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PREFACE

The conference of the Southern African Institute for Industrial Engineering (SAIIE) showcases the fantastic industrial engineering work that is being done and develops young authors, reviewers, practitioners and researchers. This is the 31st SAIIE conference and highlights its resilience and strategic importance.

Each year, I am amazed at how the submissions to the conference provide a window into the current challenges and opportunities that Industrial engineers are facing in South Africa and the world. And each year, I am proud to be associated with a community that is actively seeking ways to understand and solve problems and make the world a better place. The theme for this conference was inspired by emerging topics from the previous conference and I am pleased to see how this year's submissions emphasise how industrial engineers are truly embracing the environmental and social challenges that we all face in our future.

I was particularly pleased this year to see the diverse range of authors who have submitted full papers to the conference. We received submissions from practitioners in industry, students at university and experienced South African and international researchers. The conference proceedings also include papers from 10 of the 11 academic institutions with industrial engineering departments in South Africa which is incredibly encouraging.

For this conference, prospective speakers were offered the option of submitting full papers or abstracts only. Successful submissions from both categories were invited to submit a presentation to the virtual conference event and to take part in a virtual panel discussion in streamed 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 on-line feedback and records all reviewer feedback and editorial decisions taken during the process. Papers were allocated at least two reviewers, often teaming up an experienced academic, with a less experienced author, to facilitate a true **peer**-review process. This also provides a learning experience for the less experienced reviewer, without sacrificing the credibility of the peer-review process. Only papers that passed the peer-review process are published in the conference proceedings. In addition, each reviewer's feedback was considered, a rating calculated, and papers were then ranked. After checking for suitability, the papers with the best ratings were selected for the special edition of the South African Journal of Industrial Engineering (SAJIE).

A total of 93 full paper submissions were received and 71 of these were accepted after the peer-review process. The conference programme also includes 6 abstract and presentation only submissions, 4 invited, keynote presentations and 3 workshops. 17 papers were selected for the special edition of the journal, and as a consequence these papers were withdrawn from the proceedings.

This conference, therefore, has three outputs:

• The ***Conference Programme*** which includes an abstract of each full paper and other non-peer-reviewed submissions (abstract only submissions, workshops and invited presentations) to enable the delegates to plan which sessions to attend.

• The ***Conference Proceedings*** (this document) which is an electronic document distributed to all delegates, and contains full papers that were 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 on-line via the SAIIE website and are on the conference website hosted and archived by Stellenbosch University to ensure that the papers are accessible and indexed by scholarly search engines.

• 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.

I was excited and honoured to be given the opportunity to be the editor of the conference proceedings this year, but I could not have done it alone. Thank you to Hanneke Meijer who acted as track director. Your professional and diligent work made the editorial process so much more enjoyable. Thank you to Lynette Pieterse and Thereza Botha for all the administrative support and for re-directing so many emails and queries. In addition, these conference proceedings would not be possible without the time and wisdom that is given, voluntarily, by all our reviewers. I know that every paper that has been published is better due to your input. And 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 Corné Schutte for your guidance and mentorship and for trusting me with the proceedings this year.

I trust that you will make the most out of the combined efforts of our authors and editorial and conference team and will enjoy the 31st Annual SAIIE Conference. I also hope that everyone will find value in this publication and be inspired by the ideas and work that is included.

Dr Teresa Hattingh
Editor
September 2020

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SUSTAINABILITY OF QUALITY PRACTICES: A MAINTENANCE PERSPECTIVE

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ABSTRACT

The implementation of international quality management standards encompasses a range of variables to achieve organisational efficiency and effectiveness. Effective implementation enables process optimization, cost reduction, product conformance, and a range of other benefits. However, some adopt quality management systems (QMS) but are unable to maintain it due to its labour intensity. The aim of this paper is to investigate factors that influence the sustainability of the adopted quality management practices in a maintenance business using the ISO 9001:2008 (international organisation for standardisation) as a QMS. Qualitative data was obtained from ten purposively selected respondents who were subjected to in-depth interviews. These were analysed through a framework analysis to provide insight into the current problem and recommend possible solutions for improvement.

Keywords: quality, sustainability, industrial engineering

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1 INTRODUCTION

This paper focuses on investigating factors that influence the sustainability of quality management practices adopted by the maintenance business. Sustainability is becoming a very important element in various industries and it poses a growing challenge to various organisations [1]. Souter and Maclean [2] emphasize that sustainable consumption and production needs to be dealt with differently compared to how it had been done in the past. The challenge of sustainability is evident in the South African economy which is gradually becoming more competitive. This necessitates the evaluation and implementation of effective quality management practices to improve organisational performance [3]. Non-compliance of quality practices result in customers finding alternative suppliers and competitors taking advantage of the situation. Sabella and Kashou [4] pointed out that organisations are continuously trying to improve their processes and productivity in response to the dynamics of the industry. Increased competition, diverse customer demands and an inconsistent economy in various countries resulted in an unstable market [5].

Furthermore, it is important to sustain quality management practices adopted by organisations. Most of the significant factors affecting quality management practices are associated with inadequate planning arrangements for quality, poor communication of quality requirements and a deficiency of consciousness in terms of the benefits associated with quality management [6]. However, there are various organisations that still encounter challenges in sustaining an improved quality management system. According to Henning [3], it has lately become challenging for organisations to remain competitive during these uncertain times to keep efficient operations. Abdullahi et al [6], allude to the fact that the fundamentals of quality management and control measures are achievable as the consequence rather than preventative and continuous performance improvement. It is of paramount importance to be mindful of the quality management practices minimum requirements standards [6].

The challenges of sustaining effective execution of the quality management practices result from various aspects and are demonstrated by organisations employing other versions of quality management practices. Mokhtar et al [7] argue that globalization and technological advancements pressure organisations to seek excellence, and this has led to the question of quality management in all industries. Therefore, this paper focuses on investigating factors that influence the sustainability of quality management practices in a maintenance business. Numerous organisations strive to improve business performance through various means, however the sustainability of these initiatives are seldom evaluated.

2 LITERATURE REVIEW

Quality management practices (QMPs) involve a diversity of quality management programs and plans that can generate improved products, enhanced services, reduced costs, and improved customer satisfaction, [8], they further assert that quality management practices are perceived as organizational innovation drivers. In other words, quality management practices are quality management approaches and quality management systems that are employed by an organisation to meet quality standards as per customers' requirements. Quality tools, techniques and strategies form a vital component of Quality management (QM) practices that drive customer satisfaction [9]. QM practices encompass total quality management (TQM), statistical process control (SPC), quality assurance (QA), top management support, employee involvement, customer focus and so forth [10]. It is always encouraged that QM implementation be supported by the entire organisational team including top management to ensure smooth running of products, processes and services. The success of any business is reliant upon the adaptation of products, processes and services within global standards.

It is therefore imperative that organisations seeking competitive advantage actively embrace the maintenance and sustainability of such practices.

2.1 QM tool applications

In a study conducted by Gadenne et al [11] on QM practices within SMME performance, it was discovered that factors such as supplier partnerships, management commitment, increased communication with customers and employees foster positively to organisational performance; factors such as lack of top management support, human resources overload, aversion of change, lack of education and training, lack of external support hinder QM practices. Within QM practice, quality culture and top management support are imperative for success [12]. It is evident that QM is assisting numerous companies to experience positive results especially within the Small Medium Enterprises (SMEs) [10], [11], [12]. Jirapattarasilp [13], like other researchers in other countries conducted a research study in electrical and electronics regarding QM practices in Thailand, and discovered that QM policy, top management engagement, scientific management and process management were drivers of change [14]. The systematic review into QM practices in India evaluated factors such as the impact of education and training, information technology, project management, workforce and top management support on quality aspects as important factors for improvement [15].

2.2 Quality management system – ISO 9001:2008

A quality management system (QMS) is a method used to guide or direct an organisation in providing expected products or services based on specifications [16]. Equally important is that organisations that adopt this quality standard (ISO 9001:2008) and apply it effectively rather than using it as a marketing and promotional tool, are expected to benefit internally and externally, if effectively implemented and maintained. More importantly, the main purpose of ISO certification is to improve the quality standard of an organisation while eliminating waste, intensifying productivity and efficiency, and improving the sustainability of the company [17].

It has become a norm that organisational performance by various researchers is normally linked to successful implementation of quality management systems [17]. Talib et al [18] supports this phenomenon and argues that business performance and customer satisfaction is due to satisfactory implementation of quality management. In addition, the study conducted by Addae-Korankye [19], indicated that a quality management system has a positive contribution towards company performance with regards to cost, innovation, reliability, efficiency and effectiveness of the operation. It is of vital importance to note that any success in any company requires change in conduct in all activities. Lakhal et al [10], argue that a Quality Management system has to do with strategic planning and resource alignment that coincides with the organisational strategy.

2.3 Principles of ISO 9001:2008

The two principles applied and evaluated in this study are customer focus and continual improvement. Mahmood et al [20] define these two principles of quality management system as follows:

- Customer focus: It is argued that businesses are sustained by their customers. Thus, businesses should strive to ensure that customers' needs and requirements are met according to their specifications or expectations. This means that the survival of the organisation depends on the satisfaction of the customers, based on the service rendered.
- Continual improvement: An organisation is required to prioritize continuous improvement to ensure that it enhances its standard operations and processes.

Continuous improvement enables businesses to grow and gain a competitive advantage. In other words, a continual improvement drive is vital for the development, growth, and sustainability of the organisation. Therefore, these principles are applied in the proposed quality improvement framework.

3 RESEARCH METHODOLOGY

This paper adopted a judgmental sample, also known as purposive sample, and according to Tongco [21], this is the most familiar sampling approach. The researcher selected the most appropriate sampling method relevant to the category of participants and the research questions. In this study, 10 employees were selected to participate in this study, namely those employees who were most likely to be familiar with and have expertise in quality management practices in the maintenance environment out of a total of 12 employees in the section. The following applicable steps were adopted: deciding on the research problem; determining information required; defining qualities of the participants required; reliability and competence of the participants; application of appropriate data-gathering techniques, analysing data, and interpreting results [21]. The authors, Creswell [22]; Srivastava and Thomson [23] further articulate that data collection should be objective and systematic. In this study, in-depth structured interviews were conducted as a primary source of relevant data. Creswell [22] highlights that in qualitative interviews, the researcher focuses on face-to-face interviews, telephone interviews, and focus groups. In addition, these interviews are based on unstructured and open-ended questions. However, this paper adopted and applied a semi-structured interviewing technique. Semi-structured interviewing, especially by applying open-ended questions, permitted the researcher to gather in-depth information on pertinent issues experienced in this environment.

4 RESULTS AND DISCUSSION

The results are based on the analysis of the data collected through the application of thematic analysis followed by discussions of the familiarization process, thematic framework, indexing, mapping, and interpretation.

4.1 Familiarization process

According to Srivastava and Thomson [23], familiarization is a process through which the researcher becomes absorbed in the collected data by listening to the audiotapes and studying or reading the transcripts thoroughly. In addition, this process will enable the researcher to identify and note key ideas and recurring themes [23]. From the researcher's perspective, familiarization of the data is the first step of framework analysis required to fully understand the topic at hand in order to generate ideas and themes from the responses of all the participants during the collection of data. In this study, the author familiarized himself through early consideration of the structure, content of data collection, and ensuring consistency during the interviews. Furthermore, in the familiarization process, common themes were identified, which are elaborated upon in the next section.

4.2 Thematic framework of responses

The thematic framework comprises five main themes, each with its own subcategories. The main five themes are the following:

- Theme 1:Current practices - include failure to reach customers' demands, and substandard quality of products and service.
- Theme 2: Challenges - include attitude, skills, poor workmanship, and sustainability.
- Theme 3: Intervention - includes training and awareness, revision of quality policies, and quality audits adherence.
- Theme 4: Expectations and outcomes - include quality standard compliance and product/service quality improvement and effectiveness.
- Theme 5: Relationship - includes continual improvement and service quality effectiveness, and customer focus and customer satisfaction.

4.2.1 Relationship between the current practices and intervention themes

Failure to comply with customers' demands and preventing substandard quality of products and service requires interventions such as training and awareness, revision of quality policies, and quality audits adherence. It is clear that the current practices theme requires intervention in training and awareness, revised quality policies, and quality audit adherence in order to execute work efficiently. In other words, current practices which result in failure to comply with customers' demands and the substandard quality of products and services have to be improved through intervention. It is important to note that different core quality management practices may lead to success in the different dimensions of quality. These dimensions may function differently in terms of order winners and order qualifiers.

4.2.2 Relationship between the challenges and intervention theme

Intervention is required to address the challenges relating to attitudes, skills, poor workmanship, and sustainability. This study is based on quality management practices and is therefore geared towards addressing the challenges around quality effectiveness. It is clear that current practices can be improved through an appropriate intervention, which can also address the challenges, expectations, and outcomes viewed as outputs. The interventions employed to improve skills and responsibility levels are considered inputs, and addressing the challenges towards attaining the desired expectations and outcomes are considered outputs.

Outputs include adherence to quality standards and compliance, and product/service quality improvement, in line with the goal of this paper, namely to investigate factors that influence the sustainability of quality management practices in a maintenance business. It means that there are challenges that are embedded in the failure of effective practice and quality standards adopted by the business, and the challenges that involve attitude, skill, poor workmanship, and sustainability.

4.2.3 Relationship between the interventions, expectations and outputs

Not only do outputs include quality standards compliance and product/service quality improvement, it is also the responsibility of each organisation to ensure that quality improvement is a core component of the ethos and systems that guide that organisation. However, in order to address these challenges and accomplish effective and a quality standard of practice, the intervention theme highlights tools or strategies that can be employed such as training and awareness, revision of quality policies, and quality audits adherence. As a result, quality standard compliance and product/service quality improvement are expected as an outcome. There is clear evidence that training and awareness, revising quality policies, and quality audits adherence can influence quality standard compliance and product/service quality improvement. Equally important, in a process where there is a correlation between the challenges, inputs and outputs, it is clear that the relationships among the significant parameters are likely to be improved.

4.2.4 Relationship between the interventions, expectations, and outcomes; and relationships theme

The relationships between the various challenges, inputs, and outputs can be illustrated thus: failure to meet customers' demands; continual improvement; continual improvement and service quality effectiveness; substandard quality of products and service and customer focus; and customer focus and customer satisfaction. These relationships are also highlighted in the quality improvement framework as challenges, inputs, and outputs: firstly, failure to reach customers' demands (challenge), continual improvement (input), and service quality effectiveness (output); secondly, substandard quality of products and services (challenge), customer focus (input), and customer satisfaction (output). These sequential relationships are supported by extensive and substantive studies. Voon [24] argues that the success of quality management should be consistently monitored and evaluated, and customer satisfaction can be ensured by adhering to the relevant criteria. Therefore, customer focus is regarded as one of the main pillars in the implementation of quality management [24]. Furthermore, all resources invested in implementing QM are directed towards achieving the objective of satisfying customers. The next section discusses the analysis of indexing.

4.3 Indexing

Indexing process involves, firstly, the themes or concepts derived from the data must be identified; secondly, meticulous proofreading of the text is recommended to enable the researcher to identify which parts of the index are applicable; and thirdly, other categories may be required to refine the initial index. The index is expanded as each theme, its categories, and significant examples, are added. The themes emanate from the collected data, while the relationship between the main theme and its categories and applicable examples are based on the responses of the participants and interviews. The next section discusses the mapping of the quality improvement framework of this paper.

4.4 Mapping of the quality improvement framework

This section provides a summary of the data collected, taking into account the various themes and categories referred to in section 4.2. The relationship hierarchy (sustainability framework) highlights the results of this study. The term "hierarchy" applies to the interrelationships within an organisation [24]. Figure 1 highlights the interrelationship of the themes which are organized accordingly to their significance and influence on each other.

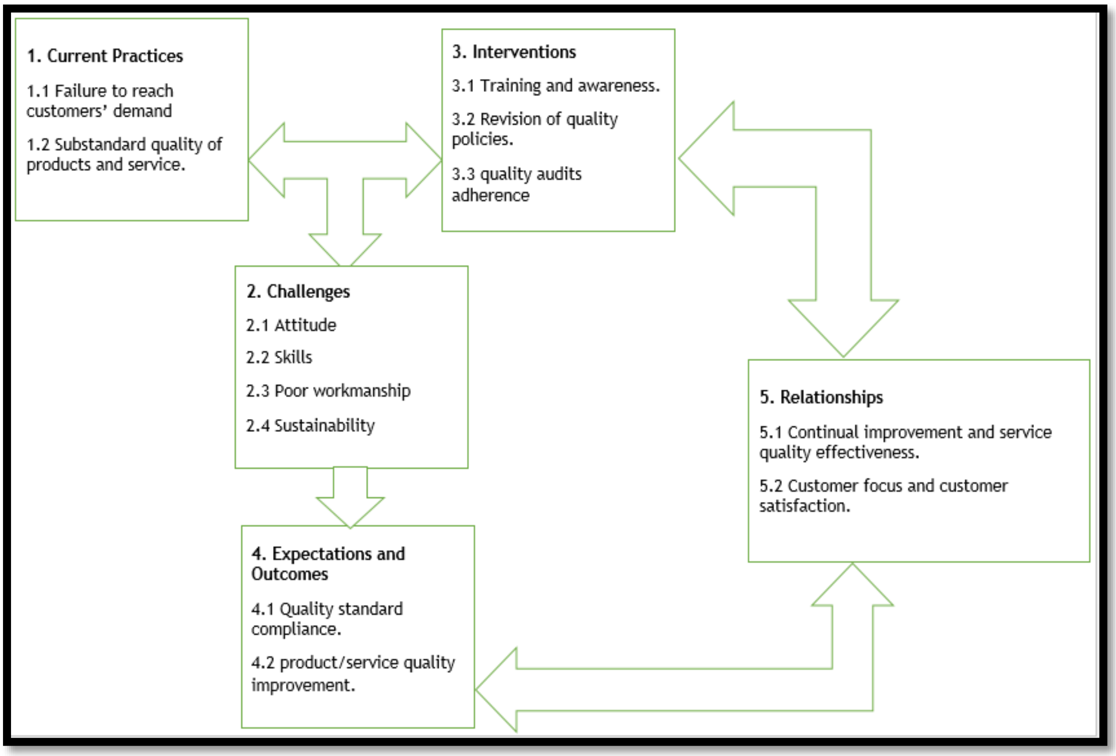

Figure 1: Sustainability framework (quality improvement framework)

4.4.1 Discussion on the quality improvement framework

The aforementioned sustainability framework is the quality improvement framework of this paper, and it highlights the relationship between the current practices, challenges, interventions, expectations, and outcomes. It is evident that the challenges, namely attitude, skill, poor workmanship, and sustainability are negatively impacted by the failure to deliver on customers' demands and the substandard quality of products and services, despite the existence of a quality management system. Intervention is therefore required to address these challenges in order to improve the sustainability of the quality management practices. The improvement in expectations and outcomes would consequently enhance the relationships within the parameters of quality management practices.

5 RECOMMENDATIONS AND CONCLUSION

Failure to implement proper training and awareness with regard to a quality management system and how it should be approached and implemented may negatively affect its effectiveness, implementation, and sustainability. The implementation and outcomes, based on set standards, must align with customers' requirements and organisational needs. These standards guide and direct an organisation to produce and render high-quality products and services that would result in customer satisfaction and customer retention. When the confidence of the customers and other interested stakeholders is attracted and retained, then sustained success is achieved. Constructive interaction with customers adds value to the sustainability of quality management. Organisations are required to understand the current and future requirements of their customers and other interested stakeholders, thus contributing to the growth and sustained success of the company.

5.1 Recommendations for policy

It is recommended that organisations not only adopt a quality standard system as a marketing tool but also deliver on its objectives. Abiding by the provisions of such a standard can influence and impact customers' expectations, customer satisfaction, customer commitment, and customer retention. The benefits can be substantive, depending on how the organisation executes its quality standard and how it addresses the challenges, from the customers' perceptive. It is mandatory that organisations provide assurances to their customers that the high quality service and products they expect, will be delivered.

5.1.1 Adoption of continual improvement drive and customer focus

It also is recommended that in order for organisations to be successful, a continual improvement drive and customer focus must be adopted. Without a doubt, customers' involvement is one of the important elements of customer satisfaction and retention, both of which could lead to growth and the success of an enterprise; equally important is quality management in achieving customers' requirements and striving to surpass customer expectations; also to communicate and understand customers' current and future needs and expectations, integrating improvement initiatives, and adopting new development processes for optimally executing the entire operations of the organisation.

5.1.2 Employees equipped with work skills

It is vital that organisations introduce up-to-date improvement strategies to ensure that employees are equipped with the necessary skills which would positively impact their attitudes and expertise. These are among the challenges identified. It is evident that there is systematic logic in these challenges, starting with skills development, and organisations ensuring that their employees are equipped with appropriate and quality skills required for the work. Improvement in skills will positively impact the attitudes of the employees towards their jobs, and will improve on, or reduce, poor workmanship. Moreover, there would be consistency and sustainability of quality work based on the specifications and requirements of the customers.

5.1.3 Recommendation for practice

It is recommended that organisations adopt the international quality standard ISO 9001:2008, employ and sustain a quality management system according to their desired goals. It is important that an organisation adopts a quality standard and quality approach to deliver its products or services in order to be considered an ISO 9001:2008-certified organisation. It has been highlighted in this paper that quality standards influence customers' expectations and satisfaction, customer commitment, and customer retention. The benefits are numerous, but it also depends on how this quality standard is implemented, and how challenges are addressed, from the customers' perceptive.

5.2 Recommendation for further research

This paper has demonstrated the various relationships between challenges, inputs, and outputs. However, a number of problems have been identified from the findings in relation to quality management practices, which need to be addressed for future study; firstly, that a quality management system - ISO 9001:2008 - be adopted and applied in an organisation as a marketing tool; secondly, the challenges that inhibit the effective quality management practices such as poor attitudes, workmanship, and skills, need to be investigated. However, should an organisation manage to adopt and implement various strategic improvement methods or practices, the challenge of sustainability remains a factor.

6 CONCLUSION

Senior management commitment to change and sustainability of systems is of paramount importance. This demands leaders who have a vision and are able to steer the organisation towards success. The implementation of QM practices requires the participation of all members in the organisation who ensure that the practices are effectively implemented in various aspects of products, processes and services.

To conclude, it is imperative that an organisation adopts the kind of quality management system that would effectively ensure that the organisation, as a supplier, complies with quality standards. It is important that the quality management system aligns with the execution of the organisation's activities and customers' satisfaction, based on quality requirements and quality compliance. However, despite the benefits and value of a QMS, organisations, especially those that are ISO certified, are undoubtedly influenced by various aspects from within the organization. Customers determine their own requirements and specifications of the service or products that would satisfy their needs.

Equally important, although customers' involvement is prioritized, there are challenges or factors that can inhibit the effective performance of quality management. The adoption of this standard and the continual advancement of customer satisfaction would enable businesses to ensure that customers' needs and requirements are met according to their specifications and expectations, as well as the organisation's development, growth, and sustainability. It has unequivocally been demonstrated that continual improvement is important for any company to sustain its current levels of performance, while also responding to changes in its internal and external conditions, and establishing new opportunities.

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ERGONOMIC ASSESSMENT OF WORKERS IN THE CLOTHING AND TEXTILE INDUSTRIES

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ABSTRACT

The production of textiles and clothing, inclusive of its associated activities continue to drive the industrial economy globally. Workplace dynamics play a crucial role in optimising productivity while reducing costs. This study adopted a reflective approach to explore on the importance of ergonomics through a comparative analysis of the clothing and textile industries due to its impact on productivity as well as the well-being of operators. Findings from the researcher's post graduate studies reflect that operators continue to perform manual labour under unhygienic and disorganised conditions. This paper highlights the spinning process that is adopted in textiles with a machining process in clothing manufacturing. The methodology employed in this study was reflective in nature using data gathered through discussions and observations during the researcher's postgraduate studies. The study extrapolates the need for effective ergonomic principles in achieving and maintaining a healthy workforce for sustainable productivity enhancement.

Keywords: ergonomics, industrial engineering, health and safety

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1 INTRODUCTION AND BACKGROUND

The garment manufacturing sector plays an important role in the economic development of countries due to its ease in set-up and the creation of jobs for masses, thereby improving the sustainability of the lower income earners. The sector contributes significantly to the process of industrialization in the developing countries. This sector later evolved into becoming a major role player in developing countries today [1].

FW Taylor, the pioneer of scientific management was able to break jobs into tasks and further into elements [1,4]. In this way he was able to achieve maximum safety, comfort and efficiency in the mining industry. The methodology of work-study was able to catapult productivity improvement by 400%. The application of work-study, with its major components of work measurement and method study is capable of significantly re-engineering current practices in all types of industry. In this study two major industry processes are compared. The first is the clothing industry where machinists sit for the major part of the day (normally from 7.00am to 4.30pm) and the second is the Ring Spinning process in the textile industry where operators stand most of the day (basically from 7.00am to 7.00pm) and manage up to 12 machines, depending on the diameter of the thread that is spun.

