literature is currently available when considering the search terms that are concentrated around the topic of this research, i.e. the extent to which sustainable transitions have been incorporated into healthcare as a sociotechnical system. The following sections presents an overview of a comparative analysis of the timeline of the publications, the subject areas of this research and the publication origin areas between the search combinations (SC1, SC2, SC3, SC4).

A selection process chart is added to indicate the acceptance of papers as possible aids to this paper. This is an outline of the articles that were selected to support the theory behind the identified search combinations. Additional sources will also be used to aid this paper, this is merely an indication of the SCOPUS article

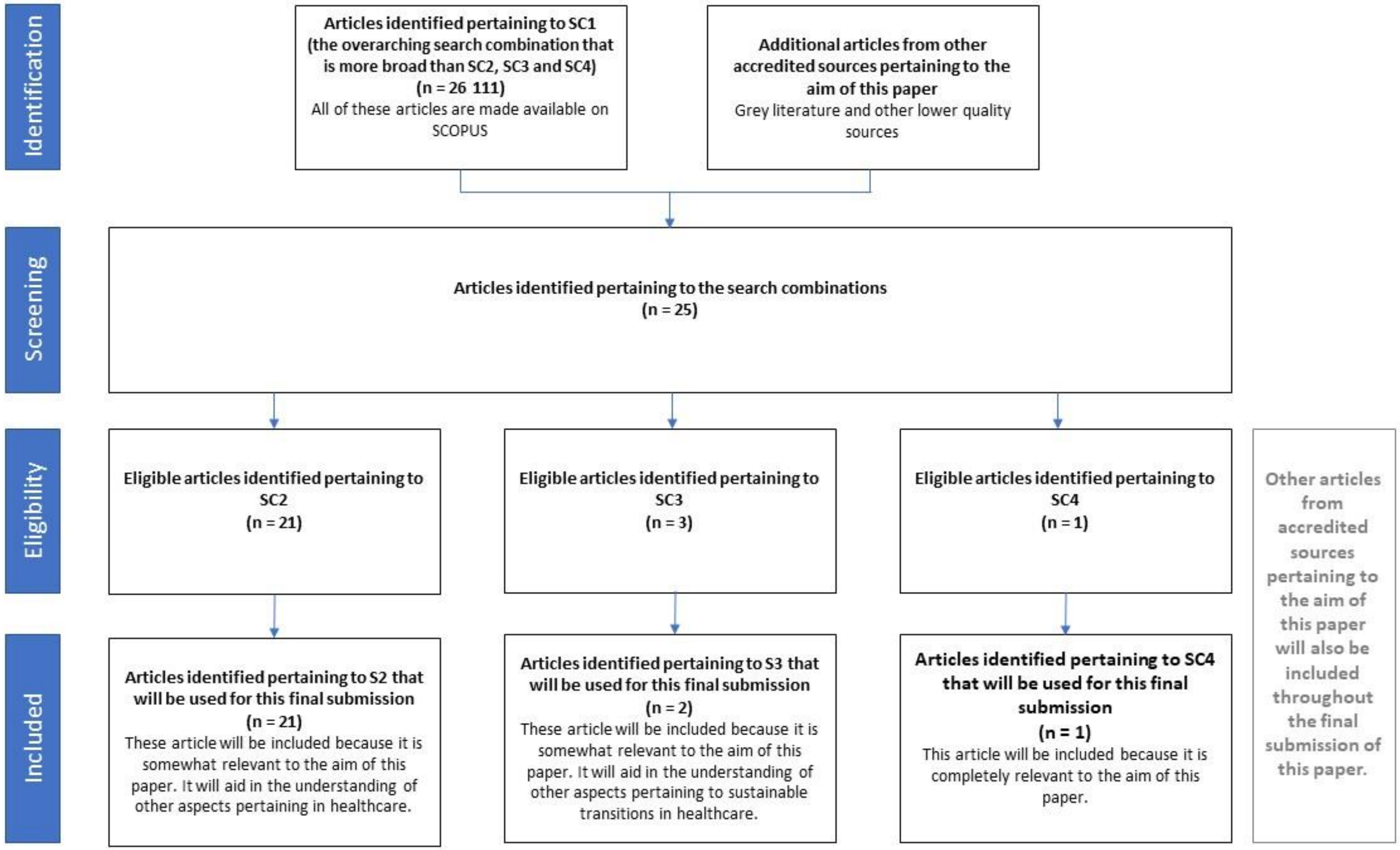

Figure 1: SCOPUS article selection (adapted from [1])

3.1.1 Timeline of publications

Figure 2 below, indicates the number of published documents per year pertaining to the four search combinations of SC1, SC2, SC3, and SC4.

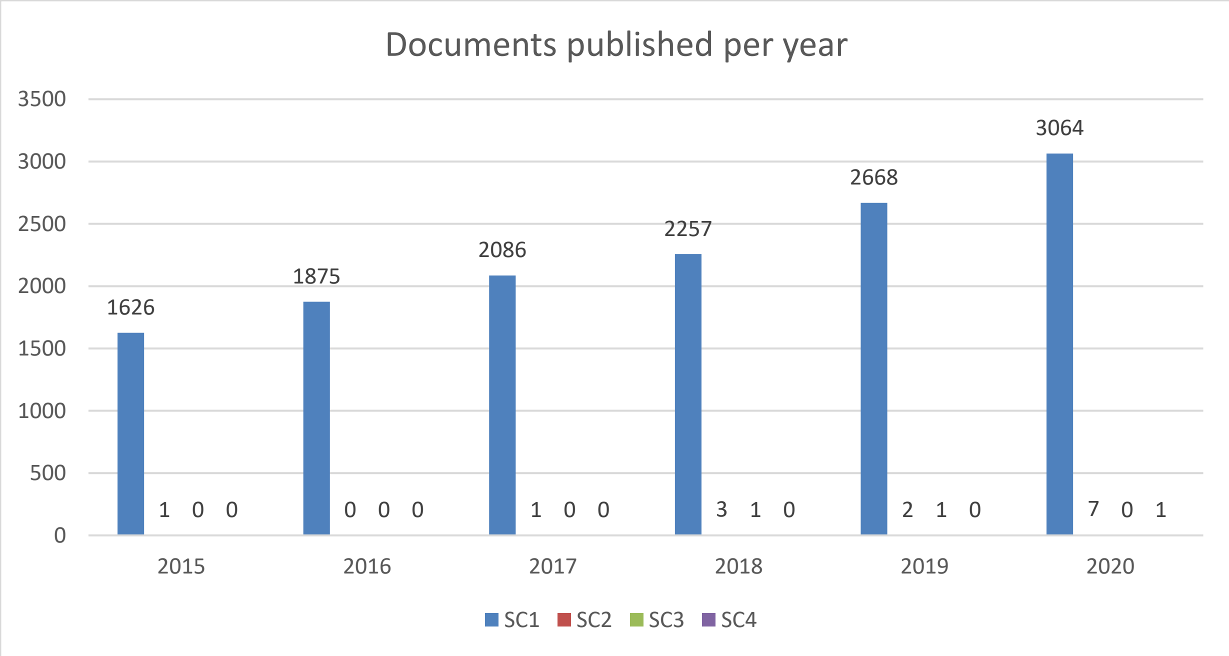

Figure 2: Documents published per year

It is evident that documents pertaining to the sustainability and sustainable development within healthcare are increasingly becoming more popular. Furthermore, it is indicative that there is a clear gap in research regarding sociotechnical systems, sociotechnical transitions, and sustainability transitions within the healthcare industry. This specific chart type relays the pivotal information that there is a clear gap in research pertaining to SC2, SC3 and SC4.

3.1.2 Subject areas of study

Figure 3 below, indicates the common subject areas within the search combinations. The most common subject area, overlapping all four search combinations are Social Sciences and Business, Management and Accounting. However, the two subject areas with the most published articles are Medicine and Social Sciences. It is also observed that the search combinations are mainly focused within the science field.

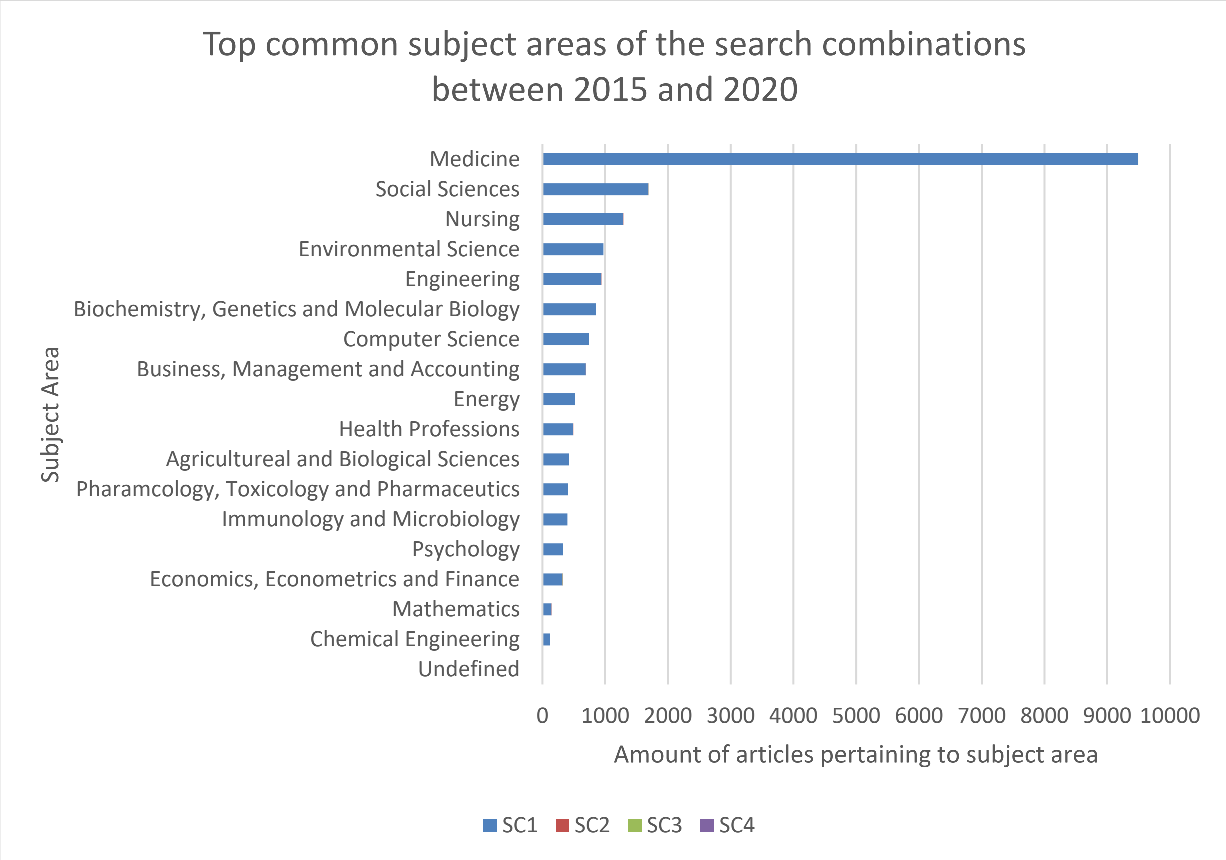

Figure 3: Common subject areas of the search combinations

3.1.3 Publication origin area

The most literature found in the search combinations have origins in the United States, as well as the United Kingdom. As seen by Figure 4 below, it is evident that there is a clear gap on the research, based on the search combinations, from other regions.

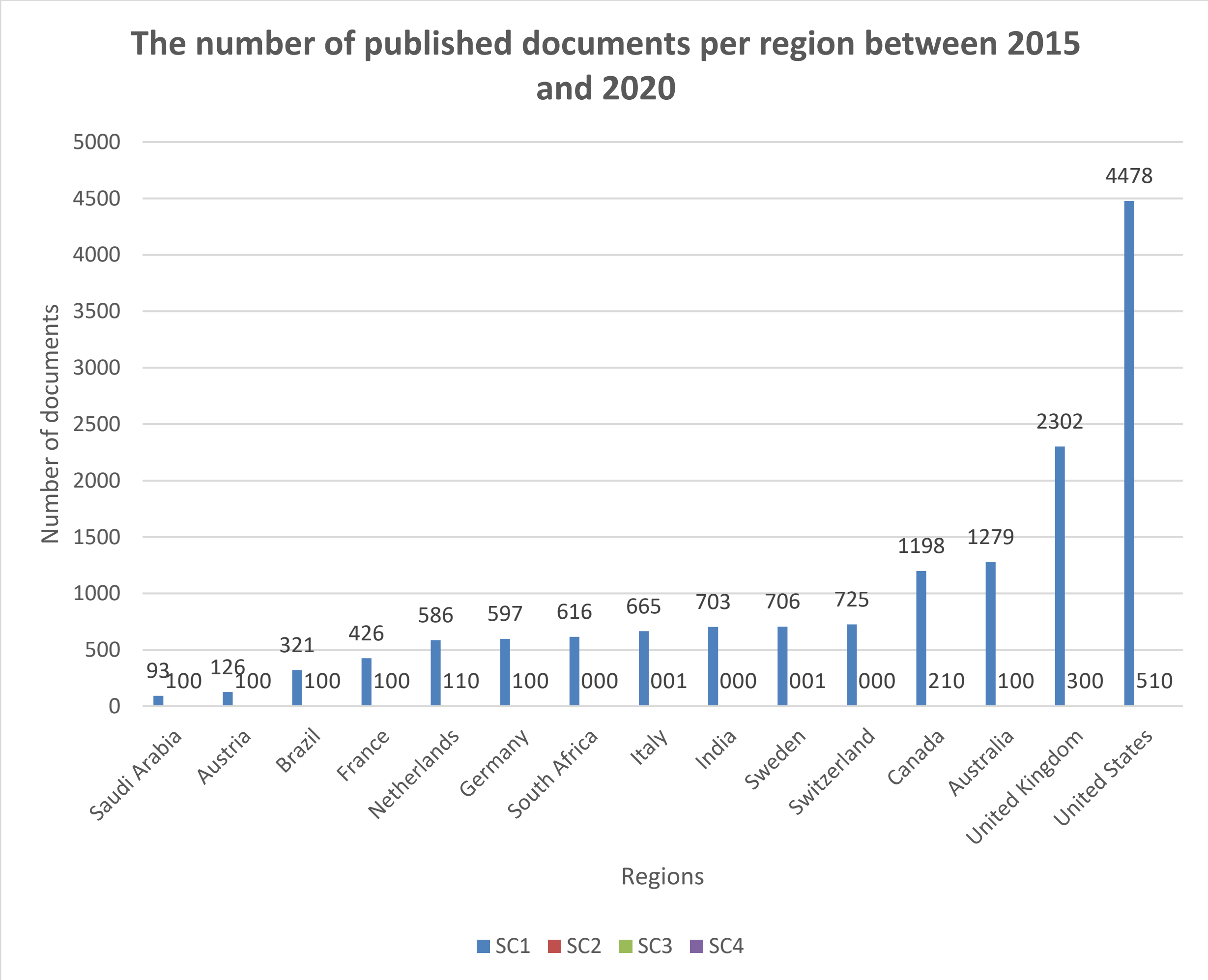

Figure 4: Common regions of the published documents

The SC1 is the search combination with the most published articles, however SC2, SC3 and SC4 have very low published articles. This specific chart type relays the important information that there is a clear gap in research pertaining to SC2, SC3 and SC4 in certain regions, thus motivating the need for this paper.

3.2 Transitions specific descriptive analytics

This paper assesses literature in the intersections between healthcare, sustainability (or sustainable development) and sustainable transitions, sociotechnical systems and transitions.

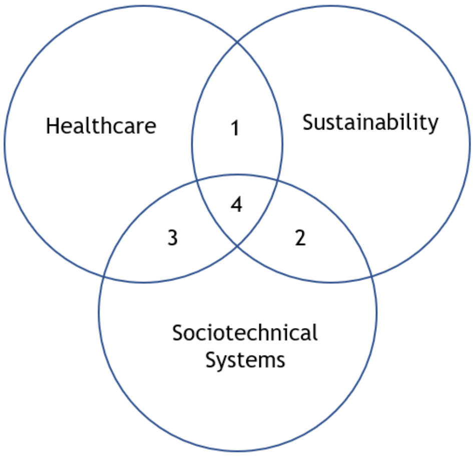

Figure 5: Intersections of literature to be assessed

As indicated by Figure 5, intersection 1 aligns with the search combination 1 (SC1), intersection 4 aligns with the search combination 2, 3 and 4 (SC2, SC3 and SC4). The difference between SC2 and SC3 however, is that SC3 focusses on sustainability transitions as well which is a pivotal aspect of this research. The search combination, SC4, is a concentrated around the main aim of this paper, which is to discover the extent to which sociotechnical transitions have been incorporated into healthcare.

This article's main categories include healthcare and sustainability (or sustainable development), which is why no further assessment will be done on intersection 2 and 3. The main focus of this article will be based on intersection 4 (SC3 and SC4), but research will also be done on all intersections in order to determine the direct and indirect relationships between all three focus areas.

3.2.1 Citation analysis

Table 4 below indicates the documents pertaining to SC3 and SC4 that are available. Given the short timeline and the rate of the output of the literature, it is understood that the citation counts are still low.

Table 4: Data of cited documents in SCOPUS search

Search Combination	Title	Author	Year	Document type	Citation Count
SC3	Human Factors Engineering: Status, Interventions, Future Directions in Pediatrics	Ponnala, S., Rivera, A.J.	2019	Review	0
SC3	Cities and sustainable technology transitions: Leadership, innovation, and adoption	van Geenhuizen, M., Holbrook, J.A., Taheri, M.	2018	Book	1
SC3	Designed to travel? Transition management encounters environmental and innovation policy histories in Finland	Heiskanen, E., Kivisaari, S., Lovio, R., Mickwitz, P.	2009	Article	49
SC4	A multi-stakeholder perspective on sustainable healthcare: From 2030 onwards	Pereno, A., Eriksson, D.	2020	Article	4

3.2.2 Content analysis

The first document, "Human Factors Engineering: Status, Interventions, Future Directions in *Pediatrics*", discusses in the form of a systematic review, the extent to which Human Factors Engineering (HFE) has identified sociotechnical systems barriers, that can be improved upon in terms of patients, employee safety and the healthcare quality. It also discusses the status of HFE in healthcare, while also discussing how the science of HFE can further be applied to improve the safety in healthcare delivery processes. This document states a few findings: HFE has been applied in many various areas within healthcare in the last few years, which include electronic health record (EHR) design, imaging, medication management, patient experience and care transitions. The HFE interventions include the combination of physical, cognitive, and macro ergonomic principles that is used to improve healthcare delivery for pediatric patients. [2]

The book, "*Cities and sustainable technology transitions: Leadership, innovation and adoption*", discusses the leadership challenges in various cities currently evident within emerging transitions towards increased levels of sustainability. It also analyses elements of three sociotechnical systems, energy, transport, and healthcare. This is simultaneously conducted while addressing the technological inventions, commercialization, mass production, and adoption. [3]

The first article pertaining to SC3, "*Designed to travel? Transition management encounters environmental and innovation policy histories in Finland*", discusses the new term transition management (TR). Transition management is a term for long-term policy design for reflexive governance of sociotechnical systems. This particular article's main aim is to explore the experiences of transferring TR model into Finnish context, based on the two case studies in different sectors. [4]

The final article pertaining to SC4, "*A multi-stakeholder perspective on sustainable healthcare: From 2030 onwards*", is aimed at addressing the topic of all the possible futures of sustainable healthcare through a collaborating foresight process. This article mentions that sustainable healthcare has been a growing term in terms of popularity, and the transition towards environmental, social, and economic viable health systems is identified as being inevitable and extremely necessary. The outcomes are highlighted in three different areas and the drivers that reform the roles of the individual stakeholders, enhancing sociotechnical transitions towards the desired scenario that is based on the collaboration between dynamic networks. [5]

4 CONCLUSION AND OPPORTUNITIES FOR FUTURE RESEARCH

The conclusion is made that there is a clear gap in research pertaining to the aim of this paper thus, there is an opportunity for research to be done that jointly analyses the fields of sustainability and sustainable transitions, healthcare, and sociotechnical systems. The lack of comprehensive literature of large parts of the world, outside of the United Stated and to some extent the United Kingdom, leaves a large opportunity for further research in other regions. This gap could contribute to the understanding, assessment, and implications of these concepts within other regions as well as contribute to the shortage of literature currently available pertaining to these concepts. Finally, as the research on these specific concepts becomes more relevant, it could be expected that future researchers and authors will become more distinguished in this field.

In conclusion, this paper highlights the need for the expansion of knowledge within the combination of the specific fields of sustainability, which includes the focus on the transitions to sustainable healthcare systems, healthcare, and sociotechnical systems. Further analysis and synthesis of existing literature in these fields are supported by these findings, in order to identify knowledge gaps to ensure relevant, meaningful, and applicable research outcomes.

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DEEP-ROOTED OBSTACLES TO LEAN ADOPTION IN THE SOUTH AFRICAN PUBLIC HEALTHCARE SYSTEM: A LITERATURE-BASED PERSPECTIVE

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ABSTRACT

Despite extensive application of lean evident in healthcare literature, there is still a dearth of both empirical and review research on the obstacles faced by healthcare organizations in underdeveloped countries in their lean implementation journey. Using literature-informed data, this paper investigates the constraints in the South African healthcare system affecting the readiness for a sustainable lean journey. The paper highlights gaps in cooperate governance, mismanagement, a lack of visible leadership support for lean rollout, and resource constraints as core obstacles undermining the success of lean in the public healthcare system. The study recommends, for lean success, hands-on lean training, support and incentives for staff participation in quality improvement, an internal resource dedicated for lean, computerized record management system, addressing clinical staff shortages, and infrastructural maintenance. Management must have the quality improvement agenda aligned with the organization's strategic objectives and commit to a focused lean journey to reap the long-term benefits.

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1 INTRODUCTION

The In the bid to improve the quality of care, healthcare systems in both public and private sectors, are confronted with the challenges of minimizing high operational cost, resource availability, energy shortage, demographic changes, increased customer expectations, and liabilities [1]. In addition, there is the need for lasting care for diseases such as cancer, HIV [2], and Covid-19. The propensity of these challenges is higher in poor economies amidst high population growth, and a decline in public healthcare funding [3]. Hence, to entrench and pursue the drive for continuous improvement, better resource utilization, the best quality of care, and acquire a competitive edge, healthcare organizations are seeking and adopting emerging technologies and improved treatment methods [1] [4]. Numerous healthcare institutions are responding to the pressure by using practical proven industrial methodologies such as lean. Although lean originated from the manufacturing sector as the Toyota Production System [5] it has found widespread application in the service industry especially healthcare [3] [4].

Various definitions of lean exist in literature. Womack & Jones [6] in their book *Lean thinking* posited one of the earliest definitions stating that

> "*lean thinking is lean because it provides a way to do more and more with less and less-less human effort, less equipment, less time, and less space- while coming closer and closer to providing customers with exactly what they want.*"

However, Graban [7], argues that this definition, in the healthcare context, might have superficially missed the quality aspect. As Graban alluded, lean is not just about waste eradication (less and less). In as much as healthcare organisatons need to do more with less, it is imperative to define lean based on the primary objective which is: providing patients with efficient, safe, high-quality care that is cost-effective, and error-free. Graban [7], defined lean as

> "*an integrated system of human development, technical tools, management approaches, and philosophy that creates a Lean organizational culture*".

Lean management is encored on two pillars: Lean philosophy (continuous and relentless drive for improvement and lean principle) and lean activities (techniques or tools and management practices) [8]. Importantly, Lean as a philosophy lived by all members of a learning organization influences how people bring improvement to their work, share ideas, and build capabilities individually and as a team [9]. If the transformation is widespread, it will not only contribute to sustainable organizational excellence and employee development [10], but also to economic growth and improved quality of life.

The recent push for costs reduction while demanding for both the delivery of safety and quality care mandate has raised the awareness of the need for healthcare institutions in the South African region to adopt lean [11]. According to the 2019 Statistics SA General Household Survey, only about 17.2% of the South African population have health insurance cover [12]. The implication is that majority of the people depend solely on the overladen public health system for medical care. In addition, the high unemployment rate increased the dependency on the public healthcare system because fewer people can afford private healthcare. Furthermore, the public health facilities lack adequate resources and there is uneven dissemination of the available resources in some regions [13]. Many of the public healthcare facilities in different regions of the country are dysfunctional, this is due to infrastructural decay, mismanagement, poor funding, and general neglect [14].

The demand versus supply mismatch is exacerbated by the surge in demand for healthcare due to urbanization, as more locals and foreigners migrate to South African cities for a better quality of life. Healthcare facilities and staff are overburdened as they strive to contend with the increasing influx of patients in need of care [14]. There are long queues in healthcare facilities, with more people experiencing difficulty in accessing public health services. At the end of the day, many have no access to suitable healthcare. These predicaments prompted the promulgation of the new National Health Insurance (NHI) scheme. Making the NHI functional, "starts with proposing innovative ways to improve the overall health system and to make it more efficient." [15]. In support of this call, the Gauteng department of health encourages its hospitals and clinics to deploy lean management system to enhance operational efficiency and improve patients' experience [49].

The South African healthcare authorities have shown greater commitment to the assurance of patient safety, and better quality of care [17]. This is demonstrated in the development of various policies, core standards, and national guidelines to assure quality compliance in the public health sector, yet the quality of healthcare service has not shown significant improvement [16][17].

Another scourge is the cost of medical negligence claims which is draining the budget of provincial health departments. In Gauteng health province, it was reported that Serious Adverse Events (SAE) has increased from 4170 in 2017 to 4710 in 2020 [18]. According to the auditor general's report, the Gauteng Department of Health, had a budget of R2.6million for medico-legal claims for the 2019/2020 fiscal year but ended up paying R501million [18]. These errors have been attributed to not only healthcare staff's unethical behavior, but as a consequence of system failure, massive staff shortages, and inadequate management of clinical operations [18]. These medical errors come with dire consequences of costs and sometimes loss of life.

Lean management when applied efficiently has the potency to reduce the occurrence of medical errors [19]. Moreover, lean culture requires that problems and errors are exposed rather than hiding them. When errors do occur, even as the problem is mitigated, it also serves as a shared learning experience for the organization to evade future occurrences.

Some South African public hospitals have initiated lean, while others are piloting lean management in some selected units of the hospitals [25][49]. Hence, a study to drive the identification of both system and organizational challenges undermining strategic lean implementation is needed [20].

Research Question: What are the obstacles to lean healthcare implementation and sustainability in South African?

2. METHODOLOGY

Implementation of interventions like lean can involve non-linear and multi-dimensional (technical and social) change management processes [21]. A contextualized realistic review unveils the black box and demystifies implementation challenges. To answer the research question, extant literature on lean and healthcare quality improvement in South Africa was extensively reviewed as a subset of the global lean healthcare literature.