The clothing industry is labour intensive while the textile industry is machine intensive. Operations in both industries require skilled manipulation of materials using the fingers, wrist and hand for the major part of the working day. Poorly designed workplaces ultimately contribute significantly to cumulative trauma disorders (CTD's) which range from musculoskeletal disorders to the hand, neck and shoulders. This group of injuries are known as repetitive strain injuries (RSI). Ergonomic interventions are able to dynamically improve and redesign workplaces and material handling equipment that create an enabling environment to reduce health problems, accidents and reduce absenteeism.

The ring spinning process is a critical process in the manufacture of sewing thread. The ergonomic issues in this process can be broken down as follows:

- Loading the machines (with the use of a ladder)
- Doffing the machines (removing output)
- Moving the spun yarn to the autoclave (movement to oven)
- Patrolling the machine
- Repairing broken thread

The machining process is the critical process in clothing manufacture. The ergonomic issues in the machining process are as follows:

- Reaching out and pick up parts of material
- Aligning parts
- Sewing parts
- Manipulation of parts during sewing
- Disposing completed unit

2 LITERATURE REVIEW

Properly implemented ergonomic interventions impact organisations positively, thus reducing workers' compensation costs, reduction in lost time during the machining cycle, reducing absenteeism, improvement in workplace dynamics, redesign of material handling equipment, labour relations, productivity and quality [1,14]. Successful ergonomic interventions improve critical operations, thereby contributing to competitive advantage of the organisation [1]. Ergonomics should also be seen from a sustainable development point of view and should be part of the overall strategy of organizations to reduce their impact on the planet while at the same time contributing to sustainable development goals [2,3]. The process of turning raw materials into finished garments has significant negative environmental and social implications, including air and water pollution [3]. The triple bottom line approach suggests that companies should consider social and environmental performance, not only financial performance, in their business operations [2]. According to the United nations [3] there are 17 Sustainable Development Goals depicted in figure 1 that impact the planet.

Figure 1: Sustainable Development Goals to United Nations [3]

The garment industry could positively contribute to Sustainable Development by designing workplaces (man-machine interface) efficiently and effectively through ergonomics principles. This would safeguard good health and well-being of operators while reducing pollution to the natural environment (air, land and water) thereby positively contributing to clean water, responsible consumption and production, decent work and economic growth [3].

Ergonomics is defined as an interaction within the system of human and material elements that enables the operator to perform optimally with minimal health and safety impacts [4]. The objective is to ensure the best fit between the worker and the environment thus maximising worker health and safety while reducing fatigue and discomfort [4]. It promotes the aspects of 5S principles so that the workplace is productive, efficient and safe [4]. Fernandez and Goodman [5] defined ergonomics as the study of the design of a workplace, equipment, machine, tool, product, environment, and system which takes into consideration a human being's physical, physiological, biomechanical, and psychological capabilities and optimizes the effectiveness and productivity of work systems while assuring the safety, health, and well-being of the workers.

2.1 Goals

The importance of ergonomics is ascribed to numerous factors that impact the health and safety of operators who are an integral part of the production process. Evidence gleaned from studies [1,2,3] include the escalating expenses due to work-related injuries or illnesses. Safety, health and environmental (SHE) related policies and procedures enable the regulation of work around the world. Continuous monitoring from government, labour unions and insurers increased employee awareness of health and safety matters in the workplace in both the service and manufacturing environments [6].

Gunning et al [7] argues that ergonomics aims at preventing injuries by controlling the risk factors such as force, repetition, posture and vibration that can cause injuries. Some fundamental ergonomic principals that should be followed in workplaces are:

- Use of proper tools: Tools should be appropriate for the specific tasks being performed.
- Keep repetitive motions to a minimum: Workstations or tasks can often be redesigned to reduce the number of repetitive motions that must be performed. Using a power-driven screwdriver or tools with a ratchet device can reduce the number of twisting motions with the arm. Some tasks can be automated or redesigned to eliminate repetitive movements and musculoskeletal injuries.
- Avoid awkward postures: Tasks/jobs should not require people to work with their hands above shoulder height on a regular basis. Arms should be kept low and close the body. Bending and twisting of wrists, back and neck should also be avoided.
- Use safe lifting procedures: Avoid lifting objects that are too heavy. Use more than one person or a mechanical device to reduce the load. Workstations should not require employees to lift objects above their head or twist their back while lifting. Employees should keep the load close to their body and ensure that they have a good grip. Heavy and frequently lifted objects should be stored between knee and shoulder height – not on the ground or above the head.
- Get proper rest: Employees need to rest their body and mind in order to prevent injuries. They should give their muscles a rest during coffee breaks, lunches and weekends by doing something different from what they do at work [8,9].

The proposition advocated by Gunning et al [7] are supported by Patil et al [10] suggests that garment workers should use proper shields on high-speed sewing machinery or safety glasses where appropriate to prevent eye injury. Also, adequate task lighting at individual workstations can prevent eyestrain.

In the South African context, the implementation and adherence to health and safety regulations are often compromised by micro enterprises, especially clothing and textiles. Systems of attaining the root cause of illnesses often go by unattended. Operators are often asked to visit their clinics for medication without proper diagnosis of the root cause of illnesses. Many SA organisations instituted penalties for organisations that do not comply with Occupational Health and Safety regulations. Fines were instituted by government through investigations requested by labour unions. Increasing government interventions, together with social media and insurer-sponsored education and training programmes have increased the awareness of ergonomics as an important component of worker-health. The increased knowledge of workplace dynamics and worker fatigue improve the practice of process improvement methodologies and method studies for appropriate ergonomic management practices [11].

The workplace is centred around the efficient movement of product within a product or process layout configuration. The clothing industry machining area is based on product flow through the various sewing operations. The textile industry is configured with a process flow where the product moves from process to process. In both instances, operators perform optimally throughout the working day. As humans, fatigue, boredom and tiredness consume energy at a rapid rate. It is therefore necessary for a workplace to be well designed to eliminate such factors. The focus in the production environment is always on maximising production without due cognisance of possible injury, production repairs (errors) and efficient motions [12].

The concept of “adaptability” of people into the workplace is generally the norm in this fast- paced industry. Operators often work under strenuous conditions in terms of space limitations, poor lighting, lack of fresh air, uncomfortable chairs and so forth. This promotes quality deficiencies, inefficient and ineffective use of resources, absenteeism, disability and disease. It is difficult for the human body to adapt to every situation. People are different and have limitations which are not thoroughly evaluated before the employment contract is signed [13].

National and international literature promulgates that the lack of an ergonomics programme promotes a multitude of issues relating to illnesses sustained by employees. Every sphere of the workplace is in need of constructive effort to improve workplaces so as to improve the current status. Simple and innovative changes would enable the operator to adapt adequately, thereby improving employee health and safety while increasing productivity and quality. Ramdass [14] argues that typical losses from the failure to apply constructive ergonomics include:

- Lower production output
- Increased lost time
- Higher medical and material costs
- Increased absenteeism
- Low-quality work
- Injuries, strains and fatigue
- Increased incidence of accidents and errors
- Increased labour turnover
- Less spare capacity to deal with emergencies
- Reduced productivity
- Reduced competitiveness

Employees show their frustration in different forms. Absence is one of the ways that employees indicate their unwillingness to operate effectively. There are numerous repercussions when employees are absent. The following are impacted in both the clothing and textile industry:

- Late delivery – cancellation and loss of orders
- Line balancing – disrupts the smooth function of the assembly line
- Price compromise
- Waste
- Reduced production
- Quality problems

With an economy that is not stable, every effort is required to improve productivity and efficiency in order to remain sustainable.

The purpose of this article is to demonstrate that effective application of ergonomics can improve performance and lead to the enhancement of organisational capability and overall sustainability of society, planet and profits.

3 METHODOLOGY

The primary methodology applied in the study is critical reflection and considers past empirical evidence gleaned from the researcher's masters and doctoral studies in the South African clothing and textile industry over a period of forty years. Reflective practice involves mental speculation that is practiced in qualitative research that re-evaluates activities that have already been done previously, to re-iterate its value as well as providing arguments to it [15,16]. Reflection is a critical rational practice in the research field [15].

In view of the decreasing size of the clothing and textile sector in South Africa, the author encourages organisations to re-examine ergonomics as a competitive strategy that would enhance operator health and safety [12].

The researcher, still experiences ergonomic inefficiencies in the working environment, reflects on the status by academic and practical relevance. The importance of this is that much can be done to re-engineer current workplaces for the benefit of the operator. A comparative analysis is done to highlight that much improvement is required in all industrial and administrative undertakings that would promote worker health and safety while reducing stress and fatigue.

4 RESULTS AND DISCUSSION

In this section, the clothing industry is evaluated in terms of ergonomics, and then the textile industry. Ergonomic aspects are scrutinised in each industry and the recommendation for improvement is provided.

4.1 Clothing industry – machinist

Demographic data in the South African clothing and textile industry in Kwa-Zulu Natal indicate that majority of workers are between 40 to 60 years old, and the new generation would not consider moving into this industry due to its volatile nature. This indicates that automation and robotics may be the machinist of the future. However, such apparatus requires computational configurations, and this is where robotics, mechatronics and artificial intelligence would play a crucial role in the processing of garments. In addition, the 4th industrial revolution creates numerous opportunities for innovation but challenges in implementation due to limited "new" expertise. The development of such innovation is still to be seen over the next decade. With the clothing industry categorization into small, medium, micro enterprises (SMME's), the scope for such impactful innovation is limited due to financial constraints.

Figure 2: Sewing operators in a clothing factory [7]

Figure 2 depicts operators in a typical clothing factory product layout. On the left side of the operator is a U-shaped wooden shuttle where garments are disposed of for the next operator. In this figure the product is sewn together starting at the back of the line. The ergonomic factors that may be considered in this setting are the following:

- Anthropometry
- Seating
- Workspace

4.1.1 Anthropometry

An important fact about anthropometry is that it considers the size of the person behind a machine in a confined space. This means that the larger the size of the person, the more difficult it is to operate the machine.

4.1.2 Seating

Seating is a major problem in the clothing industry [11]. Chairs are made of steel with chipboard as the seat and backrest. Spending eight hours on such a chair is problematic. Operators try to be innovative by stuffing a pillow with waste of cut fabric. Some feel comfortable but the problem is the density of the material may be uneven and this may cause the operator to be seated unevenly. Operators continue in this manner for the last five decades. A comfortable operator is a more productive operator.

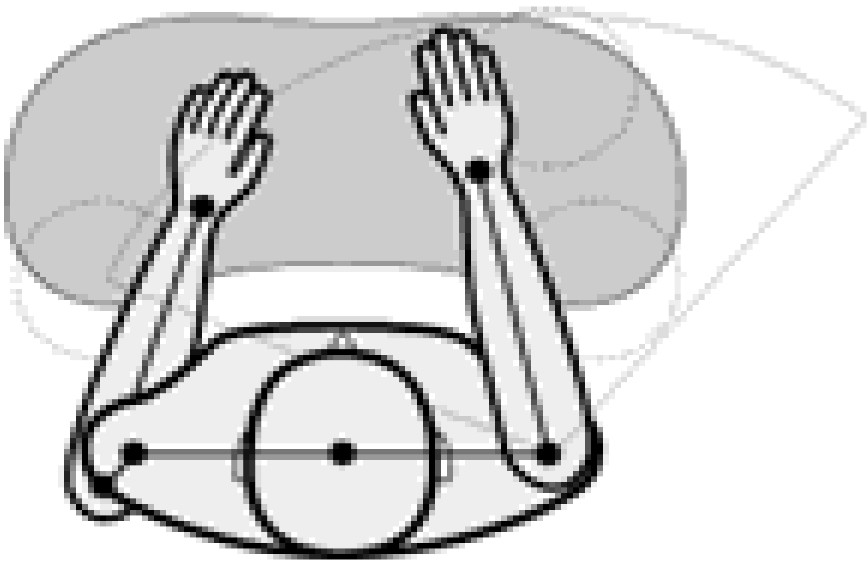

Figure 3: Normal hand movement within workspace [13]

4.1.2 Workspace

Figure 3 depicts the operator operating in a normal workspace. The operator is required to stretch out for garment parts, thread changes, bobbin changes or any other component that may be required. The stretch-out may be essential from time to time to enable the operator to move muscles that may be in one position for long lengths of time. If stretches of the upper body are regular, then the workplace requires re-organisation. This is especially important for people whose anthropometry is on the higher side. This may cause injury and strain to the upper torso.

Sewing, which is the critical component of an operator's task, accounts approximately 10-30% of an operator's time on task. Handling, manipulation and alignment of pieces of fabric is a greater portion of total time and effort in the sewing process. This is where work-aids and mechanization are important. The innovation of work-aids such as specialized foots, binding folders, disposal bins enable the operator to increase sewing time and decrease handling time. The clothing industry is accustomed to the conventional basic flat sewing table for many of workstations globally. The workstation of the future should incorporate adjustable surfaces to suit the anthropometry of the worker.

4.1.3 Workspace

The current workspace is mostly disorganized with operators moving out to do certain activities. The visibility, dust, and restrictions create an unhealthy work-area. These are the conditions under which clothing operators are expected to perform at an optimal level. Conditions are quite poor to expect productivity levels to improve.

4.2 Ring Spinning operator

The spinning process determines the quality of thread produced for the clothing industry. The ring spinning machine receives input from the preparatory machines of textile manufacturing. Figure 4 shows the roving from the speed-frame machine passes through the drafting area, the guide eye and the traveller onto the bobbin. The revolution of the bobbin inserts a turn in the roving between the traveller and the front drafting rollers. The friction of the traveller against the traveller ring and the traveller lags a little behind the speed of the spindle causing the yarn to be wound onto the bobbin. This may be different for the varied count of yarn characterized by the following conditions below:

- By increasing or decreasing the speed of the drafting rollers – it changes the twist of the yarn.
- By using lighter or heavier travellers – the further it stays behind in comparison with spindle speed, the quicker the up-winding, the less twist is inserted.

Lastly, the ring spinning process is depicted in Figure 4 and the critical areas of the process could be described as follows:

- Loading of machines with roving and filament
- Patrolling machines
- Doffing of machines

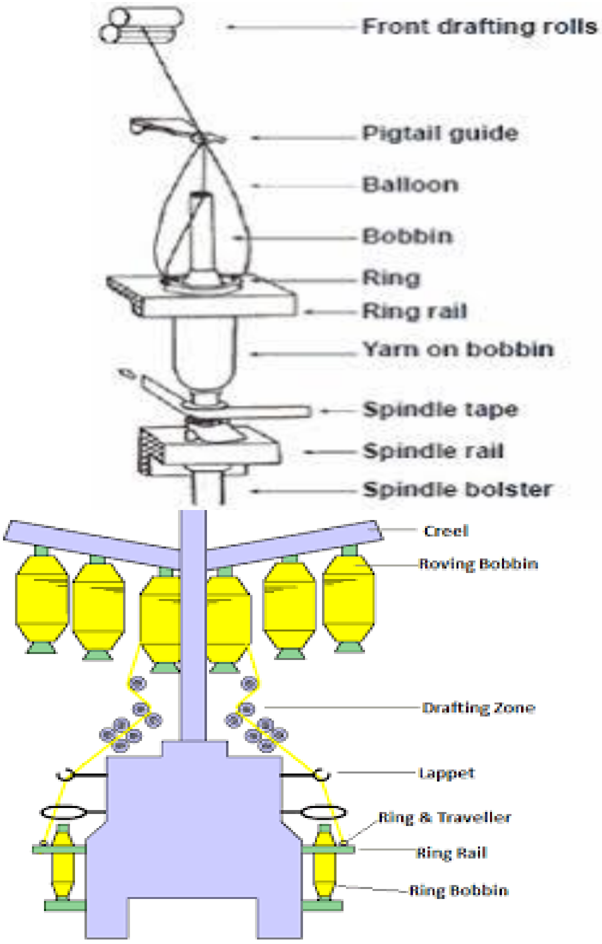

Figure 4: Demonstration of the ring spinning process [8]

4.2.1 Loading of machines

The process requires a ladder, roving and filament. This is a very demanding process and requires physical strength and stamina. Due to the variance in the running out of filament and roving, the operator may be able to cope with the work.

4.2.2 Patrolling

The operators are required to patrol between 8 to 12 machines to ensure that all 420 spindles are operating effectively. One of the problems observed was the amount of waste in the spinning area. Upon analysis of the output doff weights, it became apparent that there were major challenges in the ring spinning area. This led to a closer evaluation of the process.

Table 1: Ring spinning machine waste (Calculated)

MACHINE	NO. OF SPINDLES	NOT WORKING	LOSS IN GRAMS	LOSS PER MONTH
Machine 1	420 spindles	18 (100 GRAMS)	1800 (120)	216000
Machine 2	420 spindles	20	2000	240000
Machine 3	420 spindles	28	2800	336000
Machine 4	420 spindles	18	1800	216000

Machine 5	420 spindles	40	4000	480000
Machine 6	420 spindles	38	3800	456000
Machine 7	420 spindles	36	3600	432000
Machine 8	420 spindles	42	4200	504000
Machine 9	420 spindles	36	3600	432000
Machine 10	420 spindles	42	4200	176000
Machine 11	420 spindles	34	3400	408000
Machine 12	420 spindles	27	2700	324000
Machine 13	420 spindles	38	3800	456000
Machine 14	420 spindles	33	3300	396000
Machine 15	420 spindles	29	2900	348000
Machine 16	420 spindles	15	1500	180000
				4664000 (4664)

Table 1 depicts waste in the textile industry due to some of the reasons listed:

- Poor patrolling of allocated machines
- Broken spindles
- Machine problem
- Ring tubes that become tight on the spindle
- Spindles not started after doff (removal of outputs)

4.2.3 Doffing of machines

The operator was doing this function alone. This led to machine downtime of approximately 20 hours of machines waiting for output removal (doffing). This meant re-engineering the process. The proposed methodology proved to be effective and was implemented. The doffing process was reduced to 20 minutes. Material handling equipment was required to simplify the process. New aluminum rectangular boxes were designed with a trolley. A team comprised of 4 members started the doffing process at 4 ends of the machine. This gave more time to operators to patrol the machine. In addition, operators formed teams to help each other with the loading/offloading of machines.

Patrollers had more time to ensure that all 420 spindles operated effectively. Overall, there was improvement in quality and productivity by approximately 50%. Table 2 compares the clothing machinist with a ring spinning operator and provides an overview of the operations from an ergonomic perspective.

Table 2: Comparative analysis

Clothing Machinist	Ring spinning operator
Seated – 8 hours	Standing and walking – 12hour shifts
Chair – poor design	No chair
Anthropometry – bigger built people have a challenge in a constrained environment	Suitable for people approximately 1.7 m
Workspace - constrained	Not constrained -patrols up to 12 machines
Lighting - poor	Lighting - satisfactory
Noise levels – normally acceptable	Too high noise levels – ear muffs required
Vibration - acceptable	Vibration - acceptable
Work-area – too much dust	Work-area - Too much dust and fluff

It is important to note that the challenges faced in these two totally different operations are very similar. The operations do not provide a safe and healthy environment. It would be appropriate for operators to be given personal protective clothing to be able to function effectively.

5 RECOMMENDATION AND CONCLUSION

Ergonomics is an integral component of the system in manufacturing and service organisations. Education and training of operators, supervisors and first line management in terms of the fundamental application of work-study principles is imperative. To this end, ergonomics should become an integral aspect of the culture of the organization, where managers and operators work together to find solutions to workplace inefficiencies. Training discussions relating to ergonomics would lead to the improvement of worker health and safety, more time spent on the machining process, quality improvement, reduced defects, efficiency and productivity. This may certainly lead an organization towards being competitive in the market. It is the researcher's intention to emphasize the importance of ergonomics and its associated illnesses and its application for the benefit of all stakeholders in industry.

Technology is at the forefront of the 4th industrial revolution. The automation of clothing and textile operations would reduce the challenges experienced currently. However, it is not feasible to drastically change systems immediately. In view of this, ergonomic interventions are still applicable and would definitely improve productivity, efficiency, effectiveness and the sustainability of clothing and textile operations going into the future.

The garment industry should adopt Sustainability Development Goals (SDGs) that are relevant to its circumstances and in this study it is proposed that the garment industry should adopt Goal 3 (Good health and wellbeing), Goal 12 (Responsible consumption and production) and Goal 8 (decent work and economic growth). These three SDGs will have positive influences on the health and well-being of workers.

This article demonstrates that the application of ergonomics and a sustainable development approach to workplace design creates an enabling environment where workers can be productive. The well-being of workers not only makes business sense but is for the greater good of protecting the environment and humankind from harm. In view of the reduction of work-related injuries, time on the job would be increased, thus contributing to improved production. Ergonomics provides an excellent opportunity for organisational management to care for their employees as the human element of organisations are extremely important.

The voice of the customer in terms of a product is important, but the voice of the operator is often neglected. These interventions create the need for "respect for people" and their workspace while improving human relations. Ergonomics is a constantly growing field, and as long as people are used as the primary source of labour, there would be an endless need to make them comfortable through ergonomic enhancements in the workplace.

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DEVELOPMENT OF AN ONLINE ATTENDANCE REGISTER SYSTEM (OARS) USING BARCODE TECHNOLOGY: GOING GREEN IN CLASS

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ABSTRACT

Keeping track of student attendance in class is a key aspect in universities when monitoring potential at risk students. In most cases, tertiary institutions use paper-based registers which students sign to indicate attendance. This approach has a majority of shortcomings which include forgery of signatures on behalf of non-attending students, failure to identify struggling students and the land pollution threat posed by disposed paper. This paper focuses on the digitisation of classroom roll-call operations in a South African institution of higher learning through the development of a digital assistance system known as an Online Attendance Registry System (OARS). A morphological analysis is employed to describe the system's functionality while barcode technology was employed for the auto identification of students. The developed OARS was deployed to, and validated by three lecturers for a number of courses with improved attendance record-keeping and tracing. Results of the deployed system show an improvement in the real-time visibility of class demographics through customised dashboards.

Key words: Class attendance register, digital assistance

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1 INTRODUCTION

The importance of class attendance within the Higher and tertiary education sector cannot be under-estimated. This is essentially because of the crucial role contact classes play in ensuring knowledge acquisition in a conducive environment [1]. During class or lecture periods, learners are encouraged to adopt critical thinking, granted an opportunity to work collaboratively and ask questions, thus gaining a clearer understanding of the material presented. According to Sleigh and Ritzer [1], class attendance can enhance retention of information and helps students develop skills such as self-discipline and time management. Furthermore, a significant number of studies conducted in Asia [2] and Europe ([3]; [4]; and [5]) have shown a positive correlation between class attendance and student academic performance. However, the subject remains under debate as some recent studies revealed no significant correlation between class attendance and student performance ([6] and [7]). This is mainly because there are a variety of other reasons which can be attributed to poor student performance including financial constraints, poor preparation, stress, anxiety, sickness or a lack of accommodation [8].

Due its importance, the attendance register has been utilised for keeping track of student attendance during contact classes [9]. Different institutions use these records for varied purposes. In some cases, adequate class attendance serves as a prerequisite for qualifying to write assessments, while in most cases the records are only kept for accountability purposes. A number of instructors require information such as percentage attendance for purposes of making some decisions. Traditionally, manual methods of taking class attendance records which involve signing a circulated attendance sheet or paper are employed [10]. This approach carries a lot of shortcomings which are discussed in this paper.

With the recent rise of digital technologies such as Internet of Things (IoT) devices [11], digitalisation of class room attendance operations is an achievable reality [12]. In the paper, the development and deployment of a Digital Assistance System (DAS) which employs barcode technology known as an Online Attendance Register (OARS) is presented. In Section 2, the shortcomings of manual attendance systems is briefly discussed from the literature before the rationale for using barcode technology is outlined based on recent work. The methodology adopted is presented in Section 3, with a morphological box derived for system description purposes. We then present results based on design and use of the system in Section 4. The identified challenges during deployment are used to recommend a road map for future work in Section 5.

2 LITERATURE

Though manual attendance register sheets have been employed as the traditional means of collecting attendance data, this approach has a number of shortcomings. Firstly, the method is time-consuming and cumbersome. Nowadays, a majority of classes can be huge (with over two hundred students per contact session). The bigger the class, the more time it will take for all signatures to be captured. Secondly, the manual approach is prone to human error and fraud. The risk of having students sign on behalf of their friends is a major concern as this leads to inaccurate results. In addition, one may erroneously sign their name in the wrong row (i.e. against another person's name). After collecting attendance data over a long period of time, the instructor will need a proper filing system in place for them to manage the attendance sheets, making the process difficult to maintain. In most cases, these records are kept for purposes of determining the percentage attendance per class and per student for decision making purposes [10]. However, when there are huge volumes of attendance sheets, such manual calculations can be time-consuming and lead to inaccurate results. Thirdly, paper can easily get lost, torn or worn away. The disposal of the paper leads to land pollution which can pose an environmental threat.

Furthermore, with the recent health threat posed by the novel coronavirus (also known as Covid-19), exchange of material like paper can also present a risk of contagion (spread of the virus) [13]. The Covid-19 pandemic has seen companies include as part of their protocols avoiding the exchange of material (like paper) as the virus stays on surfaces for a certain period of time. As a result, the traditional paper-based approach can pose a serious health dilemma during these times.