The study accessed multiple sources of electronic databases. Relevant articles and thesis were obtained from bibliographies: EBSCOhost, Science Direct, Emerald, Scopus, and Google Scholar. The following keywords – "Challenges of lean healthcare implementation in South Africa" were used to identify relevant publications. The publications were carefully assessed using the titles and abstracts. A critical study of the identified literature informed the selection. Articles considered irrelevant were not included in the analysis. The literature search focused only on publications written in English. The publication selection timeframe was limited to 2014 – 2020, although few older ones were included because of their relevance.

The experience of lean healthcare implementers in South African (SA) hospitals is not well reported in the literature. Hence, the search for "Challenges to Lean healthcare implementation and sustainability in South Africa" yielded few result [11] [21] [23-29] as very few South African hospitals have started implementing lean management. The articles were selected if they addressed the absence of lean success factors as the reason behind the failure of quality improvement in healthcare. Out of 155 articles generated, 47 were selected, 30 on South African healthcare, lean, and quality improvement literature highlighting the constraints of implementing lean/quality improvement in the healthcare system. The rest were from recent global lean healthcare literature on the same topic.

Most of the articles highlighting gaps in cooperate governance and managerial incompetency the public helthacre sector. Authors alluded that the working conditions in the public hospitals are seriously affecting productivity and the quality of patient care [13] [29-31]

3 LITERATURE REVIEW

The review succinctly presents the key constraints to lean implementation in the South African Public Healthcare System.

3.1. The Progression of Lean in the South African Public Healthcare System

One of the earliest action research on lean piloted at Cape Town's G.F. Jooste Hospital found that Lean implementation could improve staff attitude, patient flow, and service lead time in healthcare, [27]. Price [28] in a Cape Town orthopedic outpatient unit, conducted a study similar to that of Faull's. He gathered data on pre and post-implementation of lean in the outpatient clinic. The study applied lean while introducing new practices - issuing numbered labels to patients on arrival, using signage and other visual tools to direct patients, booking appointments for the patient. The study established the efficacy of lean in increasing efficient resource utilization and improved delivery of healthcare outcomes: patient waiting time, reduction of waste (non-value-adding work that is unnecessary) thus, creating capacity for value-adding activities. The Lean intervention project also shows evidence of increased patient, and employee satisfaction.

Kruger [29] assessed lean implementation in the Gauteng public hospitals. The research illustrated the use of Lean Six Sigma tools, and observation to identify waste. The study indicated that Lean Six Sigma cannot provide a quick fix to long-existing systemic errors in public hospitals. The author proposed a more adaptive customized approach to the Lean Six Sigma application in the public health system.

Heathcote [25] in the book (Making a Difference: Streamlining Patient Care and Liberating resources) detailed the experience of working with a team from 4 Gauteng hospitals, including the CEOs in collaboration with top members of LIA (Lean institute Africa) to apply lean tools and principles in a 5-days Kaizen event in solving identifies problems in the specific areas in the participating hospitals. The study demonstrated how lean can be used to improve customer care and other healthcare outcomes. Other benefits of lean experienced in South African hospitals, as found in literature, shows an increase in employee job satisfaction, a boost of staff morale and motivation as operational efficiency increases following a lean application [26].

Preparing for a new quality improvement initiative like Lean can be overwhelming because it is associated with uncertainties and organizational change management efficacy. Several studies, in recent times, have delved into various aspects of Lean adoption in the South African healthcare sector [11] [20] [22] [24] and other sectors [48]; but none focused on succinctly identifying the key challenges in the implementation and sustainability of Lean in the healthcare system.

In the subsequent section, barriers to initiation and sustainability of lean system are expounded. Also, various forms of health professional resource waste have been discussed which undermines productivity and quality healthcare delivery.

3.2. Obstacles to Lean Implementation in Healthcare

According to the reviewed literature, many obstacles exist which contribute to unsustainable lean adoption in healthcare, most of which are people or system-oriented:

3.2.1. Resource Crisis

Lean implementation is resource-intensive. If the leadership of healthcare organizations desires to do it right the first time (a lean practice initiated by Juran), they must commit sufficient investment towards acquiring the competencies and securing appropriate resources required in readiness for the lean journey [32]. There is a significant difference in resource availability between the South African private and public healthcare sectors [14]. For example, the nurse-to-population ratio in the public sector has been decreasing significantly because most professionals leave the public sector for the private sector or go abroad for greener pastures. Furthermore, many healthcare organizations in the public sector are less likely to effectively implement quality reforms due to resource constraints - workload, staffing crises, poor infrastructure, inadequately training for personnel, insufficient funding, and inefficient distribution of resources amongst levels of care within the public sector ([13][16][23][33-35].

Another workload capacity versus demand challenge, in terms of sustainability of lean systems, arises when Management does not have some internal resources dedicated to lean. As Graban 2016 [7] recommended, a dedicated full-time team is required to kick-start and sustain the lean activities. Otherwise, when workload increases (some staff members are sick) especially in this Covid-19 era, the daily work of patient care is prioritized, hence lean effort is relegated or stopped altogether.

3.2.2. Competencies and Skills of Management team:

Manegers play vital roles in implementing new reforms in healthcare. The managerial competencies are essential to advance the best patient care as well as continuous drive for quality improvement. Munyewende et al. [36] conducted an empirical study to assess the competencies of PHC (Primary healthcare Clinic) managers in the Free State and Gauteng (South African provinces). Among all the capabilities investigated - problem-solving, leadership and management, financial management, staff management, planning and priority setting, and communication; the study found financial management as the area where the nursing managers have the least competency. The authors emphasized the need for appropriate training to develop financial management skills amongst the PHC nursing managers. Hence, they recommended that financial management be included in staff further professional development programs. Other than a rise in demand for healthcare, managerial incompetency and resource mismanagement have been echoed as the main reason for poor healthcare service quality in the South African public healthcare system [14] [30] [35] [37].

3.2.3. Leadership and Management Commitment

Researchers have indicated leadership commitment as a critical factor for Lean implementation success [32][4]. Many recent studies agree that leadership behavior has a direct and significant impact on the quality of patient care [10]. Management buy-in and visible support are essential for the effective adoption of the Lean philosophy. Management must come down to the frontline employees to see for themselves their challenges and observe how work is done. They must also show decisive leadership and willpower to commit resources to solve identified problems and provide enabling structures for employees' empowerment and motivation.

Leaders at all levels, as agents of change, should enable, influence, and encourage staff participation in quality improvement. Evidence from various quality reforms discussed in healthcare literature shows that the public healthcare fraternity has a keen interest in improving operational efficiency [16] [20] [50] [16]. However, authors [30] [37] allude that, most government-owned hospitals in South Africa are not well managed, especially in terms of resource deployment, organization firmness, and quality of care.

3.2.4. Healthcare governance constraints

One of the fundamental challenges in South Africa is translating policies into practice [40]. An example is the inability of healthcare governance authorities to respond to the requirement for legislation and policy changes on training and development of nurses [46]. Developing and sustaining the capacity of healthcare professionals needed to implement new reforms like lean requires both institutional and government support for new cohorts and on-the-job training of staff [47]. There is a need for the political willpower to enforce relevant policies that will expedite the deployment of needed resources.

3.2.5. Knock-on effect of bad governance, poor financial management, and corruption.

Corruption and bad governance has negatively affected the provision of health services at provincial and national level [31]. The study further unpacked the dimensions of corruption in the South African healthcare sector to include the absence of mechanisms to identify corruption, the appointment of unqualified administrators who lack the required competencies and integrity, and failure to decisively discipline those found guilty of corruption. Poor financial management capabilities have also been highlighted as a challenge [36].

3.2.6. Employee empowerment

Many studies emphasize staff active involvement in problem-solving and empowerment as essentials for Lean success [1][9][38]. Although the operations managers (lower level management) in public health facilities run the units, they do not have the sense of ownership when it comes to the implementation of strategic decisions – corporate objectives, policies and resource allocation [50]. An environment where people are not given a fair opportunity to participate in decision-making undermines the spirit of shared faith and respect for people (lean culture). The frustration of being left out emanating thereof may lead to demotivation and resistance to positive change. As authors [16] [39] reiterate, exclusion from vital decision-making process breeds a sense of disconnect, rift, and struggle in the organization as people do not take responsibility for their stake in the quality pie. Hence, despite the high level of awareness on the need to implement quality improvement initiatives and standards, there is a lack of interest and resistance to change at lower levels. This ultimately affects the quality of healthcare delivery with dire consequences. Liker [9] further emphasizes that it is much easier to deal with resistance at the planning stage of any intervention, rather than at the implementation stage.

3.2.7 Hands-on lean training

Lack of mechanisms to resolve employee concerns and unavailability of hands-on lean training is a challenge. South African health sector can train skilled workers who can deliver high-quality individualized care ([47] Benatar 2013); but policies and budgets which are in the mandate of provincial and national departments of health have grossly ignored addressing these challenges [24](Chatur, 2018).

3.2.8 Resource wastage

Previous authors [40] [41] defines human resource wastage in healthcare as "loss in the utility of health professionals due to unemployment, underemployment, attrition or poor productivity that can be prevented or managed and is over and above what is expected in normal work situation". Graban [7] describes human resource waste as loss of human potential due to lack of employee engagement, support for career development, unused talent and not paying attention to staffs' ideas. Dovlo [41] in his study identifies health workforce wastage in Africa as a major reason for the scarcity of professionals within the health sector. The study further reports various forms of human resource waste emanating from emigration/brain drain (direct wastage) of healthcare experts: inadequate support, lack of supervision, heavy workload, mismanaged skills, and absenteeism, which result in productivity losses (indirect waste). Furthermore, vacant positions are frozen, recruitment processes are deferred and qualified personnel is denied promotion as budgets are cut to save money ([40][13]. This trend is not motivating and may lead to suboptimal contribution from staff.

3.2.9. Leadership style

Toussaint & Barnas [10] discovered, having worked with hundreds of healthcare institutions across nineteen countries, in their book - *Becoming the Change*, they confirmed: "every time we examined an organization that was having trouble sustaining its improvement efforts, we found executives stuck in command-and-control style management." Leaders who desire to have their organizations transformed need to be people-oriented. They need to rethink the way they engage with others to bring cohesion and a sense of shared faith among staff at all levels. An empirical study on obstacles and enablers of lean implementation in Namibia, found the absence of management support as the strongest factor impeding lean implementation success in the medical laboratory industry; and adequate training as the strongest enabling factor ([42]). Numerous studies [4][32] agree with these findings.

4 CONCLUSION

This study investigates through existing literature, the challenges, operational and resource constraints undermining the readiness of South African public healthcare institutions for a sustainable lean implementation journey. The discussion above indicate that management visible support is a major driver in lean project planning, implementation, and sustainability. Management provides the funding for training, political willpower for decision making, and agency to drive the change management process necessary for lean. Thus, leadership behaviour among other factors paves the way for a smooth lean transformation journey.

In summary, this study's most critical findings and recommendations are as follows:

- Management of healthcare organizations who have decided to adopt lean must have the quality improvement agenda aligned with their organization's strategic objectives and commit to a focused lean journey to reap the long-term benefits.
- Visible leadership support at both institutional and governmental levels in rebuilding the public health system is required to improve the quality of healthcare service delivery. "The remoteness of leadership and its inability to support the front line in unearthing, understanding and solving problems" is a challenge [43].
- To develop a cooperate quality improvement culture, management must be willing to improve their leadership skills, embrace and demenstate new behavior based on commonly shared principles of self-discipline, humility, respect for others, and readiness to accept the needed change [44]. They must improve their communication style to support quality improvement, and have the curiosity and perseverance needed to work with lower-level employees in problem-solving.
- Top management is yet to realize the impact that wastes and poor management practices [16] have on the healthcare institutions; and the future implications if they continue to ignore waste reduction and mismanagement [30]. Leaders and policymakers need to prioritize waste identification and rooting out all forms of waste in healthcare operations.
- Allocating tasks and responsibilities based on competencies is in healthcare operations. Situations, where staff perform duties beyond their code of practice because of insufficient qualified staff, must not be allowed [13].
- The inability of healthcare authorities to understand and respond to the requirement for policy changes must be addressed [46].
- The public health system needs to address the inconsistencies in the appropriation and dissemination of national resources meant for the healthcare sector. This adjustment is imperative, given the upsurge due to relocation and urbanization, leading to capacity versus demand disequilibrium.
- Improve maintenance system and refurbishment of dilapidated infrastructure [35]. Outcomes of audit reports that identify facility and equipment requirements should receive urgent attention.
- Address supply chain management problems through electronic stocking system, supplier integration, and involvement [34] [20] [45].
- Build a culture of 'openness in the disclosure of problems and errors' and collective learning from each experience.

- Record keeping and safe data storage – secured, centralized electronic data capturing and storage system is recommended.
- Collaborative teamwork and waste elimination will marginally improve process efficiency and reduce cost. Th reduction of (unnecessary work) redundant activities will enable patients' shorter length of in-hospital stay, freeing more bed space for incoming patients resulting in greater customer pull and better customer/patient experience.
- Critical interventions to fight corruption in the healthcare sector: an open and transparent tendering system, and public involvement in health issues to ensure transparency and accountability is recommended.
- Recruitment of managers with the right competency and integrity, appropriate legislation, and effective governance for law enforcement [31].
- Address the cost implication of having over-bloated administrative support at the expense of required medical experts.
- Training on financial management competencies for managers need to be prioritized.
- Management should dedicate resources and a full-time team to lean; otherwise, when workload increases, the lean effort is relegated or stopped altogether because the daily work of patient care is given higher priority.
- Use simple lean tools like A3 for consensus in decision making, visual management to expose problems, and other tools which are easy to understand and apply to improve operations.

While very few South African hospitals have implemented lean, others are still at the planning and introduction phase. A platform for knowledge sharing on quality management practices, lean tools, and experience, from hospitals at various levels of lean maturity is required to improve healthcare quality and for collective learning which will increase the lean success rate.

Given the payoff of lean adoption in the South African public healthcare system, as evident in the success stories emanating from the few piloted cases presented in section 3.1, the national and provincial governments should provide adequate support, training, and human resource to alleviate the workload, such that health workers are leveraged to embark on lean system implementation and also participate actively in the continuous quality improvement initiatives in their hospitals. This will increase staff motivation and the value of work for workers, most critically, patient value and quality of care.

Practical Implications

The issue of health is at the core of human existence. Patients, policymakers, and the public always question how healthcare services are delivered. In the South African context, there is enormous pressure on the system to offer a better quality of care and improve health outcomes amidst the mismatch between demand for quality healthcare and capacity (required to contain the increase in demand), high incidence of medical errors, and resource inadequacies. This situation calls for a new management method like lean to advance the trajectory of quality improvement healthcare operations. Understanding and engaging with the barriers in the prevailing contexts is essential for management and stakeholders of different health constituencies, who are keen on having lean succeed to acknowledge and bridge these real implementation gaps. This approach will answer the question of "why lean, what issues are at stake, what needs to change, and how will lean initiatives be sustainable". This is imperative for dealing with adaptation challenges for a successful lean transformation journey.

Notably, in the face of these prevailing obstacles, it is infeasible to reap the full benefit of lean in the South African healthcare sector. Addressing the barriers highlighted in this paper will alleviate the constraining forces to lean transformation in healthcare.

Further studies should empirically investigate the obstacles encounterd by South African healthcare institutions who have initiated lean and what can be done to mitigate the obstacles to facilitate lean management implementation and sustainability.

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INTEGRATED DYNAMIC SIMULATION METHOD FOR DEEP-LEVEL MINE COOLING SYSTEM PLANNING

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ABSTRACT

South African gold mines are reaching record depths of over 4 km. At these depths, several key systems, such as water and cooling, are required to operate successfully and efficiently. However, the complexity of these systems increases exponentially with depth due to their dynamic- and integrated nature. A critical literature study found that current methods used to solve complex water- and cooling problems exclude their integrated and dynamic aspects. These methods often lead to wrong decisions that limit productivity and safety, while wasting capital. The industry requires a model that accurately simulates and predicts the outcome of decisions by taking the integrated and dynamic effects into account. This study considers a unique Industry 4.0 approach by applying simulation software to model the complex and integrated systems with dynamic boundaries. The model was then applied to a multi-shaft mining complex that is facing the closure of a shaft reaching the end of its Life of Mine (LOM). The closing shaft is integral to the complex's cooling needs but, if left open solely for this reason, significant costs will occur. The simulation approach was used to identify several solutions to closing the shaft in question without affecting cooling on the complex. A favourable combination of solutions was selected resulting in a LOM benefit of R2.4 billion.

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1 INTRODUCTION

During the 20th century large capital was made available for new South African mining developments through foreign and government investment [1]. The industry has since seen a decline in new investment forcing the industry to go deeper with aged infrastructure [2]. Current mining operations are reaching record depths of over 4 km which poses some interesting safety and operational challenges [3].

At the abovementioned depths, the mine virgin rock temperature can reach up to 60°C [4]. Safety regulations prohibit miners from working in workplaces where wet-bulb temperatures exceed 32.5°C [5]. It is therefore impossible to mine successfully and safely at extensive depths without the intervention of mine cooling systems [4,6]. The effective operation of the cooling- and water system also has a direct effect on the performance and safety of the mine and its operations [7].

Deep-level mine cooling systems consist of three main elements, namely dewatering, refrigeration and cooling, and water reticulation [8]. Each of these elements consists of thousands of components (e.g., dams, pumps, chillers, turbines, fans, heat exchangers, etc.) connected via kilometres of piping. The components are all integrated and therefore have a direct effect on components up- or downstream [9,10]. Therefore, environmental changes affect the entire system and is not isolated. Figure 1 is a simplified illustration of the integrated elements of the mine cooling system.

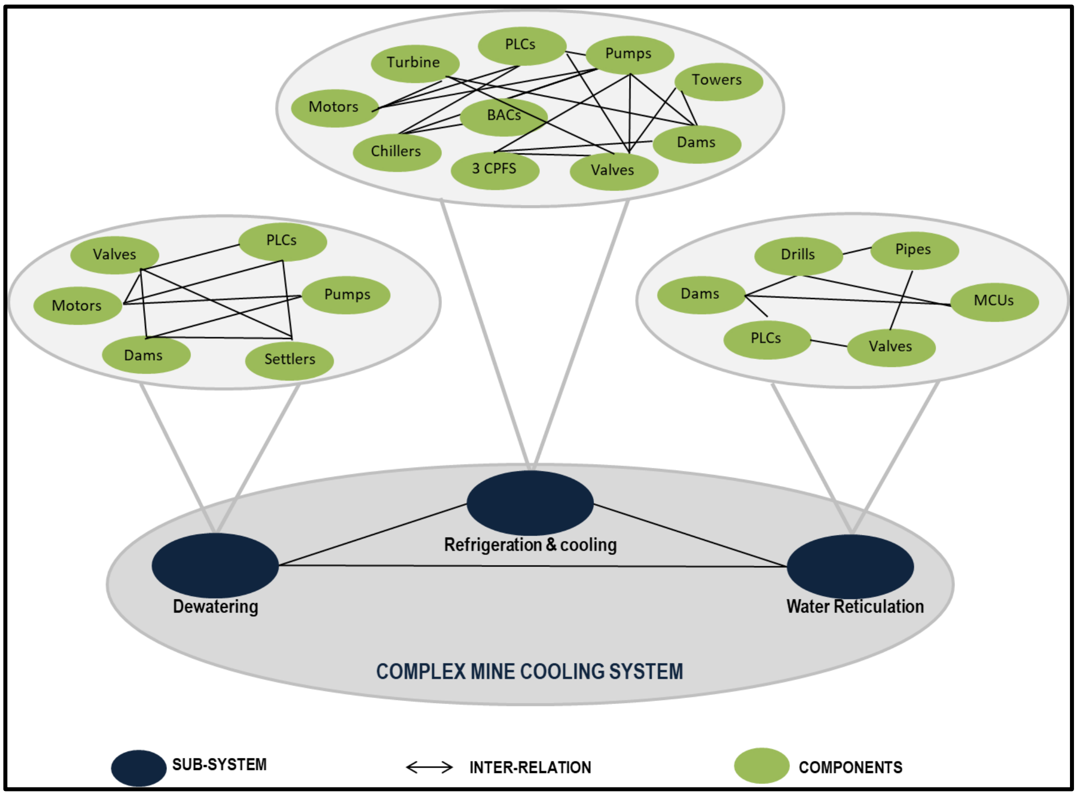

Figure 1: Simplified illustration of a complex mine cooling system (adapted from [8])

Mining in general is also known to be dynamic in nature. This is due to the varying production schedules of different mining stopes (mining areas) located at different parts of a mine [11]. Figure 2 is an example of a medium-term production plan. Each stack represents the production from each stope for a specific month.

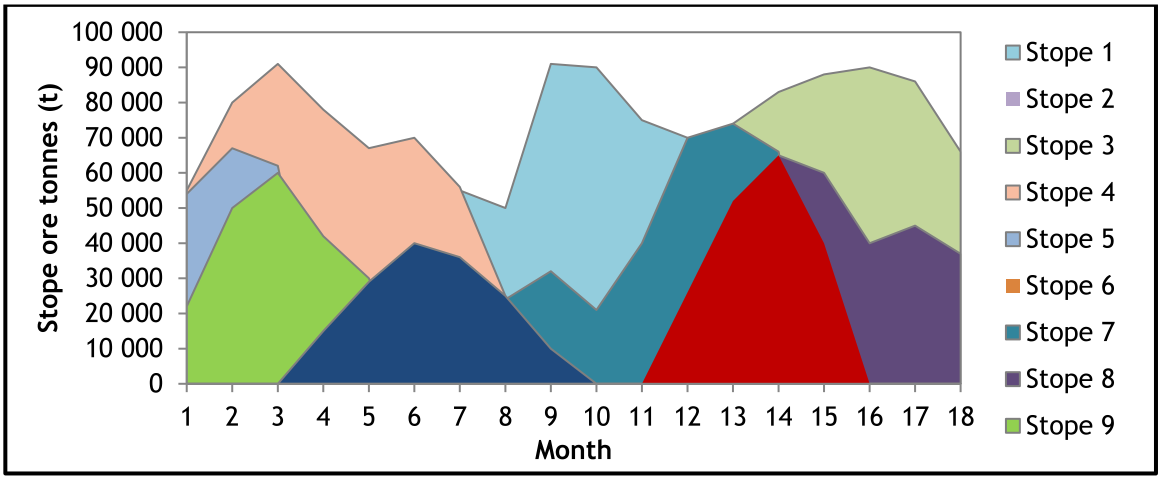

Figure 2: Medium-term production schedule (adapted from [11])

As the production varies for different areas of the mine, the cooling demand at those areas is also affected [12]. To match the cooling demand, the cooling supply needs to be adjusted. This means that operational cooling decisions need to be revised regularly. These decisions *inter alia*, include future mine planning needs and continuous system improvements to ensure optimal cooling is supplied at the lowest cost.

The dynamic, integrated, and complex nature of mine cooling systems requires that the mining industry adopt new Industry 4.0 tools to assist with complex operational questions. One tool that can address this need is simulation. Simulation is an important technology used to improve planning, decision-making and design [13]. Simulation technologies are known to assist engineers in solving integrated, dynamic and complex problems [14].

An investigation was done into the current mine modelling and simulation methods for mine planning and improvements. Some studies considered planning items such as hoist scheduling [15], mathematical models of subsea gold mining planning [16], predictive maintenance for vertical mills [17], or modelling groundwater [18]. All of these studies were focused on a single system within an integrated model. Most planning methods are for open pit, coal and shallow mining [19-32], all of which are a simpler form of mining with far fewer complexities than deep-level mine cooling systems.

The literature study also found several simulation studies on deep-level mine ventilation systems [7,33-39]. Most of these studies focus on ventilation-related challenges. Only a few of the studies recognise the importance of refrigeration and cooling systems. However, the few studies that included cooling systems did not address the integrated effects of the various components of mine cooling [10,36,40-42].

A study done by Mare [8] also indicated that the majority of simulation studies conducted in mine cooling systems only focus on a specific system in isolation, and do not consider the integrated effect of all components of the mine cooling systems. Most of the simulation methods also only considered steady state conditions, rather than dynamic conditions. Steady state simulation is often used for design purposes, where large safety factors are included [43].

Maré [8] also aimed to address the integrated and dynamic simulation need associated to deep-level mine cooling. However, the method used by Mare focused on energy management and energy savings. He did not consider the challenges associated with future planning and cooling service improvements. The same applies for studies [9,40,41,44].

From the literature review it is clear that the mining industry lacks an integrated and dynamic mine cooling simulation method to address future planning and service improvement. This is surprising as the mining environment is constantly changing, dynamic and extremely integrated. Therefore, the contribution of this study is to showcase a method whereby industry 4.0 tools, such as digital twinning, are used for future planning in the mining industry.

The method utilises cutting edge technologies to accurately characterise a mining water- and cooling system. The model is used to predict future underground temperatures and determine several possible solutions to future changes. Accurate prediction of underground temperatures is not possible using current methods.

2 METHODOLOGY

The constantly changing, dynamic and integrated nature of the mining environment, along with the quick turnaround times, necessitated a simplified method. The method was developed into a four-step process that takes information and data and transforms it into an integrated simulation model of the mine.

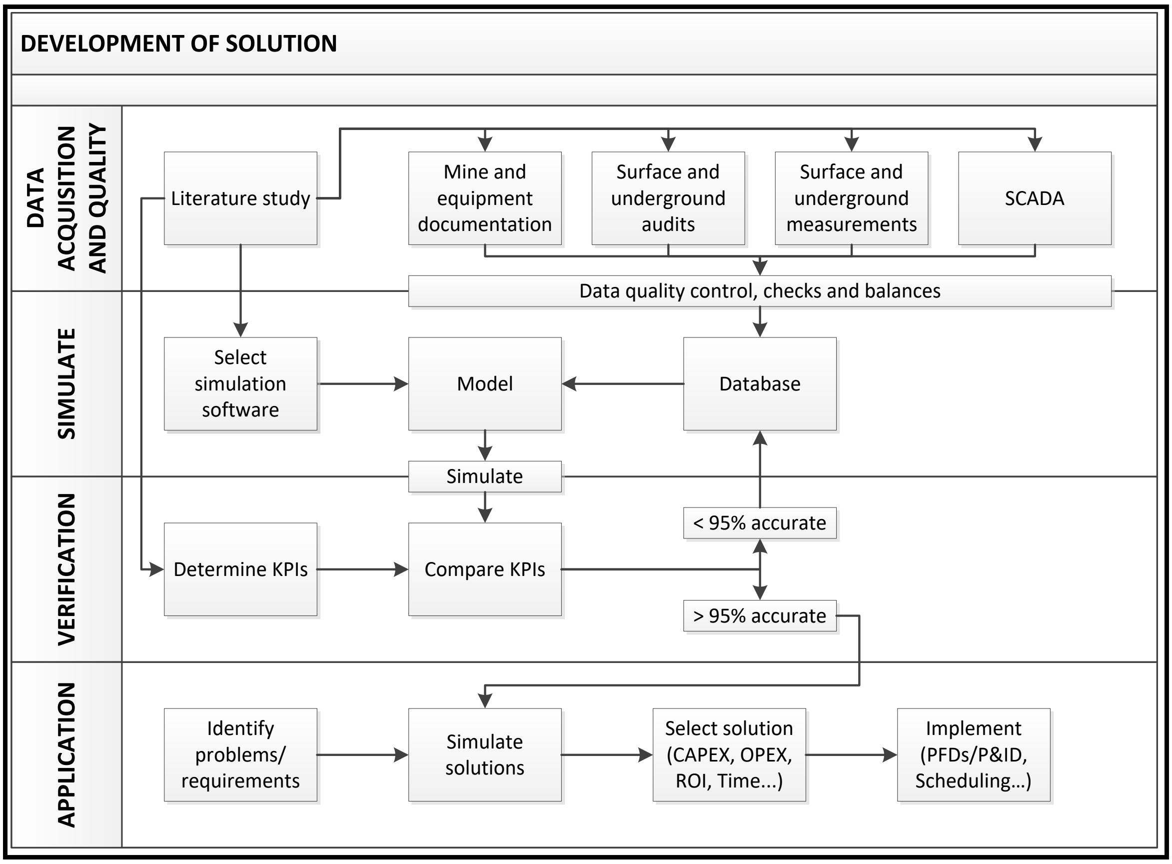

Figure 3: Four-step process flow diagram for developing an integrated and dynamic mine planning decision-making tool

The simulation model is used as a tool to "implement" several solutions virtually, and to run "what-if" scenarios to determine the outcome of the solutions. The four-step process is shown in Figure 3.

The method results in a fully integrated and dynamic simulation tool that is an exact replica of the actual system and can be used for several decision-making applications.

2.1 Data acquisition and data quality

Data is the fundamental driving force behind Industry 4.0 tools and modern systems [45]. Without sufficient data, these systems are as accurate as the user's best guess [46]. Therefore, obtaining significant amounts of data on the system to be digitalised is of high importance. Typical data required includes water- and air flow rates, temperatures, energy consumption, valve statuses, and pressures. Many different platforms are available for data acquisition. The most common in the mining industry include supervisory control and data acquisition (SCADA) systems, manual measurements (audits), and paper logs.

Once data has been collected, the quality of the data needs to be determined. Checks used include maximum and minimum limits, standard deviation limits, and balance checking. With sufficient data available it is possible to construct a digital twin of the system.

The final step is underground auditing. Underground audits provide a visual perspective not achievable with documentation and SCADA data. The exact locations, sizes, specifications, and conditions are obtained from audits. Additionally, measuring equipment is used to confirm SCADA data or obtain measurements not found on the SCADA system.

2.2 Digital twin with simulation

The first step after data acquisition and quality control is to decide upon a simulation tool. In the case of mine cooling system, Process Toolbox (PTB) is the only software able to fully simulate all integrated and dynamic mining systems [47]. The inclusion of all major systems into the simulation software allows for easy integration across all the systems and approaches a true representation. This makes it an obvious choice to model the mine cooling system accurately and successfully.

The PTB software is a semi-empirical thermohydraulic simulation tool that requires prior knowledge of the systems and significant data [47]. The cooling system consists of thousands of components that is added to the simulation model in steps. Once all components are added to the simulation, it is an exact digital representation of the water- and cooling system. An integrated and dynamic simulation can consist of thousands of components and several dynamic boundaries.

Each component requires an input or specification to calibrate it according to the actual equipment. This is achieved through using the acquired data as inputs to the components. The semi-empirical nature of the software then specifies the equipment according to the data. This ensures components or equipment are modelled exactly as it is in the mine. Once all components have been calibrated or specified the model needs to be verified.

2.3 Verification

A digital twin is only as good as its accuracy. Therefore, it is extremely important to verify the simulation model against actual data. Large integrated models can have upwards of 1 000 dynamic profile inputs and 2 000 dynamic outputs. It is therefore important to decide upon certain key areas to focus on and compare with the actual system to confirm the validity of the entire model. These focus areas are called key performance indicators (KPIs).

The model is then compared to actual data using the KPIs and calibrated to within 95% of the actual system. Calibrating the model to 95% accuracy is sufficient to provide a representative model. This falls within the typical accuracy of measuring equipment [48]. The calibrated model is then modified to represent system changes and predict the outcome of several scenarios. These outcomes are then used for decision-making purposes.

2.4 Application

Once a 95% accurate model has been achieved, it is possible to apply the model to several scenarios (initiatives). The first step is to define the scope and identify any issues or problem areas. This step is critical and requires significant research and data gathering.

From the investigation a scope can be defined and the requirements identified. Several simulation solutions can then be developed. The solutions can include *inter alia* simple infrastructure changes, changes to control philosophies, complete redesign, or installation of new infrastructure. Now solutions can be applied in the virtual environment, its effect on the system quantified, its feasibility determined quickly, and without significant cost.

Once a satisfactory solution has been identified through several iterations it can be implemented. The solution can consist of either a single change to the system or a combination of solutions. The final step is to define the solution in depth, listing each component or system change and associating a cost to each item as well as its LOM benefit.

3 RESULTS AND DISCUSSION

The approach was applied to model a three-shaft mining complex using PTB. Mine A is connected underground and on surface to Mine B and Mine C. The total complex is 15 km wide and 3.6 km deep. All three shafts are operational and require cooling. A schematic layout of the three-shaft cooling system is shown in Figure 4.

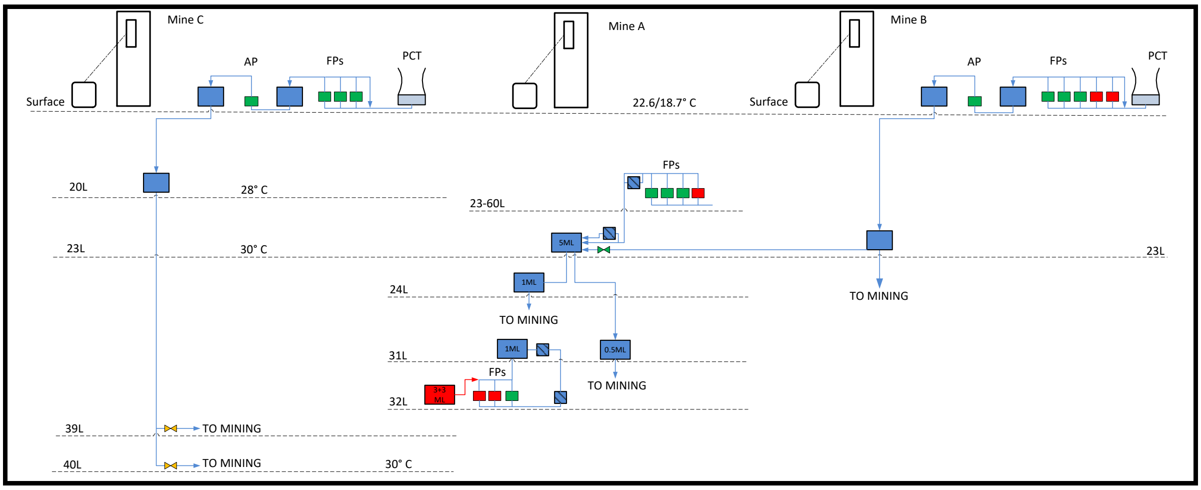

Figure 4: Simplified schematic layout of three-shaft complex cooling supply

Mines B and C supply chilled water on surface using a two-stage refrigeration system. The system's main purpose is to supply chilled water for mine cooling, drilling, cleaning, and dust suppression [40]. Chilled water is produced using a refrigeration cycle or fridge plant (FP). The FPs feed into a network of piping and dams which leads to several "water users". These users include equipment such as cooling devices (bulk air coolers and cooling cars), mining devices (drills) and cleaning devices (water jets) [8]. The annual electricity cost on this system alone is in excess of R200 million.

3.1 Data acquisition

Data for the three shafts were obtained from the SCADA system, mine documentation, and surface and underground audits. The data was combined, checked for quality, and processed. The first step is mine documentation, this might include items such as pump motor plates, pump curves, piping layouts and diagrams etc.

The second step uses the mines' SCADA system. An example of the calibration data used for the surface fridge plants at Mine A is shown in Figure 5.

Figure 5 specifically shows the change in evaporator duty as the average temperature over the evaporator changes due to environmental factors. The difference in average evaporator and condenser temperature is the driving force behind the heat transfer in the FP. Therefore, as the average evaporator temperature increases so does the cooling duty of the machine. This is one of several performance curves used to characterise the FP.

The performance curves include average cooling duty, average coefficient of performance (COP), change in cooling duty with change in average evaporator temperature, change in COP with change in average evaporator temperature and the same is done for the condenser. The data is detailed and provides an exact map of the operational performance of the machine over a wide spectrum of operating conditions.

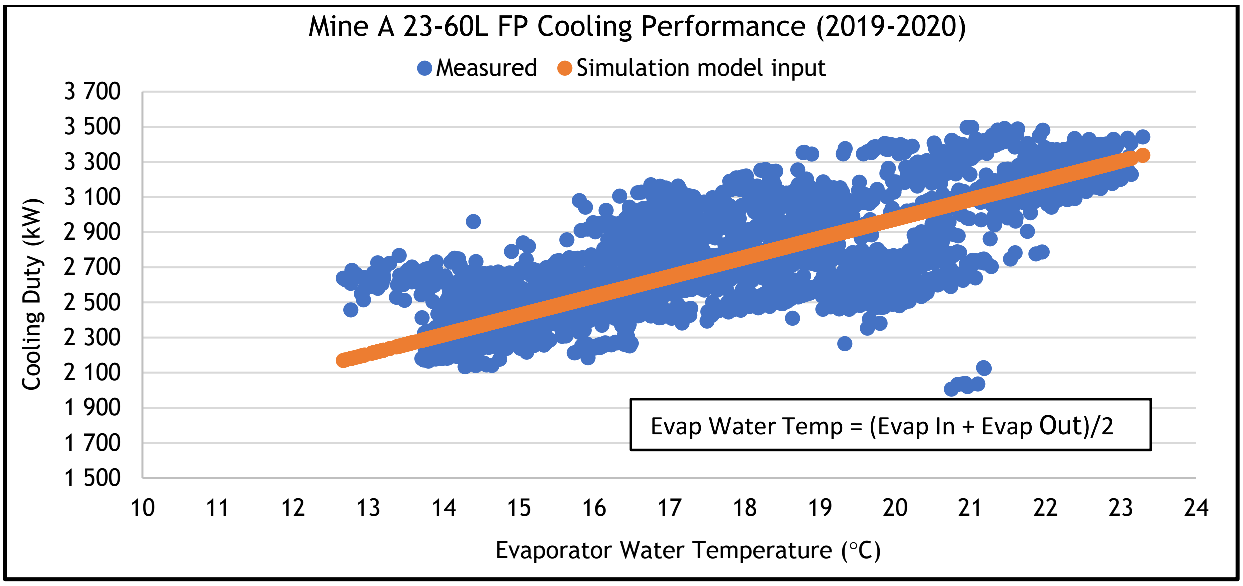

Figure 5: Mine A underground FP calibration data

In addition to calibrating the equipment, dynamic boundaries also need to be considered. This includes surface and underground atmospheric conditions, water temperatures, dam levels and water flows. An example of a dynamic boundary is shown in Figure 6.

Figure 6 shows the dynamic profile for chilled water used underground at Mine A. The profile is determined using underground flow sensors, dam level indicators and mass balance checks. The profile is determined using an average demand profile over an entire operational month.

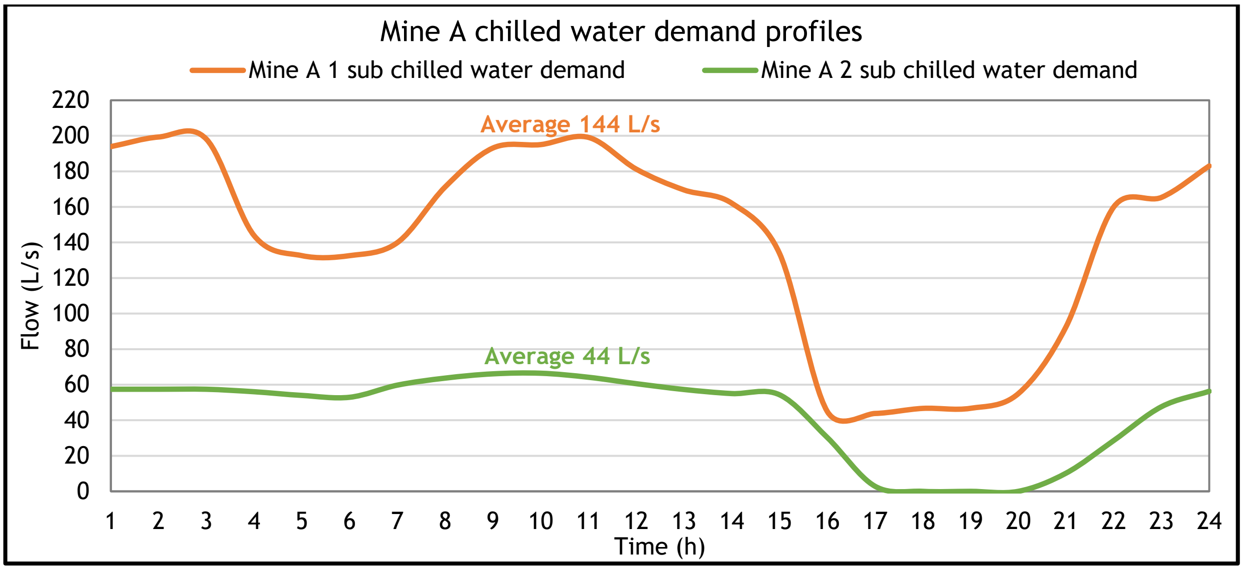

Figure 6: Mine A's dynamic underground chilled water demand

3.2 Model

The final model consists of more than 2 500 integrated components and 10 dynamic boundaries. A snapshot of the 3D integrated mine cooling simulation for the mining complex is shown in Figure 7.

The model includes all critical cooling systems found in Mines A, B and C. The three shafts are all connected underground and on surface. Mine A is connected to Mines B and C on 23L (1 800 m underground) and Mines B and C are connected on 40L (3 600 m underground). The three shafts are all reliant on each other (integrated), therefore each system is of importance for the entire complex.

The model is separated into two major systems, dewatering and cooling supply systems. The cooling supply provides chilled water to underground equipment to ensure correct working area conditions and assist with drilling operations. The dewatering systems ensures the chilled water is sent down from surface and the underground fissure water is pumped to surface avoiding flooding underground. The two systems are then combined to form a complete digital twin of the water- and cooling system. The enlarged section in Figure 7 shows the level of detail modelled in the simulation. The figure also shows the surface FPs of Mine B.

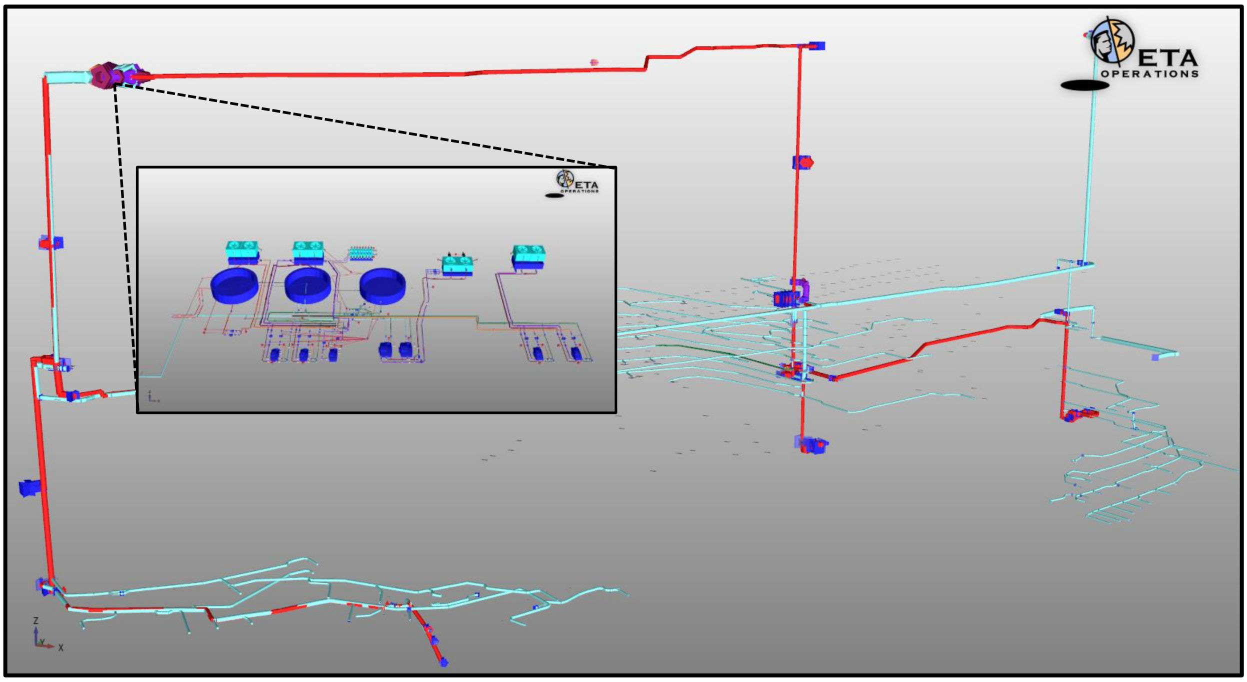

Figure 7: Mines A, B and C simulation model

3.3 Verification

Table 1 shows the KPI comparison for several key points found in the three-shaft water- and cooling system. The model is refined until a 95% accuracy is achieved. The calibration stage is most time-consuming, requiring significant iterations. However once 95% accuracy has been achieved the model is deemed an accurate representation of the actual system [48].

Table 1 shows an overall calibration accuracy of less than 5%. The next step compares the dynamic profiles of the KPIs. One such example is shown in Figure 8.

Table 1: Three-shaft complex KPI comparison of simulation to actual

No.	Area	Equipment	Measurement	Unit	Actual	Sim.	% Error
1	Surface	Hot dam	Inlet/outlet flow	[l/s]	145	142	2%
2			Level	[%]	70	67	4%
3			Temperature	[°C]	27	27.3	1%
4		FP evap	Inlet temp	[°C]	18	17.6	2%
5			Inlet flow	[l/s]	260	258	1%
6			Outlet temp	[°C]	5.5	5.3	4%
7			Outlet flow	[l/s]	260	258	1%
8			Cooling duty	[kW]	13 605	13 284	2%
9			Compressor power	[kW]	3 400	3 355	1%
10		Intermediate dam	Inlet/outlet flow	[l/s]	260	258	1%
11			Level	[%]	65	68	5%
12			Temperature	[°C]	5.6	5.5	2%
13		AP evap	Inlet temp	[°C]	5.6	5.5	2%
14			Inlet flow	[l/s]	260	258	1%
15			Outlet temp	[°C]	2	1.9	5%
16			Outlet flow	[l/s]	260	258	1%
17			Cooling duty	[kW]	3 918	3 888	1%
18			Compressor power	[kW]	1 500	1 465	2%
19		Chilled dam	Inlet/outlet flow	[l/s]	145	143	1%
20			Level	[%]	66	67	2%
21			Temperature	[°C]	2.1	2.2	5%
22	Underground	20L chilled dam	Inlet/outlet flow	[l/s]	145	143	1%
23			Level	[%]	66	64	3%
24			Temperature	[°C]	6.2	5.9	5%
27		39L	Flow	[l/s]	80	79	1%
28			Temperature	[°C]	10.2	10.1	1%
29			Pressure	[kPa]	1 750	1 730	1%
30		40L	Flow	[l/s]	65	64	2%
31			Temperature	[°C]	10.5	10.3	2%
32			Pressure	[kPa]	1 650	1 630	1%

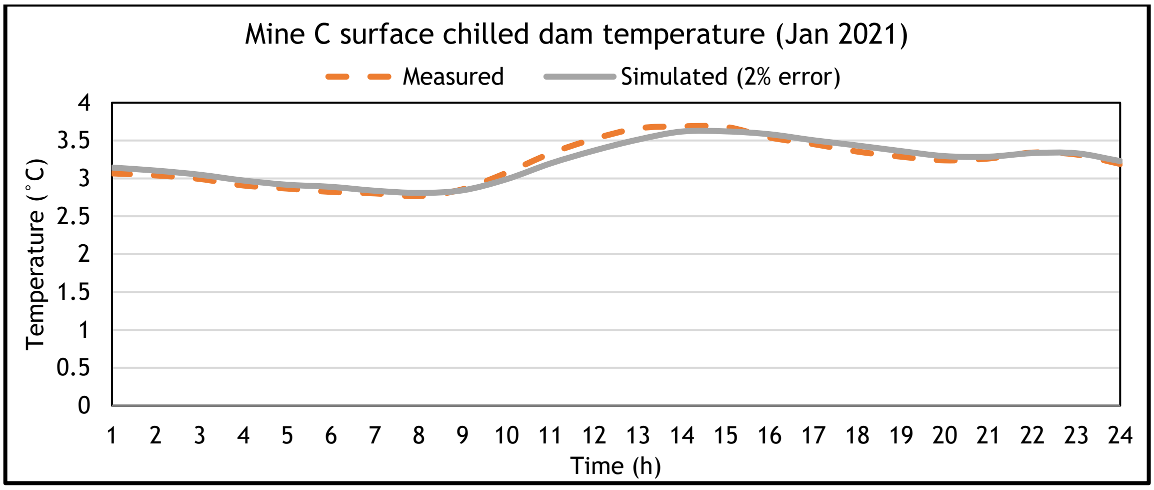

Figure 8: Simulated vs actual Mine C surface chilled dam temperature

3.4 Application

The case study considers the closure of Mine B in 2022. The care and maintenance costs of keeping Mine B operational to ensure chilled water supply to Mine A is significant (approximately R70 million per annum). Therefore, it is beneficial for long-term planning to consider an alternative solution to supply Mine A with chilled water.

In order to successfully close Mine B, underground water temperatures should not be affected. Therefore, two key underground temperatures had to be considered for a successful solution.

The two key performance indicators (KPIs) were:

1. Mine C 40L chilled water temperature, and
2. Mine A 23L chilled dam temperature.

The requirements were set at 11°C and 12°C, respectively, shown in Figure 9 as an orange and blue box. The underground water flows were also considered, and the solution had to meet current demands with a 10% safety factor. The requirements are summarised in Figure 9.

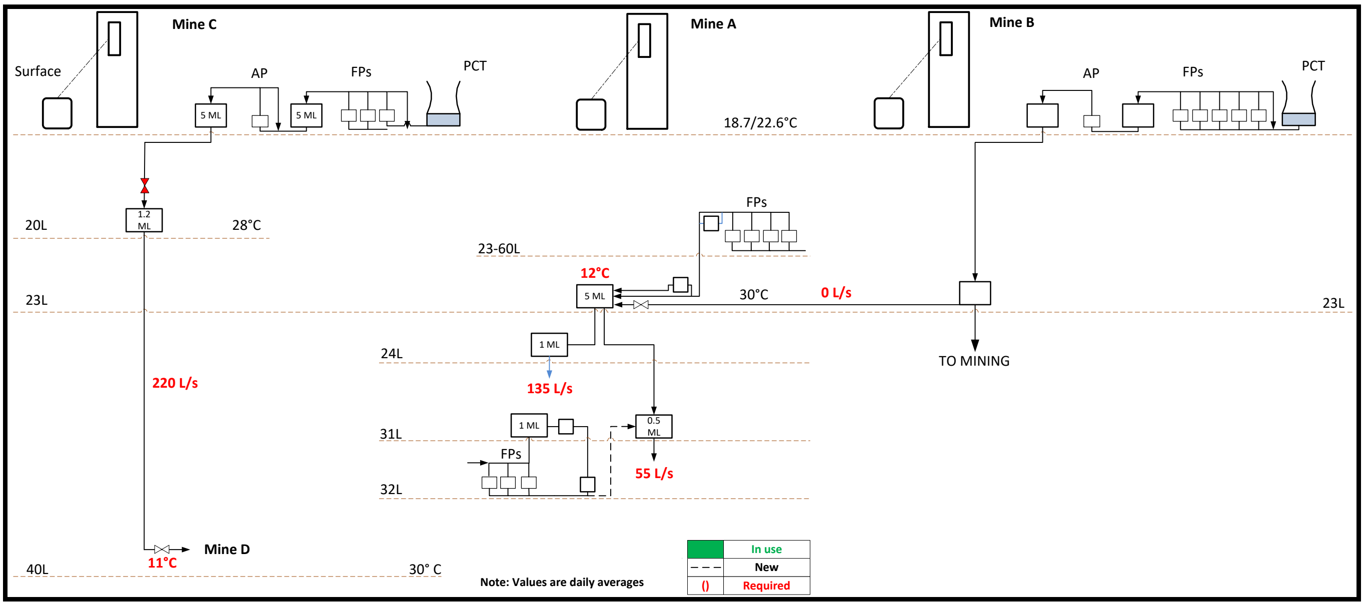

Figure 9: Mine B's closure requirements

The simulation tool was then used to investigate several solutions to close Mine B and meet the requirements. The solutions each considered a system change which effected underground temperatures. More than 50 possible solutions (system changes) were evaluated. However, for simplification purposes, only six are considered in this study. The system change areas are shown in grey on Figure 10 and their impact on the two KPIs are summarised in Table 2.