Based on these shortcomings, other methods of collecting class attendance records need to be explored and employed. One approach can involve the digitising of the class attendance process. The fourth Industrial revolution (also known as Industry 4.0) has ushered the world into a new phase where manual processes can be digitised [14]. Though most efforts have focused on the digitalisation of operations in other domains like the manufacturing sector [15], digital assistance systems have also been under development for use in the education sector.

Green business practices basically involve the implementation of sustainability principles during business operations to promote environmentally friendly and sound operations. These sustainability principles are centred on four Rs which are; Reduction, Reuse, Recycling and Recovery. Studies have revealed that reduction in use of paper-based systems significantly reduces waste while protecting the environment [16]. The design presented in this paper involves the replacement of a paper-based system with a system which employs recyclable plastic barcoded cards and barcode technology (readers) thus transforming the attendance data-capture operations by making them become eco-friendly. The next section looks at the State-of-the-art with regards to digitalisation of class attendance records systems.

2.1 State of the art

The process of digitising different parts of business operations to support workers or users results in the development of Digital Assistance Systems (DAS) [16] and Technical Assistance Systems (TAS) [18]. Hinrichsen, Riediger and Unrau [19] defined an assistance system as a system (either technical or digital) which receives and processes information from its environment in order to support workers carrying out their tasks as illustrated in Figure 1. The purpose of a DAS is to bridge the gap between the information an operator has and the one required to conduct a task through detailed digital representation of information. As a result, DASs reap benefits in causing reduction of training time, search time, operating errors and improving work in stressful scenarios [20].

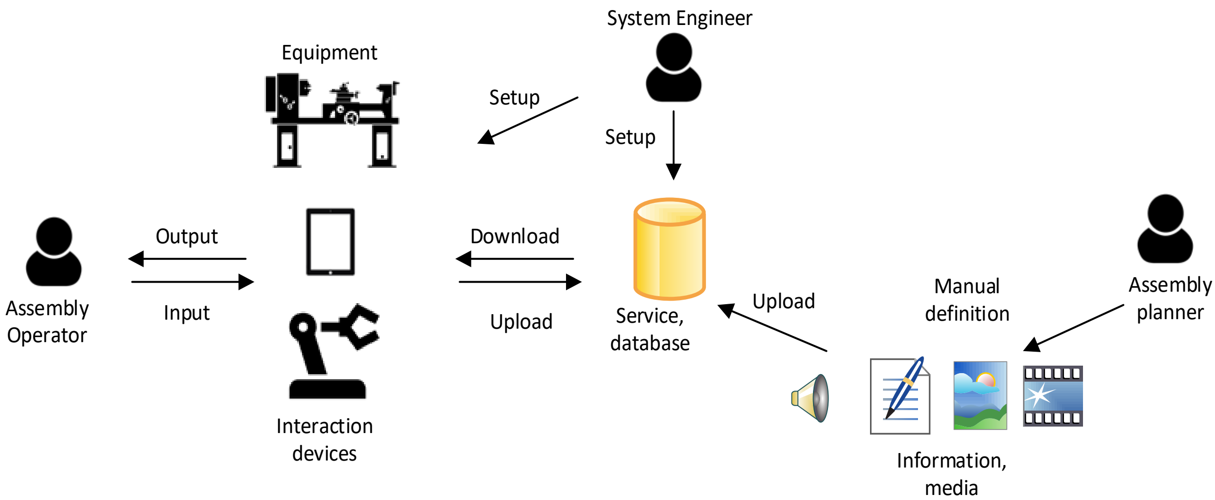

Figure 1: Schematic Structure of a Digital Assistance System (Adapted from Reisinger et al.[21])

Though DASs have been employed widely in manufacturing as discussed above, emerging work is also seen in the education sector. Different digital technologies have been used to digitise the attendance registry system. Web-based solutions for class attendance have been developed in the past few years [22]. A number of Higher and tertiary education institutions employ Learner Management Systems (LMS). These are web-based solutions and in most cases they have the functionality of capturing class attendance records. However, due to the investment cost required to obtain LMSs, this solution is not viable in some cases (where there is low capital investment for such systems). Furthermore, a sustained internet connection is required for the process of capturing learner attendance via a web-platform. In other work, a biometric approach was employed to obtain class attendance records [23]. The finger print scanning technique is the most commonly used approach via this route, with students having their fingerprints scanned through a device (fingerprint scanner) to reckon their presence for a lesson [23]. Though this method shows improved speed of data collection, the risk of contagion discussed earlier is possible if the surface on the fingerprint scanner used is not continuously cleaned. One recent breakthrough in the use of biometrics is the use of face-recognition technology to record student presence for class [24]. This approach is similar to that of scanning the iris of each pupil since every human being has unique eye characteristics. Though the biometric approaches have proven successful with regards to security and speed merits, installing such systems is usually an expensive venture which also requires clearance with regards to ethical predicaments. Mobile technology [25] and SMS [26] functionality have also been employed for purposes of recording class attendance. Though both methods require a reliable network, they have merit in that the data collection can be conducted in a distributed manner. In other studies, Near Field Communication (NFC) and Radio Frequency Identification (RFID) technologies have been employed for class attendance to speed up the process through the scanning of cards [27]. Both methods also require a huge capital investment and maintenance of a conducive environment for the readers (both RFID and NFC).In this paper, barcode technology will be employed as the auto identification technology for capturing student attendance. This method was selected due to the merits of barcode technology has as an established, widely used approach which is cheap and reliable.

3 RESEARCH METHODS AND MATERIALS

According to Oks, Fritzsche and Lehmann [28], the digitalisation of any process is a complex exercise which requires a strategic and systematic approach. Unfortunately, the current literature lacks sufficient information on generic models or methodologies for the strategic digitalisation of processes [29]. In the paper, the generic product development process [30] shown in Figure 2 is used in the development of the OARS.

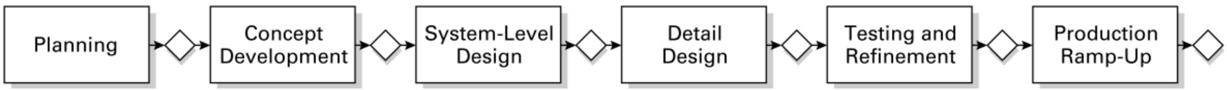

Figure 2: Generic product development process [30]

3.1 Concept generation

To identify the customer needs, a focus group interview with the selected system users was conducted to derive the requirements. A total of five lecturers congregated and were interviewed from the Engineering Faculty of a University of Technology. The focus group session followed a semi-structured format which required information on user needs when collecting attendance records. During the semi-structured focus group interview, questions regarding desired features in an automated attendance registry system were discussed. The focus group session lasted approximately sixty minutes.

Only one of the five respondents indicated that they had once used an online attendance register embedded within the LMS used by the institution. The other four, always used the manual attendance register sheets and indicated that it wouldn't be feasible to use the available online register as it depended on a consistent internet connection. Based on the discussions, the key features which stood out are:

- Ease of use;
- Ability to function without the need of a consistent internet connection;
- Ability to generate an attendance register in PDF format;
- Ability to compute percentage attendance per class;
- And ability to compute the percentage attendance per student so as to determine the at risk students.

According to all the focus group participants, the required calculations would enable swift response in monitoring both class and student behaviour. Though a digital solution was recommended as an improvement to the manual approach, all five respondents indicated the need for the digital attendance sheets to be stored for future reference, hence the need for PDF file generation and backup of the registers.

The House of Quality was used to turn the customer requirements into the system needs. Five concepts were developed and the concept selection methodology proposed by Ulrich and Eppinger [30] to select the final concept was employed. The methodology consists of the processes of concept screening and scoring. The concept scoring phase involved preparation of selection matrix, rating of concepts, ranking of concepts, combining and improving the selected concepts and reflection on the results.

3.2 System Level Design

A systems engineering approach which follows the user-centric model [11] was selected as the most suitable approach in the development of the system during the system level design. The Vee model [31] was utilised to decompose the system and determine the system requirements. At a high level design, UML modelling was used. Thereafter a morphology box was used in the component detailed design while Google sheets and AppSheet were used in the implementation of the software. The system was verified and validated by lecturers in the engineering faculty.

3.2.1 Requirement analysis

Functional requirements of the system were developed from the customer requirements determined in the concept development stage. The basic functional requirements of the system are that the system should be able to enrol/register a student and lecturer, update the student and lecturer information while managing and updating attendance records.

3.2.2 UML Modelling

The basic Use case diagram which outlines the system's primary functionality is shown in Figure 3. A conceptual model for the system was developed using the MS Visio software. The basic functions of the system include lecturer and student enrolment, lesson planning and definition and attendance register capturing. An Entity Relationship Diagram (ERD) shown in Figure 4 was developed to represent the class diagram for the system. One-to-many relationships between the different parts of the system were established. In some cases, the principle of abstraction was employed to simplify the design for instance in reality a many-to-many relationship exists between the topics and lessons entities. However, the system adopted a one topic to many lessons relationship.

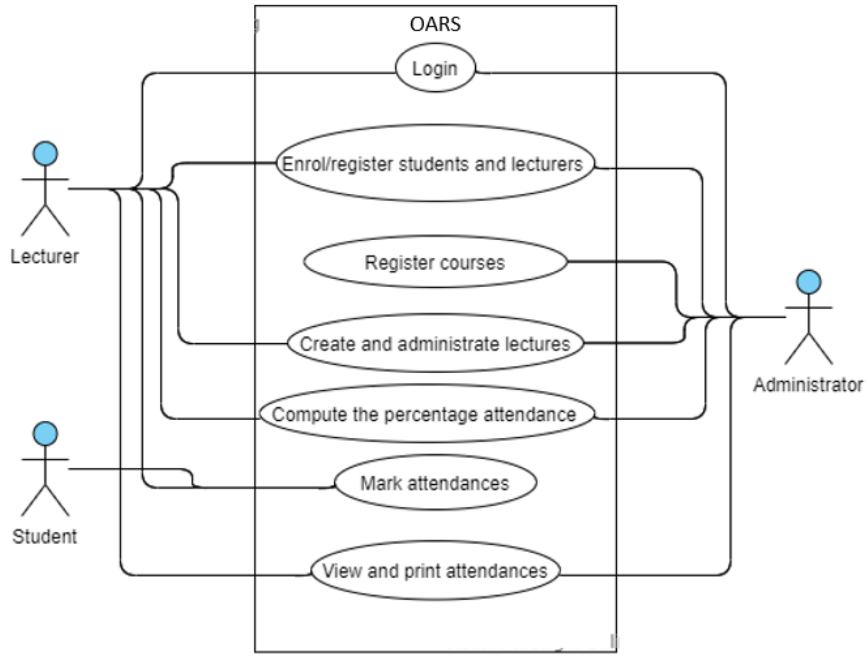

Figure 3: OARS Use Case diagram

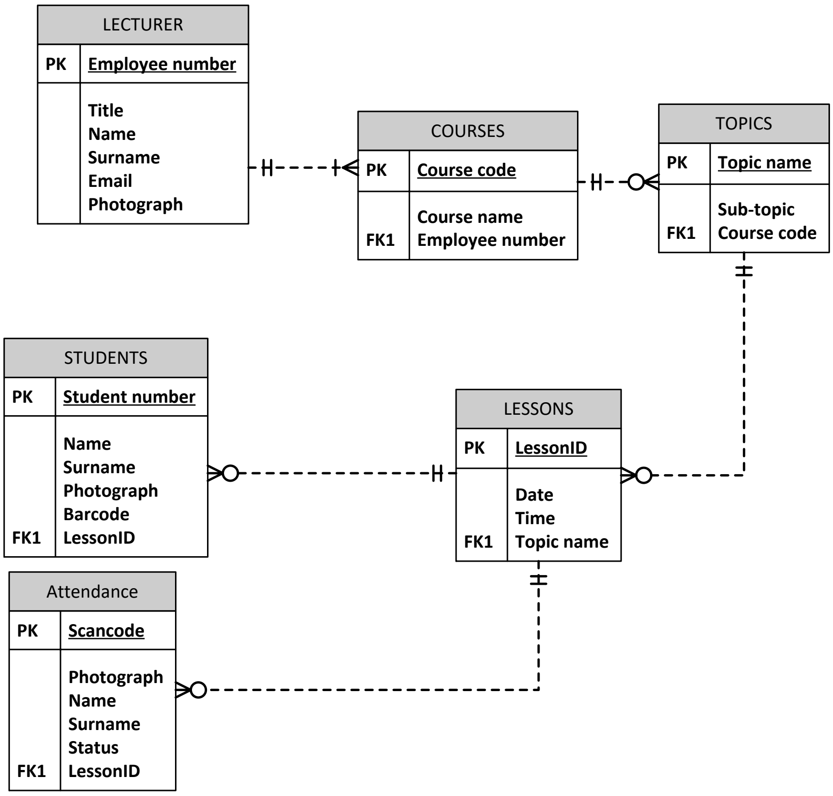

Figure 4: Entity Relationship Diagram for OARS

3.3 Detailed design and system implementation

The AppSheet platform was utilised to develop a mobile web-based solution [15]. A morphology box was utilised to describe the system functionality. Mobile technology was used due to its ability to scan barcodes as well. As a result, there would be no need to invest in stand-alone barcode scanners as each instructor will be able to scan cards using their own mobile phone. The third stage involved system testing and deployment. During this phase the developed system was tested in a real classroom environment and the results obtained.

3.3.1 System characteristics

The characteristics of a developed DAS can be described using a morphology box. The purpose of the morphology method is to present a solution description by breaking down a complex situation into individual characteristic values. Through a morphology, the characteristic values of a specific DAS can be described relating the individual features of the characteristics. Hinrichsen, Riedieger and Unrau [32] developed a morphological box for describing the features of a developed assistance system. This box (presented in Table 1) will be adapted and used during the system description in section 3.3.2.

Table 1: Morphological analysis of a designed Digital Assistance Systems [32]

CHARACTERISTICS	CHARACTERISTIC VALUES						
TYPE OF SYSTEM SUPPORT	Physical				Informational		
TYPE OF DIGITAL ASSISTANCE SYSTEMS	Stationery (fixed installation)	Mobile (mobile installation)			Hand device	Wearable -Head -Upper body -Arms/Hands -Legs/Feet	
DATA TRANSFER	Wired				Wireless		
TYPE OF SUPPORTED OPERATIONS	Joining	Handling		Adjusting	Controlling	Auxiliary processes	Setting up the Assembly system
SCOPE OF PROCESS SUPPORT	Partial process(es)				Total process		
HUMAN-MACHINE INTERFACE	Unimodal				Multimodal		
TYPE OF INFORMATION OUTPUT	Visual (optical)			Auditory (acoustic)		Tactile-kinesthetic (tactile)	
TYPE OF VISUAL INFORMATION OUTPUT	On-screen display			Representation in the working area		Working area display superimposed over the assembly object	
SCOPE OF VISUAL INFORMATION OUTPUT IN THE WORKING AREA	No output	Selective presentation		Limited display of symbols, images and drawings		Extensive presentation of items such as images, videos and animations	
TYPE OF THE INFORMATION INPUT/SYSTEM CONTROL	Manual (via actuators)	Verbal (voice control)			Gesturing (tracking system)	Automatic (sensory)	
SCOPE OF USER CONFIGURATION	Set configuration of information input and output			Individual configuration of information output		Individual configuration of information input and output	
USER RECOGNITION	None			Registration and uploading of user profiles		Automatic registration and uploading of user profiles	
SITUATION/MOTION DETECTION	None		Via measurement sensors		Via optical sensors	Other	
COMPATIBILITY/INSTALLATION EFFORT	Entire workplace has to be newly configured		Basic adjustments made to the workplace		Minor adjustments made to the workplace	No adjustments made to the workplace	
FLEXIBILITY IN RECONFIGURING THE WORKPLACE	Substantial adjustments to be made to the main hardware		High software reconfiguration effort (done by qualified specialists)		Average software reconfiguration effort (done by specialists on site)	Low software reconfiguration effort (done by user on site)	

Assistance systems can be classified in terms of the purpose they serve [33]. These application areas can include manual, maintenance, inspection, costing or logistics operations (especially in the context of production). Physical assistance involves the use of robotic systems to assist in tasks which can be complex or strenuous on workers [34] while informational assistance involves availing task related data to workers so as to support decision making and reduce task-related errors [35]. Furthermore, the type of system supported determines the assistance system installation requirements. The assistance system can either be stationery, mobile, hand-held or use wearables [36]. This will eventually influence the data transfer medium used in the system, which can either we wired in a localised environment or wireless in a distributed setting [37]. The tasks supported by the assistance system can also be employed as a classification criteria. Hinrichsen et al. [32] only used assembly operations in the description and went on to distinguish support of all or some of the operations. However in some contexts, the tasks may differ depending on the area in which the assistance is required. Depending on the type of system (application area) being supported, physical or informational assistance may be required.

Furthermore, the interaction requirements of system users can also be employed in distinguishing assistance systems. The type of user interface [38], recorded input data [39] and displayed information output [40] define the interaction characteristics of an assistance system. Similarly, the system users also contribute the system characteristics in terms of the need for configuration and recognition by operators while using the system [32]. Finally, some assistance systems may require the recording of environmental information. As a result, situational and motion detection by sensors may be needed. In such cases the need to reconfigure the workplace facility or not needs to be evaluated while monitoring the compatibility of the assistance devices with the systems already existing in the business ecosystem [32].

3.3.2 System description and architecture

To facilitate distributed collection of class attendance records, mobile technology was selected and employed for the edge devices. A majority of mobile devices carry a number of important sensors embedded in them which capture textual, video, image or audio data. Some smart mobile devices also have advanced sensors like gyroscopes, accelerometers, fingerprint sensors and barcode scanning capabilities [41]. Likewise, the AppSheet platform allows for capture of barcode data. As a result, a low investment will be required to deploy and run the system as each instructor will be able to scan student and staff cards using their own smart devices, eliminating the need to purchase and install stand-alone barcode scanners. Figure 5 below illustrates the system architecture of the OARS. The system facilitates enrolling of student and lecturer information. Thereafter, the primary users (lecturers) can define their courses. In addition on a daily basis, lecturers can load their lesson details and collect attendance information during the class using their mobile devices.

All captured information is stored in the backend Google sheets database. Upon saving a record, a pdf file of the attendance register is generated and emailed to the Lecturer's email address.

The system properties were described using an adapted version of the morphological box presented in Table 1. The morphological box for the system is presented in Table 2 below. The developed system is an informational system which utilises hand-held mobile devices for data collection. The scope of operations supported include enrolment of users (students and lecturers), course definition, lesson planning and attendance register recording via scanning barcodes of student cards. The users can see information displayed via their user interfaces. The system can work with wireless internet connectivity. All the information in the system is manually collected. The types of data captured include textual data (like names), date or time data (day and time of class), images (photos of students and lecturers), barcodes and files (lesson guides). However, barcodes can be scanned while the system is not connected to the internet, with the backend database only updated once a connection is established. Due to the distributed nature of the data collection, the system will not require any changes to the workplace layout.

Table 2: Morphological box for the developed OARS

CHARACTERISTICS	CHARACTERISTIC VALUES					
TYPE OF SYSTEM SUPPORT	Physical			Informational		
TYPE OF DIGITAL ASSISTANCE SYSTEMS	Stationery (fixed installation)	Mobile (mobile installation)		Hand device	Wearable	
DATA TRANSFER	Wired			Wireless		
TYPE OF SUPPORTED OPERATIONS	Staff enrolment	Student enrolment	Course definition	Lesson planning	Scan student cards	Generate PDF register and results
SCOPE OF PROCESS SUPPORT	Partial process(es)			Total process		
HUMAN-MACHINE INTERFACE	Unimodal			Multimodal		
TYPE OF INFORMATION OUTPUT	Visual (optical)		Auditory (acoustic)		Tactile-kinesthetic (tactile)	
TYPE OF VISUAL INFORMATION OUTPUT	On-screen display		Representation in the working area		Working area display superimposed over the assembly object	
SCOPE OF VISUAL INFORMATION OUTPUT IN THE WORKING AREA	No output	Selective presentation	Limited display of symbols, images and drawings		Extensive presentation of items such as images, videos and animations	
TYPE OF THE INFORMATION INPUT/SYSTEM CONTROL	Manual (via actuators)	Verbal (voice control)		Gesturing (tracking system)	Automatic (sensory)	
SCOPE OF USER CONFIGURATION	Set configuration of information input and output		Individual configuration of information output		Individual configuration of information input and output	
USER RECOGNITION	None		Registration and uploading of user profiles		Automatic registration and uploading of user profiles	
SITUATION/MOTION DETECTION	None	Via measurement sensors		Via optical sensors	Other: Barcode scanning	
COMPATIBILITY/INSTALLATION EFFORT	Entire workplace has to be newly configured	Basic adjustments made to the workplace		Minor adjustments made to the workplace	No adjustments made to the workplace	
FLEXIBILITY IN RECONFIGURING THE WORKPLACE	Substantial adjustments to be made to the main hardware	High software reconfiguration effort (done by qualified specialists)		Average software reconfiguration effort (done by specialists on site)	Low software reconfiguration effort (done by user on site)	

Three Lecturers agreed to test the system for their courses (nine different courses in total). The results from the testing phase are discussed in the section 4. The OARS system consists of three main modules for enrolment of students, lecturers and lesson planning as shown in the system architecture in Figure 5.

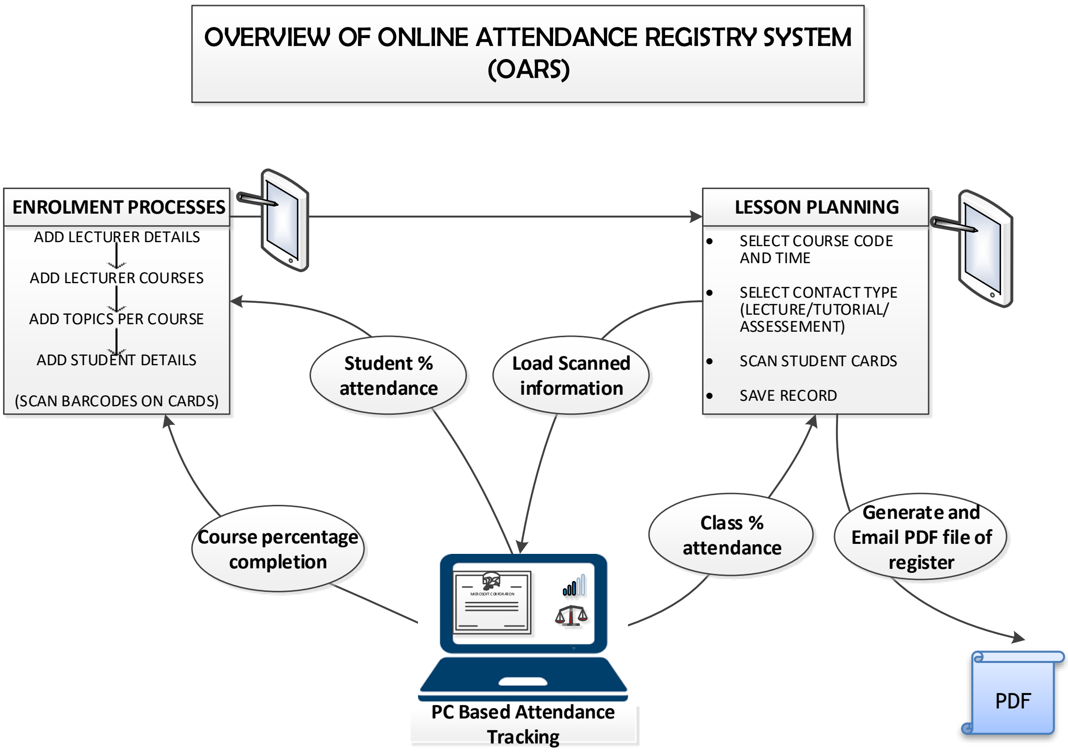

Figure 5: System architecture OARS

4 RESULTS

4.1 System testing, deployment and dashboards

The system was validated through testing it during an entire academic year (two semesters) of study. Three lecturers and a total of 131 students participated during this phase. The administrator of the system deployed the system to the lecturers via their email addresses for them to install on their mobile smart devices. Both lecturer and student cards have barcodes of type Code 39. The AppSheet platform can read a wide variety of barcodes. The scan time per barcode was approximately less than a second with the read distance been one meter. The main shortcoming of employing barcode technology is that the quality of the barcode embedded on the card can affect the read time. As a result in some instances the read time took slightly longer depending with the barcode clarity or resolution. Another drawback experienced was that the application could only read one barcode at a time.

4.2 Analysis of the results

The system was developed with simple user interfaces. Three main input interfaces for staff enrolment, student enrolment and lesson planning were developed (see Figure 6**).** In the paper, only user interfaces which do not reveal student, lecturer or institution information are shown. Before a contact session, the lecturer defines the nature of the class by inputting the course, topic covered, lesson time and nature of class (e.g. lecture, tutorial or assessment etc.). For a defined lesson, the barcode on student cards is scanned to denote their presence for a class. During the scanning, the system automatically records the details of each student in attendance and computes the total number of students attending class. This information is displayed in report format and converted into a pdf document which is automatically sent via email to the Lecturer. A major shortcoming of the method was that at times students would not bring their cards to class. To overcome this shortcoming, students were encouraged to take photos of their student cards using their smart phones. That way, the barcode would still be scanned from the phone.