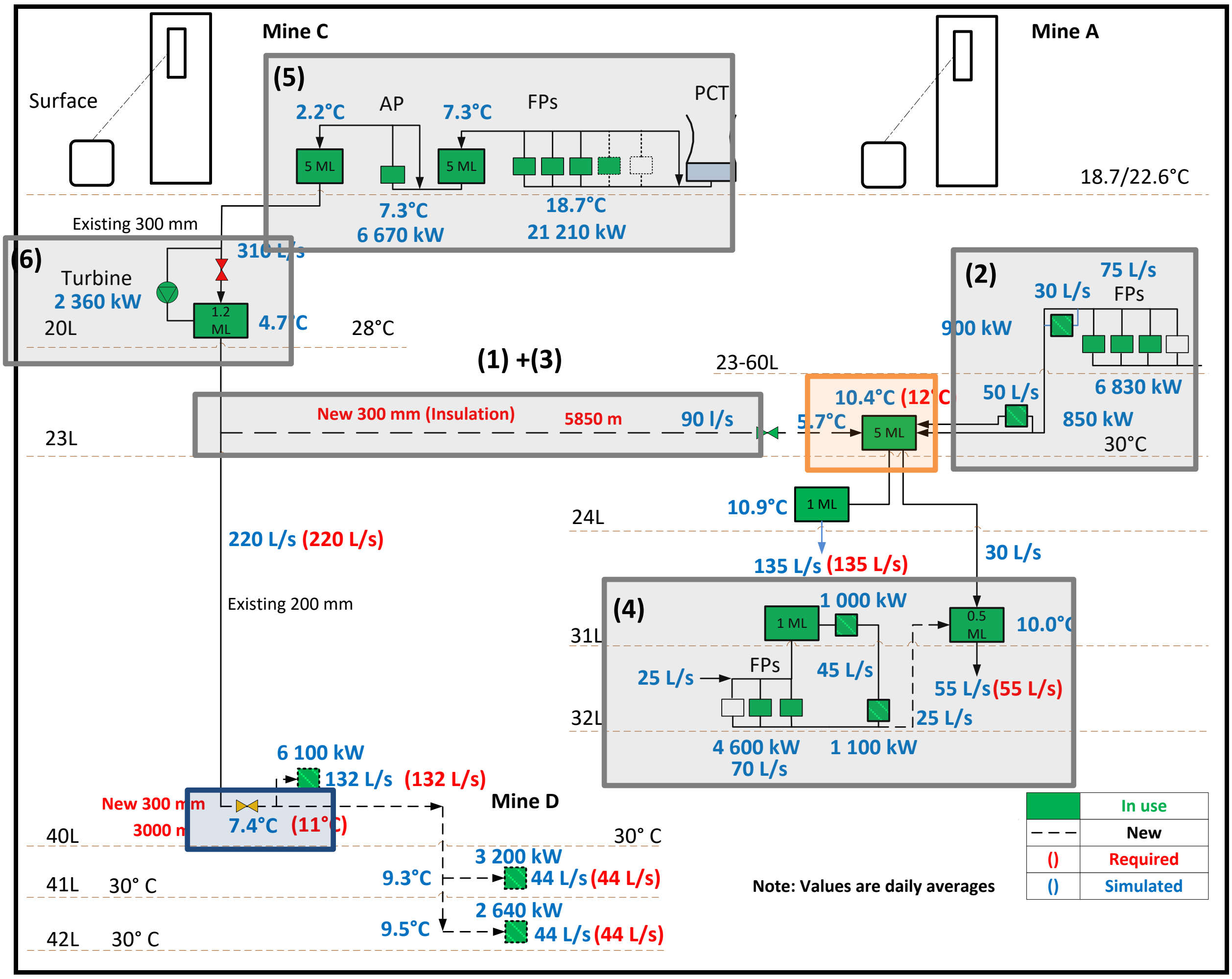

Figure 10: Combination of Mine B closure solutions

The iterative approach led to a combination of several possible solutions to maintain Mine A's chilled water supply. Each subsequent solution includes the previous solution and therefore is a combination of the current solution and all previous solutions. Solution 5 (i.e., Solution 1 – 5 in combination) met the criteria without the use of a water turbine as it was part of the scope not to rely on a single piece of machinery to achieve chilled water temperatures. However, the addition of the water turbine further reduces underground water temperatures and generates power.

Table 2: Integration scenario results

Solution #	Mine C FP supply	Mine A FP supply	Configuration	KPI 1	KPI 2
-	[L/s]	[L/s]	-	[°C]	[°C]
1	350	60	New mine C to mine A 23L column	13.2	13.8
2	320	90	Soln 1 + 3x mine A 23-60L FP	12.1	13.4
3	320	90	Soln 1 + 2 + insulated mine C - mine A column	12.1	12.9
4	310	100	Soln 1 + 2 + 3 + integrate mine A 32L FPs	11.8	12.5
5	310	100	Soln 1 + 2 + 3 + 4 + move 2x mine B FPs to mine C	9.3	11.5
6	310	100	Soln 1 + 2 + 3 + 4 + 5 + mine C 20L turbine	7.4	10.4

The final results for the two key requirements areas are shown in Figure 11 which clearly indicates that the mine's requirements were met and exceeded. The average daily temperature of 23L chilled dam and 40L chilled water was 0.4°C and 1.4°C below their temperature requirements of 12°C and 11°C, respectively.

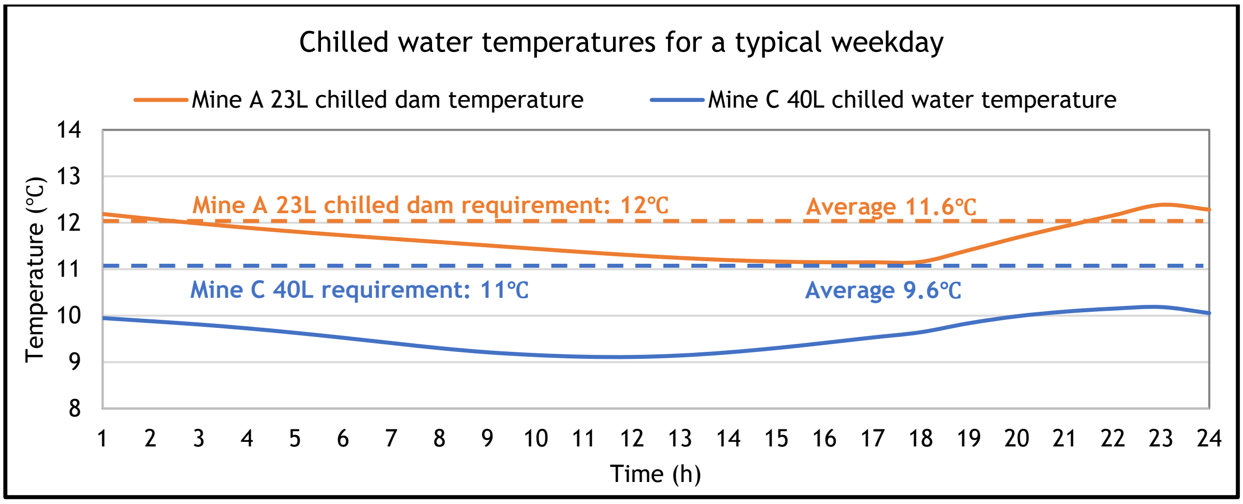

Figure 11: Mine A 23L chilled dam and Mine C 40L chilled water temperatures

The feasibility of the project was then considered using several factors, most important of which was the cost and LOM benefit. The project costs to completely close Mine B amounted to R97 million, broken down in Table 3.

Table 3: Total cost required to close Mine B

No.	Description	Cost
1	Mine C surface FP critical spares	R14 640 000
2	Moving 2x mine B FPs to mine C	R45 580 000
3	Mine C - mine A underground column	R26 820 000
4	Mine A - mine C overland column	R9 450 000
	Total	**R96 490 000**

The cost to implement Solution 5 was then compared to the estimated cost savings of closing Mine B (Table 5). This was done by estimating the cost of care and maintenance of Mine B if it were to remain open to supply chilled water to Mine A. The total cost savings per year from care and maintenance costs was calculated at approximately R73 million.

Table 4: LOM benefit from Mine B closure

No.	Description	Cost [R/yr]
1	Payroll 1	R18 600 000
2	Payroll 2	R10 200 000
3	Contractors	R7 700 000
4	Water	R320 000
5	Stores	R24 600 000
6	Electrical energy	R11 200 000
Yearly cost saving (2020 tariffs)		**R72 620 000**
LOM net benefit (16 years at 5% inflation)		**R2 413 100 000**

The calculated total LOM benefit over 16 years amounts to R2.4 billion, including inflation. The significant cost savings over the 16-year period assists in the decision-making process.

The method discussed can be used for several applications similar to the one described. The tool can be used for future ventilation planning, water and cooling planning, and compressed air planning. The method provides a prediction of the future operating conditions (including temperatures, flows, dam levels etc.) based on inputs such as mining locations, tons ore planned and shaft closure. The tool can also be used for safety and redundancy applications where equipment can be simulated to fail at certain times of the day and the effect seen.

The method, however, does not determine the future mine planning in terms of geological features, ore reserves and financial planning. These are inputs to the method. The method focuses on the thermohydraulic effects of adding or removing load on the system and changing operating conditions.

4 CONCLUSION

This paper discussed a process to successfully create a dynamic and integrated simulation of a deep-level mine cooling system. The process was then applied to a three-shaft integrated mining complex with over 2 000 integrated cooling components. Several dynamic boundaries were quantified and applied to the simulation. The model was then verified to within 95% of the actual system to create a near exact model of the water- and cooling system.

The simulation was then applied for decision-making regarding the future planning of a three-shaft mining complex. A critical cooling supply shaft is approaching its end of LOM and the effective closure of the shaft could result in a significant benefit over the entire future LOM.

The use of modelling helped generate several possible solutions for the successful closure of Mine B. The process, and resulting digital twin, produced a final solution suggesting R97 million expenditure in new infrastructure at current shafts to achieve a grand total LOM benefit of R2.4 billion.

The method accurately predicted future temperatures, flows and system performance. The predicted results were used to determine the best course of action for future planning using simulation. The accuracy and flexibility to test several solutions is not possible with current methods. Therefore, the developed is a powerful tool for mine services planning and determining significant cost benefits whilst ensuring sufficient supply for safe mining.

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DEVELOPMENT OF STRATEGIES TO IMPROVE IMPACT OF OPERATIONAL EXCELLENCE PROGRAM AT FMCG MANUFACTURING COMPANY IN SPRINGS SOUTH AFRICA

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ABSTRACT

In manufacturing companies, there is a massive demand for productivity improvement using Operational Excellence (OE) methodology. Other factors namely, process rejects, and equipment failures contribute to poor efficiencies. In addition, the lack of suitable maintenance strategies is another crucial factor in equipment failures and frequent shortstops in operations. Pareto analysis of line 1 and 5 revealed the top three equipment contributors to breakdowns. A team-based failure mode effect and analysis (FMEA) was adopted to rate the failure modes and effects of critical equipment. A risk priority number (RPN) was calculated, and suitable strategies were assigned. The suitable maintenance strategies revealed corrective, preventative and predictive methods to reduce breakdowns. In summary, lack of innovations, maintenance strategies, and spares contributed to the ineffectiveness of the program and poor efficiencies. A maintenance strategy framework that included operational excellence methodologies was recommended to address the impact of the program and improve overall equipment effectiveness.

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1 INTRODUCTION

Globalisation has exerted excessive pressure for companies in both developing and developed countries to compete and survive, [1]. Companies are compelled to react rapidly by investing in innovative systems, technology and people in order to survive the challenges brought about by globalisation.

The 2008 global economic crisis negatively affected sales in the alcoholic beverages industry leading industries to adopt innovative systems and technologies, [2,3]. Numerous global firms resorted to technological means in adopting best practices from operational excellence in their manufacturing processes from end-to-end, [4]. Operational excellence (OE) became a reliable philosophy in the workplace where problem solving, teamwork and leadership result in on-going improvement, [1]. Nolan and Anderson [5], define OE as the ability of an organisation to achieve and sustain leading performance in reliability and efficiency while adhering to the highest standards of safety, health and environmental stewardship in cost-effectively and profitably.

Overall Equipment Effectiveness (OEE) is a technique that measures the overall effectiveness of the equipment that enables the evaluation of the nature of the production process to the level of product quality, [6]. Araujo and Castro [7], define OEE as a metric that measures the effective management of manufacturing operations. Esa and Yusof [8], further state that OEE has the capability of creating the culture of excellence in the organisation. OEE measures and distinguishes three components of an operation such as maintenance, quality and production effectiveness, [9], and the formula is:

[OEE = Availability x Performance efficiency x Quality rate] *(1)*

where:

Availability rate = Operating time (h)/Loading time (h)

Performance efficiency = Theoretical cycle time (h) x Actual output (units)/ Operating time (h)

Quality rate = [Total production (units) – Defect amount (units)/Total production (units)]

In 2016 FMCG company in Springs adopted the OE program on their production lines with the aim of improving OEE. Despite efforts and energies invested in performance of production line 1 and 5 has fallen significantly short of the OE program expectations, with both lines performing below 50% in Overall Equipment Effectiveness (OEE) and Machine Efficiency (ME). The expectations of the OE program were to achieve 70% OEE and ME for line 1 and 5 in a period of 18 months from the initiation of the program. Figure 1 and 2 depict the Overall Equipment Effectiveness of production line 1 and 5 in a period of twelve months.

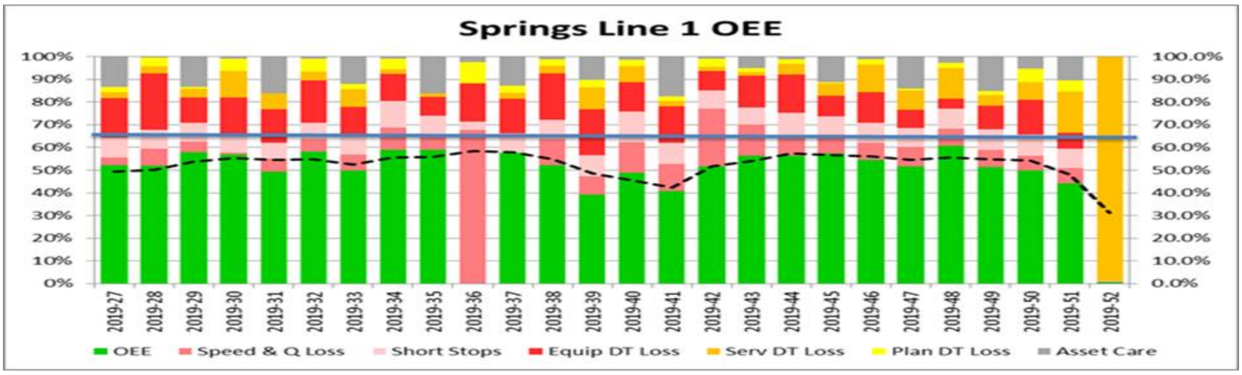


Figure 1: Production line 1 OEE

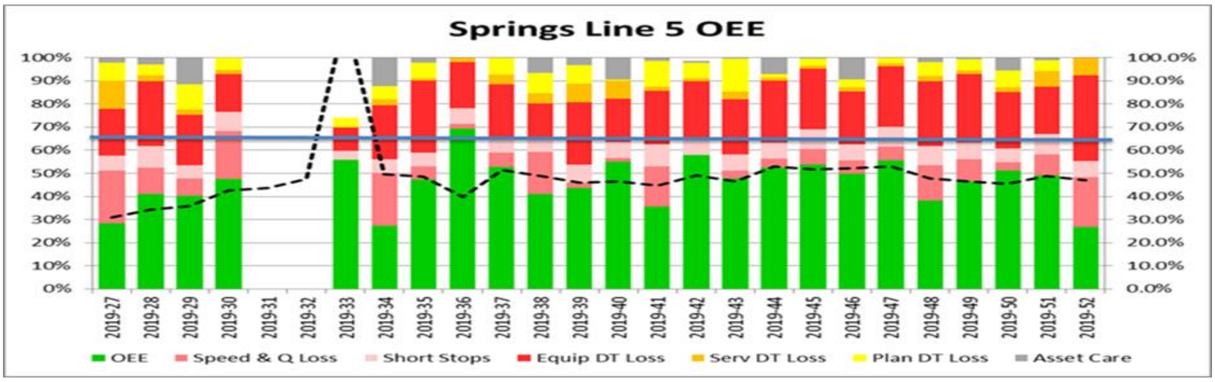


Figure 2: Production line 5 OEE

The research study purposed to provide a critical analysis of the OE program at the case study company's production line 1 and 5, by examining the practical factors that contributed to their ineffectiveness in operational productivity, and further develop a framework to assist in the identified challenges for sustainability assurance.

1.1 Research Objective

In addressing the research aim of the study, the following research objectives were outlined:

- Assessing the factors contributing to ineffectiveness of OE program in line 1 and 5 manufacturing process.
- Establishing the root causes of breakdowns in line 1 and 5 manufacturing processes.
- Developing maintenance strategies to reduce downtime in line 1 and 5 manufacturing processes.

1.2 Research Questions

The above research objectives were translated into to the research questions, which are:

- What are factors contributing to ineffectiveness of OE program in line 1 and 5 manufacturing process?
- What are the root causes of breakdowns in line 1 and 5 manufacturing processes?
- What are maintenance strategies to reduce downtimes in line 1 and 5 manufacturing processes?

1.3 Significance the Study

Implementing Operational Excellence (OE) program in production lines was to improve productivity, reduce breakdowns, eliminate costs and increase equipment uptime. It was also to ensure a clean and safe production environment, encourage teamwork, visualize problems, and enable quick problem solving.

2 LITERATURE REVIEW

The first part of this chapter critically studied in detail various theories of Operational Excellence and their applications from other researchers by examining the various Operational Excellence definitions and methodologies in multiple organisations. The second part explored Overall Equipment Effectiveness (OEE) measurement and calculation. Subsequently, this part also reviewed in detail types of machine breakdowns and machine life cycle. The root causes of machine breakdowns were explored.

The third part reviewed maintenance management, available maintenance strategies and modern maintenance strategies. Failure Mode Effect and Analysis was explored as a tool for selecting suitable maintenance strategies.

2.1 Operational Excellence defined

Operational Excellence (OE) was defined differently by various researchers based on the nature of their research suitable for their organisations for short and long-term benefits, [7,8,9,10,11]. Baxter [13], argued that Operational Excellence remained comprehensive than a single definition; hence it should be communicated, discussed, measured and lived in order to achieve benefits. According to Hohmann [14] and Ozumba [15], Operational Excellence is a management philosophy of leadership, teamwork and problem-solving.

Leadership Consultants at BearingPoint, Lucker and de Pree [16], describe Operational Excellence as a method and philosophy aimed at speeding up and improving processes, resulting in higher customer satisfaction and lower costs.

Ohtonen [17], illustrated Operations Excellence as the 'elements of strategy deployment, performance management, high performance work teams and process excellence'. Companies that invest in people through empowerment benefit in high performing culture and effective teamwork. Strategy deployment entails that organisations should define their strategic goals first before looking into implementing the program, [18]. Sheahadeh *et al*. [1] and Hohmann [14] shared the same sentiments by emphasizing that leaders need to formulate strategies, plans and vision through motivating, stimulating, and encouraging employees. The successful implementation of Operational Excellence depended greatly on the commitment of the leadership. The effectiveness of leadership was described as systems-based and enterprise-wide rather than individual-based in order to achieve and sustain Operational Excellence, [19].

The Canadian Steel manufacturer struggled to stay in business due to global competitions for many years. To turn things around, the company decided to revamp its own business goals, [19]. The strategy of Operational Excellence methodologies was successful in such a way that the company became the most profitable company in North America in 1999 and rated the best company to work for in Canada by Business Magazine.

2.2 Overall Equipment Effectiveness (OEE) performance indicator

In the late 1990s, the effectiveness of Total Productive Maintenance (TPM) was measured with OEE, however, current changes have brought OEE to measure the actual performance of production in companies, [20]. Hence, the case study company uses OEE to measure performance and the effectiveness of operational excellence program. Singh *et al*. [21], defined OEE as the ratio of how much of a product or part is being produced free of defects versus how much could be produced according to the equipment design capacity.

For a world-class performance an overall 85% OEE is a benchmark, and a long road of improving processes and eliminating downtimes, [22]. An OEE of 40% is considered low and presents opportunities for continuous improvements. According to Niazi [23], there are six big losses in any equipment; that are due to ineffective maintenance:

- Shutdowns. These are losses due to unplanned stoppages, such as breakdowns.
- Set up and adjustments. Losses due to changing tools, fixtures or adjusting speeds.
- Reduced speed. Losses due to reducing speed of the machine and increasing cycle times.
- Quality. Defective work, scrap or rejects generated by the process
- Start-up rejects. Defective works scrap or reject during the start-up of the process.

According to Andrews [40], OEE can be a flawed manufacturing metric as it does not provide the 'why' if problem occurs. OEE measures and analyses the three measures (performance, availably and quality) separately, and factory performance at a slower rate means low performance. High rejects produced affect quality rate and breakdowns, unplanned stoppages and short stoppages affects availability rate. One measure can affect the whole OEE as a percentage in the organisation. In this paper, breakdowns and short stoppages were affecting the availability rate which in turn affected the whole OEE of the line.

2.3 Types of breakdowns and machine life cycle

Each equipment breakdown can be classified into four groups of stresses such as thermal, electrical, ambient and mechanical (TEAM). Thermal breakdown is due to heat generated that results in elastic energy density, while electric breakdown is caused by high electric energy and damage in machine electrical components, [24]. Machine has electrical components such as electric cables, power switch, motors, circuit breakers, transformers, distribution boards, pumps and HVAC systems. These electrical components such as circuit boards can stop working if exposed to water. Mamanee *et al.* [25], reported that an increase in ambient temperature ie.100 °C can cause thermal failure mode in equipment. Other factors that can contribute to ambient failures are dirt, grease and sand from poor 5S. Mechanical breakdowns are equipment failures due to inability to undertake maintenance and replace parts, wear, tear explosions and fire. Bialy and Ruzbarsky [26], brainstormed the causes of mechanical breakdown as bad motivation of employees, lack of employee training, small number of employees, improper maintenance, overrunning the machine, irregular inspections, bad quality material and components, insufficient knowledge of machine, not replacing worn parts, machine system errors, ignoring warning sensors and improper operation.

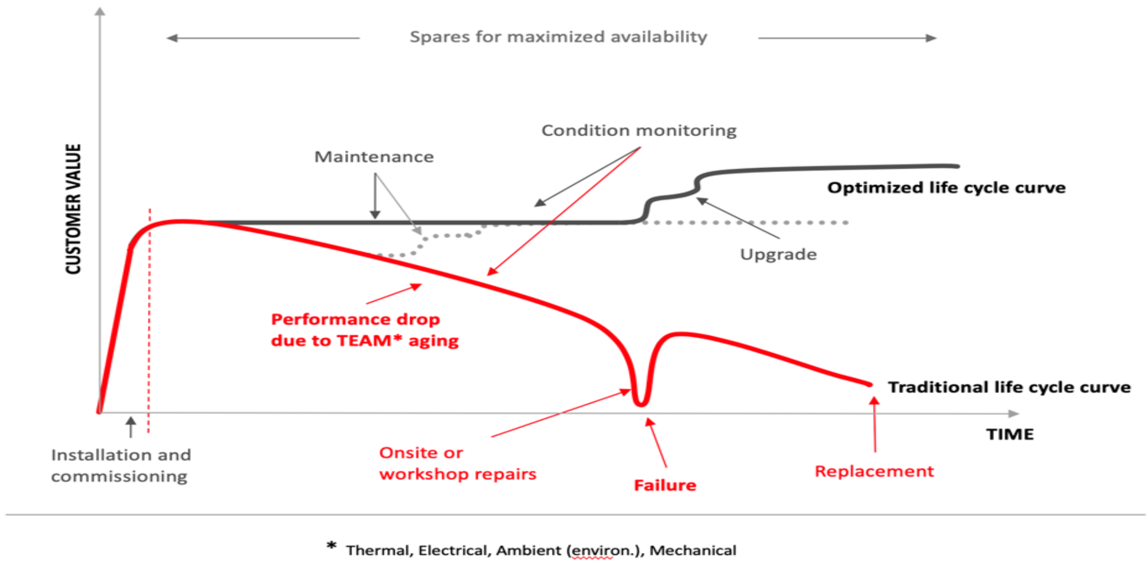


Figure 3: Types of breakdowns and machine life cycle [24]

Figure 3 depicts the life cycle of the equipment and exposure to thermal, electrical, ambient and mechanical failures with or without maintenance. During commissioning, without maintenance in place; machine performance is normal, and the customer value is achieved. As the time progresses, machines start to experience thermal, electrical, ambient and mechanical degradations and eventually fail. With the presence of proper maintenance, the design standard of the machine can be improved and maintained while satisfying customers.

2.4 Maintenance management and strategies

The existence of various maintenance functions requires maintenance management and a suitable strategy based on industry specific goals. Mkalaf [27], listed maintenance management goals, such as:

- Maintenance extends equipment lifetime by repairing damages and replacing missing parts, thus increasing the mean time to the next failure.

- Improving the equipment and system reliability, improving health and safety which will impact better quality and higher profits, reducing maintenance costs and frequent service stoppages.

Dhingra [28], described maintenance strategies as the systematic approach of keeping processes and equipment in an acceptable condition by identifying faults, fixing repair and replacing damaged parts. According to Mkalaf [27], maintenance strategies fall under two categories. The first category refers to unplanned maintenance activities such as fixing breakdowns. The second category includes planned activities, such as proactive and reactive maintenance. Trojan and Marcal [29], classified maintenance into preventative, and corrective. Under corrective maintenance machines are operated until failure, then corrective maintenance activities are performed to fix the machines. Preventative maintenance involves investigating declining behaviour of critical equipment and stopping and resolving the error before a severe breakdown takes place, [30].

The suitable strategy should meet the individual equipment's needs and focuses on the past performance, production target and maintenance budget. There are three critical factors (maintenance key performance indicators, resources definition and alignment with production and overall organisation strategic goals) that should be considered when selecting maintenance strategy, [42]. Due to the unprecedented degree of changes in management approaches, technology, techniques, market, products and customer demands, companies tend to investigate advanced technologies and approaches in the maintenance field. The third industrial revolution (Industry 3.0) was mostly associated with automation, electronics and the expansion of information technology. Three modern strategies came about during the Industry 3.0 were Total Productive Maintenance (TPM), Reliability Centred Maintenance (RCM) and Outsourcing, [40].

A study done by Gupta and Garg [31], showed that successful implementation of TPM could improve Overall Equipment effectiveness of a Broaching machine by 11.26%. Shiftily improvements were recorded on operating time, availability, output, expected output, efficiency, number of rejects and quality. Table 1 presents the result of a machine in 450 minutes per shift.

Table 1: Improvement in OEE using TPM [30]

Before TPM			After TPM		
A	Shift Time	450	A	Shift Time	450
B	Planned Downtime	60	B	Planned Downtime	60
C	Running Time (A-B)	390	C	Running Time (A-B)	390
D	Running Time Loss	78	D	Running Time Loss	58
E	Operating Time (C-D)	312	E	Operating Time (C-D)	332
F	Availability (E/C) X 100	80.00%	F	Availability (E/C) X 100	85.10%
G	Output	180	G	Output	207
H	Machine Speed	0.75	H	Machine Speed	0.75
I	Expected Output (H X E)	234	I	Expected Output (H X E)	249
J	Efficiency (G X 100)	76.90%	J	Efficiency (G X 100)	83.10%
K	Rejection	8	K	Rejection	2
L	Quality (G-K X 100)/G	95.50%	L	Quality (G-K X 100)/G	99.00%
	OEE= Availability x Efficiency x Quality	**58.75%**		**OEE= Availability x Efficiency x Quality**	**70.01%**

The above improvement of 11% was achieved by selecting the Broaching machine as the model of TPM. 5S was firstly implemented as the foundation of TPM, followed by autonomous maintenance which involved production and engineering team in maintenance activities. Lastly, education and training and standards were set to sustain the changes.

Reliability Centred Maintenance (RCM) was initially developed for the aircraft industry, and later became available to other industries with the aim of identifying potential problems within the equipment and proposing solutions to ensure maximum production efficiency. Vishnu and Regikumar [32], defined RCM as a method used to select the most appropriate strategy based on criticality score from historical data and reliability measurements of the equipment. Subsequently, the appropriate strategy for the equipment is selected using the Analytical Hierarchy Process (AHP) methodology. Analytical Hierarchy Process (AHP) methodology involves the application of a multiple criteria decision method in a complex situation, whereby a decision is based on the perceptions of the individuals who make the final decision, [33].

Another tool that is referred to as the heart of RCM is Failure Mode Effect and Analysis (FMEA). Puthillath and Sasikumar [34], described FMEA as the tool or methodology intended to identify potential failure modes of equipment or process, to evaluate the risk associated with those failure modes, to rank the issues in terms of importance and to identify and carry out corrective actions to address the most serious concerns. According to Puthillath and Sasikumar [34], combined with criticality analysis can be used to select the best maintenance strategy of the equipment.

The objective of FMEA report is to calculate the Risk Priority Number (RPN) of the component or process. To get the RPN number, the team should brainstorm using Fishbone analysis or 5Whys; rate the severity (S) of each failure, likelihood of occurrence (O) and likelihood of detecting (D) the breakdown before it stops production. The equation is given by, RPN = S x O x D, the higher the RPN, the higher the failure that can be the potential cause of process or equipment unreliability, [34].

In order to achieve the research objectives, FMEA was used in conjunction with surveys to find the suitable maintenance strategies for operations.

3 RESEARCH METHODOLOGY

In order to satisfy the objectives of the study, a primary and secondary data collection was utilised. Manu [35], and Ajayi [36] defined primary data as the original data that has been collected for a specific objective and has not been published, while secondary data may be extracted from literatures, databases and mathematical models of processes. This study used survey, and literature and pareto analysis of top three process failures of the production lines.

Categories making up the survey instrument were: (i) Training and transfer of knowledge and skills, (ii) Employee morale and motivation, (iii) Workplace organisation and conditions, (iv) Quality (Rejects and Rework) and Inspections, (v) Minor Stoppages and Speed losses, (vi) Overall Equipment Effectiveness measurement and calculations and (vii) Maintenance of equipment and breakdowns.

The sampling procedure involves non-probability purposive sampling of all production line 1 and 5 employees due to the OE programs that were implemented in the lines. According to Etikan, Musa and Alkassim [37], purposive sampling also called judgement sampling is an intentional selection of participant due to the attributes the participant possesses. Both management and employees working (line 1 and 5) in different operations participated in the study to provide valuable information instrumental for decision-making. The questionnaire was distributed via handouts and emails to 91 employees of production line 1 and 5. The breakdown of employees were 10 managers, 70 operators, 6 specialists and 5 general workers.

The analysis of data collected during the survey was analysed with IBM Statistical Package for Social Sciences (SPSS) 2016 version 24 for descriptive statistics. SPSS is statistical software developed by IBM Corporation and widely available to researchers for academic purposes, [38]. Descriptive statistics were used to calculate the frequencies, mean, min, max and standard deviation for each question. For a small number of missing cases, the researcher attempted to collect the data from the participants.

Failure Mode Effect and Analysis (FMEA) problem solving methodology on the top downtime process areas was conducted in a group session with engineering personnel, specialists, artisans, process owners and planners. The Risk Priority Number (RPN) was found by rating the severity of each effect of failure, rating the likelihood of each occurrence of failure and rating the likelihood of detecting the problem, [34]. From calculating the RPN, strategies to solve the challenges of company operation efficiencies were brainstormed; the suitable solutions to resolve the encountered challenges within the production were selected. Puthillath and Sasikumar [34], described the criteria for selecting the suitable maintenance strategies from calculating RPN as shown in Table 2.

Table 2: Criteria for suitable maintenance strategies [34]

Rank	Maintenance Strategy	Criteria
1	Predictive Maintenance	RPN>300
2	Preventative Maintenance	200<RPN<300
3	Corrective Maintenance	RPN<200

Preventative maintenance - This maintenance is conducted every two weeks with schedules generated by the computerized system.
Predictive maintenance - This is a Condition Based Maintenance (CBM). Prediction is performed using special predictive equipment (temperature, pressure, vibration etc.); statistical process controls and human senses (smell, taste, hear, touch and see). Such maintenance would require the company to invest in installing these predictive tools in the equipment.
Corrective maintenance - This should be allocated for minor failures that allows production to run and can be fixed quicker.

4 RESULTS

The results were presented in two sections. Section 4.1 presented on the quantitative results and section 4.2 presented on FMEA report.

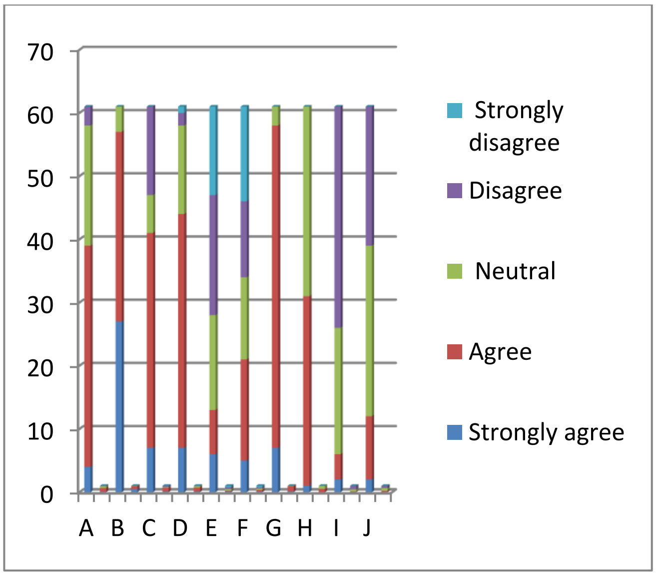
4.1 Quantitative results

Eighty-five (85) questionnaires were distributed to participants at Distell using printed copies and an email system. Out of 85 questionnaires, 63 responded. 61 were accepted while 2 came with incomplete information. Fincham [39], formulated the response rate as (captured + rejected) total distributed x 100%, which is the ratio of the number of usable responses to the number of eligible participants in the sample: (61+1)/85 x 100% = 74.1%. Valid response rate was 61/63 x 100% = 96.8%. The good response rate was based on the researcher following up on the participants during team meetings.

Table 3 shows demographic information of participants for both lines.

Table 3: Demographic information

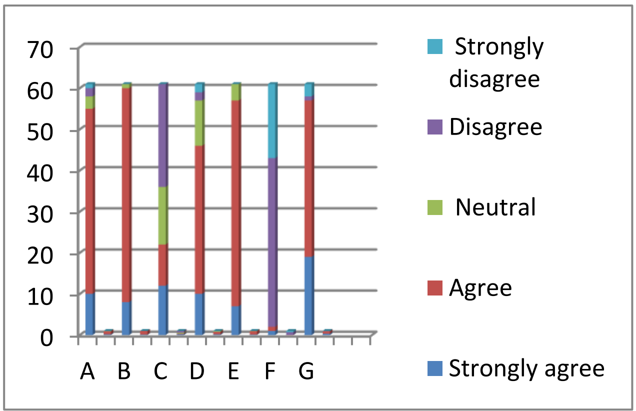
Gender	Frequency	% contribution
Female	7	11.5%
Male	54	88.5%
Age Range	**Frequency**	**% contribution**
20-29	15	24.6%
30-39	37	60.7%
40-49	7	11.5%
50-59	2	3.3%
60+	0	0.0%
Work experience	**Frequency**	**% Contribution**
Less than 3 years	19	31.1%
4yrs- 7yrs	33	54.1%
8yrs-11yrs	5	8.2%
more than 11 years	4	6.6%
Department	**Frequency**	**% Contribution**
Packaging	61	100.0%
Total	61	100.0%
Education level	**Frequency**	**% Contribution**
Grade 12	49	80.3%
Grade 12 plus trade test	7	11.5%
National Diploma	4	6.6%
Degree	1	1.6%
Honours Degree+	0	0.0%



Legends	Code
Employees are well trained on all practices	A
Employees were trained on 5S (Sort, set in order, Shine, Standardise and Sustain)	B
Employee knows about productivity	C
Employees have production process knowledge	D
Employee/Operators understand the plan to achieve the target production	E
Employees are familiar with OEE of the machine	F
Employees are well trained on SOP	G
Company offers operators to improve skills	H
Training on OEE improve manufacturing productivity	I
Operators understand 5S	J

Figure 4: Responses about Training and Transfer of Knowledge in the company

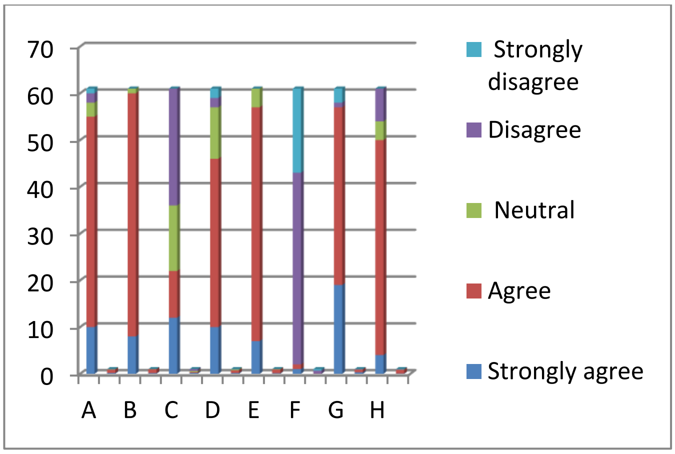
Figure 4 shows that more than 60% of participants were trained on practices, including 5S and standard operating procedures, however,44% did not understand the implementation. The 57% participants were not trained on OEE and six big losses affecting it.



Legends	Code
Employees are remunerated on time	A
Employees are motivated to do more	B
Incentives are paid to employees for meeting targets	C
Employee's absenteeism are low	D
Suggestion boxes are provided to employees	E
Protecting equipment is supplied to all employees	F
Employees work overtime from time to time	G

Figure 5: Employee morale and motivation

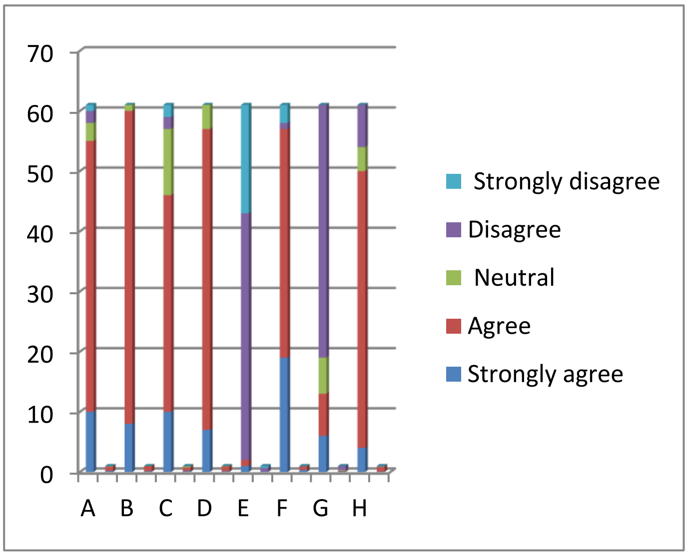
Figure 5 shows that employees were remunerated well, and that overtime was available, However, suggestion boxes where employees suggest ideas and improvements were not applicable. Suggestion box is the system that is normal implemented by companies to motivate employees by involving them in improvements of the business.



Legends	Code
Working conditions are acceptable	A
Working floor space allows movement	B
Working area is clean and organized	C
Safety procedure are followed in the manufacturing process	D
Plant demarcations are clear	E
Waste is identified and eliminated	F
Operating tools are available to all employees	G
Operating procedures are adhered to	H

Figure 6: Workplace organisation and conditions

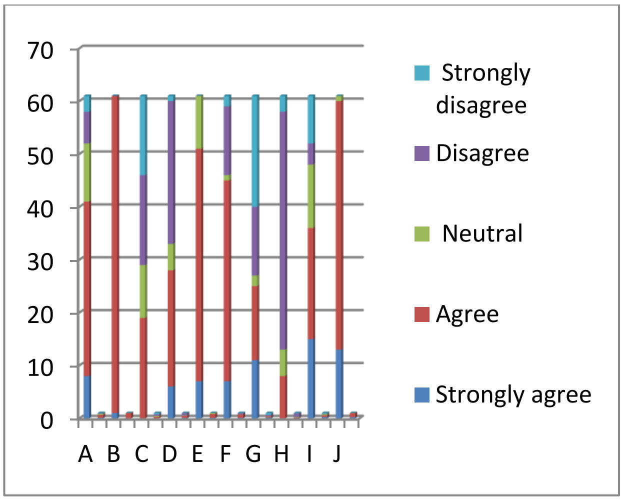
Figure 6 depicts that working conditions were acceptable and procedures were followed by employees.



Legends	Code
Inspection of incoming material is conducted	
In process inspection is conducted	
Final product is checked and tested	
Scrap generated in the manufacturing process is low	
Reworking is low	
Test certificates are attached to delivery final product	
Waste generated in manufacturing process is low	
Final product is delivered on time	

Figure 7: Quality (rejects and rework) and inspections

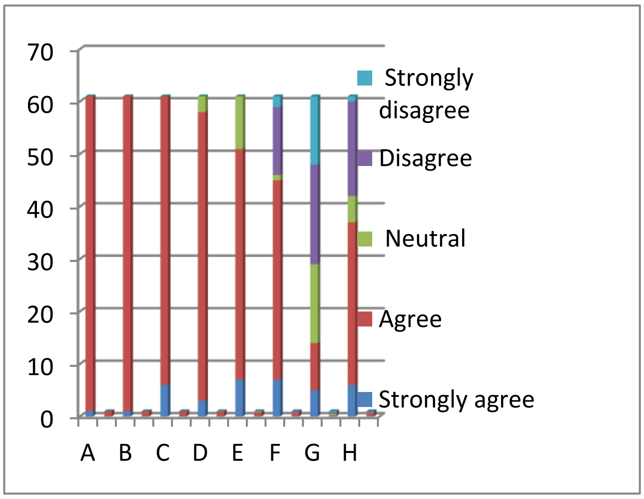
Figure 7 depicts that quality of incoming material was not an issue, however, reworks on the lines were high. Rework does not mean the product is thrown in the bin; however, resources are wasted in correcting the errors.



Legends	Code
Production line is running at a rated design speed	A
There are minor stoppages of less than 2 minutes in the line	B
Minor stoppages are as the result of skills shortages	C
Speed loss are due to v-profiles imbalance	D
Bottlenecks in the system are there	E
Minor stoppages include bottle breakages	F
Minor stoppages are due to inferior material or contamination	G
Material is produced within provided time	H
Raw material is delivered on time (dry goods)	I
Production line is fully automated from end to end (no human intervention)	J

Figure 8: Minor stoppages and speed losses

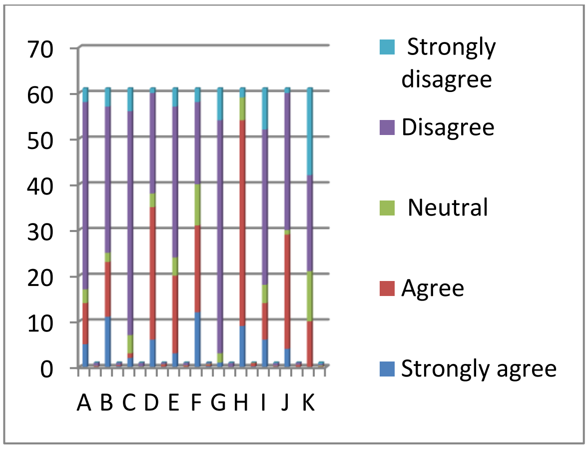
Figure 8 shows that minor stoppages were present in both lines as almost all participants (more than 90%) agreed that the two lines were suffering from short stops. Participants also agreed that minor stoppages could be due to inferior material and contamination. Both lines are fully automated, with no human intervention.



Legends	Code
OEE Calculation are carried out per hour	A
OEE is an important management tool for productivity, Quality and Maintenance	B
Use of OEE is critical to performance of operations	C
Regular measurement and monitoring of OEE	D
Focused improvement discusses root causes	E
OEE identify opportunity for improvement	F
Employees understand six major losses of OEE	G
Continuous improvement meetings are conducted	H

Figure 9: Overall Equipment Effectiveness calculation and measurements

Figure 9 reveals that OEE was calculated (99%) and was an important productivity measure, however employees did not understand six big losses.



Legends	Codes
Machine breakdown are low	A
Preventative maintenance is conducted in manufacturing process	B
Spares are available to repair the machine	C
Latest technology is employed in the manufacturing process	D
Machine breakdown is attended on time	E
Maintenance costs are minimised	F
Total productive maintenance is practiced in manufacturing process	G
Planned maintenance are carried out	H
Cost in manufacturing process is minimised	I
Change overs are minimal	J
Production set targets are met	K

Figure 10: Maintenance of equipment and breakdowns

Figure 10 shows that machine breakdowns were high (67.2%) and preventative maintenance was not conducted in reducing breakdowns (52.5%). The other issue was the spares were not available when machines break down (80.2%). Total productive maintenance was not part of the practice in the company (83.6%). The lines had multiple changeovers and production targets were not achieved.

4.2 FMEA results and discussions

The analysis report for critical equipment in the selected processes of line 1 and 5 as per the pareto analysis revealed critical process areas as the Labeller, Filler, Tray packer and Conveyor System.

Maintenance strategies were based on the criticality of equipment. It was studying what would happen should the failure occur, what is the impact in production? Does the equipment give an alert prior to failure? What causes the failure? How long will it take to fix? Some failures such as the breakdown of labeller station cannot entirely stop the line, therefore regarded as minor breakdown. However, failures such as convey derailing at any point, can stop the whole production as no movement will happen. Other failures that contribute to underfills can run the line at a reduced quality and production rate. Maintenance strategies that were derived from FMEA and deemed suitable in reducing breakdowns and achieving the required OEE in the critical process areas were the combination of preventative, predictive and corrective maintenance strategies. In the order of criticality, the following combinations were obtained:

- **Filler machine:** predictive, preventative and corrective maintenance strategies. This meant that the filler machine has critical processing areas that could stop the entire line should they broke. Hence, the two strategies came the highest.
- **Labeller:** preventative, predictive and corrective maintenance strategies. The labeller has some critical areas, however not as critical as the filler machine. However, the availability of spares could be an issue that prolongs a downtime.
- **Conveyor system:** predictive and preventative maintenance strategies. Conveyor system were found to be critical in such a point that a breakdown could stop the entire line completely.
- **Tray packer:** preventative and corrective maintenance strategies. This area contributed a lot into material wastages if it breaks down. Hence, preventative and corrective were derived to be fit for this machine.

4.3 Maintenance strategies framework to improve OEE in FMCG lines

Figure 11 depicts the process that starts by defining the maintenance key performance indicators and objectives, select critical equipment, conduct and FMEA, intervene with strategies, allocate resources, execute and control, measure trends, apply Operational Excellence methodology tools and achieve the objectives. 5S is aimed to keep the workplace and equipment in conditions, visual management (VM) is aimed to visualise KPIs and improvement, asset care (AC) is aimed at spare parts management. In addition, the model included modern strategy TPM which aimed to involve production operators in executing basic maintenance tasks.

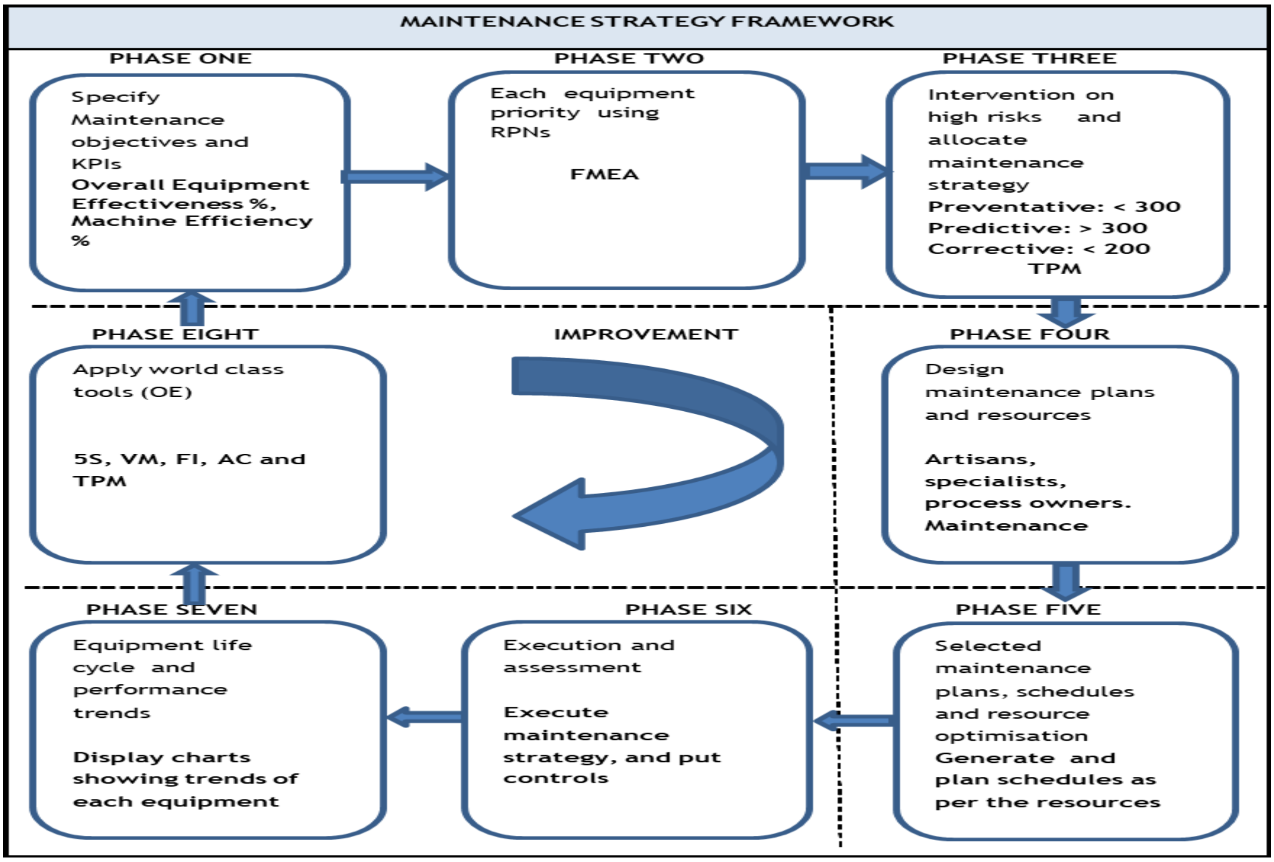


Figure 11: Maintenance strategies framework

5 CONCLUSIONS

This concluded the research that was conducted on production line 1 and 5. Research objectives were revisited and evaluated based on theories and participants' responses. Recommendations provided were based on the findings from both lines and could be used as a framework for future roll out in other areas within the company.

From the survey results, factors contributing to ineffectiveness of the program were summarised leadership failing to provide incentives as a form of motivation and encouraging innovations from employees. Root causes of breakdowns were attributed to improper maintenance, bad quality material, components and machine system errors. Machine system errors can be electrical failures and causes frequent short stoppages. Improper maintenance can influence mechanical failures due to faulty and broken parts that could not be addressed. Broken bottles can be caused by thermal temperature and pressure which could break bottles. Other factors revealed lack of TPM, issue of spares and delay in resolving breakdowns. Therefore, it was evident that not rolling out TPM contributed to breakdown, as TPM is a proven methodology that eliminates six big losses of equipment such as short stops, start-up rejects, breakdowns, set up, speed and quality.

It was recommended that the company employ the service of the best TPM consultant and start training all employees on the pillars and advantages. This could mean rolling it out in one line and record improvements. Another recommendation to reduce downtime was to ensure execution of maintenance activities regularly. With a proper maintenance system, downtimes and short/ minor stops are eliminated; therefore, the recommendation was to adopt suitable maintenance strategies as discussed in section 4.2.1. Developed framework depicted reactive (corrective), preventative predictive and TPM maintenance strategies as suitable to reduce downtime in manufacturing processes. Corrective maintenance was suitable for minor equipment breakdowns. Preventative was a suitable time-based maintenance as regulated by manufacturers of the equipment, and predictive was aimed to predict and prevent failures before manifestation.

To address the problem of spares, the recommendation was to employ Computerised Maintenance Management System (CMMS). CMMS is a standalone maintenance system that deals with assets by keeping historical records of parts used and current critical spares stock levels.

The experimental work was designed to analyse line 1 and 5 operations; the other lines were excluded because of limited experience in Operational Excellence. There is thus further scope for investigative work to be carried out in other areas going forward as the company continues with its Operational Excellence journey.

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INVESTIGATING THE CAUSES OF POOR CUSTOMER EXPERIENCE AT A TELECOMMUNICATIONS PROVIDER IN SOUTH AFRICA USING QUALITATIVE METHODS

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ABSTRACT

This paper reports on a study to determine the causes of the poor customer experiences at a selected telecommunications provider. Poor customer experiences negatively affect the efficient functioning of any telecommunications provider. A Customer Satisfaction Index survey indicated that the Net Promoter Score for customer experiences in the telecoms industry decreased by 17.5%. The study pursued three objectives: to determine the causes of poor customer experiences, to assess current business processes, and to recommend implementing fourth industrial revolution technologies. The study adopted a qualitative research approach, using interviews. Purposeful, non-probability sampling was used to select the sample for the study. Using thematic data analysis, five critical themes, regarding the challenges facing the provider, emerged. The findings revealed various challenges regarding customer queries. The recommendations included the implementation of 4IR tools to improve customer experiences. This paper succeeds in analysing the causes of poor customer experiences and showing the benefits of implementing 4IR tools.