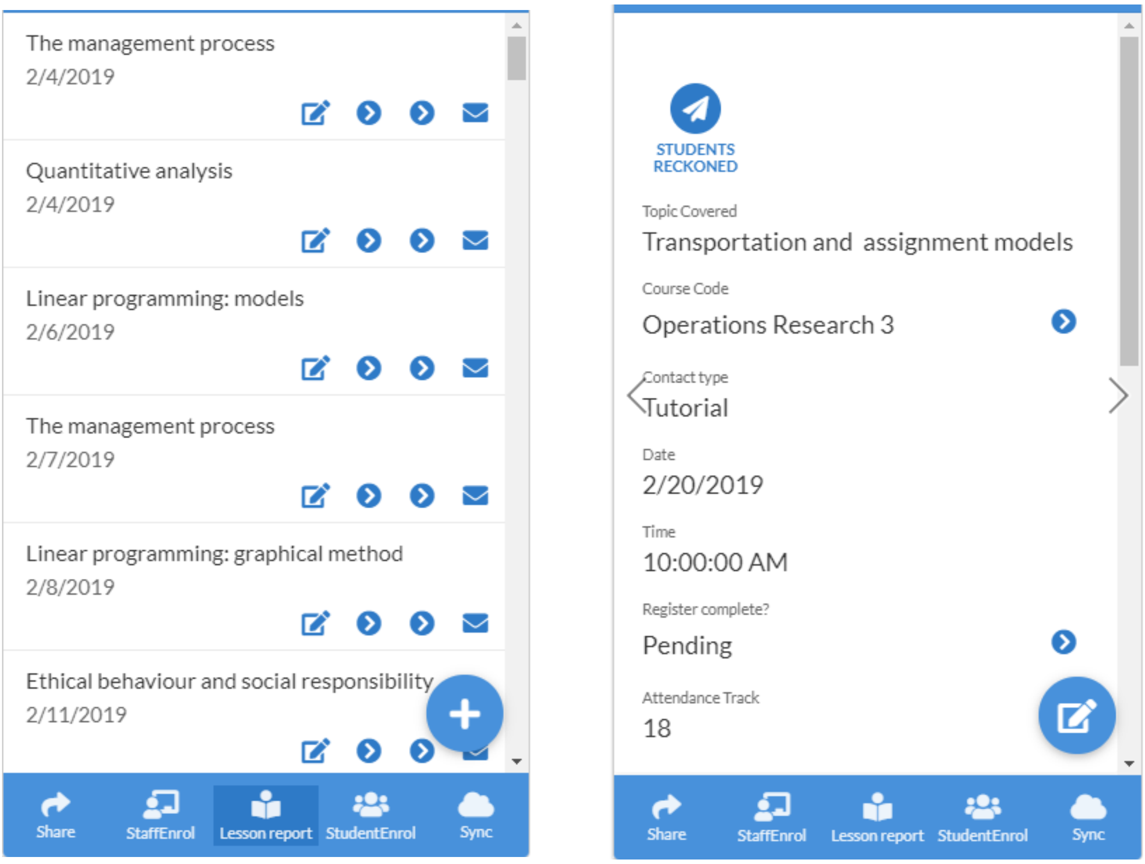

Figure 6: Screen shots of OARS (Lessons - (left) and attendance record - (right) interfaces)

The system was programmed to display two crucial dashboards: percentage class attendance per semester and individual student attendance. These dashboards were included as a result of the requests placed by the lecturers during the focus group interviews. The percentage class attendance dashboard is presented in Figure 7 below.

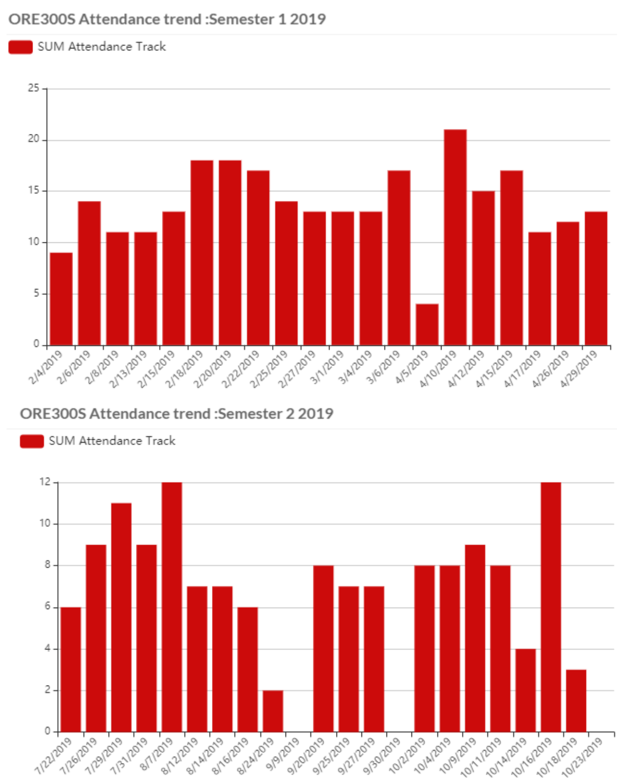

Figure 7: Course attendance trend dashboard (Semester 1 and 2)

Eventually, the use of the system eliminated the need for a paper-based attendance sheet while improving the efficiency and efficacy of attendance record keeping. This boosted the interaction between the lecturers and students concerning matters related to class attendance. In some instances, lecturers would communicate attendance trends with students in a way to find out reasons for non-attendance and encourage it.

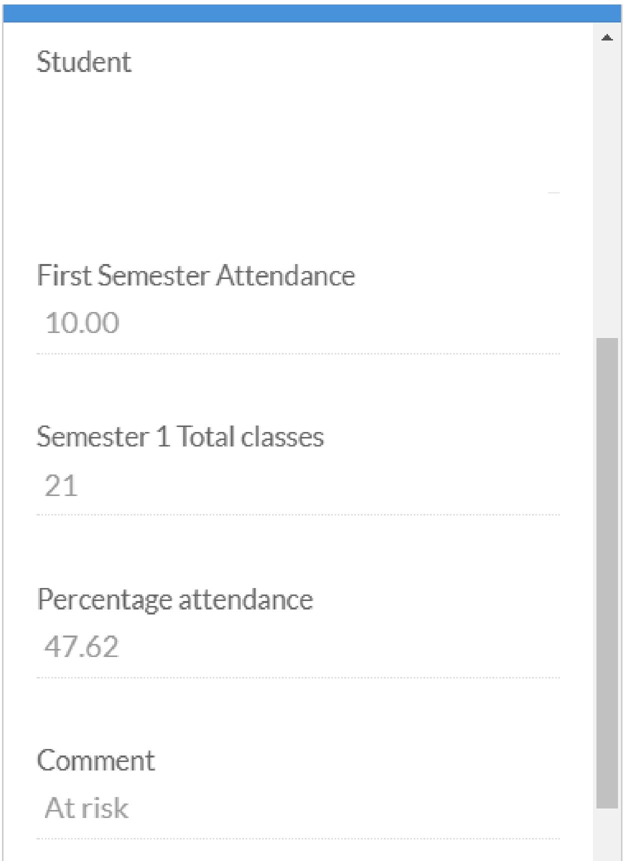

Figure 8: Example of student attendance record

Another key dashboard embedded in the system is the ability to track individual student attendance trends within a specified period of time as illustrated in **Figure 8** above. Upon selecting a student from the database of enrolled students, and selecting the course and period details, the total number of classes the student will have attended are displayed. The percentage attendance is then computed with a comment of either good attendance or poor attendance (at risk) shown.

5 CONCLUSION

The developed Online Attendance Registry System (OARS) significantly improved the speed of attendance registry data collection. Eliminating the use of paper is a significant step in ensuring green practices are adopted in the classroom environment. This results in immense benefits as records kept in digital format are easy to access, manipulate and analyse. More dashboards for tracking of different parameters associated with class attendance can still be developed and extended within the system to facilitate a richer analysis and ensure real-time alerts. An example of such an extension is the inclusion of real-time alerts or communication to students showing trends of poor attendance. Using event-driven platforms like Zapier [42], triggered alerts to students not attending classes can be generated and sent via email or SMS to encourage participation. Furthermore, future work can be conducted on integrating barcode readers which conduct bulk reading of students' cards to speed up the process. One of the main benefits of digitising the class attendance registration process is the ability to obtain crucial information regarding classes in real-time, eliminating the need to keep huge files of attendance sheets, hence going green.

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OPTIMISATION OF THE VALUE STREAM THROUGH REVERSE LOGISTICS: A RETAIL CASE

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ABSTRACT

This research paper is based on the optimization of current reverse logistics processes and practices at a major retailer. The objective is to develop a positive revenue stream and to respond to sustainable development aspects which demands an environmentally friendly organisation. Managing merchandise returns is a costly exercise and in turn affects profitability. Organisational returns can cost retailers billions of Rands in lost sales therefore it is important to take the necessary steps to drive efficiencies in order to reduce costs associated with these returns. The implementation of continuous improvement powered by the combination of Lean Six Sigma and SIPOC offers a considerable prospect in optimizing and streamlining business processes. A case study methodology using a descriptive, qualitative approach was applied to highlight current practices and the monetary loss experienced by the organisation with recommendations for improvement.

Keywords: Lean, Six, Sigma, value stream, industrial engineering, reverse logistics

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1 INTRODUCTION

The retail group XYZ retailers started trading in 1924 and is listed on the Johannesburg Stock Exchange (JSE) since 1941. The retailer expanded its collection of brands to become a forerunner in the South African retail industry, offering a wide range of products from clothing to jewelry and accessories to the upper market segment of the country. Ten of these brands can also be purchased through e-commerce channels. With a footprint of 3328 outlets in 34 countries, the group continues to expand their international footprint with a reported turnover of R23.5 billion for 2017.

The growth of logistics became a focal point in the business realm by taking into consideration the management of input materials, by-products, products, services and information flows. Accordingly, the globalisation of the economy generated both challenges and opportunities for businesses across the globe.

Reverse logistics appeared as a reaction to the growing acknowledgement of environmental impact on the movement of materials, parts, components and supplies and of the need to manage these movements of goods in an environmentally and responsible way[1]. Reverse logistics (RL) is engrossed on the reclamation of products at the end of their lives or can no longer be used with a view to obtain an economic return through reuse, recycling, or remanufacturing [2].

2 LITERATURE REVIEW

The literature review focused on reverse logistics as a concept and as applied in the retail environment and lastly, on the implementation of lean six sigma principle, DMAIC in order to identify and eliminate waste to optimize revenues and reduce environmental impacts.

2.1 Reverse logistics

Reverse Logistics (RL) is an expansive term referring to the management of returning products. This encompasses the disposal of both hazardous and non-hazardous waste from packaging materials and products at their end of shelf-life. The focus is on the flow of information and products in the reverse (opposite) direction [2], [3], [4]. The concept of RL has received growing attention in the last years, due to competitive and market motivations, direct commercial motives and ecological concerns. Governments across the planet are enforcing legislation to protect the natural environment [5]. According to Srivastava [6] the reverse logistics activities are detailed in Figure 1 which depicts the lifecycle process of various streams of products which includes reassembly, remanufacturing, recycling and disposal streams.

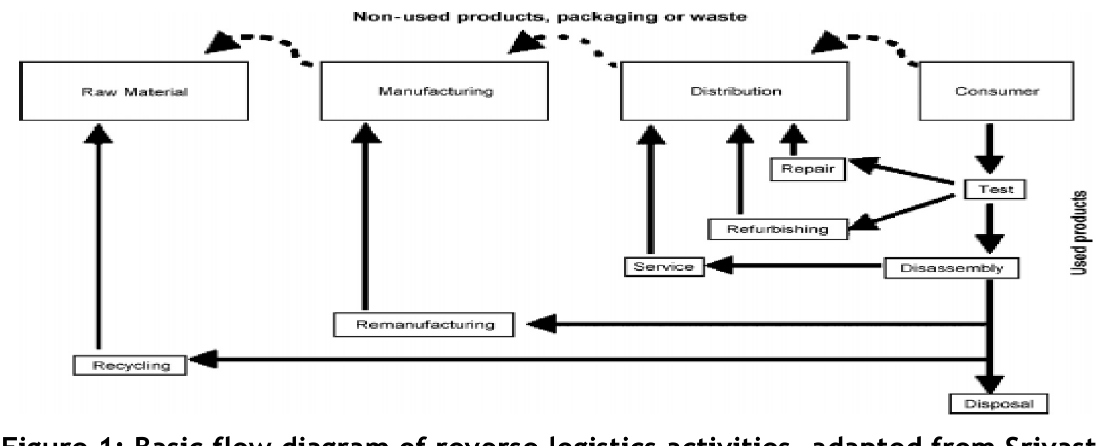

Figure 1: Basic flow diagram of reverse logistics activities, adapted from Srivastava

2.2 Six Sigma, Lean and Lean Six Sigma

2.2.1 Six Sigma

The concept of "Six Sigma" relates to a statistical measure arising from the relationship between the variation in a process and the customer requirements associated with the respective process and is fundamentally depicted as 3.4 defects per million opportunities [7]. The objective of the Six Sigma technique is the removal of process variation while striving to achieve defect-free products. The methodology is associated with the acronym DMAIC which stands for Define, Measure, Analyse, Improve, and Control. It involves a methodical five-step problem-solving methodology to define the problem and resolve variation in the process [8].

Six Sigma was first introduced in the 1980s and its main goal is sixfold (a) Elimination of defects (b) Reduction of process variations (c) Reduction of quality cost (d) Demonstration of hard cash savings to the bottom line (e) Improvement of customer satisfaction (f) Improvement of product quality; through the deployment of statistical tools [12].

According to Fursule et al. [13], [8] and [14] Six Sigma is a statistical data-driven problem-solving methodology to determine process variation at an early stage. The implication is the reduction of defective products or services and greater customer satisfaction with improved revenue. It reduces the amount of defective products manufactured or services provided, resulting in increased revenue and greater customer satisfaction. Problem-solving in Six Sigma is accomplished using the DMAIC framework which consists of the following 5 aspects:

1. Define. In this step, the problem is defined and project objectives outlined. A project charter is formed as the blueprint document for the six-sigma project. The project charter is approved by senior management and provides a holistic view of the project plan with timelines and estimated benefits.
2. Measure. Data is collected at this point and variables then measured. Baseline performance is compared with the final performance where process capacity is determined.
3. Analyze. Root cause analysis is conducted using tools such as histograms, Pareto charts and fishbone diagrams. Hypothesis tests are also conducted to verify root causes.
4. Improve. This stage affords solutions to the respective problems. Some of the techniques used to improve and maximize performance are simulation studies, design of experiments and prototyping.
5. Control. After solutions have been implemented, the performance is monitored. A fall-back plan, process standardization, control charts and project benefits are developed and discussed. The purpose of this phase is to ensure that the solutions implemented are sustained.

2.2.2 Lean

Lean manufacturing is about the analysis of processes with the objective of waste elimination. Beitinger [11] proposes that the five principles of lean have a plethora of applications and are as follows:

1. Identify your customers and what they value. Customers define value. Process activities should be classified into non-value added, value-added and enabling added activities.
2. Map the value stream. Value stream mapping depicts the workflow of process steps for products and services. It assists in identifying and eliminating non-value-added activities which in turn assist to reduce process delays.

3. Create flow. Ensure that there is a continuous system flow and optimize the process.
4. Establish pull. Establish a pull approach. A pull approach ensures smooth workflow of the process and also assists in diminishing inventory levels.
5. Seek continuous improvement. Continuous efforts to improve existing processes and procedures to remain competitive are key to ensuring elimination of waste and process optimization.

2.2.3 Lean Six Sigma

Lean Six Sigma is a hybrid continuous improvement methodology applied to processes with the drive for improvement [9]. Snee [10] argues that Lean Six Sigma application enables improved customer satisfaction through process performance monitoring. It is a strategy that improves business performance in its bottom-line results [12].

2.3 Plan-Do-Check-Act (PDCA) Cycle

The plan-do-check-act cycle is an iterative, four-step model used for continuous improvement of processes, products, services and problem-solving. It was popularized by Dr W. Edwards Deming and is an effective approach for problem-solving and managing change [15], [16]. Moen [17] argues that PDCA is used for one of the following reasons: (a) model for continuous improvement (b) when initiating a new project (c) to create a new or improved product, process, or service design (d) to evaluate repetitive work process (e) to plan data collection and analysis in the prioritization of problems (f) when implementing change.

Moen [17] further proposes that PDCA cycle steps are as follows (a) Plan – The problem is identified, relevant data is collected and the problems root causes are identified. Thereafter, the hypothesis are developed and the decision is made as to which will be tested (b) Do – The solution is developed and implemented, measured, tested and the results are monitored. (c) Check – The results from before and after the implementation is compared. Results are studied to measure effectiveness and it is decided whether the hypothesis is supported or not. (d) Act – The results are documented, change management is executed and recommendations for future is documented. The PDCA cycle is repeated [18].

According to Albliwi et al. [12] SIPOC is the acronym for supplier, input, process, output, customer. Suppliers are those who supply goods or services to an organisation. Inputs are resources such as raw materials, people, machines, finance and information that are positioned into a system to obtain a desired output. Process enables the transformation of inputs into outputs. Finally, products or services reach the customers of the SC (Supply Chain).

3 RESEARCH METHODOLOGY

The research approach adopted in this study is descriptive and qualitative research. This research provides insights and reveals complexities of using observations, discussions, documents, past records and audio-visual materials. In this paper, data was collected from both primary and secondary sources.

3.1 Primary data

1. Telephonic and face-to-face discussions were conducted with various staff at various levels in the organizational hierarchy. Open-ended questions were posed to the warehouse management, transport management and business divisions in order to understand current processes and decision-making factors.
2. Data collection from warehouse management system (WMS) reports and dashboards.

3. Distribution Center (DC) process and flow observation on the DC floor.
4. Observations and discussions were conducted on current processes to identify improvement opportunities.
5. Using the six sigma (DMAIC: Define, measure, analyze, improve and control) methodology for problem-solving.

Secondary data was collected from reports, periodicals, organizational databases and journal articles. This provided the fundamental direction and consolidation of information from the various sources.

4 FINDINGS AND DISCUSSION

The application of the Lean Six Sigma DMAIC methodology was used in order to explore the problem and in turn highlight improvement areas to be implemented to solve the problem.

1. In the define phase the project charter was used to document the project objectives, how the project will be carried out and identifies who the key stakeholders are.
2. In the measure phase, data sources were used as inputs to measure the current reverse logistics process at XYZ Group. A SIPOC-R (retail), the current VSM state, the merchandise returns distribution centre (DC) unit history and merchandise returns DC cost history was used as measures to present the current process.
3. In the analyze phase, the SIPOC-R, current state VSM and raw data tables shown in the measure phase was analyzed to highlight process and procedural issues and improvement areas.
4. In the improve phase, recommendations were made to the current processes and procedures in order to ensure that XYZ Group reverse logistics is developed into a positive revenue stream.
5. In the control phase, a plan was formulated to standardize, monitor and further improve performance to assist with the future development of the reverse logistics processes and procedures.

The DC recycle/disposal method selling value are depicted in Table 1 to Table 3.

Table 1: Selling value for actual units processed for FY 2014/2015

SELLING VALUE FOR ACTUAL UNITS PROCESSED FOR FY 14/15					
	Disposal/recycle method splits				
	Total Unit selling value	Re-sell Unit selling value	Charity selling value	Destroy selling value	RTV Unit selling value
Apr	R 12,841,029	R 5,136,412	R 3,698,216	R 25,682	R 3,980,719
May	R 9,773,607	R 3,616,235	R 5,023,634	R 58,642	R 1,075,097
Jun	R 9,158,216	R 2,472,718	R 2,756,623	R 82,424	R 3,846,451
Jul	R 11,421,553	R 2,170,095	R 3,540,682	R 0	R 5,710,777
Aug	R 11,186,837	R 3,803,525	R 4,318,119	R 44,747	R 3,020,446
Sep	R 11,898,547	R 3,212,608	R 4,780,836	R 97,568	R 3,807,535
Oct	R 12,165,808	R 3,284,768	R 5,569,507	R 26,765	R 3,284,768
Nov	R 12,508,678	R 3,377,343	R 5,241,136	R 12,509	R 3,877,690
Dec	R 7,343,601	R 1,762,464	R 3,010,876	R 0	R 2,570,260
Jan	R 12,900,530	R 2,838,117	R 6,063,249	R 0	R 3,999,164
Feb	R 12,228,925	R 2,323,496	R 7,716,452	R 110,060	R 2,078,917
Mar	R 9,730,543	R 2,140,719	R 3,255,840	R 52,545	R 4,281,439

TOTAL	R 133,157,875	R 36,063,591	R 54,630,238	R 519,316	R 41,944,731

Table 2: Selling value for actual units processed for FY 2015/2016

SELLING VALUE FOR ACTUAL UNITS PROCESSED FOR FY 15/16					
	Disposal/recycle method splits				
	Total MRS Unit selling value	Re-sell Unit selling value	Charity selling value	Destroy selling value	RTV Unit selling value
Apr	R 14,972,892	R 2,545,392	R 4,461,922	R 29,946	R 7,935,633
May	R 13,459,166	R 2,557,242	R 3,499,383	R 0	R 7,402,541
Jun	R 10,859,843	R 2,932,158	R 3,160,214	R 97,739	R 4,669,732
Jul	R 13,605,356	R 2,312,911	R 4,897,928	R 0	R 6,394,517
Aug	R 11,657,314	R 2,331,463	R 5,082,589	R 46,629	R 4,196,633
Sep	R 10,289,005	R 2,057,801	R 3,909,822	R 102,890	R 4,218,492
Oct	R 11,375,762	R 1,365,091	R 3,273,944	R 25,027	R 6,711,700
Nov	R 9,816,014	R 1,079,762	R 3,916,589	R 9,816	R 4,809,847
Dec	R 12,011,187	R 4,444,139	R 3,723,468	R 0	R 3,843,580
Jan	R 14,434,541	R 4,763,398	R 4,041,671	R 0	R 5,629,471
Feb	R 11,471,289	R 5,965,070	R 4,703,228	R 229,426	R 573,564
Mar	R 6,502,369	R 780,284	R 1,460,432	R 35,113	R 4,226,540
TOTAL	R 140,454,738	R 32,421,635	R 46,073,836	R 627,364	R 61,331,902

Table 3: Selling value for actual units processed for FY 2016/2017

SELLING VALUE FOR ACTUAL UNITS PROCESSED FOR FY 16/17					
	Disposal/recycle method splits				
	Total Unit selling value	Re-sell Unit selling value	Charity selling value	Destroy selling value	RTV Unit selling value
Apr	R 16,455,071	R 2,797,362	R 6,565,573	R 16,455	R 7,075,681
May	R 11,714,089	R 4,685,636	R 3,409,971	R 104,255	R 3,514,227
Jun	R 11,466,323	R 4,471,866	R 3,772,420	R 11,466	R 3,210,570
Jul	R 11,001,093	R 4,950,492	R 4,851,482	R 99,010	R 1,100,109
Aug	R 24,593,928	R 3,443,150	R 6,999,432	R 132,807	R 14,018,539
Sep	R 17,279,919	R 3,110,385	R 5,667,814	R 34,560	R 8,467,160
Oct	R 15,489,406	R 4,182,140	R 4,708,780	R 92,936	R 6,505,551
Nov	R 11,708,742	R 3,629,710	R 4,109,768	R 105,379	R 3,863,885
Dec	R 6,502,975	R 3,121,428	R 2,536,160	R 0	R 845,387
Jan	R 11,659,278	R 932,742	R 10,306,801	R 69,956	R 349,778
Feb	R 25,228,049	R 756,841	R 9,884,350	R 206,870	R 14,379,988
Mar	R 13,128,051	R 4,988,659	R 4,172,095	R 28,882	R 3,938,415
TOTAL	R 176,226,924	R 48,168,693	R 69,188,159	R 862,043	R 58,008,029

Based on the information presented above which characterize the measure phase, the tables present valid information in terms of the monetary value lost. In financial year (FY) 2016/17, the organisation processed a total of 62.7 million units across their clothing, footwear and homeware divisions. In the same year 432 629 (0.7% of total units) of these units could not be sold in-store for one of two reasons; either the garment had a manufacturing fault or merchandise was returned by customers.

For each return type, reverse logistics processes have been established and documented to recycle/dispose of the merchandise. The reverse logistics activities includes the process of collecting the products, transporting from stores across SA to the DC, assessing, sorting, storing and finally and arranging for collection for the recycling/disposal option. The processes in place have however not been prioritized to be reviewed, improved or re-engineered in the last 5-7 years.

Also, a disconnect was found between the costs of goods sold, including cost price, transport and processing costs and factoring all these costs into the selling price decided on by the trading division. The trading division re-sells returned and recalled merchandise at selling price in isolation to the total cost of goods, resulting in a loss made from current returns and recalls process.