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1 INTRODUCTION

Unsatisfactory customer experiences in the telecommunications (telecoms) industry are among the industry's significant challenges today. McKane [1], states that the 2018 South African Customer Satisfaction Index (SA-CSI) survey of customer perceptions indicates that the Net Promoter Score (NPS) for customer experiences in the telecoms industry decreased from 37.4% in 2017 to 19.9% in 2018. This indicates a significant decrease of 17.5% within a one-year period which cannot be taken lightly or ignored. For this study, the selected telecoms provider will be referred to as Company A. These unsatisfactory customer experiences are also prevalent at Company A. Poor customer experiences refer to the failure of a company to meet customer needs and expectations. Failure to respond to customer queries and complaints regarding company products and services also results in poor customer experiences [2]. Lemon and Verhoef [3] advise that poor customer experiences are directly linked to the social environment in which companies exist.

The telecoms industry is experiencing an increase in competition due to continual technological innovations, various products, and ever-increasing prices; hence, providing excellent customer experiences is one of the critical success factors to combat this competition and remain sustainable. These factors also affect Company A. Good customer experience is a decisive factor for building customer loyalty and retaining customers, especially in a highly competitive industry like the telecoms industry. Poor customer experience leads to the loss of customers to competitors, loss of revenue, negative publicity and a tainted brand image, if the issue of poor customer experience is not urgently addressed.

Currently, there are three main areas of concern regarding poor customer experience which impacts Company A negatively. These are service fulfilment, service assurance and customer account billing. Dicey [2] states that the SA telecoms industry is regarded as one of the most advanced in Africa. Company A was founded in 1991 and provides broadband services such as data hosting, wireless services and landline services. It is South Africa’s number one wireless telecommunications provider and a leading Internet Service Provider (ISP) in the industry. There are four other prominent companies in this industry that compete against each other for the market share. However, these companies are also facing various customer experience challenges regarding the quality of service which they provide. The challenges include poor quality network coverage, network outages, inadequate call centre responses, unsatisfactory turn-around times, billing issues, contract cancellation process issues, staff issues and other customer impacting challenges.

This paper focused on customer experience challenges at Company A, good customer service and its advantages, the status of Company A in SA and lastly the fourth industrial revolution (4IR) and benefits associated with it. The essential contribution of this paper was to investigate the underlying challenges of poor customer experiences at Company A and will also explore how 4IR technologies such as the Internet of Things (IoT) and Artificial Intelligence (AI) can assist to overcome these challenges. As such, this paper will aid Company A to understand and improve its customer experience challenges.

2 PROBLEM INVESTIGATED AND THE RESEARCH OBJECTIVES

2.1. Problem investigated

According to Ngwenya [4] poor customer experiences are bound to be a challenge in the telecoms industry and subsequently Company A, where information moves very quickly, and changes happen unexpectedly. Mckane [1], adds that poor customer experience remains a significant challenge for the telecoms industry. Social media platforms overflow with a significant amounts of complaints regarding poor customer experiences at Company A and other companies in the industry. These challenges include poor network quality in certain areas, especially in the central business districts and townships where there are always network congestion issues.

The latest South African Customer Satisfaction Index study conducted in the mobile telecoms industry indicated a significant decline in the customer service satisfaction [5]. This was mainly due to poor customer experiences. The report indicates that customer satisfaction is at its lowest level since inception and has dropped from 77% to 73% overall. While the network operators have focused more on the infrastructure improvements, customers indicate that poor customer experiences remain a challenge. Some of the challenges include less value for money, poor quality relationships with the network providers, non-adherence to service levels and incompetent handling of their queries, network connection issues, such as dropping calls or being unable to download information, long queues to get through the call centres, long turnaround times to solve technical faults, tedious systems and staff attitude when visiting stores. Some of these challenges have been escalated to ICASA for interventions, when resolutions could not be reached between the customer and the service provider [6].

The challenges of poor customer experiences are detrimental to a company's profitability and sustainability and impacts negatively on customer loyalty and retention.

2.2. Objective of the research

The aim of this paper is to identify and analyse the underlying challenges of poor customer experiences at Company A. The study was conducted to indicate how 4IR technologies can help resolve the challenges of poor customer experiences at Company A. The research objectives of the study were:

a. To determine the causes of poor customer experiences at Company A.
b. To assess whether the current business processes and technology are making any positive impact on customer experiences at Company A.
c. To recommend possible solutions to the current poor customer experiences at Company A.
d. To recommend the implementation of the 4IR technologies to resolve the challenges at Company A.

3 LITERATURE REVIEW

The literature review topics consisted of the customer experience, customer service, the telecoms industry and 4IR. 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. Customer experiences

There are various definitions of customer experience; however, there are similarities in the way customer experience is defined. According to Mayer and Schwager [7] customer experience can be defined as a personal response and perception that customers have to any direct or indirect contact with a company regarding the service of that company. Therefore, customer experience can be viewed as a process that involves the views of customers about service quality and product quality based on their interaction with the company.

According to Morgan and Govender [8] customer experience concerns the entire customer journey, it starts from acquiring the customer and covers all aspects of the journey from marketing to using the product and providing the after service. It is critically important to understand customer needs and to manage customer expectations to instill good customer experience to customers. Company A aims to provide the best possible customer experiences to ensure customer retention.

3.1.2. Customer experience attributes

According to Schwab [9] customer experience attributes can be defined as the competencies, skills and qualities required to provide superior customer experience. The customer experience attributes phase focuses on the interaction between the customer and the service provider. The frontline employees who normally interact with customers in all channels and customer touch points, play a critical role in the interaction between the customer and the service provider. These interaction channels include call centres, online channels such as company websites, emails and social media platforms and walk-in stores. The employees who assist customers in these channels are entrusted to provide adequate and quality service and they are the image of the company they work for.

Another attribute is the quality of the product that is being provided or sold. Product quality is one of the most fundamental market differentiators which customers always look out for. The product should have qualities that have dimensions to meet customer needs. It must have the right features as advertised and must be reliable enough for customers to trust. A combination of good quality service and good quality product results in a good company brand. These two attributes form the basis of customer experience; hence they are critically important for Company A to consider.

3.2. Customer service

Kursunluoglu [10] defines customer service as value adding activities that are related to products or services which are meant to meet customer expectations, provide customer satisfaction and build customer loyalty. Some of the key elements of customer service include professionalism, empathy, attentiveness, responsiveness and product knowledge. These elements are very instrumental during customer engagement and can lead to customer loyalty and superior customer experience. Customer engagement is also very critical in building superior experience using the right channels and having simple and flexible business processes which are convenient to customers.

Good customer service refers to delighting and impressing customers with superior quality interactions and experiences to build customer loyalty [11]. In today's world, customers use various channels to interact with businesses and every channel is expected to provide superior customer experiences, consistently. This process of interaction is commonly referred to as customer engagement. Monferrer, Moliner and Estrada [12] define customer engagement as mechanisms of interacting with customers to create value and enhance relationships between the customer and business. The customer service channels include amongst others, call centres, interactive voice response, store walk-in visits, online shopping through company websites, emails, company applications, and social media platforms such as Facebook, WhatsApp, Twitter and Instagram.

It is fundamentally important when one examines customer service platforms, to also look at the responsiveness and turnaround times of these platforms to customers. Customers demand convenience and quick response service and one of the recommended strategies to achieve quick responses and efficient service is the application of the 4IR tools. Ngwenya [4] also agrees that good customer service is about the quality of service that is rendered to customers. Superior quality service leads to customer satisfaction which in turn leads to good customer experiences. Good customer service also leads to customer retention, which automatically results in gaining competitive advantage and the subsequent higher revenue generation for the company.

3.2.1. Customer satisfaction

Kotler [13] defines customer satisfaction as a customer's response of pleasure of disappointment because of perceived product or service performance or against their needs and expectations. Similarly, Farris [14] defines customer satisfaction as the number of customers, or percentage of customers whose experience with a company, its products and services meet and exceeds customer expectations. Based on the above two definitions, one can conclude that customer satisfaction has something to do with customer feelings, customer experience, customer needs and customer expectations. From a business point of view customer satisfaction is a foundation that influences customers' purchasing decisions, post-purchase behaviour and encouraging positive feedback to both business and other customers. In other words, a satisfied customer becomes a brand ambassador and a promoter of the service provider, hence the importance of good quality product and superior service.

According to Khan [15] there are five criteria for measuring the satisfaction level of customers and their consumption of goods and services. The first criterion is satisfaction which speaks to the customers perception of goods and services received from the provider. The second criterion is the content measure which refers to the features and benefits of the services and goods received. The third criterion is called relived, which refers to the eradication of negative attitude towards the provider's services and replacing with the positive mindset. The fourth measure is novelty which is the excitement and freshness that the services or goods bring to the customer. The last measure of customer satisfaction is called surprise criterion which is basically the excitement and enthusiasm that the service gives the customer.

3.2.2. Customer loyalty

Most researchers seem to concur that there is a positive relationship between customer satisfaction and customer loyalty. In fact, consistent customer satisfaction is a foundation for customer loyalty. Khan [15] defines customer loyalty a feeling of association and identification which a customer has towards a brand. This feeling of association and sense of identity compels the customer to purchase goods or services repeatedly from the same service provider.

According to Saleen and Raja [16] customer loyalty has two dimensions namely, behavioural and attitudinal dimensions. The behavioural loyalty means the customer has the intention to repurchase the goods or services from the same service provider repeatedly. The attitudinal loyalty on the other hand suggests that the customer intends to repurchase and recommend the service provider brand to others using various platforms such as the word of mouth or social media. Customer satisfaction and customer loyalty are a very good foundation for customer great customer experience.

3.2.3. Challenges of customer service

There are various challenges that are facing Company A. These challenges include data product prices, network issues, service response times, billing issues, system outages and general poor quality of service received from the many service channels. These challenges have a huge impact on customer satisfaction and customer experience. Customer service has a direct correlation with customer relationships and customer loyalty, and it is heavily impacted by the challenges mentioned above. Markowitz [17] states that, recently, we have witnessed the "data must fall" campaign, which was targeted at the reduction of the high cost of purchasing mobile data. This campaign originated because of customers being dissatisfied with high data prices in the mobile space. As a result of this campaign and other complaints received, the Competition Commission instructed telecoms service providers to reduce data prices.

According to Rahman [18] customer service is about building and sustaining a strong relationship with customers by understanding evaluating, understanding and satisfying their needs. It is therefore critically important for the telecoms companies to prioritise customer service and ensure timeous resolution to the escalated complaints regarding, billing, network and system related issues. The envisaged resolution of these issues could have many benefits for Company A and the other companies in the industry.

3.3. Overview of telecommunications

Telecommunications can be defined as the exchange and transmission of information between individuals, businesses and societies through electronic means such as voice, data and videos, [19]. The South African (SA) telecoms industry is evolving and transforming from the voice and simple data era to a multiple broadband service industry. Most of the services that are provided by telecoms industry are internet related and require the adoption of the 4IR tools such as online communication channels to provide flexible and convenient customer service that leads to better customer experience. The SA telecoms providers and Company A have realised that customer experience plays a key role as a market differentiator and are starting to pay more attention to it. The telecoms industry is at the core of the South African economy and the mobile telecoms segment has closed the communication gap that existed in South Africa and in the entire African continent since its inception. Company A is an important role-player in this economy. According to [8], by year 2012, the mobile subscriber base was estimated to be around 67 million (multiple SIM cards) customers in the entire country. The market share is split between the four prominent providers in the market.

The South African telecoms sector is a highly competitive market, which is a common trend in an oligopoly market. Oligopoly can be defined as a state of limited competition where there are few suppliers of the service, [20]. The oligopolistic nature of the telecoms market makes it difficult to build customer loyalty and customers can easily move from one service provider to the other and keep their numbers through Mobile Number Portability system. Dicey [2], advises that the market for mobile voice customers is getting matured and saturated and the competition is moving towards data services.

Affordability and customer experience are very central elements of the competition between the service providers. The entire telecoms market is moving towards the 4IR and the IoT is playing a very critical role in facilitating the move. In a panel discussion of the 21st edition of AfricaCom, it was advised that customers have a compelling need to access internet and as more customers are connected to internet there will be more demand for digital services.

3.4. The 4th Industrial Revolution

The 4IR can be defined as the latest innovative technology solution to the global challenges that are facing both businesses and society today. The 4IR technology solution is designed to be more effective, efficient and sustainable using artificial intelligence and innovative technology [21]. The 4IR tools such as the Internet of Things (IoT), Robotics and Artificial Intelligence (AI) are designed to provide business agility, flexibility and efficiencies by applying the correct technology in the right places. The application of the 4IR tools should be holistic to the entire company and linked to customer centricity strategies and customer experience. However, with all the challenges that the telecoms industry is facing, it is questionable if the industry is ready to deal with the demands of advanced internet (5G) and 4IR technology.

3.4.1. Major characteristics and benefits of 4IR

According to Markowitz [17] the 4IR generates intense discussions about digitisation, the IoT, and smart systems. These debates are usually stimulated by the impact that the 4IR innovation technology will have in various sectors such as telecoms, mobile, cloud, social media and big data. There is also a concern about whether the business world is ready to accept, exploit and implement this game changer innovation. According to [22] there is also a growing concern that the focus is more on the technological development and innovation and there is little focus on the impact of the 4IR on the individual human beings and society. However, the telecoms industry is more likely to benefit from the 4IR technology to address some of the challenges and inefficiencies that have a significant adverse impact on customer experience. Markowitz [17] states that the key aspect of the 4IR is the use of machines to perform multiple tasks that were previously performed by humans, which is improving business efficiency and margins.

One of the key benefits of 4IR is office automation which is highly effective in managing time, service, costs and quality of both service and product. Office automation can be defined as computer machinery and software used to digitally create, collect, store, manipulate, and relay office information needed for accomplishing basic tasks [23]. Most of the highly effective companies will adopt 4IR as part of their strategy to provide effective and high-quality service to their customers. However, there are challenges that are associated with the implementation of the 4IR particularly in the South African context. According to [24] some of the key challenges of the 4IR include ICT infrastructure, electricity provision, lack of required skills, financial Investment and cyber security.

4 RESEARCH METHODOLOGY

4.1. The research design and instrument

The research design consisted of a qualitative research approach which was used to gather data, which enabled the researcher to come to conclusions and to make recommendations regarding the causes of the poor customer experiences at Company A. Data collection consisted of interviews and an interview guide was compiled and used to conduct the interviews. Certain of the interview guide questions required participants to rate the services provided by Company A. 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 120 employees from the customer touch-point departments such as Customer Services, Social Media and Customer Value Management of Company A. Non-probability sampling was used to select the sample for the study. For the purposes of this study, a sample was drawn from approximately 120 employees in the targeted departments and a maximum of 10 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 responses as to the causes of the poor customer experiences 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 customer experience in the telecoms company.

4.3.1. Thematic analysis

The thematic data analysis technique was utilised to obtain more insights on the customer experience challenges facing the company today and to provide recommendations on how to improve the unsatisfactory customer experiences in Company A. The researcher analysed the data to identify themes that arose from answering the research questions. The themes were derived from the list of customer experience challenges and categories obtained from the research interviews. The goal was to accurately identify themes that would answer the research questions, attain the objectives and solve the research problem.

A six-phase guide framework as suggested by [25], for conducting thematic data analysis, was applied. The first step in the thematic data analysis process was to get familiar with the data which was captured from the interviews, by reading and understanding the data while highlighting the key relevant phrases of the information provided by respondents. 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, [26].

5 FINDINGS

5.1 Presentation of analysis and findings

The findings 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 responses to interview questions.

5.1.1. PART A: Thematic analysis

Initially the data was grouped using the main constructs of the study and codes were created based on the responses for each main construct. After the codes were created and reviewed, the main themes were generated from the codes using the four phases of theme development process, namely: Initialisation, Construction, Rectification and Finalisation, [26]. The themes were reviewed and defined to create a meaningful connection to the research objectives and customer experiences. Table 1 shows the core themes, the categories as well as the findings, which emerged from the data analysis of customer experiences at Company A. These themes are the key causes of poor customer experiences at Company A.

Table 1: Core themes, categories and findings

Theme	Categories	Findings and results
System efficacy: The first theme explains the problems experienced with the systems and applications at Company A.	Multiple systems; Slow system response; System stability/Down times; and Order processing.	a. The system efficacy theme was generated because of 100% responses from the participants who mentioned systems and applications as one of the major challenges at Company A. b. This linked very well with research objectives 2.2.2 and 2.2.4 of the study. Various system related challenges included the usage of multiple systems to service customers, systems always offline, systems taking too long to respond and systems not completing the orders. c. Systems and application challenges at Company impacts employee performance and impacting customer management systems such as fault escalation applications and billing applications. d. Respondents mentioned that they handled significant number of billing complaints from customers that are mainly due to inaccurate billing caused by billing systems. e. In most cases, this creates more work, as they must manually reconcile the bills and create debits and credits for customers. f. The analysis indicated that the current systems are not functioning effectively and efficiently and therefore the company needs to invest in acquiring the latest systems and applications to improve the poor state of customer experience in company A.
Turnaround times: The second theme describes the challenges impacting the turnaround times and service level compliance at company A.	Service level compliance, Prompt feedback, Response times, and Resolution time.	a. One of the most significant challenges which 90% indicated was turnaround times. They found this to be excessively long and created frustration to both customers and the customer care consultants. The turnaround times challenges that were highlighted included, customer waiting time on service queues, providing customer feedback on the logged incidents or faults, time taken to attend to faults and resolution times to the logged faults. b. According to 90%, the service levels of twenty-four hours response time and forty-eight hours resolution times are not always adhered to and sometimes it takes between five (5) and seven (7) days to provide feedback to customers. Some of the faults take up to two (2) weeks to be completely resolved which creates a poor experience to customers. c. The results indicated that customers are forced to contact the call centres repeatedly or visit the company stores to follow up on their logged incidents and to get feedback. This linked very well with the research objective 2.1.1. d. 90% agreed that service levels regarding customer feedback and resolution times are not always adhered to and this is a major challenge for Company A. This was linked to research objective 2.1.1. that sought to identify the underlying challenges of unsatisfactory customer experiences at Company A. e. The results indicates that Company A needs to enhance its processes and systems to improve customer experiences.
Business processes (BP): The third theme explains how the business processes affect customer experiences in the company and their impact to customer experience.	BP existence; BP definition; BP visibility; and BP adherence.	a. This theme linked very well with research objective 2.1.1. of the study. b. 80% highlighted a lack of business processes in some areas and functions of business at Company A. This was one of the key challenges of customer service that results into poor customer experiences. c. 50% indicated that business processes are not visible enough for them to follow and as a result, believe that they are non-existent. d. 20% believed that business processes are non-existent. e. 30% advised that business processes do exist, however, they are not adhered to, which contributes to the delay in response times and the subsequent impact on customer experiences. f. Business processes remain a major challenge in Company A, especially for the service departments. This ties in with the business objective of whether the current business processes are helping to improve customer experience in the company. g. These findings strongly suggest that the company needs to transform its business processes to improve customer experience.

Theme	Categories	Findings and results
Interdepartmental communication: The fourth theme explains the impact of the lack of communication and collaboration between departments on customer experience.	Working in silos; Collaboration/team work; Mailboxes/Emails; and Relationship Management.	a. Interdepartmental communication forms part of the business processes which links to objective 2.2.2. b. 80% indicated a lack of communication between the different service departments. This is a cause of huge concern. c. 90% of respondents advised that most departments are operating in silos and there is no transparency regarding their processes and functions. d. 80% indicated that the use of emails and mailboxes as the mode of communication as one of the key challenges within the service departments. e. Too much reliance on e-mails that are not receiving urgent attention and mailboxes with no defined turnaround times led to poor customer experiences. f. It is recommended that the company needs to invest in the modern communication tools and enhance communication between service departments to improve both employee and customer experiences.
Customer Experience Prioritisation: The fifth theme describes the lack of customer experience prioritisation and its impact on customers and customer satisfaction at Company A.	Customer centricity, Sense of urgency, 1st contact resolution, and Customer relationships.	a. The results of the study indicate that Company A is lacking in this customer-centric perspective based on the feedback received from majority of respondents of the study which links to objective 2.1.1. b. 90% indicated that some of the service departments are not customer-centric and their processes are not built around customer experiences. c. 50% mentioned that the company pays more attention to sales and acquiring new customers. Very little attention is paid to the experiences of existing customers. d. 80% advised that Company A is not making customer experience a priority. e. First contact resolution was also one of the lacking components of customer experience. f. 90% agreed that the image and the brand of the company does not look good, due to poor customer experiences. g. The poor experiences are due to undefined processes, poor internal and customer communication, lack of customer prioritisation, poor response times and system challenges. h. Good customer experiences are not one of Company A's priorities and it is recommended that customer experience is included as one of its business objectives.

5.1.2. PART B: Presentation, interpretation and discussion of the results of the analysis of the interview questions

Part B of the Presentation, interpretation and discussion of the results was categorised into four sections, namely: customer service, customer experience, image and brand and the 4th Industrial Revolution.

5.1.2.1. Customer service

The purpose here was to gather information regarding the challenges facing customer service at Company A. The respondents were asked specific questions about customer service challenges and the root causes of the challenges. Figure 1 depicts the challenges as highlighted by respondents.

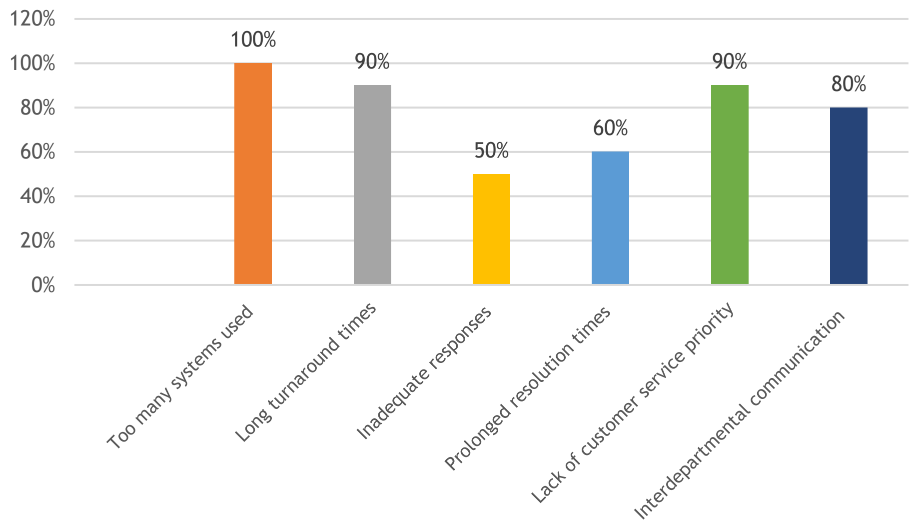

Figure 1: Customer service challenges

Findings: Most respondents (90%) rated the quality of customer service below six (6) which is concerning for Company A. The challenges that were highlighted also originated from internal processes. There were no external factors that were highlighted as the cause of poor customer experiences. These highlighted challenges correspond with the identified themes of poor turnaround times and lack of urgency which are the main causes of poor customer experiences in Company A. These findings are inconsistent with the literature review descriptions of good customer service.

Tony and Tuomas (2017) describe good customer service as delighting and impressing customers with superior quality interactions and experiences to build customer loyalty. Good customer service results into customer satisfaction and customer loyalty while poor customer services lead to customer disloyalty and high customer churn rate. Ngwenya [4] also concurs that superior quality service leads to customer satisfaction which in turn leads to good customer experiences. Good customer service also leads to customer retention, which automatically results in gaining competitive advantage and the subsequent higher revenue generation for the company.

5.1.2.2. Customer experiences

The purpose of this was to obtain the respondents' perspectives about customer experience at Company A. This section requested respondents to provide their views of customer experiences at Company A. Figure 2 depicts how respondents described customer experiences at Company A:

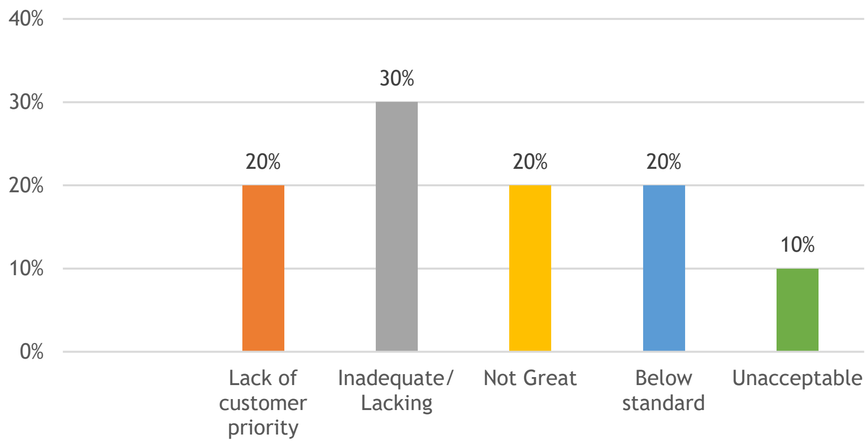

Figure 2: Customer experiences

The responses on the view of customer experience question were all in agreement that customer experience in the company is not up to standard and required serious attention. Some respondents referred to the customer experience as inadequate, lacking, not great, below standard and unacceptable. The majority of respondents (90%) advised that customer queries are not responded to promptly and efficiently and this is due to system issues and business processes that are not clearly defined and non-existent in some areas of business. A very high percentage (80%) indicated that customer experience is not treated as a priority. The abovementioned findings underpin the five themes linked to the poor customer experiences that emerged from the thematic analysis.

5.1.2.3. Image and brand of Company A

The purpose of this was to obtain the respondents' perspective about the image and the brand of Company A to customers and the outside world. This question was based on the respondents' feedback that they receive from customers, their peers, friends and relatives, and the general media, especially the social media platforms where customers usually vent their frustrations. Respondents were also asked whether they thought the current business processes were addressing the customer experience challenges in the company. Lastly the respondents were asked how they would rate the service of the company. Figure 3 depicting how respondents described the brand and the image of Company A:

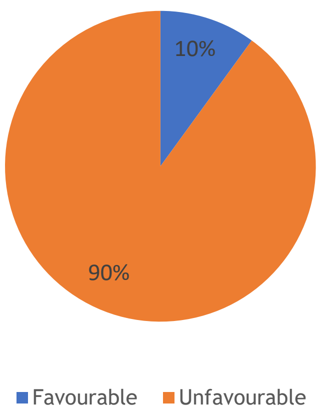

Figure 3: Image and brand of Company A

Almost 90% of the feedback received regarding the image of the company was that the outlook of the company was not favourable. Only ten (10%) respondent advised that the image of the company was still looking good even though there were serious customer experience challenges faced by customers. All respondents agreed that the brand of the company is tainted as a result of poor customer experiences and something needed be done to turn the tables around. The findings indicate that customers are generally not satisfied with the service rendered by the company.

5.1.2.3. The 4th Industrial Revolution

Here the researcher sought to obtain respondents' perspective and understanding of the 4IR and its technologies. The aim was also to establish whether the respondents believed that the 4IR technologies could assist to improve customer experiences at Company A. Figure 4 depicts the 4IR awareness level of the respondents.

Based on the feedback received from the respondents, the findings showed that all respondents (100%) did have some idea about the 4IR. However, 80% of respondents were not aware that Company A has implemented any 4IR technologies and 20% advised that Company A was using robotics in some areas of business. All respondents are of the view that the 4IR technology is necessary and can contribute immensely towards the improvement of customer experience at Company A. According to [17] most of the highly effective companies will adopt 4IR as part of their strategy to provide effective and high-quality service to their customers.

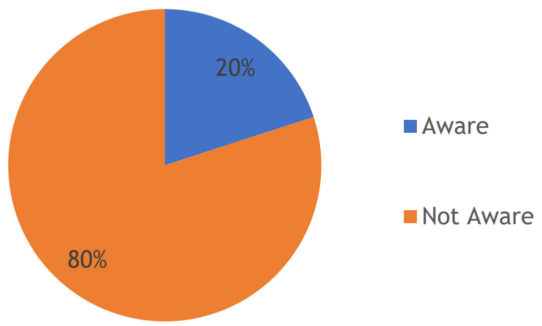

Figure 3: 4IR Awareness

6 LIMITATIONS OF THE RESEARCH

As with all research, this study was not without limitations [13]. The typical limitations of qualitative research apply. One of the potential limitations of this study was the unavailability of respondents for interviews due to the implementation of Covid-19 lockdown process that had been announced by the South African president to limit the spreading of the Corona virus. To mitigate this limitation, business Skype, MS Teams and/or telephonic interviews were arranged with the interviewees. As further research, this study could be extended to the other 4 prominent companies in the telecommunications industry.

7 MANAGEMENT IMPLICATIONS

The achievement of the study objectives and the implementation of recommendations highlighted above will assist management of Company A to improve customer experiences which will lead to improved customer service, customer loyalty and customer retention. The implementation of the 4IR tools will benefit the management in various ways including decision making, saving costs and resource planning. It will also assist Company A to improve their brand image, gain a greater market share, gain competitive advantage, improve the integrity and the financial status of the company.

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 are note-worthy conclusions, linked to the findings and results of the study.

It was found that customer experience in the company is not up to standard and required serious attention to be treated as a priority for improved business profitability. It can be concluded that the quality of customer service as very low, which is a cause of great concern for Company A.
An increase in usage of self-service tools will result in less customer effort, increase customer convenience and improved customer experiences. The number of calls to the call centres and visits to the stores will also be reduced through self-service, thereby improving the waiting time in the queues and reducing response times in the call centres. Customer satisfaction will also improve through reduced turnaround and resolution times. It is recommended that Company A prioritise customer experiences to improve customer satisfaction, loyalty and retention.
The current business processes are some of the major challenges impacting customer experience at Company A. The primary business processes challenges are advising customers about its existence, properly defining them, communication and visibility. It is recommended that Company A needs overhaul and streamline their business processes in all their customer service departments

The brand and image of Company A was found to be unfavourable. Respondents indicated that the brand of the company was tainted because of poor customer experiences and a turnaround strategy was necessary. Complaints on social media platforms are detrimental to a company. It is recommended that the brand and image of the company is revisited to align with customers perceptions.

The implementation of 4IR tools could assist to improve customer experiences at Company A. The high percentage of respondents indicated that were not aware that the company had implemented any 4IR technologies. Many companies have already implemented 4IR technologies to their benefit and their customers benefit. It is recommended that Company A invest in the latest 4IR tools and latest technological advancements to improve their customers experiences. The Chief Executive Officer of Ericcson stated that in Africa, the demand for data services will increase by 60% in the next 5 years, [27]. It is therefore evident that Company A, needs to accelerate the implementation of the 4IR technologies to meet the customer demands of internet solutions. According to Markowitz [17], most of the highly effective companies have adopted 4IR technologies as part of their strategy to provide effective and high-quality service to their customers.

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BENCHMARKING BEST PRACTICE IN NEW PRODUCT DEVELOPMENT PROJECT IN A SOUTH AFRICAN CINEMA

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ABSTRACT

Failure to successfully launch new products in the film industry in South Africa negatively impacts the company competitiveness, market share, customer perception and organizational profitability. The objectives of the study were to evaluate the New Product Development (NPD) processes in the South African film industry benchmarked against international best practice, to identify the critical dimension in terms of project success in cinemas. Methods included a questionnaire using the NPD best practice framework to benchmark the NPD best practice, using SPSS statistical analysis tool, and structured interviews. The findings from this study provided evidence that the process dimension is a critical success factor. Furthermore, there was no relationship that exists between Company Culture and Research, similarly between Company Culture and project climate. The study recommends that cinemas must invest in strengthening the process dimension characteristics as they impact on the success of NPD projects success.

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1 INTRODUCTION

Cinema Companies seek to bring about new ways of providing value in their cinema offering through their innovative approach to business [1]. To gain competitive advantage through the organizations innovative approach, Cinema Companies attempt to introduce new products first to market, products that compliment movie experience offering. However, this exercise of introducing new products first to market is very costly for the organization due to the need of educating the market about the new products [2], as opposed to the competitive response of the follower firms that follows other companies footsteps as their only focus is on the rapid and effective implementation of the products when they launch into market [3]. Competitive analysis is critical in determining the product's current and future price, the quality of the product and the acceptance of the product by the market [4]. The problem that was identified with cinemas lies in the fact that the success rate of new product launches in the film industry is low. Failure to successfully launch new products in the film industry in South Africa negatively impacts on the company's competitiveness, market share, customer perception and organizational profitability. Furthermore, the execution of the product rollout activities is done in isolation with limited linkages with cross functional departments. Hence, the need arises to refine the current NPD project approach. The objectives of this study are to evaluate the NPD processes in the South African film industry benchmarked against international best practice; to identify the critical dimension project success in the company's cinemas and the gaps in the NPD processes; To make appropriate recommendations on how to improve the success rate of new product launches in cinemas. To minimize the new product launch costs, a New Product Development (NPD) Best Practice Tool was adopted and used to benchmark a cinema company's NPD project approach with an NPD Best Practice Tool framework that is made up of eight dimensions. These dimensions areas of importance were identified when executing NPD projects and data collected using an electronic questionnaire survey, results were consolidated using a statistical analysis tool, SPSS. The NPD process dimension was found to be critical for the success of NPD projects when measuring the equal importance of the eight dimensions presented by the framework [5].

2 LITERATURE REVIEW

Barczak and Kahn [6] developed an NPD best practice tool that can be used to benchmark NPD practices. The framework is designed to identify poor practice versus best practice by such determining the difference between success and failure rate of NPD projects [6]. Perks et al. [7] used the NPD best practice framework to benchmark the NPD best practice in Small and Medium sized Enterprises (SME) and large organizations in the United Kingdom (UK) and Ireland. The research results of the study of the seven dimensions indicated that strategy is the most crucial dimension in the success of NPD projects. The research, process, commercialization, and project climate dimensions were found to be of medium importance. Finally, company culture, metric and performance evaluation as of low importance. They further indicate that there is common view in both SME's and large organizations with regards to NPD projects [7]. This would suggest that top management supports the NPD process and the company actively works with customers to develop new solutions as per best practice [8]. A research study examining the relationship between NPD innovation and NPD performance adopted the best practice dimensions from Barczak and Kahn [6] NPD best practice framework found that the organizations that strongly implement NPD best practices have a positive effect on NPD performance. Furthermore, the stronger the NPD innovation, the higher the NPD performance; and stronger organizations' ability for NPD innovation has positive relationship with NPD best practices [9]. To improve the success rate of NPD projects, the process dimension has been identified as a critical success factor [10]. The NPD process plays a critical role in achieving the competitive advantage by setting the rules of the competition to satisfy customer needs. This is achieved by reducing time to market, increasing product performance and creating new business arenas [11].

3 METHODOLOGY

In this study, data was analyzed sequentially as presented in Figure 1 using the SPSS tool for descriptive statistics, A survey was conducted to gather information to modify the service in NPD projects and identify the gaps in practice to understand the work carried out [13]. The sequential explanatory design utilized the connected data analysis approach to explain the results [14].

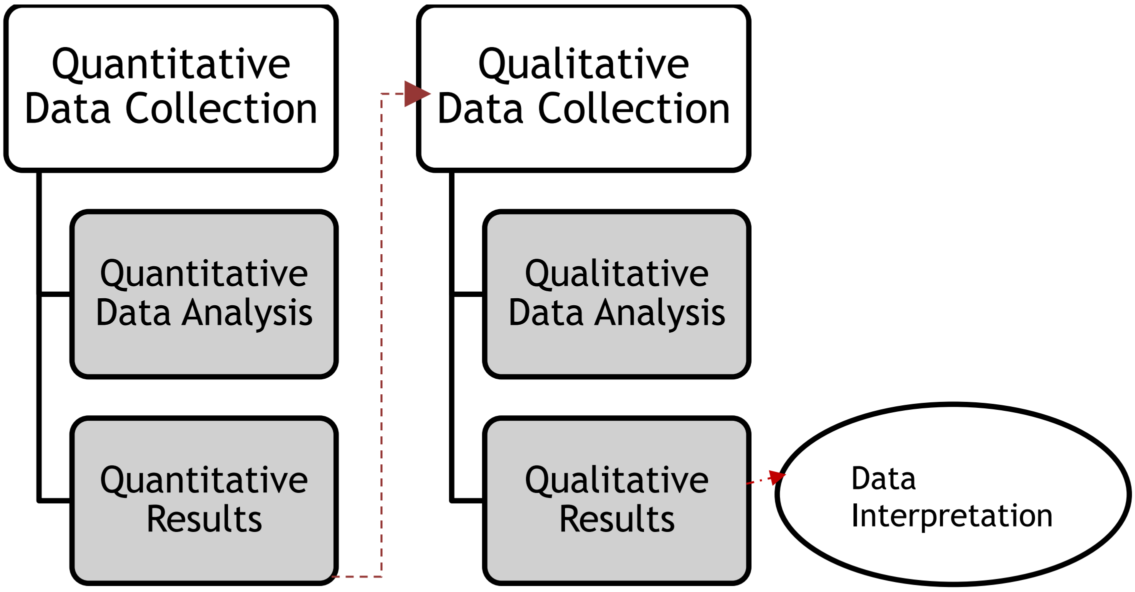

Figure 1: Sequential Mixed methods design adapted from [12]

The questionnaire was pre-tested in a form of a pilot survey to ensure the questions asked are clear, unambiguous and not repetitive. Data collection in sequential mixed methods is collected in sequential phases such that the quantitative data collected first contributes to the phase of qualitative data collection [15]. A cover letter was sent out with the questionnaire that explains the purpose of the study, the respondents are anonymous, and thanked them for their time [16].

4 RESULTS

The results in Figure 2 provide useful insight about the dimensions that are considered most important by cinemas. These results present a different view that was not expected, which is rating company culture as the most important dimension as opposed to the strategy dimension.

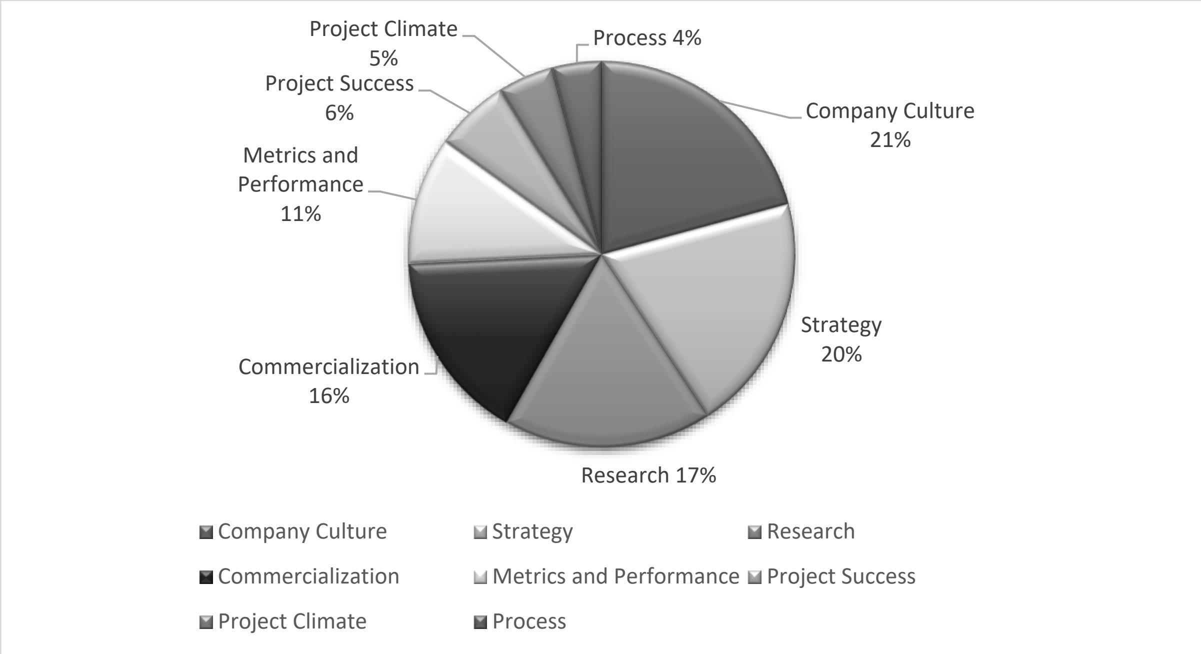

Figure 2: Relative Importance

Company Culture dimension was the most crucial dimension in guiding the NPD projects as presented in Figure 2. This result contradicts the theory that strategy is the most crucial in guiding NPD project roll out [7]. This would suggest that top management supports the NPD process and the company actively works with customers to develop new solutions as per best practice. As a result, is opposed to the view that strategy is the most critical factor of the dimensions assessed [8] .

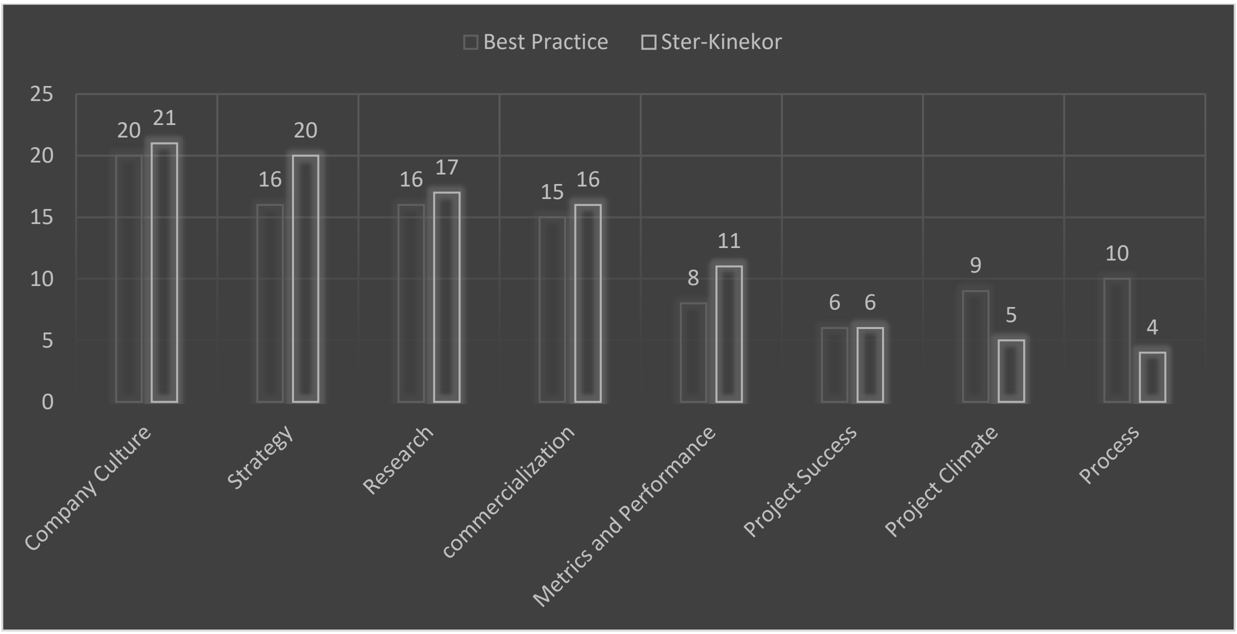

Figure 3: Best Practice VS South African Cinemas

The overall results in Figure 3 reflect that organization performs best at Company Culture dimension followed consecutively by Strategy; Research; Commercialization; Metrics and Performance; Project Success; Project Climate with process being the least high performer.

4.1 Reliability of Instrument

The instrument reliability was carried out using the Cronbach Alpha approach. According to McIntyre and Stephen, a value above 0.70 indicates a good consistency of the dimensions in the scale used [1]. The adequacy cut off limit for Cronbach's alpha is 0.7 [2]. The scores presented in Table 1 of the eight dimensions are acceptable as the dimensions where all above 0.7 [17].

Table 1: Cronbach Alpha Distribution

Dimension	Cronbach's Alpha
Strategy	0.842
Research	0.851
Commercialization	0.855
Process	0.931
Project Climate	0.881
Company Culture	0.870
Metrics and Performance	0.714
Project Success	0.834

These results presented in Table 1 illustrate that there is good consistency on the data collected. This test validates that the questionnaire used stated its consistency with the scale used.

4.2 Correlation Analysis

A correlation analysis was undertaken to determine the significance of the relationship between the predictors and the dependent variables [3]. Figure 4 and Figure 5 represent the results of the correlation analysis carried out in order to ascertain whether a significant relationship between the independent variable and the dependent variable exists [18].

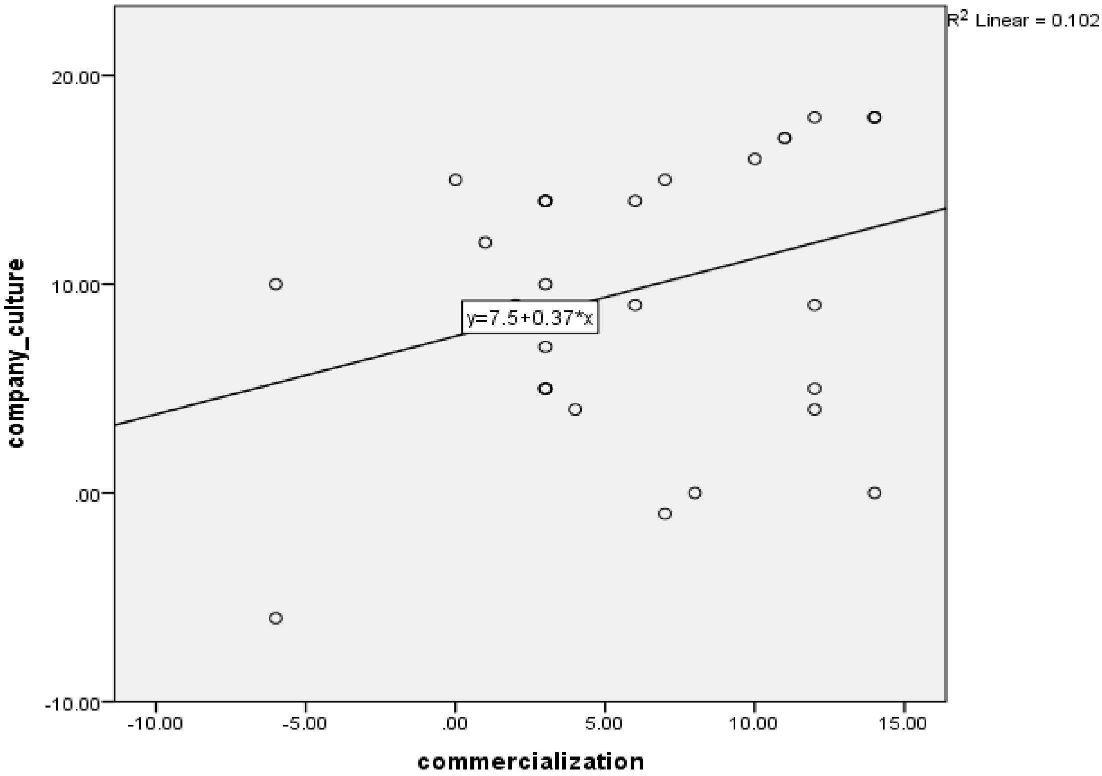

Figure 4 : Company culture VS Commercialization

Figure 4 shows that there are no trends that exist between Company Culture and Commercialization [19]. This suggests that there is no correlation between Company Culture and Commercialization dimension [20].

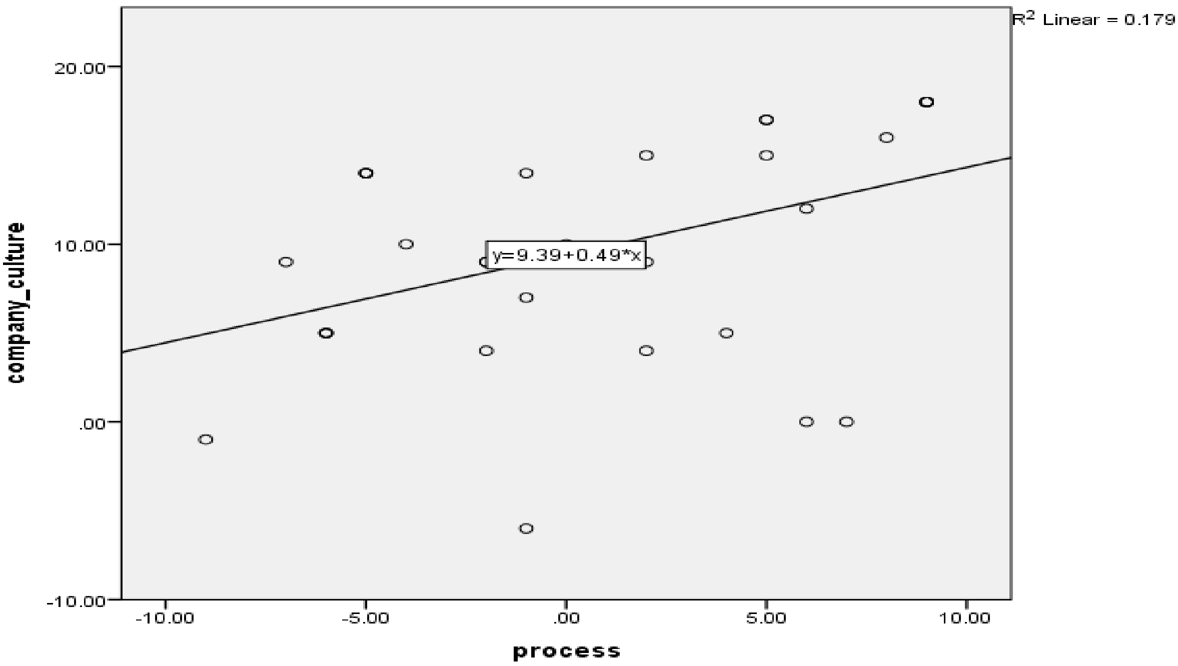

Figure 5: Company culture VS Process

Figure 5 shows that there are no trends that exist between Company Culture and Process [19]. This suggests that there is no correlation between Company Culture and Process dimension [20].

4.3 Regression Analysis

The regression analysis that was carried out to test the performance of the dependent variable against the predictors. The model was found to have been useful as the R square is 0.619 as per Table 2 and not equal to zero [4].

Table 2 : Regression Distribution

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	0 .787a	0 .619	0.523	2.04731	1.589

The regression analysis model presented in Table 3 predicts that if the organization wants to improve project success, the dimension to focus on is process, as this has the strongest correlation with a high F value of 6.487 to maintain the 0.00 significance [5].

Table 3: Regression Analysis Model

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	163.147	6	27.191	6.487	.000b
	Residual	100.595	24	4.191		
	Total	263.742	30			

The results of the survey conducted could be validated using the structured interviews approach that could be aligned with the regression analysis conducted. The results in this paper suggest that there is value in strengthening the process dimension characteristics as they impact on the success of NPD projects directly.

5 CONCLUSION

The objectives of the study were achieved through descriptive analysis methods that were deployed. Regression analysis was carried out to determine the critical dimension that will influence successful launch of new products at cinema, Process dimension. Focus on the process dimension will not only improve the success rate of NPD projects but close the gaps identified where best practice is not complemented. This information is contained in the Process dimension section of the questionnaire. The correlation analysis undertaken indicated that six out of eight the dimensions pairing showed very strong positive relationships with only two exclusions noted: The Company Culture versus Commercialization and the Company Culture versus Process.

These findings provide useful insight about the dimensions that are considered most important by cinemas. The survey results present a different view that was not expected, which is rating company culture as the most important dimension as opposed to the strategy dimension. The results in this paper suggest that there is value in strengthening the process dimension characteristics as they impact on the success of NPD projects directly. This research has contributed on benchmarking on the new context of the cinema industry by applying the best practice tool developed for NPD projects. This tool was developed using expert advice and as such has been put to the test in a cinema industry to measure performance of NPD projects against best practice, presented in Appendix A.