Furthermore, units recalled and returned have shown an average growth of 3% year- on-year since 2014 as compared to the average unit growth of 4% year-on-year. The organisations multi-channel model, adding to that, the shifting consumer shopping habits, has significantly impacted and given rise on the rate of returns. In August 2018, the organization reported a 40% growth in its e-commerce division. Bringing its total online sales from 0.6% of total sales to 0.84% which amounts to 525 804 units in FY 17/18. The value for only the destruction of goods over three years amounts to 2 million Rands.

4.1 Charity

The decision to give merchandise to charity takes place for one of the following reasons:

1. The recalled merchandise cannot be returned to the supplier because either the supplier refuses the return or the supplier is abroad, thus it is too costly to return.
2. The merchandise is in a good condition, however it cannot be re-sold within the required 30-day time frame.
3. Low-profit merchandise, still in good condition, is returned by a customer. In this case, a loss is made as the total cost of goods, as well as the reverse logistics costs, cannot be recovered.

4.2 Analyse Phase - Non-Value adding activities

The non-value adding activities on the value stream map (VSM) include the following observations:

1. Print goods return slip (GRS) and place GRS in carton and seal – In the current process, the goods return slip (GRS) generated by the material resource system (MRS) system is printed. The reason for this is so that the end customer receiving the sealed carton has visibility to its contents. This step can be removed if the GRS slip is emailed to the end customer when they are contacted toward the end of the MRS DC process.
2. Each business division provides a selling price based on the cost price of the units communicated by the DC. This selling price is usually equivalent to or sold below cost price if the units are defective. This selling price is made in isolation to the other businesses and takes place in isolation of the total units already given to charity, recalled or destroyed. This selling price is a critical factor in developing

the reverse logistics into a positive revenue stream. In order to make a calculated, the decision should lie with a body that has access and visibility to all factors impacting the forward and reverse logistics costs to ensure that it results in a positive revenue stream. The selling price should therefore be determined by the MRS DC. Ideally the MRS DC should have a costing tool that monitors both income and expenses on a day-to-day basis and determines the best selling price that the XYZ Group profits from.

3. Customer service to authorize and advise on charity – At the moment, there are only two charities that XYZ Group donates merchandise to. In order to speed up the process of authorization to whichever charity, the department should provide the DC with clear guidelines as to when either one should be chosen. This way the DC can make a split-second decision and eliminate a process step.
4. "Authorized by charity" report is printed and attached to pallet – Adding to the point above, the 'authorized by charity' report will no longer be needed if the process recommended above can be implemented. The stock waiting to be collected by the charity should be placed in a demarcated area. Further to the above-mentioned points, there were additional areas of improvement identified in the current state VSM as follows:
   - In the current process, the code number is manually captured. The time to capture the number can be reduced by having a handheld Bluetooth scanner to scan the code number which is also represented as a barcode on the paperwork.
   - In the current process, before processing of customer returns begin, the inbound team (IBT)prints carton sorting labels and should the processing team run out of labels, they are required to go back to the inbound team for additional labels. This tedious process can be improved if the DC were to pre-print blank carton labels, unique to the process, and apply these labels to the sorting carton when the sorting process step begins. As the sorting of units takes place, the blank label and unit being put into that carton can be scanned and associated on the MRS system, thereby tracking each sorting carton and its contents.
   - The business is currently being notified, via email, once an IBT has been processed and informed of the destination of each carton processed. There is a time saving opportunity if this information existed on a real-time dashboard on the MRS system that the business could access and monitor IBT's. If need be, the DC could still send a report with the same information on a weekly basis

From the information provided above, the organization is able re-evaluate its current in-efficiencies and re-engineer processes so as to minimize the current losses.

5 RECOMMENDATION AND CONCLUSION

Businesses across the globe face many challenges in terms of sustainability of itself as well as preserving the environment. With COVID 19, organisations are able to evaluate current experiences and change them accordingly so that more profitability may be realized. The sustainability drive has forced organisations across the globe to be environmentally friendly and to improve efficiencies across the value chain. The reverse logistics concept was presented and reviewed in terms of its intricacies, with DMAIC as a primary tool for improvement.

In conclusion, XYZ Group is growing, returned and recalled units are growing, the cost price and potential sales lost for the returned and recalled units is increasing and with the current processes and procedures in place, XYZ Group reverse logistics is not profitable.

However, it was proven that through the application of the Lean Six Sigma DMAIC problem-solving technique, the current reverse logistics processes and procedures can be optimized to result in a profitable reverse logistics system at XYZ Group.

The recommendations to be implemented to ensure XYZ Group reverse logistics can be optimized to result in a positive revenue stream are as follows:

1. Implementation of the future state VSM to decrease DC lead times and cost.
2. Implement the costing tool to ensure that profit is realized.
3. Monthly update meetings to ensure the costing tool is updated and remains relevant and useful.
4. Develop a real-time productivity dashboard on the MRS system so the business can monitor orders statuses.
5. Weekly communication held between store, DC, and trading division for all parties to make better decisions.
6. Implementation of weekly PDCA cycle groups to be held at store level, DC level and trading division.

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EFFECT OF PROCESS PARAMETERS ON PRODUCTION OF BIOFUELS FROM BIOMASS RESIDUES THROUGH PYROLYSIS: USING PALM OIL HUSK

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ABSTRACT

Environmental degradation and the negative impacts in the utilization of fossil fuels on climate change have resulted in the production of biofuels and to that effect Biomass becomes promising. A dried sample of Palm Oil Husk (POH) of the mass 0.5 kg was loaded into a steel retort, and the retort interior was airtight. Thereafter, the retort was inserted to the furnace chamber and at first, the POH was pyrolysed at 300^{0}C. This process was rerun for temperatures of 400^{0}C, 500^{0}C, 600^{0}C and 700^{0}C and in all the runs the produce of biochar, bio-tar and bio-gas was determined. Response Surface Methodology (RSM) was applied to develop a polynomial regression model and to investigate the effect of temperature and time-duration on the product yields, Centre Composite Design (CCD) was used. The characterization of temperature and holding time and their squares (A, B, A^2 and B^2) are significant to the developed model.POH feedstock was optimized to yield 95.22% charred POH at 300^{0}C in 10 mins, 51.02% tar (bio-oil) at 500^{0}C in 30 mins, and 47.70% biogas at 700^{0}C in 30 mins. The p-value <0.05 for the process parameters indicated the significance of the factors as the temperature was observed the most significant factor based on the highest F-value. The results obtained showed that biofuels can be produced at an industrial scale for optimum yields.

Keywords: biomass, thermochemical conversion, pyrolysis, temperature, holding/resident time, RSM.

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1 INTRODUCTION

The world population from the report published by the United Nations in 2013 is 7.2 billion. It will reach 8.2 billion as it gets to the year 2025 [1]. The exploration of fossil fuel due to massive economic and industrial development vis-à-vis population increase has resulted in energy insufficiency and environmental pollution in which greenhouse gas (GHG) is the main contributor. In our world today, energy is of great importance. The relevance of energy cuts across all sectors; among them is industrial, transportation, agricultural, power generation activities and many more. High-income countries have an annual average per-capita energy consumption of 5,228kilograms of oil equivalent (kgoe). That of low-income countries amount to 250 kgoe [2]. Due to the periodic changes in high pump price and low petroleum deposits utilizing alternative energy sources is deemed to be important.

Fossil fuels are presently the main source of energy explored globally, It is limited in abundance and with time it will no longer meet the world's increasing energy demands [3]. Furthermore, due to the use of fossil fuel greenhouse gas (GHG) emissions are rapidly increasing. Thus, governments across the world are making policies to grow the utilization of renewable energies such as solar, wind, hydroelectricity, and biomass. Therefore, researchers are making efforts to replace fossil fuels with an alternate energy source that will be more environmentally sustainable[4,5].

Biomass includes the following: crop residues, woods and animal wastes [6]. Biomass with its distinctive potential of re-cultivation is the only renewable source of fixed carbon. Its inclusion in the global energy mix is an essential constituent to reaching many of the energy targets [3]. Biomass is abundantly available almost every corner of the world [8].To date, it has already provided 14% of global energy needs. Apart from its abundance, the residues posses insignificant contents of sulfur, nitrogen and ash with the required carbon content. Consequently, biomass releases lower emissions of CO_2, SO_2, NO_x and soot compared to fossil fuels, hence having a less negative environmental and human impacts[9,10].

The utilization of biomass as combustible fuel is a carbon-neutral phenomenon. The capturing and release of CO_2 by biomass through photosynthesis is in balance. This is significant if compared to the carbon stored in fossil fuels, which when combusted increases the net concentration of CO_2 by releasing it from the carbon depositories. Biomass combines solar energy and carbon dioxide into chemical energy in the form of carbohydrates through photosynthesis. Biomass wastes are ideal energy source which includes agricultural wastes, forestry residues, woods, by-products from the processing of biological materials, and organic parts of municipal and sludge wastes. The process of photosynthesis captures around 4000EJ/year in the form of energy from biomass and the current world energy use is just about 500EJ[11,12]. This indicates that the present and prospective biomass utilization is of immense significance.

The use of biomass for the industrial production of energy harnesses the natural photosynthesis-respiration cycle of the vegetation to reduce the atmospheric concentration of CO_2. This is a significant advantage over the use of fossil fuel in energy production[13]. It is commonly agreed amongst scientists that most of the world's CO_2 emissions come from the way energy is produced and utilized [14]. Bioenergy production as a technology holds the benefit that it simultaneously improves energy security supplies, grows the rural weak economies and aids to mitigating the threat of global climate change.

Thermochemical and biochemical conversions are the main methods used in bioenergy conversion [5,13]. The thermochemical conversion method involves subjecting the biomass to heat and chemical catalysts in the production of energy which resulted in three end-products namely biochar, biotar (bio-oil), and the non-condensable biogas [17,18]. The biochemical method uses biological catalysts and organisms to yield energy. The biochemical method comes with a drawback in the area of the swift and total conversion of biomass into energy. This has channelled the engagements of researchers towards a thermochemical conversion process [13].

With the inherent need to decouple economic growth from CO_2 emissions, there exist a range of technology options in various stages of application such as solar thermal-PV, carbon capture and second-generation biofuels. However, only one class of technologies offers the ability to reduce atmospheric CO_2 and produce renewable energy -- the use of biofuels [4]. The worldwide adoption of biofuels production has been modelled to sustainably abate the required minimum of 12% (CO_2 equivalent) of the global emissions (CO_2, CH_4, N_2O) without causing harm to soil conservation, food security and habitat [21].

The threat to climate change secured access to energy and maintaining the agrarian economy are among the top governmental policies across the world. This could be supported in the promotion of bioresources for food, material, and energy production. Convincingly clear, these represent the three dimensions of sustainability, namely, profitability (affordable energy), planet (climate change), and (social stability) the people [22,23].

The inception of the modern millennium has witnessed a rapid connection of technical, economic, and societal demands for sustainable green technologies. As such, we may develop a new economy that is “carbohydrate-lignin” based which can firstly supplement the petroleum economy and, as these renewable energies are utilized, then become the primary sources for fuels, chemicals and materials [20].

Moreover, in the aspect of manufacturing and energy processes, there is a need to responsibly manage our environment to develop sustainable green technologies which may lead to potential solutions. In retrospect, the trend in the adoption of Biofuel production technologies and alternatives have shown reasonable progress till current date leading to the need to optimise the production methods and management of biofuels related technologies [15,19].

Due to the required improvements, research works on thermochemical production of biofuels is becoming more popular. Evidence from literature studies reveal the necessity to investigate the effects and behavioural patterns of process parameters in the experimental production of biofuels and the varying optimization circumstances with the application of Centre Composite Design (CCD) using Surface Response Methodology (RSM). Hence, elaborate studies are required in researching the relationships among those parameters in maximizing high and qualitative yields. The focus feedstock (POH) which is a waste product that is readily available. Based on the analysis of variance (ANOVA) the effects of the major process parameters namely, pyrolysis temperature and resident (holding) time were assessed on POH products.

2 MATERIALS AND METHODS

Various bioenergy routes have been taken in the conversion of biomass to the required biofuels. The conversion technologies that have been developed are based on the

physical nature and chemical composition of the residues and the needed end-use energy such as, electricity, transport fuel, heat and power
.
Torrefaction and pyrolysis are being developed to convert a large quantity of raw biomass into denser and more practical energy carriers for efficient transport, storage and ease of use in subsequent processes. The production of energy by direct decomposition of biomass to produce biofuels is among the leading and cost-competitive bioenergy approaches [21].

2.1 Palm Oil Husk Material Preparation

The oil palm husks were obtained from a local oil-palm establishment in Ife-Odan of Ogbomosho, Oyo state (Nigeria). The husks were kept outdoor as the investigation is carried out. The husks were cleaned to minimize contamination. To reduce moisture content the husks were exposed to the natural sun for four days. Before pyrolysis, the husks sample were milled and sieved from unwanted particles. The sample weight, W_1, was taken using a digital weighing balance Ohaus top-loading (Model: PA4102, range: 0-4100g, Ohaus Switzerland Pty. Ltd). The residues were oven-dried to 105℃ to obtain a fixed weigh of W_2, ASTM D5373-02 (2005) standard.

2.2 Pyrolizer set-up

The pyrolysis process line, as shown in Figure 1, consists of the furnace (electrically operated) with a built-in glass fibre designed to minimize heat loss. Seated inside the furnace is the retort that is fabricated using mild steel which housing the residues that is to be pyrolysed. Mild steel is considered due to its high melting point of 1400 to 1600℃, tensile strength, good machinability and good resistance to corrosion. A thermocouple is fixed to the furnace to indicate the temperature at which pyrolysis takes place with a Controller in place to maintain the specific temperature of a pyrolysis process.

The hardened lagged pipe leading from the retort to the condensate receiver (in the process maintains a temperature of 100 to 120℃) captures the gas, condensable and non-condensable gas thereby condensing it. The condensate receiver is made up of the cooling unit, pressure gauge which indicates the movement of gases to the receiver. The condensate receiver is fabricated with galvanized sheet metal and mostly preferred for its high resistance to corrosion, machinability and heat exchanging property. The unit of the gas collector takes in the gases directly from the retort to the gas cylinder. Within a controlled environment, the gas cylinder serves as a storage device for the received gas from the collection unit. The connection is made to collect the filtered gas.

(1) Furnace
(2) Controller
(3) Thermocouple
(4) Lagged pipe
(5) Pressure gauge
(6) Condensate receiver
(7) Uncondensed unit
(8) Water bath
(9) Relief valve
(10) Gas cylinder

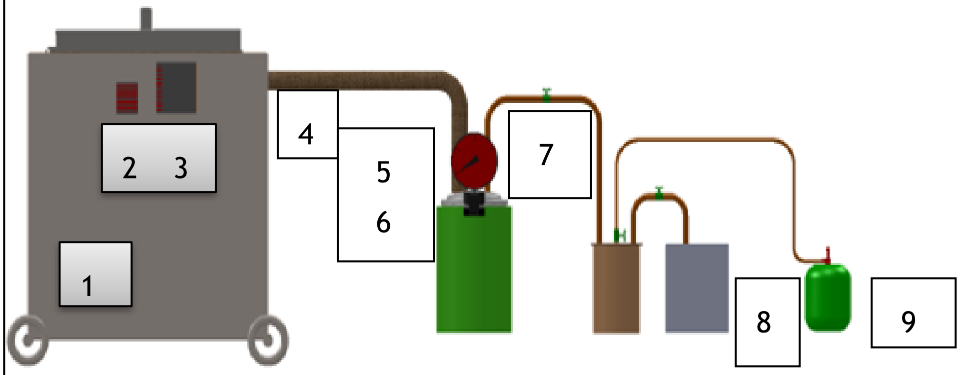

Figure1: Set-up of orthographic front views in biofuels production

2.3 Activation set-up

An apparatus on the standard of thermogravimetric analysis (TGA) at Ladoke Akintola University of Technology, Ogbomosho, Nigeria was utilized. Thermal, thermochemical conversion process of pyrolysis on biofuels were conducted in the course of the investigation. This was to determine the effect of process parameters in the production of biofuels from oil-palm husks (POH) residues. Dried POH of 500g was channelled to the retort and inserted to the furnace then subjected to the temperatures of 300, 400, 500, 600 and 700℃ in a controlled environment to avoid unwanted oxidation. The temperatures were increased at time interval of 10 minutes. As the retort is led via a hardened metal pipe to the condensate receiver fixed to a cooling unit for rapid recovery of the condensed biotar (bio-oil), the uncondensed gas passes through the hose pipe to the gas collection unit. The readymade biochar seating in the retort and the condensate in the receiver were removed and weighed. The mass of biogas is deduced by subtraction from the known values of biotar and biochar.

Mathematically, mass of biogas is calculated as;

$$w_{gas} = W_{PH} - w_{char} - w_{tar} \quad (1)$$

The yield of biogas, the yield of bio-tar (oil) and the yield of biochar are represented as Yg, Yt and Yc respectively. Mathematically, we have the percentage of product yields (Y_{Product}) calculated as:

$$Y_{\text{Product}} = \frac{mass\ of\ Product\ (W_{\text{Product}})}{mass\ of\ sample\ POH\ (W_{PH})}\ x\ 100 \quad (2)$$

The ANOVA analysis was used to perform statistical analysis, this includes linear, quadratic and coefficient of interaction. Centre Composite Design (CCD) in RSM was used to optimize the process parameters factors, these are pyrolysis temperature and holding time. There are boundaries of the lowest and highest value of factors proposed by RSM to optimize the pyrolysis product yields. The investigation carried out twelve experimental runs based on CCD with the process parameters as reported in the result.

Once the experiments have been carried out. The response variable (mass yield) was correlated with the considered independent parameters (resident time and pyrolysing temperature). This relationship between response and the variable factors are mathematically represented as follows:

$$Y = f(X_1, X_2, X_3, ..., X_n) \quad (3)$$

Y is represented as the response variable, f is the function relating response to the independent variables as X_1, X_2… X_n are the independent variables which affected the response.

Following the second-order of polynomial equation the functions were approximated as suggested by central composite design method shown:

$$Y = b_0 + \sum_{i=1}^{k} b_i X_i + \sum_{i=1}^{k} b_{ij} X_i^2 + \sum_{i_{i>j}}^{k} \sum_{j}^{k} b_{ij} X_i X_j$$

(4)

Where Y is represented as the response variable, b_0 is the value of the fitted response at the centre point, and i, j and ij are linear, quadratic and cross-product regression coefficients respectively. Where k is the number of independent factors considered in the investigation which are two in number.

2.4 Product Yields Optimization

Following the vector optimization of equation (4), a nonlinear programming problem is formed. In maximizing the mass product yields the optimization problem statement that was deduced is stated:

Maximize $Y = f(X_n)$

(5)

Subject to $P_A \le A \le V_A$

$P_B \le B \le V_B$

Y represents the product yields, P_i is the lower limit of the independent factors and V_i represents the upper limit of the independent factors. Using ANOVA and regression analysis the line search problem as defined in equation (4) was characterized and solved in the optimization technique of Design Expert Version 11 to obtain the optimal mass yields and the resulting optimal process variables.

3 RESULTS AND DISCUSSION

Based on the results of the ANOVA and regression analysis from the t-test the regression coefficient that is significant only at 95% were the only ones used in developing the final model while the rest are discarded.

3.1 Experimental design and statistical analysis

The investigation adopts a statistical approach. The optimization of the biofuel yields was achieved with Face Central Composite Design (FCCD) of response surface methodology (RSM) using Stat-Ease Design-Expert Software Version 11 to evaluate the effect of separate and the interaction of process parameters on the response.

The coded level for the two independents process parameters is listed in Table 1. Where -alpha and +alpha represents the lowest and highest bearable point of responses as shown in Table 1.

Table 1: Experimental Domain of Process Parameters

Process parameters	Code	Unit	-alpha	-1	0	1	+alpha
Pyrolysis temperature (°C)	A	°C	280	300	500	700	710
Holding time	B	Mins	8	10	20	30	32

Table 2: POH Responses Based on CCD Design Arrangement

Coded Level			Variable Values		Responses		
No	**A (°C)**	**B (min)**	**T (°C)**	**t (min)**	**Yc_{POH}**	**Yt_{POH}**	**Yg_{POH}**
1	0	0	500	20	38.85	47.93	13.16
2	1	0	700	20	24.60	38.91	36.58
3	1	1	700	30	18.86	33.62	47.70
4	-1	-1	300	10	95.22	1.83	3.02
5	-1	0	300	20	69.38	15.24	15.89
6	-1	1	300	30	49.06	26.71	24.23
7	0	0	500	20	38.12	47.86	13.11
8	0	1	500	30	29.88	51.02	19.97
9	0	0	500	20	38.86	47.98	13.14
10	0	1	300	30	50.01	24.77	23.24
11	1	-1	700	10	71.09	15.35	13.47
12	0	-1	500	10	81.00	11.17	7.19

By default from Table 2, the high levels of the factors are coded as +1 and the low levels are coded as -1.

The selected process parameters were the primary impacting factors (pyrolysis temperature and holding time) which were optimized with the application of Centre Composite Design (CCD) in RSM.

3.2 Bio-Oil Production

3.2.1 RSM Equation for Bio-oil Mass Yields from POH

The selected process parameters were the primary impacting factors (pyrolysis temperature and holding time) which were optimized with the application of Centre Composite Design(CCD) in RSM. The effect CCD on the product (bio-oil, biochar and biogas) yields of oil-palm husks is as shown in table 2. Furthermore, the parametric results of all the responses were elaborated to pinpoint the impact of the selected process parameters in the pyrolysis process. Using CCD the relationship between the real values of factors (A, B) and their responses, percentage of biofuel yields were framed. Evaluation is carried out with ANOVA analysis gives an appropriate model which indicates a quadratic model as the best to fits the experimental data. Regression equation to produce bio-oil (tar) on the bases of coded parameters is shown:

$$Y_t = 44.39 + 7.35A + 11.29B - 1.65AB - 12.02A^2 - 15.64B^2 \quad (6)$$

Where A is the pyrolysis temperature and B is the holding (resident) time. The equation in the form of coded factors is used to predict the effect of process parameters on the production of bio-oil as indicated in Table 3. The results proved that the model is statistically significant as the value of $p<0.05$. Furthermore, the lack of fit value of 0.67 indicated that it is not significant, this proves the existence of ignorable random and systematic error in both the model and experimental activity.

The model also proved the effect of process parameters on bio-oil (tar) were in the holding time then followed by pyrolysis temperature i.e. (B)> (A). Each of the variable factors was of significance as it has its p-value to be >0.05. As (B) factor has the largest value of 8.95 among all values for the significant factors, (B) is taking as the most influencing parameter of the experiment. The lack of fit value of 3.42 proved that it was non-significant hence confirmed the validity of the model. In the application of ANOVA analysis in the production of bio-oil, the value of R^2 was 0.8151 this showed the existence of a good correlation between the experimental and the predicted value from the CCD.

Table 3: ANOVA Quadratic Model for Bio-oil Production

Source	Sum of squares	Degree of freedom	Mean square	F-value	p-value	Remarks
Model	2540.15	5	508.03	5.29	0.0332	Significant
A-pyro temperature	324.13	1	324.13	3.38	0.1158	NS
B-resident time	859.46	1	859.46	8.95	0.0243	Significant
AB	10.92	1	10.92	0.1137	0.7474	NS
A^2	414.43	1	414.43	4.32	0.0830	NS
B^2	684.08	1	684.08	7.12	0.0371	Significant
Residual	576.22	6	96.04			
Lack of fit	231.69	3	77.23	0.6725	0.6239	NS
Pure Error	344.54	3	114.85			
Cor. Total	3116.38	11				
R^2	0.8151					

3.2.2 Parametric Behaviours of Bio-oil Production

To indicate the direction at which to change a given factor to best maximize the yields to bio-oil, response surface methodology was utilized for optimum pyrolysis process of the POH residues.

More so, for the understanding of the varying factors that effected the pyrolysis process. Resident time (B) has demonstrated to be the highest effected process parameters in the production of bio-oil with a result of a larger F-value 8.95 having a smaller p-value of <0.0243. As shown in Figure 2 (A), bio-oil (Y_t) yield increased up to 51.02% of pyrolysis temperature at about 500°C.

From Figure 2, the interaction between parameter A and B appeared to be significant as they are interdependent. Pyrolysis temperature (A) hence, is the next most sensitive effecting parameters to bio-oil production due to the relatively larger F-value of 3.38.

The relationship between the two factors, pyrolysis temperature and resident time on bio-oil production are illustrated in Figure 2. We have bio-oil yield percentage for pyrolysis of Oil-palm husks at relatively low resident time of 20 mins and pyrolysis temperature of 500°C to be 47.98%. Consequently, with the same value of pyrolysis temperature and increase in time by 10 mins, bio-oil yielded to 51.02%.

In another way round, resident time was made fixed as the pyrolysis temperatures were altered, such that at a relatively high pyrolysis temperature of about 700 against resident times of 20 mins higher percentage of bio-oil yield of 47.93% was produced.