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APPENDIX A: QUESTIONNAIRE

Organization:

Department/Division:

Position:

Gender:

Age:

Experience in years in current position:

Answer the following questions by selecting the appropriate block as applicable to all dimensions:

Questions	Yes	Maybe	No
Dimension 1: Strategy			
The company has NPD goals?			
All New Product Development (NPD) projects fit in with company's mission?			
NPD goals are clearly defined and visible within the company			
The company considers NPD as a long-term strategy			
The company has a formal strategic planning process			
NPD goals are clearly aligned with the company's mission and strategic plan			
NPD projects and programs are reviewed on a regular basis			
The company carefully considers the resource requirements necessary to support the types of NPD projects being developed			
Opportunity identification is an ongoing process			
Strategic plan can be redirected in real time to respond to market forces and new technologies			
NPD projects are prioritized			
There is a clear process of undertaking portfolio management			

Questions	Yes	Maybe	No
There is consideration for balancing the number of projects and available resources			
NPD projects are aligned with the company's mission/strategic plan			
Trade-offs among NPD projects are made using a set criterion			
Dimension 2: Research			
The studies of customers are focused on both current and future customer needs and problems			
Market research is an integral part of all NPD projects			
Concept testing is an integral part of NPD process			
Market testing is an integral part of NPD process			
Product/product use testing is an integral part of NPD process			
Testing results are formally evaluated			
Customers are an integral part of NPD process			
Testing results are accessible for use by NPD project teams			
The organization have a formal market research function			
The organization truly employ voice of the customer studies for NPD projects			
The organization have a formal budget for market research			
NDP project team can readily access market research results			
Market research is used to develop product definitions			
Market studies on customers, competitors and macro environment trends are undertaken to understand the market place for every NPD project			

Questions	Yes	Maybe	No
Testing and market research results are used to improve new products being developed			
Dimension 3: Commercialization			
The company has a standard launch process for new products			
There is a team responsible for planning the launch of a new product			
The launch planning team oversees the implementation of the launch plan			
The company avoids dramatic changes to marketing budget to the point of the launch			
The launch team is cross functional in nature			
The cross functional team is involved in development decisions of a new product			
The cross functional team is involved in logistics and supply chain decisions of a new product			
The cross functional team is involved in marketing decisions of a new product			
The cross functional team is involved in sales decisions of a new product			
The cross functional team is involved in customer service and customer support decisions of a new product			
Post project implementation meeting is held after a new product is launched			
The customer service and customer support team are part of the product launch team			
The NPD team is different from the Product launch team			
Commercialization is a formal part of the NPD process			
Dimension 4: Process			

Questions	Yes	Maybe	No
The criteria for evaluating NPD projects is defined			
There is an NPD process that exists			
The NPD process that exists cuts across all departments			
The NPD process that exists is documented			
Is the NPD process flexible and adaptable to meet the needs and risks of individual projects?			
All individuals involved in New Product Development understand the NPD process			
The IT infrastructure with appropriate hardware and software is available to all NPD personnel			
The NDP team has access to the same IT infrastructure			
The NPD process has a process owner			
Dimension 5: Project Climate			
The company climate is conducive for NPD project work			
There is a defined NPD team in the company			
Each project has a core cross functional team			
There is an identified NPD project leader			
There is careful consideration of how personnel are assigned to NPD team			
NPD is cross functional in nature			
NPD team is only dedicated to NPD work			

Questions	Yes	Maybe	No
Formal communication is properly coordinated for NPD activities			
Dimension 6: Company Culture			
Does the company culture facilitate the NPD efforts			
Is NPD a senior management priority			
Does senior management provide the necessary resources to support NPD activities			
Can NPD ideas come from outside the company			
Does top management actively work with customers to identify new product opportunities			
Does the company co-develop products with customers			
Does senior management encourage knowledge sharing across different departments			
Does the company culture embrace the concept of open innovation			
Does the senior management encourage risk-taking with respect to NPD projects			
Does the company support open innovation			
Do senior management interests go beyond just meeting revenue and financial targets regarding NPD efforts?			
Does the organizational culture promote its employees to remain in the employment?			
Does the organizational culture promote open communication with management			
Does the organizations induction program include information about organizational culture?			

Questions	Yes	Maybe	No
Does the organizations environment allow for diverse individuals to work together			
Does the organizational culture promote teamwork			
Does the organizational culture promote continuous process improvement			
Does the organizational culture emphasize on customer experience			
Dimension 7: Metrics and Performance			
The company has performance metrics in place for NPD projects			
There is a standard criterion to evaluate the overall NPD effort			
There is a standard criterion to evaluate the individual NPD effort			
The NPD performance matrix is understood by personnel affected			
The NPD performance matrix is available for senior management for decision making			
Team approach is used to evaluate NPD projects			
Multiple review points are used to evaluate NPD projects			
Dimension 8: Project Success			
Are projects completed on time?			
Are projects completed within a defined scope?			
Are projects completed within budget?			
I am always informed of the project plan and progress of all activities highlighted.			

Questions	Yes	Maybe	No
There is good communication between people in different departments of the organization			
I feel comfortable discussing issues with my manager			
Consent			
Would you be interested in participating in a follow up verification interview?			

THE IMPORTANCE OF THE WORKFORCE FACTOR IN CONTINUOUS IMPROVEMENT STRATEGIES

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ABSTRACT

The study explores the 'Workforce' factor in Continuous Improvement (CI) strategies at selected South African investment companies by employing quantitative research methods including factor analysis, linear and multiple regression to test the relevant hypothesis. 'Workforce' was found to be statistically significant and supported by prior research on CI factors. It was found that Workforce plays an important role in the success of a CI strategy whereby a continuous improvement culture needs to be initiated in the organisation and the CI strategy requires buy-in from senior management to the most junior employee. Once CI becomes embedded in an organisation the chances of a successful CI program is improved. The findings in this research can inform companies in the sector on what they could focus on in terms of their CI Strategies to ensure a greater chance of success.

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1 RESEARCH CONTEXT

1.2 Background

Companies that compete in the global marketplace need to consistently improve to stay ahead and remain leaders [1]. Continuous Improvement (CI) has therefore become a vital strategy in the success of companies [2]. Only by continuing to improve can a company remain innovative and avoid becoming routine [3]. There has been an evolution of CI programs over time which initially stemmed from the manufacturing industry into hybrid models that focus on all aspects of an organisation and resulting in a wide range of benefits for the organisation [4].

CI strategies have become an essential factor leading to success in organisations. Success, in this context, is outlined as either an improvement in customer satisfaction, efficiencies within the organisation or an improvement in profitability.

1.2 Problem Statement

To increase competitiveness within an organisation CI is an important tool that can be used [5]. To attain market leadership or to maintain it an organisation needs to continuously improve. Knowledge of the CI factors that lead to success is vital when embarking on a CI program to ensure resources are effectively allocated.

The aim of this research project is to conduct an exploratory study by investigating the importance of the "Workforce" factor in continuous improvement successes at selected South African investment companies. The "Workforce" factor incorporates 'Management and stakeholder commitment to continuous improvement' and 'Staff Engagement.'

2 LITERATURE REVIEW

2.1 Continuous Improvement

CI is not a new concept and dates to the 1800s where various incentives were introduced to encourage continuous improvement in organisations. More scientific methods were developed in the late nineteenth and early twentieth centuries [6]. Americans developed service training techniques to improve national industrial output during World War II and these techniques now form the basis of modern CI principles [7]. Following the war, experts like Deming [8] (1986) exported these programs to Japan where it was further enhanced, and Japanese quality programs were developed. The tools found their success in manufacturing and evolved into management tools for CI across organisations [9].

The definition of Continuous Improvement (CI) was initially started by Deming [8] to implement CI in systems of production and service. Continuous improvement literature has evolved and the definition has been adapted to various sectors or studies. Michela [10] defined continuous improvement as a set of activities to achieve performance improvements. CI is defined more generally by Bhuiyan [6] as a culture of sustained development and the elimination of waste. A common thread from the literature reviewed, is that CI is a continuous process implemented by organisations to constantly improve and is a core part of the organisation.

2.2 Critical Success Factors for CI

In investigating Critical Success Factors (CSF) of CI programs Gonzalez-Aleu [11] reviewed 98 publications to create a list of CSF in the literature resulting in a list of 53 different factors. Further research was conducted by Gonzalez-Aleu [11] investigating CSF in hospitals and found that 47 of the 53 factors identified by Gonzalez-Aleu [11] were vital to the success of CI programs in hospitals.

Table 1 below summarises the various factors relating to CI success from the literature reviewed and the frequency of occurrence. The data bases used to explore the literature were Google Scholar and Wits e-Journal library.

Table 1: Summary of factors found in the literature reviewed by the authors from Google Scholar and Wits e-journal databases.

	Factors from literature review											
Source	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**L**
Lodgaard [2]	1			1	1	1	1					
Oprime [15]	1	1						1		1	1	
Bessant [38]	1		1									
Imai [9]	1											
Alvarado [37]			1									
Yokozawa [45]			1									
Singh and Singh [12]			1									
Liker [41]				1								
Nonaka [42]				1								
Smadi [43]	1											
Marin-Garcia [5]	1	1										
Berger [39]	1											
Suárez-Barraza [44]		1										
Gaplin [40]									1			
Nguyen [14]	1	1			1			1				1
Gonzalez-Aleu [46]	1	1	1	1	1	1	1		1			
Total Occurrences	**9**	**5**	**5**	**4**	**3**	**2**	**2**	**2**	**2**	**1**	**1**	**1**

Key for the factors above:
A - Commitment from management/stakeholders
B - Staff training, motivation, development, and commitment
C - Quality Management Systems & Tools
D - Organisational (involvement, teamwork, motivation, structure)
E - Participation of change agents/champions
F - CI method used
G - Knowledge (availability, sharing)
H - Incentive systems
I - Measurement Systems & data
J - Incentive suggestions
K - Communication
L - Management development

As highlighted in Table 1 above the five most common factors prevalent in the literature are firstly commitment from management or stakeholders. Secondly, staff engagement which includes training, motivation, development, and commitment. Thirdly, quality management systems and tools used. Fourthly, organisational setup covering involvement, teamwork, motivation, and structure. And finally, participation of change agents and change champions. Of the top 5 factors those involving the “Workforce” occur four times highlighting the significance of the factors in previous research.

2.3 Continuous Improvement Strategies

Continuous improvement strategies are the accepted industry methodologies reducing waste with the use of incremental improvements.

Singh and Singh [12] reviewed the existing literature to research the various CI strategies utilised by manufacturing firms and found that CI strategies formed part of an effective manufacturing processes, and this was common in the manufacturing industry. The findings showed that CI strategies included factors like CI culture, management commitment and awareness of the CI strategy among employees. These findings established the same basis with the conclusions in the research by Garcia [13] and Nguyen [14] mentioned earlier. However, similar studies were untested within the financial service industry. This research focuses on the “Workforce” factor that is highlighted in the narrative created by García [13] as well as Nguyen [14] .

The outcome of a CI program differs depending on strategy selected [11]. A conceptual model was developed by Oprime [15] which showed six outcome indicators, namely productivity increase (efficiency), quality improvement (customer satisfaction), lead time reduction (efficiency and profitability), cost reduction (profitability), customer satisfaction increases and employee ability development (efficiency).

2.4 Organisational Culture and Strategy

While culture is not an explicit strategy in CI, Dale [16] found that organisational culture and style of management plays an important role in the success of CI strategy and therefore vital to the success of the strategy. Research on the quality organisation by Malhi [17] revealed that the aim is to constantly improve to meet customer needs and that the culture of the organisation enables realisation of the strategic goals. Schein [18] alluded to culture being part of the strategy of an organisation by management operationalising culture. Habtoor [19] supported these concepts with the finding that human factors aided an organisation’s performance.

2.5 Conclusion to the literature review

From the literature review it was found that the top five factors that feature prominently are firstly, commitment from management and stakeholders, secondly, staff engagement, thirdly, quality management systems and tools used, fourthly, organisational setup and finally participation of change agents and change champions. These factors form the basis for the success of a CI program which is fulfilling the set outcome that a program intends to achieve.

The ultimate goal of CI programs was to improve the performance of the organisation. Leading performance outcome indicators were highlighted as customer satisfaction, profitability, and efficiency. Throughout the literature [15]; [13]; [20]; [21] success was noted if one or more of the outcome indicators of the program were achieved.

This study tested whether the chosen CI factors impacted one or more of the outcome indicators with a focus on the significance of the “Workforce factor within investment companies the financial service sector”.

3 RESEARCH DESIGN

For this study a quantitative research method was chosen as it can be applied to large samples and is beneficial in obtaining results that form a statistically significant sample of the total population being tested [22]; [23].

Various phases formed part of the study which was initially a literature review to establish which factors to focus on that lead to CI success. The factors that were the most common in the literature formed the basis for the factors tested in this study. These factors were used as the variables to conduct the research and a survey in the form of a questionnaire was designed using the factors. Surveys are a cost-efficient tool that can be used to collect data from several participants [24]. A five-point Likert scale was used to determine the participant's attitude towards the given subject.

The focus of the research is an exploratory study using selected South African investment companies. Their identities are anonymous due to ethics requirements. The participants within these organisations were from project teams that implement CI strategies, senior and junior managers of teams where CI strategies have been implemented and line staff that are affected by the implementation of CI strategies. The data were collected over a two-month period from 16 January 2019 to 15 March 2019.

The questionnaire was split into sections with the purpose of gathering information on the demographics of the respondent, how the respondent viewed the importance of the various factors of the study and the outcome indicators of the study. The factors tested in the study were commitment from management and stakeholders; staff engagement; quality management systems and tools used; organisational setup; and participation of change agents and change champions. The success measures or outcome indicators that these factors were measured against were, an improvement in customer satisfaction, an improvement in efficiency and an improvement in profitability of the organisation.

Finally, statistical analysis of the data collected was done in two stages.

Stage 1:

1) Preparation and editing of data were done by removing outliers and missing data and applying Mahalanobis distance analysis [47, 48].
2) Normality of the data was determined by reviewing the skewness and kurtosis of the data [49].
3) The relevant descriptive analysis was conducted, reviewing frequency and percentages of various aspects of the demographics of the respondents.

Stage 2:

Exploratory Factor Analysis (EFA) was done by firstly conducting a Principal Component Analysis (PCA) to determine if the data were suitable for factor analysis.

1) A Kaiser-Meyer-Olkin (KMO) analysis was done to measure the sample adequacy of the data for factor analysis (appropriateness). A KMO factor output of above 0.8 is considered acceptable to conduct an EFA study [50].
2) Bartlett's Test of Sphericity was conducted to compare the factors in the correlation matrix [51]. The significance level was set with a *p*-value of less than 0.05 to ensure that the pattern is not an identity matrix which is a prerequisite for EFA.
3) In order to determine the number of factors to analyse a Cattell's Scree plot was conducted and a Keiser Eigenvalue of 1 was applied [52] and only factors with an Eigenvalue of >1 were analysed.
4) Orthogonal rotation (Varimax) was used to improve the factors for more precise alignment [50] to reduce the number of variables.
5) A Cronbach Alpha analysis [53] was used to measure the reliability of scales with values >0.8 considered good.
6) Regression models was developed using linear and multiple regression analysis of variance (ANOVA) on the factors against the outcome indicators [54].

4 RESULTS

4.1 Principal component analysis

A principal component analysis was run to determine the number of factors to analyse. Results of this test with an Eigenvalue of >1 is considered significant [25]. Only four components (which will be analysed further) met the criteria and explained 66.986% of the variation and therefore the rest of the components are not significant for this study.

4.2 Orthogonal rotation (Varimax)

To ensure that factors remain uncorrelated and easier to interpret orthogonal rotation was used [26]. Only factors above 0.4 were accepted for use in the pattern matrix of the factor structure to ensure convergent validity [26].

The following constructs emerged from the study:

1. Questions relating to 'Management and stakeholder commitment to continuous improvement' and 'Staff engagement' clustered together. This is seen as a single factor called '**Workforce**'.
2. 'Quality management systems and tools' questions clustered together however some of the questions did not meet the significant criteria of 0.4 and were excluded. This factor is termed '**Quality Management**'.
3. 'Organisational setup' and 'Participation of change agents and change champions' questions clustered together and is grouped as a single factor going forward called '**Organisational Change**'.
4. Questions relating the success factors relating to customer satisfaction, efficiency and profitability clustered together. This is labelled as a single factor going forward call '**Successes**.'

4.3 Correlation matrix

A correlation matrix to ensure factors are considered distinct and uncorrelated was performed. A correlation value of above 0.7 is considered highly correlated [27]. In the analysis of the data, it was found that only five questions marginally exceeded the limit of 0.7. It is, therefore, determined that there are no highly correlated questions in the study and factors can be considered distinct.

4.4 Cronbach alpha analysis

To measure reliability of the four constructs highlighted in the varimax analysis, a Cronbach Alpha analysis was performed to measure reliability. Values of greater than 0.8 were acceptable [28].

The results indicate that

1. Workforce returned a Cronbach Alpha score of 0.92 with a significant level of <0.001 making it highly significant. It was observed that if an item was deleted the Cronbach Alpha returned a score of <0.92 across all the questions. Therefore, the score cannot be stronger if any questions were removed.
2. Quality management returned a Cronbach Alpha score of 0.887 with a significance level of 0.117. There were only two questions in this construct and therefore none could be removed in the analysis.
3. The organisational change had a Cronbach Alpha score of 0.894 with a highly significant level of <0.001. Deleting any specific question resulted in the same score of <0.894.
4. Successes had a score of 0.927 at a highly significant level of <0.001. Removing specific questions in the test does not result in the score increasing making all the questions significant.

The overall result from the Cronbach Alpha analysis showed that all the constructs are reliable, and therefore the dataset is suitable for regression analysis.

4.5 Regression Analysis

A Pearson Correlation study was done to see the extent to which the constructs are linearly correlated. The results show that there are significant correlations between the constructs. The constructs can, therefore, be used in a regression model.

4.6 Linear Regression

The correlation between the variables workforce (independent) and successes (dependent) explains 53.8% of the variance with an acceptable significance level of $p<0.001$. The result of the model led to the workforce having a coefficient of 0.638 which is significant and a low standard error of 0.059.

The correlation between the variables organisational change (independent) and successes (dependent) explains 47.7% of the variance at a significance level of $p<0.001$ which is highly significant. This is lower than Workforce, but the significant level is still high. The model returned a coefficient of 0.605 for Organisation Change which is significant and a low standard error of 0.063.

Quality Management (independent) had a correlation of 33.32% with successes (dependent) explaining 33.32% of the variance at a significance level of $p<0.001$ which is very significant. This variable did return the lowest regression in the model. The result of the model led to Quality Management having a coefficient of 0.408 which is significant and a low standard error of 0.057.

4.7 Multiple Regression

A multiple regression model was run to better understand how the variables, interact with each other using all the variables in the linear regression. The result of running the model was an improvement in the output with an explanation of 59.3% of the variation. This was at a highly significant with a p-value of <0.001. The Durbin-Watson result of the model of 1.79 is between 1.5 and 2.5 signifying that no autocorrelation exists between the constructs.

The collinearity statistics from the model returned Variance Inflation Factor (VIF) values for all constructs of <10, resulting in all of them being suitable. One of the variables, Quality Management did however fail the model as this variable only showed a marginal influence without a statistical significance.

The multiple regression model was rerun after removing the variable Quality Management. The result showed that there was no change in the R squared in the improved model demonstrating that the variable Quality Management added no value to the regression. The results are also highly significant with a p-value of <0.001. The beta of Workforce at 0.49 shows a much better influence than Organisational Change; however, the combination of both variables is stronger. Both factors are very significant with p values <0.001.

The results of this study show that only four factors have a positive impact on the outcome of CI strategies in a statistically significant way. Taking the study further and running a multiple regression model showed that only two of the factors explained the variation in a statistically significant manner, namely Workforce and Organisational Change. Quality Management is shown as not being statistically significant in the success of Continuous Improvement strategies.

5. DISCUSSION

5.1 Workforce

'Management and stakeholder commitment to continuous improvement' and 'Staff Engagement' were clustered together in the study, demonstrating the significance of both. When workforce commitment was investigated in the survey these questions were aimed at establishing management and stake holder commitment to CI as well as the staff engagement in the programs. Stelson [20] looked at successes of CI programs in healthcare and found managerial and employee factors to affect success. Managerial restrictions limited project team effectiveness in the study, which supports the finding that managerial support is important. Management commitment as a driver for success is emphasised in various studies [13]; [11]; [14]; [20] which is comparable to the findings of this research.

From the survey participants were asked whether there was consistent feedback by management on several factors. These included CI and whether management encouraged innovation and prioritised critical improvements of the organisation. Staff development to improve expertise in continuous improvement and whether these commitments led to the success of the program were also investigated. All these questions related to management and stakeholder commitment.

The survey also investigated consistent communication in the organisation, process improvement and training opportunities; and whether these led to the success of the CI program. These questions were to investigate staff engagement.

When referring to the significant factor of "Workforce" all the key views mentioned above is incorporated in the definition and therefore a broader description of the factor should be applied. For organisations to achieve successful CI programs it was found in the research that there needs to be commitment among the workforce which stems from the executive level through all levels within an organisation.

Dale [16], noted that there needs to be an open communication framework whereby staff and management can engage; with the ability to give feedback up the chain of command. The feedback is vital for incorporations into the strategy for CI implementations.

Management's commitment to continuous improvement forms part of the "Workforce" construct, which implies ongoing commitment to the CI change program. As CI runs through all levels in an organisation it becomes part of the culture of an organisation as noted by Malhi [17] which outlined the elements of a quality organisation. A quality organisation is based on the concept of Total Quality Management which in turn is a CI strategy [16].

The findings in this research report were that management commitment and training have a positive impact on the success of continuous improvement which is supported by the findings from Milner [29] that modelled CI improvement evolution in the service sector and looked at critical success factors (CSF) as part of the investigation. Furthermore, Milner [29] noted that instituting a CI system in the organisation reinforces continuous change as the corporate culture, supporting the findings in this study of the importance of organisational change.

A study of corporate culture by Schein [18] signified that leadership is an important requirement for instilling a corporate culture. CI is driven by the culture of an organisation highlighting the significant of the commitment by the workforce as a finding in this study. Culture is the tool that ensures the commitment across all levels in an organisation [17] and in turn can lead to the success of a CI program. These similar factors from Milner [29], Schein [18] and Malhi [17] are highlighted in the findings of this research, whereby commitment from management and stake holders has led to the success of CI.

5.2 Organisational change

The other significant factor highlighted in this research, “Organisational Change,” is linked to the culture of an organisation. The two constructs ‘Organisational Setup’ and ‘Participation of Change Agents and Change Champions’ were clustered together to form the factor “Organisational Change”. The questions from this section in the survey were seeking to establish whether the organisation emphasised and supported a culture of change.

CI therefore needs to be embedded in the culture of the organisation. Habtoor [19] found that human factors positively influenced the quality of improvement, and this led to an increase in performance. Innovation also needs to be encouraged in the organisation with the necessary change programs and part of the CI strategy. As part of a framework developed by Heavey [30] improvement specialists should form part of the components, highlighting another link of change and CI.

CI is a strategy of ongoing change; hence the factor of organisational change is intuitive and backed by the findings in this research. By instilling change into the culture of the organisation, CI becomes part of the organisation’s targets and commitment or resources by the leadership team is essential for the strategy.

5.3 The relationship between Workforce and Organisational change

The important success factors of this research, “Workforce” and “Organisational Change” can also lead to failure. Mazur [31] conducted research on the factors in Kaizen and they recommended that a team’s commitment to change, managements understanding of CI and the organisations investment into building a CI knowledge base, are important success factors. Further supporting the constructs that defined the significant ‘Workforce’ factor.

The development of an explicit behaviour change program with measured improvements targets, and reward system was found to support successful CI programs from the study on organisational values that underlie CI by Jabnoun [32]. Lodgaard [2] investigated the main organisational and managerial barriers to CI success and found an inconsistency between the perceptions of CI among senior management and workers. Whereby senior management identified the shortcomings of the program to be information systems and improvement methods, while workers identified their shortcoming as the lack of commitment from management.

These shortcomings compare with the findings in this research, whereby the core constructs of ‘Workforce’, namely management commitment and staff engagement, are significant to the success of CI. Further support into these findings of significant factors i.e., workforce and organisational change, is the study of CI in an emerging market by Nguyen [14]. They identified top management commitment, change agent participation and management and employee development as critical in facilitating CI practices.

CI needs to be prioritised within the organisation and staff and management are required to be adequately trained and to understand their purpose. Management commitment and training was a key finding for successful CI programs according to the study by Garcia [13]. The two significant factors in this study, being Workforce and Organisational change, are supported by the findings in Garcia [13]. Namely, the element of management commitment to the CI programs is significant as well as the organisational change. These factors together lay the basis for a successful CI strategy. The framework for CI programs gets created when the is commitment from senior management who assign resources to the program and creating a vested interest for success. This is where the commitment is translated into organisational change programs. Awareness and training are how the commitment is communicated within the organisation. Eventually the culture of the organisation becomes one of continuous improvement. By focussing on the right factors, the necessary outcomes of a CI program can be achieved and becomes part of the culture of the organisation, as noted in the findings of this research.

5.4 Quality management system and tools are not initially important

The factor "Quality Management" that formed part of the regression analysis was not statistically significant. This factor focussed on the tools, used as methodologies, in CI programs. The methods included the resources allocated, the processes executed and the performance metrics and measurements of the CI program. From the literature quality management or quality tools were found to have shortcomings when it comes to implementation of the programs [33]; [34]; [35]; [36]. When considering quality management as a factor it cannot be successfully executed as part of a strategy if there is no commitment from leadership highlighting the importance of the "Workforce" factor. Therefore, workforce and organisational change are the foundational factors to be executed in terms of a CI strategy, prior to any additional factors being implemented.

6. CONCLUSION

The key focus of this study was to investigate the significance of the "Workforce" factor in CI that led to successful CI strategies in South African investment companies. This was a novel study in the South African context. The leading factors for CI successes were identified from the literature review and were used to conduct the research project.

From the results it was determined that the "Workforce" factor was statistically significant in contributing to the success of CI strategies. Therefore, the null hypothesis was rejected in favour of the alternative hypothesis, which was confirmed.

6.1 Major Findings

The major finding of this research paper confirmed that the "Workforce" factor plays a significant role in CI strategies in investment companies in South Africa. Another factor that was deemed to be statistically significant was "Organisational Change". Other factors investigated were deemed to be statistically insignificant and did not materially explain the variance in the data.

The most significant factor highlighted in the study, "Workforce" consisted of various constructs that were clustered together, which included 'Management and stakeholder commitment to continuous improvement' and 'Staff Engagement.' Workforce commitment was particularly centred around management and stakeholder commitment to continuous improvement, and staff engagement. The findings from the research regarding this factor are that workforce across all levels of the organisation is part of the critical success of a CI strategy. Success stems from the commitment and investment that management has in the program and the buy in and execution of the program across all staff in the organisation.

6.2 Implications for organisations

The significant "Workforce" factor highlighted in this research is an important focus area for South African investment companies to successfully implement CI strategies. A successful CI strategy needs senior management commitment, and the entire workforce of the organisation needs to be involved in the CI strategy. The success of the strategy is when the entire workforce is committed, they understand the strategy and are part of the change.

6.3 Significance of findings

This research into the significance of the "Workforce" factor of continuous improvement strategies in selected investment companies within the financial service sector in South Africa has not been done before. The findings of this research lay the groundwork for future studies in a sector that had been under researched as noted in the literature review. The findings in this research can inform companies in the sector on what they could focus on in terms of their CI strategies to ensure a greater chance of success.

6.4 Limitations of the Research

Although this study has statistically significant results the sample size is relatively small in relation to the overall industry. Caution should be applied when drawing inferences to other organisations in the investment sector.

The factors investigated were predetermined in the study and drawn from previous research. There may be other factors that could play a significant role in CI programs in the industry that were not covered in this research.

The study has employed a convenience sampling technique, which is a type of non-probability sampling method. The negative aspect of this method is that the results of the study cannot be extrapolated into the wider population.

The survey participants were responding to scenarios within their organisation at a point in time. Organisations could be in different stages of CI implementations or programs and therefore the results could change if taken again at a different point in time.

There is a lack of prior research in this area relating to South African investment companies thereby limiting the comparisons. However, this report can serve as a baseline study for future research on South African investment companies.

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