The findings showed that reaction temperature and reaction time are both influential process parameters for bio-oil production.

The three-dimensional cubic in Figure 2 depicts the variances in pyrolysis temperature against holding time and the resulting yield of tar.In Figure 2 a scale of -1, -0.5, 0,0.5 and 1 to represent 10, 20, 30, 40 and 50 minutes respectively on Time (B) axis. Scale of -1, -0.5, 0,0.5 and 1 to represent 300, 400, 500, 600 and 700 ^{0}C.

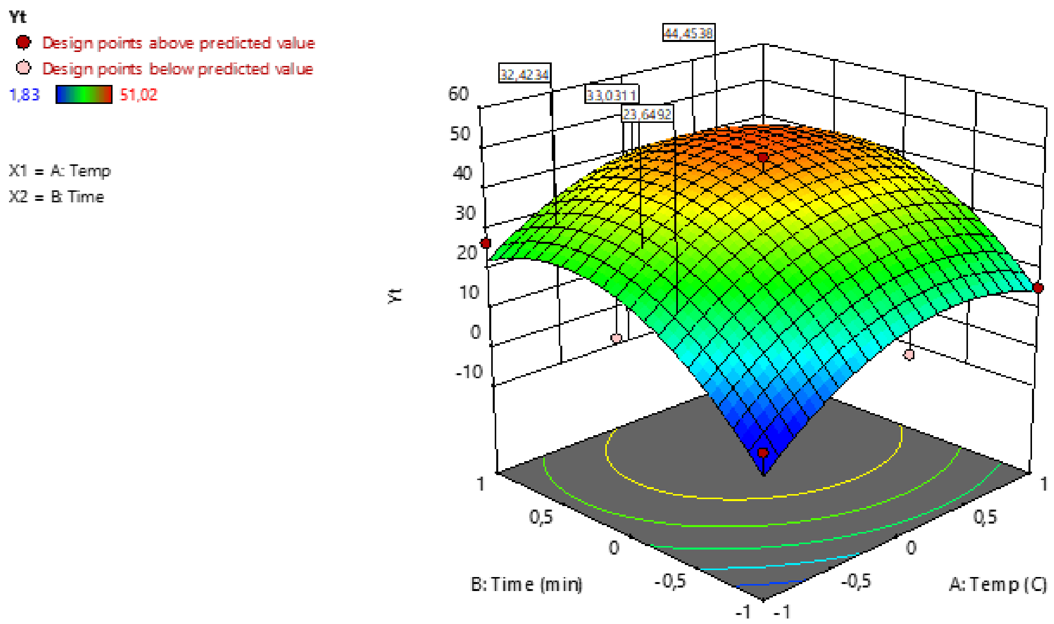

Figure 2: Cubic plot of 3-Dimension RSM depicting the effect of Pyro temp (A) and Resident time (B) on bio-oil yield from POH.

3.3 Biochar production

3.3.1 RSM Equation for biochar mass yields from POH

In the production of biochar, a regression equation was formulated with the aid of CCD as given in the equation (7). The joint and interdependent influence of biochar production and process parameters were investigated with the use of ANOVA. The results of the analysis showed that the quadratic model is a better fit for the biochar production.

$$Y_c = 39.79 - 16.29A - 25.15B - 1.17AB + 5.43A^2 + 13.88B^2$$
(7)

Where A represents pyrolysis temperature as B represents the resident time.

Table 4 shows the analysis of ANOVA in the production of biochar. At higher F-value of 58.18 and lower p-value of <0.0001 the model was found to be significant. In such analysis, p-value shows the validity of the model as the f-value indicates the effects of the parametric process on the yields [22].

At a significant point where F-value is 199.25 and p-value is <0.0001 the resident time (B) has the highest impact on the yield of biochar consequently, the pyrolysis temperature (A) of F-value 83.56 and a p-value of <0.0001 followed. Lack of fit for this model seemed to be significant as the p-value is 0.0009. The coefficient of multiple correlations (R^2) of the 0.9798 depicts a good model. The results of the actual values plotted against the predicted responses on biochar production in Figure 3 shows that the regression was statistically significant.

Table 4: ANOVA Quadratic Model for Biochar Production

Source	Sum of squares	Degree of freedom	Mean square	F-value	p-value	Remarks
Model	6108.32	5	1221.66	58.18	<0.0001	Significant
A-pyro temperature	1754.50	1	1754.50	83.56	<0.0001	Significant
B-resident time	4183.93	1	4183.93	199.25	<0.0001	Significant
AB	6.36	1	6.36	0.3028	0.6020	NS
A^2	76.49	1	76.49	3.64	0.1049	NS
B^2	500.09	1	500.09	23.82	0.0028	Significant
Residual	125.99	6	21.00			
Lack of fit	125.18	3	41.73	154.26	0.0009	Significant
Pure Error	0.8114	3	0.2705			
Cor. Total	6234.31	11				
R^2	0.9798					

3.3.2 Parametric Behaviours of Biochar Production

To observe the effects of process parameters on biochar yield, cubic plots of a 3-dimension response surface methodology was adopted. The results of the response parameters from the analysis of variance in Table 2 shows the highest percentage of biochar that can be obtained with significant model terms of A and B.

As shown in Figure 3 cubic response surface plot for process parameters influenced the biochar yields. As indicated, the minimum value of biochar yield was 18.86% at the highest pyrolysis temperature of 700℃ due to secondary decomposition of biochar feedstock into oil pyrolysis product [21]. Thus, the maximum yield of biochar was 95.22% at the lowest boundary of pyrolysis temperature of about 300℃. This implies that hemicellulose decomposition at a lower boundary of pyrolysis temperature led to the high feedstock and biochar yield [22].

The three-dimensional cubic in Figure 3 depicts the variances in pyrolysis temperature against holding time and the resulting yield of biochar.

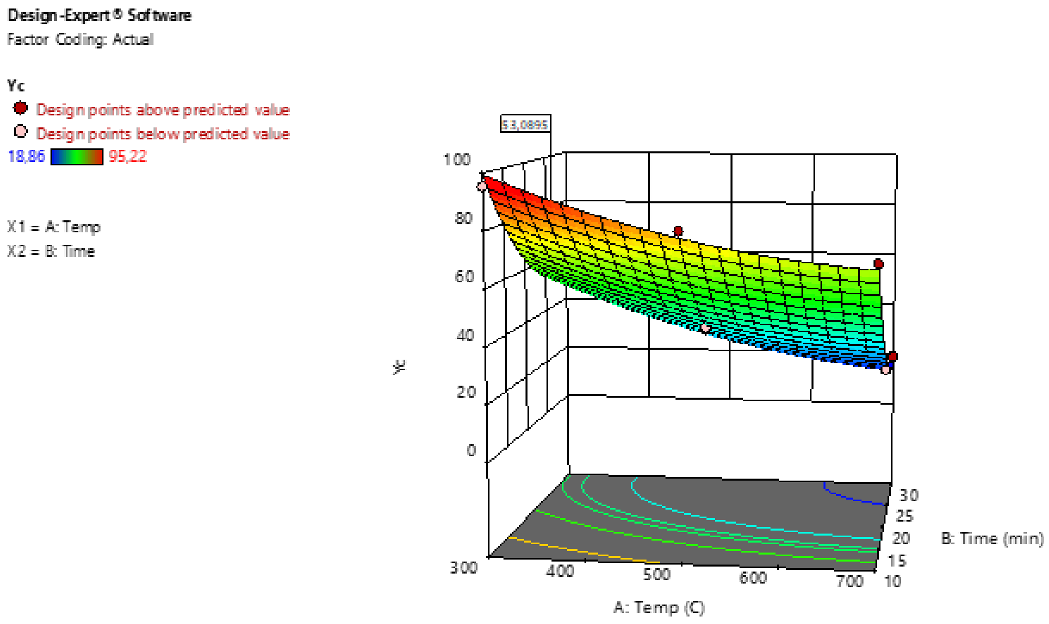

Figure 3: The Cubic plot of 3-Dimension RSM depicting the effect of Pyrolysis temperature (A) and Resident time (B) on biochar yield from POH

3.4 Biogas production

3.4.1 RSM Equation for Biogas mass yields from POH

To formulate RSM coded equation a mathematical model for biogas was developed to determine the effect of process parameters on the product yield. The quadratic model fitted into the behavioural pattern is shown in equation (8).

A represents the temperature of the pyrolysis and B is denoted as the resident time. The data of analysis of variance for the production of bio-gas are given in Table 5. The 21.2 of F-value depicts that the quadratic model was significant and having the p-value of 0.0010 that was relatively smaller to 0.05 also gives support to the significance of the model. To this experiment, coded process parameters that effected the yield of bio-gas were, A (pyrolysis temperature), B (resident time), AB (product of pyrolysis temperature and resident time), A^2 (square of pyrolysis temperature) and B^2 which is the square of resident time as shown in equation (8):

$$Y_g = 14.08 + 9.10A + 11.34B + 3.26AB + 10.74A^2 - 2.01B^2 \quad (8)$$

The two process parameters namely, the pyrolysing temperature and the resident time posses high impact in the production of biogas.

Table 5: ANOVA Quadratic Model for Bio-gas Production

Source	Sum of squares	Degree of freedom	Mean square	F-value	p-value	Remarks
Model	1624.34	5	324.87	21.12	<0.0010	Significant
A-pyro temperature	497.04	1	497.04	31.31	<0.0013	Significant
B-resident time	867.49	1	867.49	56.39	<0.0003	Significant
AB	42.38	1	42.38	2.76	0.1480	NS
A^2	330.52	1	330.52	21.49	0.0036	Significant
B^2	11.25	1	11.25	0.7312	0.4253	NS
Residual	92.30	6	15.38			
Lack of fit	86.95	3	28.98	16.26	0.0233	Significant
Pure Error	5.35	3	1.78			
Cor. Total	1716.64	11				
R^2	0.9462					

The lack of fit for the model was also significant as the F-value is 16.26and the p-value of <0.0233. In general, the goodness of the model was obtained from the value of R^2= 0.9462 with the relationship of the predicted values over the actual values in the production of biogas.

3.4.2 Parametric Behaviours of Biogas Production

The impacts of process parameters on bio-gas produce in pyrolysis process were investigated from the designed cubic plot RSM as shown in Figure 4. Effect of pyrolysis temperature and resident time indicates a lower biogas yield at 500 ^{0}C and 20 mins [23]. Consequently, with the decreasing pyrolysis temperature of about 300℃ and the minimum resident time of 10 mins there exist the lowest production of bio-gas of 3.02%. Subsequently, increasing pyrolysis temperature up to 700℃ with resident time increase of 30 mins resulted in a larger value of biogas amounting to 47.70% production. These show that there was a favourable interaction between pyrolysis temperature and resident time on the production of bio-gas in the pyrolysis process of OPH proved with a larger F-value of 56.39 and p-value of 0.0003.

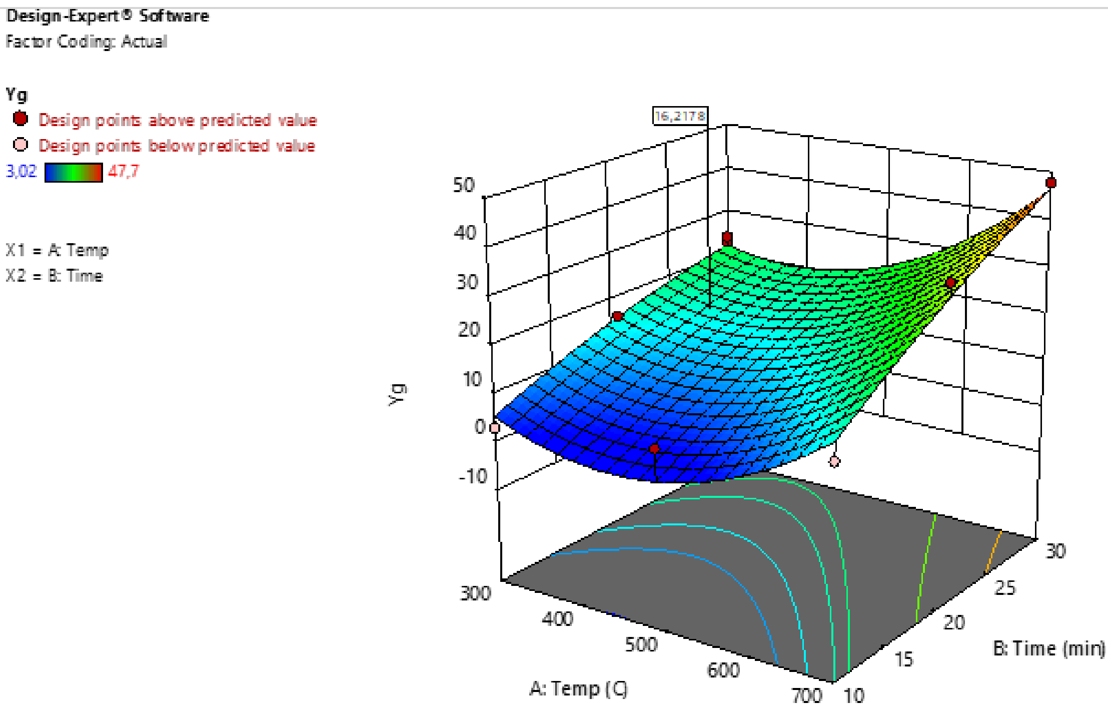

Figure 4: Cubic plot of 3-Dimension RSM depicting the effect of Pyrolysis temperature (A) and Resident time (B) on biogas yield from POH.

3.5 Experimental Validation and Optimization

From the results of the investigations carried out as obtained by response surface methodology, the optimization of process parameters from the pyrolysis of Palm Oil Husks (POH) was partially achieved. The relationships that exist between the selected process parameters were researched using analysis of variance (ANOVA) with the application of Design Expert 11. The analysis deduced that with an optimized working condition of process parameters such as pyrolysis temperature and resident time biofuel product yields are maximized. By optimizing process parameters POH feedstock yielded 95.22% of biochar with pyrolysis temperature of 300°C at 10 mins, 51.02% of tar (bio-oil) with pyrolysis temperature of 500°C at 30 mins, and 47.70% of biogas with pyrolysis temperature of 700°C at 30 mins. Additionally, optimum utilization of the lignocellulosic decomposition of POH organic structure was explored in the production of bio-oil, biochar and bio-gas at the value of 51.02%, 29.88% and 19.97%, respectively.

4 CONCLUSION

The study has shown that optimum condition of process parameters can be attained for maximum production of biofuels through pyrolysis of POH under a well-controlled set-up of a pyrolizer using CCD of RSM. By applying ANOVA analysis, process parameters optimum conditions were determined at approximately 500°C pyrolysis temperature and resident time of 30 mins to produce energy yields of 51.02% of bio-oil, biochar and bio-gas at the values of 29.88% and 19.97% respectively. Process parameters namely, pyrolysing temperature (A) and holding time (B) were both investigated to have a high impact on biofuels production.

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AN INVESTIGATION INTO THE EFFECTIVE USE OF TOTAL QUALITY TOOLS TO IMPROVE PRODUCTION PERFORMANCE AT XYZ RUBBER: CASE STUDY

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ABSTRACT

The dynamism of customer demands has provoked organizations to embark on a strategy of continuous improvement initiatives to improve business processes. The problem examined was that although the company employed Total Quality (TQ) tools in the context of Mission Directed Work Teams (MDW) to help improve processes and solve problems, the problems persisted to impact the achievement of ninety percent delivery accuracy due to scraped products, late supplier deliveries, and other business related problems. The research aimed to develop a framework that the organization may utilize concerning the application of the TQ tools to improve processes and problem-solving. The investigation was quantitative in nature using questionnaires as the primary instrument. The outcome of the study is presented by the developed framework which was validated by practical application. In addition, the current experience of COVID 19 re-iterates the importance of the management of quality and its implication for sustainability.

Keywords: TQM, customer satisfaction, process improvement

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1. INTRODUCTION

The success of a company is measured by its financial performance. Management and shareholders want to increase productivity and profits. The problem of productivity needs to be addressed to increase the profit margin [1]. It is essential to improve productivity through smart technologies for any manufacturing or service industry. The value of volume lets a business survive in competition. Technology has been increasingly established to meet the demand of the customers. The manufacturing sector will aim for the elimination of waste with increased productivity that leads to increased profits [2].

Global competition and changing customer demands have changed the business environment in recent years. Any company that does what is necessary to improve its quality by reducing deficiencies in key areas (cycle time, scrap and rework, time delivery, etc.) will reduce overall costs without sacrificing essential services, operations, product features, and staff [3].

In the first half of 2018, the manufacturing and mining and quarrying sectors were the major negative contributors to GDP growth in the first quarter. The manufacturing sector decreased by 6.4% and contributed -0.8% to GDP growth. In the first quarter, six of the ten development divisions posted negative growth rates. The biggest contributors to the downturn were the basic division of iron and steel, non-ferrous metal goods, metallic products, and machinery [4].

According to Brand South Africa, the manufacturing sector provides a place to stimulate the growth of other operations, such as services and to achieve specific outcomes, such as job creation and economic empowerment [5]. This manufacturing platform offers an opportunity to dramatically accelerate the growth and development of the country.

The main problem that led to the study was that given the investment in the use of Total Quality Tools/MDW to help the company recognize, quantify and address issues, output and quality problems persisted. The goal for performance to measure the accuracy of output as a 90 percent target in the enterprise was not achieved.

The study aimed to develop a framework that could be used by the company concerning the use of TQ tools to enhance processes and solve problems by examining factors affecting the successful use of Total Quality tools, evaluating the impact of Total Quality tools on quality and establishing a level of understanding of Total Quality tools by organizational personnel.

2. METHODOLOGY

The quantitative approach was the research technique adopted for the study because it was meant to evaluate the connections of one item (an independent variable) to another aspect (a dependent or outcome variable) in a population [6].

Quantitative analysis is primarily based on the fact that the information is obtained with structured research instruments and the findings are based on the larger samples that are representative of the population. The research study may generally be reproduced or validated as it is extremely reliable. To collect information from participants, the questionnaire was a method for the study composed of several questions.

Information was also accessible in numbers and statistics, mostly organized in charts, diagrams, graphs or other non-textual types. The focus of the research was more descriptive and the researcher's involvement was limited to prevent biases [7]. No participant preparation was conducted to avoid biasing the participants.

Given the true event, the population of XYZ Rubber is 69, and 59 people were selected as a valid sample for the study. Taro Yamane formula was used to determine the sample size.

However, the results showed that 68 people participated in the study, which showed a positive participation within the population

3. LITERATURE REVIEW

The overall Total Quality Management (TQM) activities have been positively linked by several researchers to efficiency and output performance, quality achievement, employee satisfaction/performance, innovation success, customer satisfaction/results market share, financial performance and total company performance [8]. Several researchers also found little reason to conclude that TQM practices are positively performing, but found that TQM practices have significance in corporate leadership in various organizations [9].

The deficiency of professional organizations is the lack of support and dedication to the use of quality improvement tools and techniques, especially concerning the basic tools; on the other hand, it must also be acknowledged that some businesses have not benefited from and enhanced their efficiency by using these techniques and tools [10]Quality may also be described as a benefit investors should be prepared to pay a higher price [11];[12].

Ron Basu states that TQM is not a system but a philosophy that supports the overall culture of a company [13]. Dr George Power described the evolution of TQM in five stages i.e. Mass Inspection, Quality Control, Quality Assurance, Total Quality Control, Company-Wide Quality Control, and then Total Quality Management. The below figure shows a representation of these stages [14].

Training and Development are often used to address current performance gaps and expected future performance gaps. Typically, in many organizations, this is a feature of the Human Resources (HR) Department with a division called the Training and Development (T&D) Division [15].

These seven basic quality control tools, which were introduced by Dr Ishikawa, are: Check sheets, Graphs (Trend Analysis), Histograms, Pareto charts, Cause-and-effect diagrams, Scatter diagrams, and Control charts [16].

The Mission Directed Work Teams (MDW) tool is the property of Competitive Dynamics International ® (CDI) and aims to help organizations become world-class competitors. The current subsection is entirely based on CDI information. Mission Work Teams Program ensures that the most critical success objectives of the organization are recognized in every division and that each team in each department has clearly defined improvement goals to achieve these objectives. The curriculum also includes the necessary processes and tools for meeting these targets and continuously monitoring progress [17].

A Quality Management System (QMS) is a tool for managing quality in an organization. The Quality Manual is a way of recording how quality is managed throughout the organization so that everyone does his or her job in a coherent and quality manner. It ensures that a performance guide represents the organization and the quality management system [18]. The framework of the standard is divided into 10 main clauses i.e. (1) Scope, (2) Nominative References, (3) Terms and Definitions, (4) Context of The Organization, (5) Leadership, (6) Planning, (7) Support, (8) Operation, (9) Performance Evaluation, and (10) Improvement [19].

4. RESULTS AND DISCUSSION

This section includes the evaluation, interpretation, and presentation of the results as obtained through the questionnaire and interview technique, and the debate of the results will be discussed in the next section.

4.1 Analysis of the Questionnaire

The questionnaire was the primary source of data collection. Although interviews were performed, the same set of issues was used by a field employee to collect information from ground employees who did not have access to computers. The questionnaire was split into three primary parts, namely Section A-Demographics, Section B-Scales, Statements and Ratings, and Section C-Management Commitment and Continuous Improvement.

4.1.1 *Section A - Demographics*

Section A of the questionnaire specifically collected data on demographics in terms of gender, age groups, departments, and the years that respondents spent working within the organization.

4.1.1.1 *Gender*

Of the 68 respondents, 8.8% (6 participants) of the participants were female and 91.2% (62 participants) were males. This demonstrated that gender diversity in today's workplace is an obstacle.

4.1.1.2 *Age Groups*

Different age groups data was collected as results shown in the below table where a majority of the participants (47.1%) were aged between 36 years and 45 years (both inclusive), followed by 23.5% who were between the ages of 46yrs and 55yrs.

There was confirmation that most individuals had between 11 and 15 years of work experience. MDW methods were launched about 8 years ago, most of which were already employed by the company. This suggested the likelihood of incorrect execution at the start-up. Since the beginning, there had been a lack of understanding and information.

4.1.1.3 *Departments*

Figure 1 below summarizes the number of participants per department and the percentages of participants. The information below demonstrates that the production department had a large amount of participants 73.5, followed by a technical/quality reaction of 11.8 percent, followed by a field service reaction of 10.3 percent. The Commercial Department's reaction rate was 2.9 percent and the last one was 1.5. Accordingly, no response has been obtained from the Sales Department.

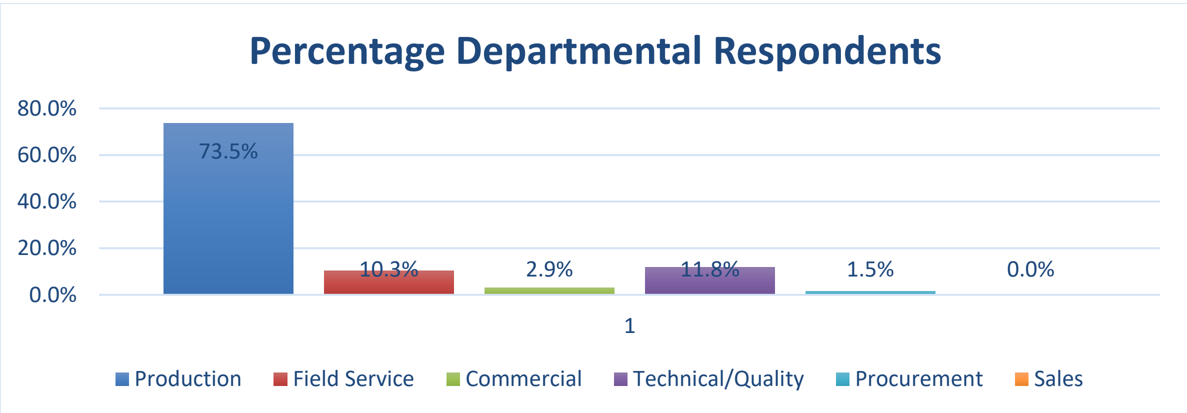


Figure 1: Percentage of departmental respondents

4.1.1.4 *Work experience*

Years of experience were broken down from 1 to 5 years with 17 participants, 5 to 10 years with 20 participants, 10 to 15 years with 24 participants, 16 to 20 years with 7 participants and none for 21 years and above as demonstrated in the figure 2 below.

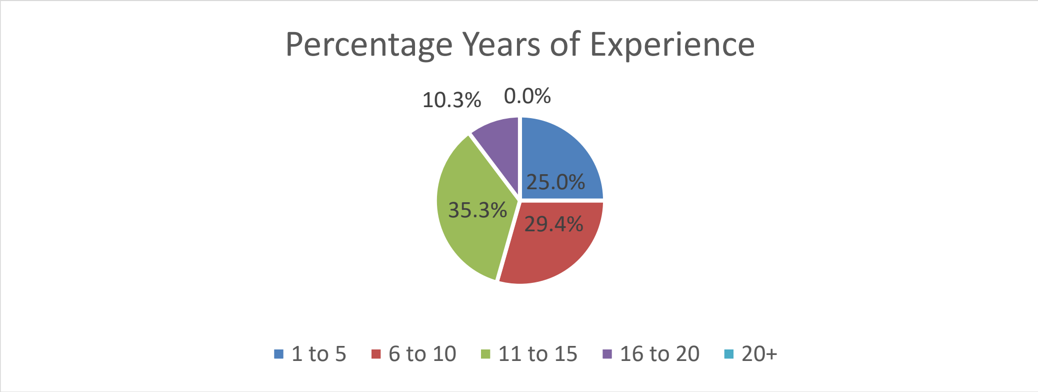


Figure 2: Percentage of years of experience

4.1.2 Section B - Scaled Questions and Statements

Section B of the questionnaire observed the scaled questions and statements of the respondents to gather how certain aspects were perceived.

4.1.2.1 *Knowledge of the TQ tools.*

Respondents were asked if they have heard about the seven basic Total Quality (TQ) tools. Figure 3 below summarizes the responses to the question. The first relevant part was that although the majority replied that they had heard about the tools and when questioned to briefly mention what they thought about the tools, it was evident that most of them didn't understand them.

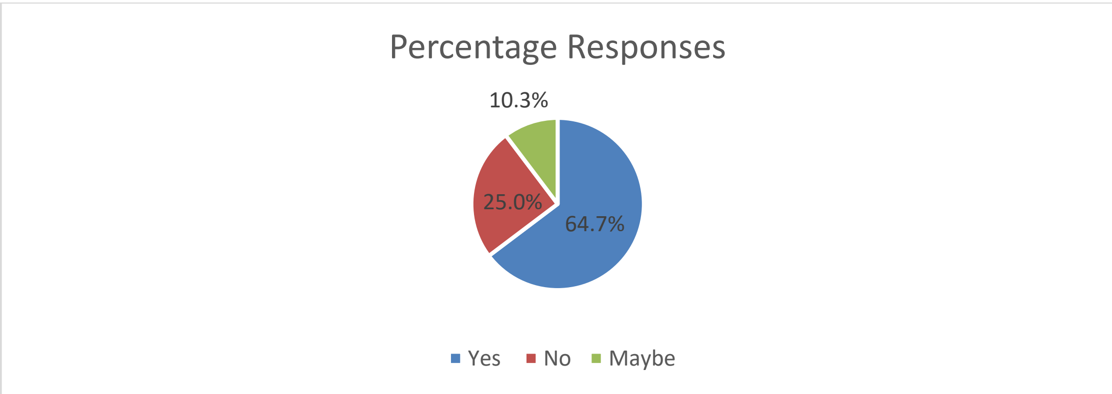


Figure 3: Percentage Responses About Knowledge Of The TQ Tools

4.1.2.2 *Has your company implemented the TQ tools?*

The following pie chart (figure 4) shows the response in terms of percentages of the issue whether the company has introduced the TQ tools. 51.5 percent of respondents believed that the TQ tools had been implemented, 14.7 percent believed that the TQ tools had not been implemented, 7.4 percent believed that they were still planned, 1.5 percent believed that they had been discontinued, and 25 percent did not know whether the TQ tools had been implemented.

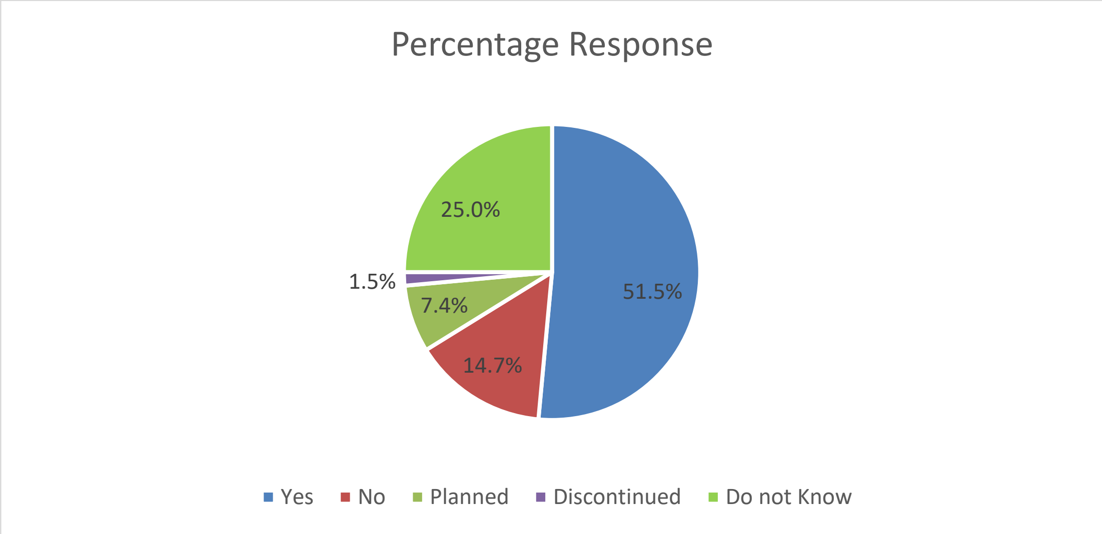


Figure 4: Percentage Response If TQ Tools Were Implemented

4.1.2.3 *Impact of TQ tools in organizational performance*

When asked at a scale of 1 to 5 whether the use of TQ tools has a positive impact on organizational productivity, the responses were summarized in figure 5 below. The percentage reactions of respondents where 11.8 percent rated 1 (strongly disagreed), 7.4 percent rated 2 (disagreed), 35.3 percent rated 3 (average), 20.6 percent rated 4 (agreed), and 25.0 percent rated 5 (strongly agreed).

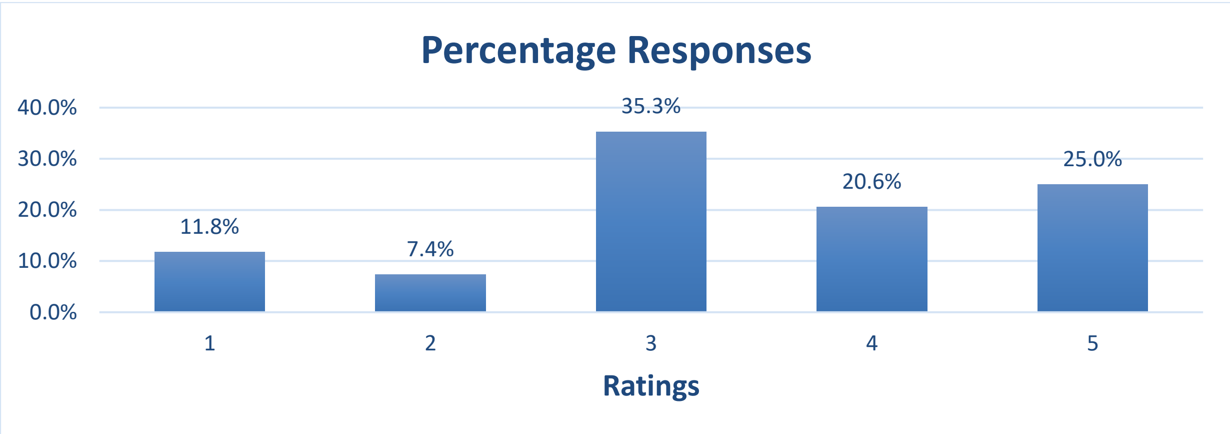


Figure 5: Bar Chart Summarizing Whether The Utilization Of TQ Tools Have A Positive Impact On The Organizational Productivity.

4.1.2.4 *Effect of failure to apply all TQ tools during their implementation*

As illustrated on figure 6 below, 77.9 percent replied that all alternatives on the subject were applicable to the question, followed by 8.8 percent said that failure to apply all TQ tools would result in elevated scrap, while 7.4 percent said that it would result in low productivity, 4.4 percent thought that it would delay deliveries, and only 1.5 percent thought that it would result in high rework.

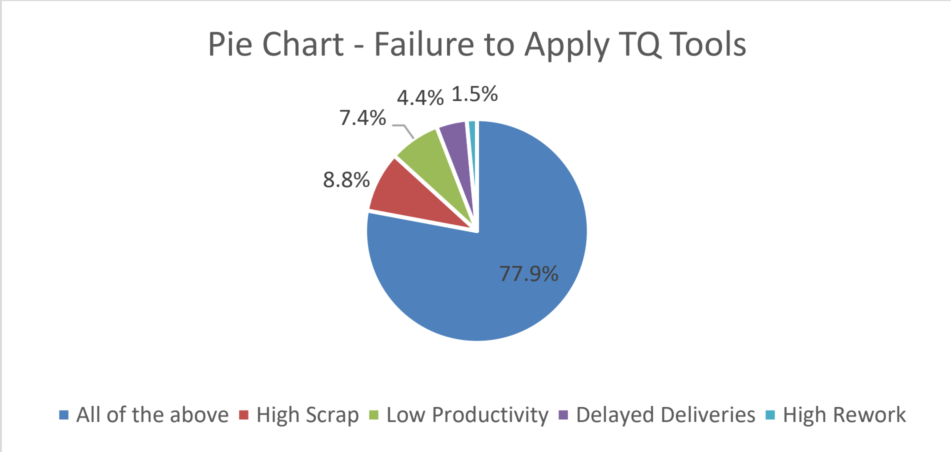


Figure 6: Effect Of Failure To Apply TQ Tools

4.1.2.5 *Challenges disrupting the effective utilization of the TQ tools in the organization*

51.5 percent of participants thought that difficulties were facing the organization in the effective use of the TQ Tools. Figure 7 below summarizes the proportion of respondents' answers.

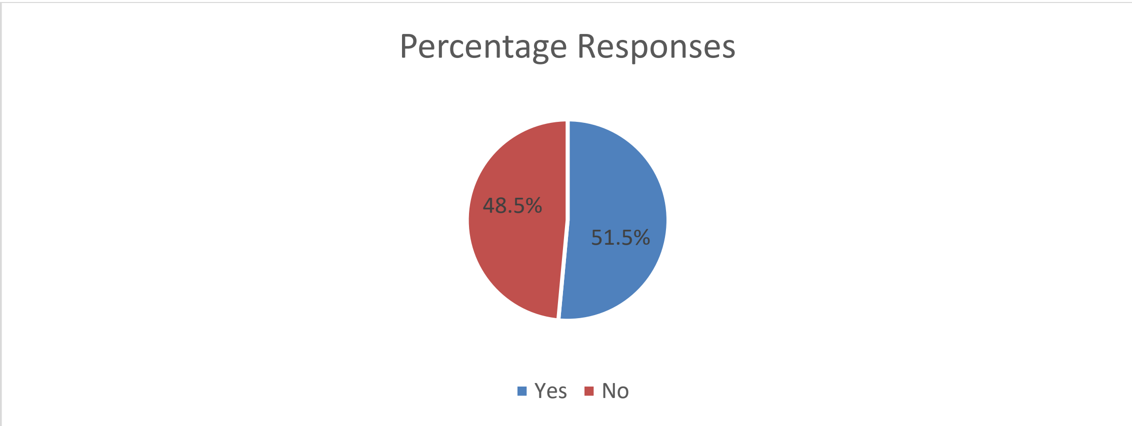


Figure 7: Percentage Responses of Challenges Disrupting The Effectiveness Utilization Of TQ Tools

4.1.2.6 *Time allocation for utilizing the TQ tools*

The following pie chart presents the outcomes of the answers when the participants were questioned if they had enough time to use the TQ tools to explore root causes of recognized non-compliance, with which 64.7% agreed that the organization would allow workers sufficient time to use the TQ tools.

4.1.2.7 *Employee training frequency*

Respondents were asked how often they have received training regarding the utilization of TQ tools with 79.4% said they never received training, 19.1% said only once in a year, and 1.5% said they received training every once three months.

4.1.2.8 *Failure to organize frequent employee training*

From the respondents, 35.3 percent believed that failure to organize frequent employee training could result in low productivity, with 27.9 percent said that it would lead to excessive scrapping and waste, 23.5 percent thought that it would result in bad quality, 7.4

percent did not know the effect of failure to organize frequent employee training, and 5.9 percent said that it would lead to bad quality.

4.1.3 Section C - Management's Commitment

Section C noted the Management Commitment in terms of practices and importance, and the results of the reactions are graphically presented in the following subsections.

4.1.3.1 *Management's Commitment - Practices*

Figure 8 below represent the management's commitment to practices, as per the answers collected. Respondents were asked to you rate the management's commitment to the organization and how they perceived importance for each factor.

	Management is actively involved in establishing and communicating the organization's efficiency, plans, and results. A	Management strongly empower and encourage employees to identify and implement improvement opportunities. B	Management allocates adequate resources for education and training in efforts to improve efficiency. C	Management view efficiency as an importantly factor to meet customer expectations. D	All Heads of Departments (Planning, Quality, Technical, Production, etc,) accept their responsibility for efficiency E
Scale on Practices 1	16.18%	13.24%	13.24%	2.94%	8.82%
Scale on Practices 2	13.24%	7.35%	13.24%	1.47%	10.29%
Scale on Practices 3	32.35%	29.41%	27.94%	10.29%	25.00%
Scale on Practices 4	25.00%	20.59%	25.00%	27.94%	32.35%
Scale on Practices 5	13.24%	29.41%	20.59%	57.35%	23.53%

Figure 8: Management Commitment On Practices

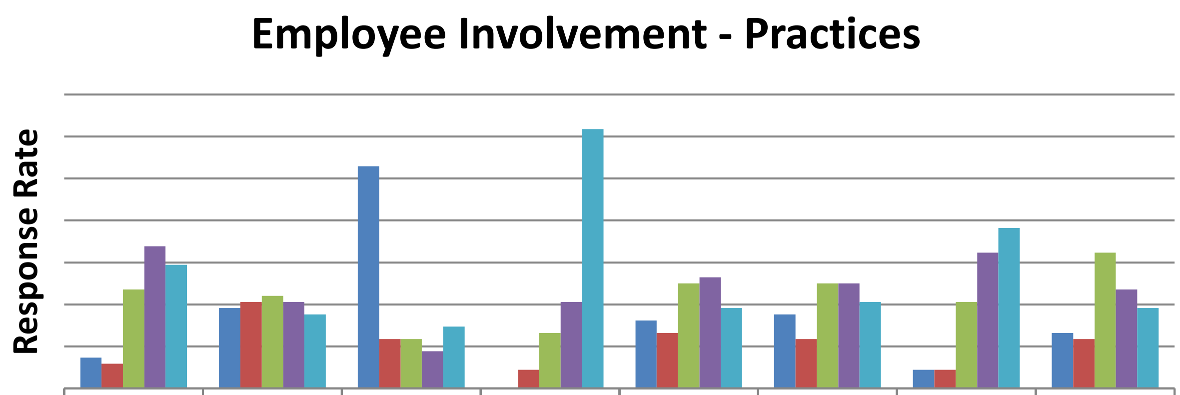
4.1.3.2 *Employee Involvement - Practices*

The present subsection noted several questions directed at exploring whether employees were directly involved in helping an organization better perform and achieve goals by implementing their ideas, abilities, and expertise, and attempts to solve issues and make choices. The responses and the issues described are presented graphically in figure 9 below.

Question A examined whether team efforts were encouraged and recognized by management and appointed to resolve issues. About 33.82% of the participants agreed that this was occurring within the organization, 29.41% strongly agreed, 23.53% selected average, 7.35% strongly disagreed, and 5.88% disagreed that this had occurred.

The second question (B) was directed at researching the involvement of staff in decision-making and whether they were accountable for taking action to fix issues. On average, 22.06% stayed with the perspective, 20.59% disagreed with the organization's perspective, and another 20.59% agreed, 19.12% highly disagreed and 17.65% highly agreed that this was the case.

When asked whether employees participated in the quality-related initiative on Question C, 52.94% of the employees strongly disagreed, 11.76% disagreed, 11.76% remained on average, 14.71% strongly agreed that they would participate in the initiative, and 8.82% agreed.



	Management encourages and recognise team-work efforts and team-approach to solve problems.	Employees are involved in decision making and are responsible for taking action to fix problems they find.	Employees are actively involved in quality related such as QC circles.	Employees are very committed to the success of our organization.	Employees have knowledge of using TQ tools to measure and investigate problems, make recommendation and implement solutions.	Management allocates enough time for employees to utilize the TQ tools to solve problems.	Reporting work problems is encouraged in our organization	Employee suggestions are implemented after an evaluation.
	A	B	C	D	E	F	G	H
1	7.35%	19.12%	52.94%	0.00%	16.18%	17.65%	4.41%	13.24%
2	5.88%	20.59%	11.76%	4.41%	13.24%	11.76%	4.41%	11.76%
3	23.53%	22.06%	11.76%	13.24%	25.00%	25.00%	20.59%	32.35%
4	33.82%	20.59%	8.82%	20.59%	26.47%	25.00%	32.35%	23.53%
5	29.41%	17.65%	14.71%	61.76%	19.12%	20.59%	38.24%	19.12%

Figure 9: Employees Involvement On Practices

4.1.3.3 *Continuous Improvement - Practices*

Figure 10 below is the representation of the observed ratings of the practices regarding the continuous improvement within the organization to assist an organization to perform better and attain objectives by applying continuous improvements methodologies to improve processes and solve problems.

When asked whether they frequently measure the product that is received from suppliers (external and internal), and the product quality sent to the customers on question B of the figure, 40.35% of respondents strongly agreed followed by 31.58% who agreed that that was the practice in the organization.

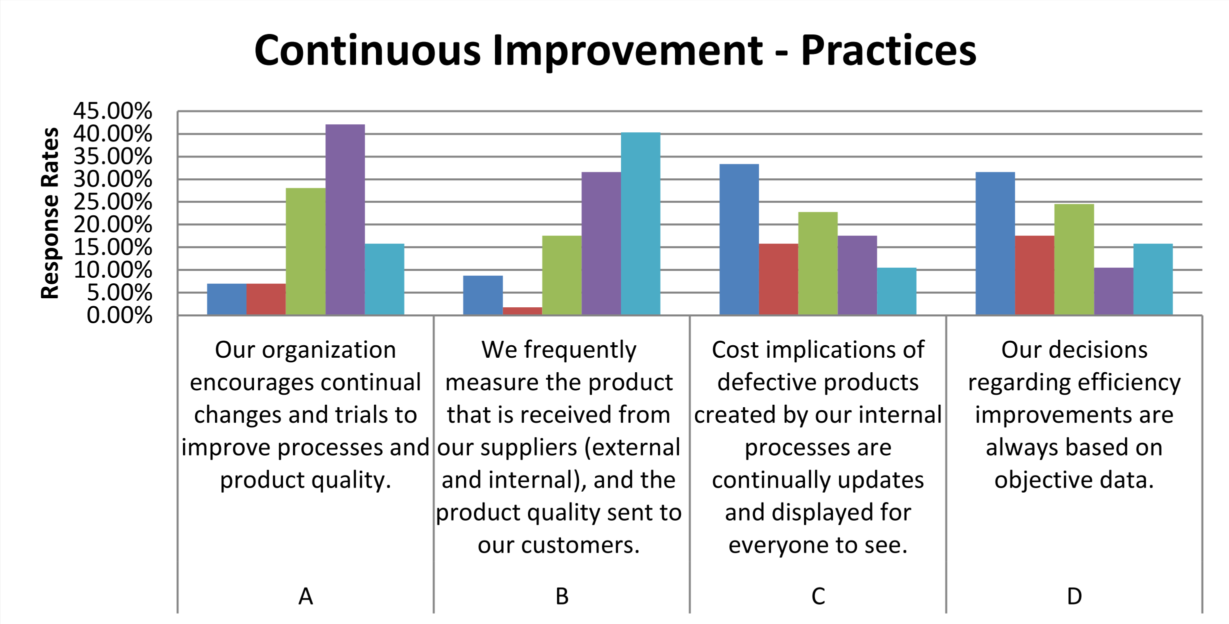


Figure 80: Continuous Improvement On Practices

4.1.4 *Trial Run Results*

A trial run was conducted at the trimming shop by collecting data on the number of defects the factory had in three months (May 2019 – July 2019). The researcher saw it necessary to conduct a trial run in the trimming shop which is one of the main/critical operations at XYZ Rubber.

During the data collection phase, it was discovered that the incorrect chamfering defects were more than any other defect (32 products), preceded by the delamination of the wear plates (WP) and the Off Centre WP holes of 18 products. These three were regarded as vital few and the rest as trivial many. Below spec followed by 12 products and over-spec followed by 6 products. The incorrect labelling consisted of 3 products obtained with nothing recorded on porosity.

5. CONCLUSION AND RECOMMENDATIONS

To further enhance processes and problem-solving, the study was aimed at developing a framework in which the company could deploy TQ tools as part of a new culture. A framework was developed with a view of improving the efficiencies and effectiveness of the organization through the deployment of TQM tools. Figure 11 below depicts the proposed framework that demonstrates the flow from data collection to solution implementation.

The process begins by gathering data on the number of errors, non-compliance, and deviations–depending on what is measured–using the check sheets. The data collected during a specified period is plotted on the histogram, otherwise, the data collection process would recur i.e. start from the beginning with the data collections step.

Once data is plotted on the histogram, it is sorted and prioritized using the Pareto diagram. In the Pareto diagram, the critical few will be prioritized for further root cause analysis through the cause and effect diagram. From the Cause and Effect (C&E) diagram, the quality circle group should be able to identify any probable cause(s) that can be further explored using the 5 Why's model, otherwise, there may be a need to review the C&E diagram.

When carried out successfully, the 5 Whys root cause analysis should be able to help get to the depth/root of the problem, where possible solutions can be generated and the better selected and applied through the use of the Plan-Do-Check-Analyse (PDCA) process. To ensure its viability, the plan must be tested. The system reboots and becomes a continually improved loop when the solution applied resolves the problem(s). The team may also have to return to the C&E diagram and then continue with the process until the best solution is obtained.

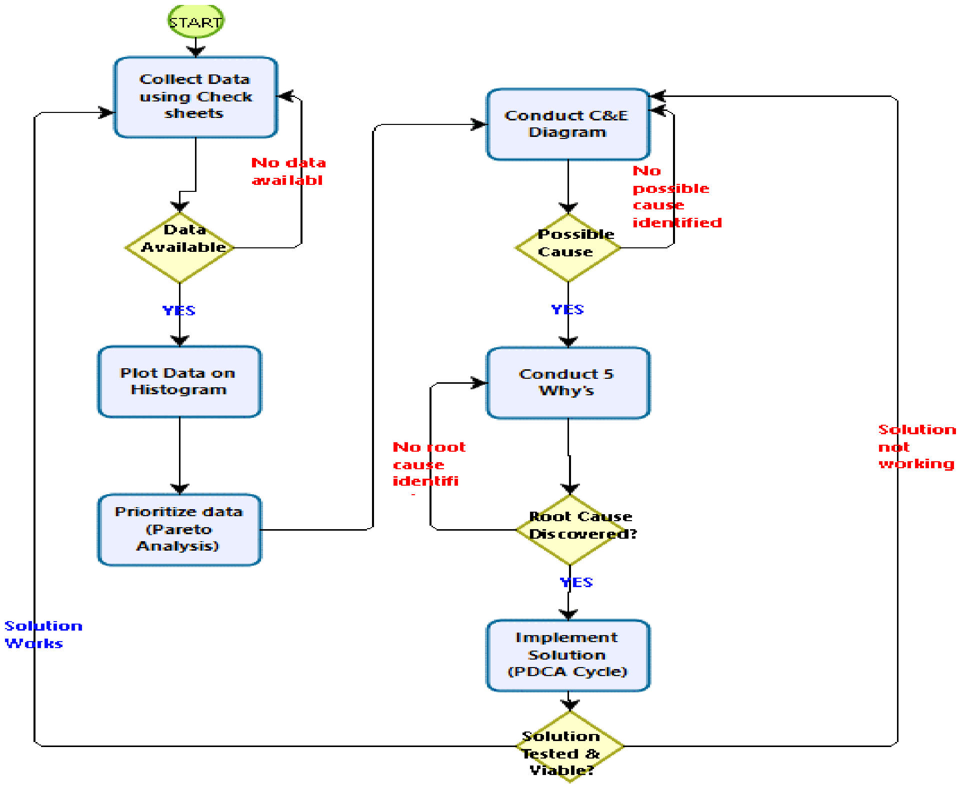


Figure 91: Framework for utilizing the TQ tools

After the trial run was conducted, it was necessary to collect data as prescribed on the above-proposed framework. The results showed significant improvements as shown in the Pareto diagram below as compared to before the problem-solving methodology was applied as shown in section 4 above.

The Wear Plate (WP) delamination problem was still apparent after the repeat collection of data. However, there was a decrease in the number of occurrences, which could be a result of fewer orders requiring the same product line during the data repeat collection. The reason why this problem still occurs might have been because the product was supplied to Multotec by an external supplier; the Quality Manager was tasked to resolve the problem with the supplier.

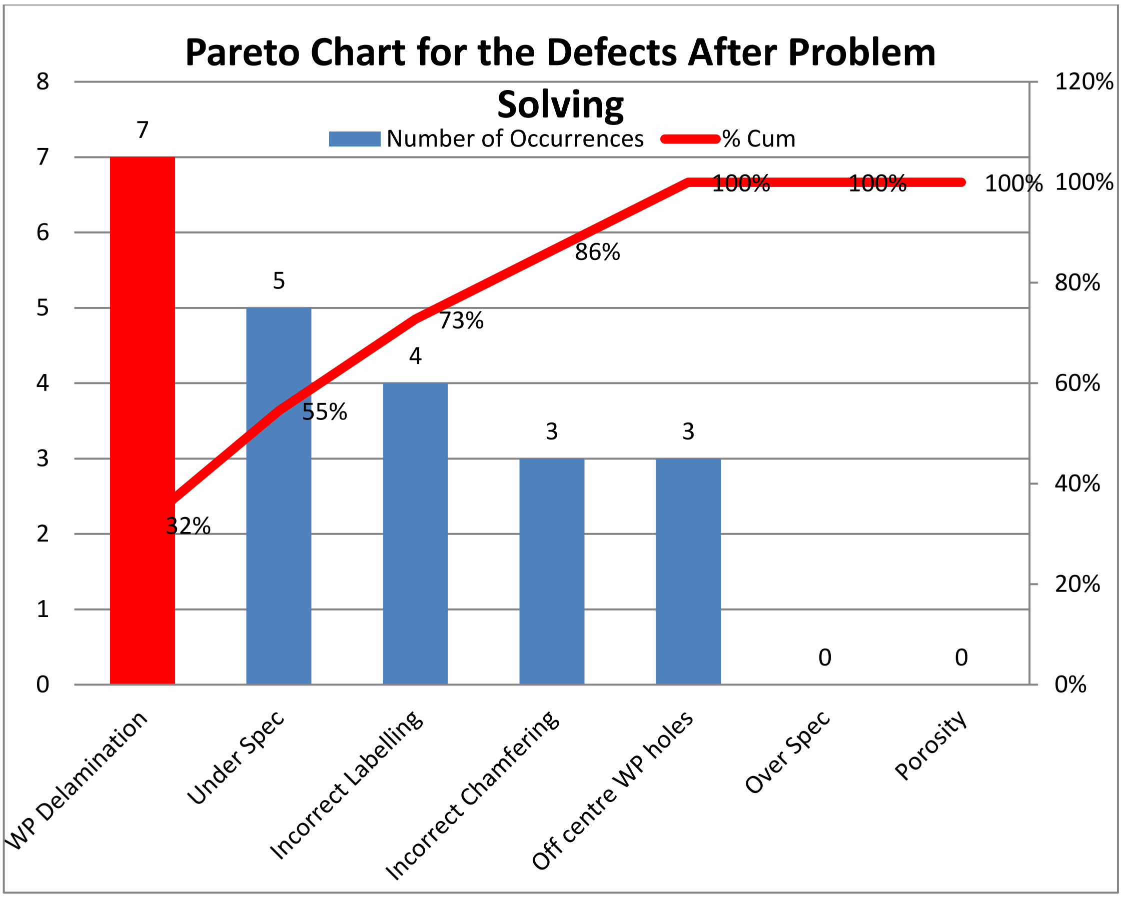


Figure 102: Pareto Chart for the Defects after the Application of Problem-Solving Methodology has been applied

The QC Circle measures the tests and validates the approach during the defined time period while faced with the highest defect. Such approaches can be used as preventive measures for affected processes/equipment. The team then re-stratifies the defect and addresses the latest largest defect and collates until the faults are resolved.

Manufacturing firms face many challenges that centre on efficiencies of processes, this research outlines how XYZ Rubber can improve efficiencies through deployment of Total Quality tools throughout the organization. The TQ tools were studied and presented as well as the proposed framework to address the research problem as presented in the introduction.

There is a need for a high level of commitment on the part of the management personnel of the company for all the suggestions set out in the section to bear the results they ought to achieve. Otherwise, these tools would seem like "other" tools made available to workers just to "see" what they can do with them.

Like any other part of business growth, e.g. training (informal/formal) is provided to workers on safety health and environmental standards and training should also be a priority within the company for the use of MDW/TQ tools. This will improve workers' intellectual capacities to assess the severity of the problems, prioritize issues to be addressed, examine the root causes, establish possible solutions, introduce and track solutions wherever possible.

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GREEN STRATEGIES AND TECHNO-INNOVATION PENETRATION: SUSTAINABILITY ADVANCEMENT AND MANUFACTURING SECTOR IN PERSPECTIVE

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ABSTRACT

The urgency to transform consumption and production patterns, while combining modern strategies and techniques for long term resolve calls for more focus. "Green" terminology has been propagated in different fields of study, and continues to be the motivation for efficiency and innovation in manufacturing operations, to address the major societal, and environmental challenges, as captured in the Bratland declaration (1987). To contribute to the above premise, the generic concept of go-green manufacturing in promoting environmental performance is proposed for sustainable manufacturing businesses. The authors developed objectives and hypothesis to examine the proactiveness of manufacturing companies in developing countries of Africa, despite the economic and technological mismatch with its foreign counterparts. The authors proffer sustainability-oriented manufacturing measures that apply green strategies and lean innovations to advance sustainability in manufacturing operations. The article provides insight into green supply chain management practices and performance, lean innovation in manufacturing for cleaner production, and the corporate social responsibility of manufacturing industries to project environmental performance.

Keywords: Green, sustainability, environmental performance, lean innovation

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1 INTRODUCTION

Despite the huge success of supply chains and their spread on a large field by companies, they are subjected to many pressures by governments, associations, individuals and environmental bodies, which call for the importance of taking into account the environmental aspect, because of the negative effects on the environment for all stages of the product. Introducing greening solutions in manufacturing, redefines business processes, thus changing not so much the elements that make up the supply chain as the rules that govern it [1]. However, the supply chain is linked and supported by an efficiently implemented environmental management system, supported by environmental certification and the recognition of environmental protection elements as one of the objectives of the activity [2]. The implementation of the green supply chain strategy and its management is possible with the use of many activities, the most frequently used of which include the use of recycling, reverse logistics, supplier selection using ecological criteria, green planning (design), advanced technologies as well as appropriate scientific instruments, and indicators to measure the greening of manufacturing, and application of lean principles.

Green supply chain management (GSCM) is a new field that contends with the traditional supply chain weaknesses like environmental efficiency [3,4]. It encompasses the implementation of all procedures, processes, and policies that include minimizing the negative impacts arising from the activities and processes contained in the supply chains. A well-established GSCM focus upon sustainability on each operational process from product design, material selection, manufacturing, distribution of the product to user via forward logistic process, and receiving the used product from consumers, for either repair, recondition, remanufacture, recycle or dispose of by implementing the reverse logistic practice [5]. In short, the prerequisite understanding of GSCM is to recognize the need and importance to preserve the environment during the creation of products (goods) or services. It is important to also understand the consequence of Overall Equipment Effectiveness (OEE), which is instrumental for Total Productive Maintenance (TPM) that measures the effectiveness of machines or systems in use. The implication of GSCM to improve product quality, increase productivity, and labour efficiency while reducing machine downtime and maintenance costs is a key aspect to be considered for sustainability advancement in manufacturing [6].

The majority of the solutions do not fit the African context, and therefore, a future analysis is needed from a general perspective to inform the aspects of environmental performance; technical preparedness, financial contingency, technology readiness, and governance (policies and intellectual properties). The details can be used by key players and stakeholders to determine the priority level in making final decisions on green strategy [7]. These decisions are expected to effectively and efficiently advise, in regards to maximizing resources and lead sustainability in the manufacturing sector. This is because industries in the present era are demanded not only to optimize profit but also to pay attention to social and environmental factors [8]. The research paper aims to explore and evaluate the proactiveness manufacturing practitioners on environmental performance through the application of green manufacturing and lean requirements as a sustainable pathway for future manufacturing. The authors proffer an understanding of green supply chain management practices and performance, lean innovation for cleaner production, and the corporate social responsibility of manufacturing industries to project environmental performance. The paper focus is on how the factors of environmental performance affect sustainability advancement in manufacturing in developing African countries.

2 IMPROVING SUSTAINABILITY IN MANUFACTURING

The Sustainable Manufacturing concept is created to ensure that the production process minimizes the adverse impacts on the environment, conservation of energy and natural resources, safe for workers, communities, and consumers but still economically healthy [9]. Additionally, to design the most efficient distribution system at a reasonable cost and latest time, including but not limited to workers allowance, waste generation, and security and safety [10]. The concept of Value Stream Mapping or VSM as a lean management tool finds great application in a sustainable manufacturing process that promotes operational improvements and information of the activities which give added value [11,12]. Whereas sus-VSM is a development of VSM by combining existing metrics with sustainability metrics, namely the triple bottom line (figure 1), it is expected to reflect a company's performance from the perspective of the economic, environmental, and social aspects [13]. These indicators, according to Danese [14], include economics; profit, cost savings, economic growth, and research and development. Environmental; use of natural resources, environmental management, and pollution prevention. Social; the standard of living, education, community, and employment equity.

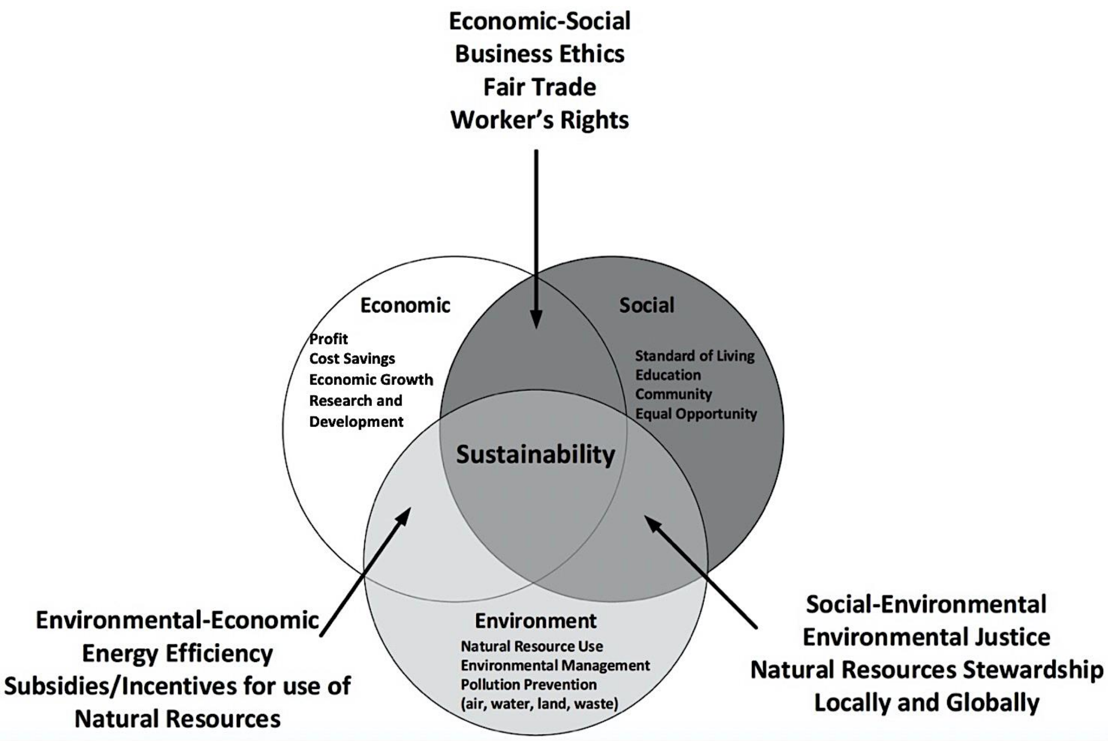

Figure 1: The three pillars of sustainability performance (Adapted from Danese [14])

While value stream mapping has been adopted, mostly for identifying hidden waste and the source of the waste itself. The disposal of these wastes and residues from manufacturing that causes environmental imbalance has prompted companies to add the green element to supply chains as a new concept, called green supply n management. More so, the application of nascent technological initiatives, such as lean innovation, and the requirement by manufacturing companies to become proactive to deliver sustainable products to customers is timely. Research [14] has demonstrated that lean practices can yield sustainability improvements, even if they have not been particularly aimed at doing so.

2.1 Greening of Manufacturing Process

From conventional practices, the production process relies on equipment and machinery that contribute to environmental damages, and wastes of natural resources, or burning of fossil minerals leading to environmental disruptions from the emission of toxic gases that affect society and the environment. Hence, companies need to assess and reconsider the product manufacturing process to minimize environmental impact [15–17]. Green production from the manufacturing context is defined as the strategy that focuses on cost-effective, environmental operations management that combines appropriate equipment, technologies, and practices necessary to reduces waste and pollution, and optimal utilization of material resources [18]. In essence, green production seeks to reduce the negative effects on the environment in the process of making products by reducing the use of raw materials that enter into production and conserve energy by maintaining machinery and manufacturing equipment, and the use of alternative sources of energy [19–21]. Other concepts in line with the green initiatives in manufacturing include eco-friendly designs (green products i.e., necessary for packaging and safe disposal), to ensure environmental sustainability.

Green manufacturing is mainly aimed at reducing the companies' environmental footprint by minimizing the use of materials and energy consumption, eliminating the use of toxic substances, and reducing green lists forms of wastes (Sheet zinc scrap, cast zinc parts, plates and mouldings, and materials from storage batteries, etc). Recently, consumers have become conscious of the nature of products that they patronize, as people have become more aware of the importance of energy-saving and recyclable products. In a survey conducted by National Geographic Society and Globescan, in 2014, it was established that India, Brazil, and China were the top countries with the highest level of scores for consumer green attitudes "*Consumer Greendex*" [22]. The same study noted that developed and industrialized countries like the USA, Russia, and others were found to have poor attitudes. Various types of green products are currently in the market, the most prominent being recycled textiles and doormats, bricks, and bottles made from recycled products, including environmentally friendly products (toilet papers, shoes, and cosmetics to name a few).

2.2 Green Supply Chain Management Practices and Performance

The following section highlight how implementing GSCM is leading future research on the impact of manufacturing on the environment. Green initiatives are being applied by industries to respond to the demand for implementation of green practices from different sources, with specific inference to government support to strive. Investigations are ongoing on GSCM, relating to; drivers, barriers, practices, and outcomes. Recently, the concept and application of GSCM for operational improvement in SMEs is researched and evaluated for effectiveness after adoption by key industry players and conglomerates [8,23]. The implementation of GSCM is dependent on the drivers, which may vary from one to another country. Significant research has been done in developed countries, that ranged from supplier selection, including all direct and indirect operators that affect the supply chain [5,24,25]. Hence, further research needs to explore substantially the extent of GSCM, adoption in developing countries like South

Africa, Nigeria, and Kenya (i.e., economically advanced Sub Saharan African countries). It is inevitable for the players and stakeholders to find which types of drivers are more effective to implement GSCM and what type of drivers needs to be enforced to achieve the environmental goals.

An important aspect of GSCM: the green or eco-design approach that combines GSCM practices is the key contributor toward the successful implementation of GSCM. Internal environmental management happens to be the first step toward the implementation of Eco-design, which combines the life cycle assessment and Design for Environment (LCA and DFE) approach [26]. Several researchers used green purchasing, cooperation with customer and investment recovery practices to explore the impact of mentioned practices upon environmental, economic, operational performance outcomes generally but lack of research exist about green information system in manufacturing industries in developing countries, it is highly needed to enrich the research about green information system as information is the mainstream of communication between departments and stakeholders of a firm [27]. Nowadays, researchers are investigating green marketing and green human resource practices and trying to find the impact of these practices on performance [28]. The potential of such research being carried out in advanced African economies may help to boost the implementation of GSCM in industries. Lastly, it would be of great benefit to explore the motives of GSCM practices to provide an in-depth understanding of the benefits to advance sustainability in manufacturing, which is the main reason for this paper.

2.3 Lean Innovation in Manufacturing for Cleaner Production

Continuous improvement in the manufacturing system is a guarantee to be able to survive in an increasingly competitive industrial world [29]. One method that can be used to carry out continuous improvement is to apply the concept of lean thinking, wherein this concept there are various recommendations related to waste elimination action. Waste elimination action is a way to eliminate waste in manufacturing systems so that the processes in the system can run effectively and efficiently [30]. In essence, implementing the concept of lean thinking, allows companies to cut costs that occur during the production process by reducing all types of waste that occur. Lean manufacturing is recognized as a business system that combines various lean tools to help identify and consistently eliminate waste to improve quality, flexibility, responsiveness, production time, and reduce costs [30–32]. The combination of various lean tools such as Just in Time (JIT), Total Quality Management (TQM), statistical control is positively related to quality improvement, delivery, flexibility, and cost reduction [33–35]. For example, Nandurkar [36] contributed to the use of SCM, JIT, and TQM to greatly influence cost reduction and improvement in quality, flexibility, and responsiveness.

Lean innovation has been conceptualized into three dimensions that relate to the following. (1) The ability to identify new opportunities through the use of design thinking. (2) The ability to quickly, and with fewer resources, develop, prototype, learn, validate, and improve business solutions. (3) The ability to apply lean processes, which enable teams to reduce waste, make incremental improvements, and eliminate the bureaucracy that often hinders innovation [37]. The concept focuses on initiatives that promote customer feedbacks and waste minimization throughout the product development life cycle [38]. This improves the effectiveness and efficiency of an organization's operations function. Moreover, the implementation of lean strategies still has problems that fail in their implementation [39]. Companies search for high impact lean tools to transform their organizational outcomes without considering the stages of the process, technical or technological capabilities, and financial consequences in achieving the corporate goal of the company. To succeed in the lean journey, lean thinking must be translated into all organizational activities, as an integrated system [40].

2.4 Corporate Social Responsibilities of Manufacturing Companies

The increasing consumer demand has led to a global competition which increases the degree of individualization and competition among manufacturing companies. Manufacturers are now trying to meet consumer demand by creating high product variety (mass customization) [41]. Researchers [42–44], have used cost-benefit analysis to evaluate production processes, in line with the impact on the condition of the surrounding environment when compared with the social implications. Also, as part of the corporate social responsibility of manufacturing companies to reduce carbon footprint, the concept of eco-innovation is introduced [45–47]. Eco-innovation, in terms of the policy, technology, and finance, has been evolving steadily as the guiding principle of production at the national and international level across public, private, and partnership models. It is expected that the international bodies and national governments should initiate a discourse for the global transfer of green technologies and related knowledge capital through international collaborations. The consequence of this is exemplified by the carbon emission trading (CET) framework, where the competition for green technology and patent rights becomes a challenge. Hence, companies are reluctant to share knowledge (information exchange) with the rest of the world as each technology becomes a crucial factor for earning carbon credit points, leading to the marginalization of smaller enterprises [48,49].

3 METHODOLOGY

The present study has been conducted using quantitative research methodology whereby practitioners with the experience of green strategies and lean innovations were the focus. Qualitative research provides a researcher with the opportunity to understand and discern meaningful resolves from a data-set. It also offers the chance to conceptualize the specific context of relational entities, and clarifies the interrelationship between the philosophical subjectivity of the researcher, with that relative to the particular features or outcomes of the study [50]. The qualitative study applied the methodological approach as seen in figure 2. This allowed the researcher to explore the depth and complexity inherent in manufacturing SMEs.

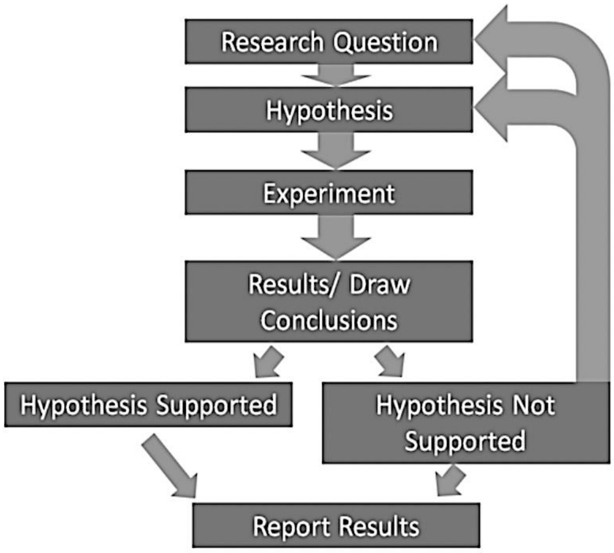

Figure 2: Research Methodology

3.1 Data Type

To facilitate the process of primary data collection from the category of respondents chosen for this study, an online questionnaire survey was conducted for a period of six months, spanning, August 2019-Jan 2020.

3.2 Sampling Plan

The current study used a convenience sampling procedure whereby the practitioners who are knowledgeable in green manufacturing principles and conscious of the applications of a lean approach to achieve environmental performance were targeted from different manufacturing companies within the Sub Saharan region of Africa. The respondents were conveniently chosen for inclusion in the study. The sample size was calculated using the formula:

Sample size = N*X / (X + N –1), [51].

Where:
N is the population size,
X is calculated using the formula below (using a margin of error and confidence level of 95%):

$X = Z^2 * p * (1-p) / e^2$,

Where:
Z is the z-score (1.96),
p is confidence level (0.05 or 95%),
e is margin of error (5%).

After the manual calculations, the expected sample size was found to be 189. However, out of the total sample size, 183 valid responses for the questionnaire were received and 6 responses were rejected on account of inadequacy (invalid and incomplete response).

3.3 Data Collection and Analysis

Since the study used an empirical study, a structured close-ended questionnaire was prepared, in which the responses of the innovation conscious green manufacturing practitioners were gathered. The questionnaire had two major sections, the descriptive and the inferential assessment. The descriptive section had categorical values, whereas the inferential section was presented in the form of a 5-point Likert scale, ranging from 1 strongly disagree, to 3 being neutral to 5 strongly agree. The first section of the questionnaire was further split to capture demographic and the general background information of the respondents. The inferential assessment section was based on different aspects of environmental performance factors linked to greening manufacturing to advance sustainability in the manufacturing sector and Africa in perspective. To check the reliability and validity of the questionnaire, a reliability test was conducted amongst 18 respondents who were asked to fill an online version of the questionnaire for pretesting. The data gathered from the survey was further analyzed using SPSS v23 and both descriptive and inferential tests were conducted.

3.4 Hypothesis

A hypothetical statement was found as the study uses an inductive research approach to access the practitioner's perceptions of the application of green manufacturing and lean requirements as a sustainable development pathway for manufacturing companies in the future. Hence, the present study conceptualizes the green strategies and lean principles as the environmental performance measure. Based on the conceptual framework, the following hypothesis was proposed.

$H_0$1: There is no significant relationship between sustainability advancement and technical preparedness.

H_A1: There is a significant relationship between sustainability advancement and technical preparedness.

$H_0$2: There is no significant relationship between sustainability advancement and financial contingency.

H_A2: There is a significant relationship between sustainability advancement and financial contingency.

$H_0$3: There is no significant relationship between sustainability advancement and technological maturity.

H_A3: There is a significant relationship between sustainability advancement and technological maturity.

$H_0$4: There is no significant relationship between sustainability advancement and governance.

H_A4: There is a significant relationship between sustainability advancement and governance.

4 ANALYSIS

4.1 Descriptive Analysis

A complete overview of the demographic and the general background of the respondents have been illustrated as shown in table 1. The total number of respondents considered for the study was 183, out of which 129 (70.5%) were male and 54 (29.5%) were female. The majority of the respondents belonged to the age group of 25 –35 years, which forms 35.0% of the total sample. As observed a large number of respondents emerged from Nigeria (49.7%), and 78.7% of them had completed their degree program to facilitate in a manufacturing company. Also included in the frequency distribution were the details of the respondent's employee level of experience. As shown in the table, more than 45.0% (N=89) of the respondents had worked up to five years and 12.5% (N=23) have had an experience of the application of proactive measures to ensure environmental performance.

The frequency of the practitioners' perspectives on the green manufacturing and lean process strategies were assessed. Information on their level of awareness was also generated at this stage. Majority of the respondents indicated that they have facilitated operations involving the manufacture of green products while applying systemic technologies and best practices. Although few respondents were unaware of the concept, over 80% of the practitioners have had a course to contribute to the environmentally sustainable production operation. Therefore, the selected participants of the study implicate a strong knowledge of green strategies and lean innovation in manufacturing.

Table 1: Demographic Variables of the Respondents

Variable	Frequency	% of participants
Gender		
Male	129	70.5
Female	54	29.5
Age		
18-25	14	7.6
25-35	64	35.0
35-45	54	29.5
45-65	47	25.7
Others	4	2.2
Africa		
South Africa	13	7.1
Nigeria	91	49.7
Kenya	52	28.4

Rwanda	24	13.1
Botswana	3	2.0
Educational Level		
High school	24	13.1
Graduate	144	78.7
Post Graduate	11	6.0
Doctor and above	4	2.2
Year of experience		
Less than 4 years	71	38.8
Between 5-8 years	89	48.6
Above 8 years	23	12.5

4.2 Reliability Test

To assess the reliability of the constructs, validation of the questionnaires was conducted. According to Pallant [52] the acceptable alpha coefficients for items on a scale should be above the threshold value of 0.70. The Cronbach's alpha has been presented as seen in table 2. It illustrates the resulting alpha values of items that are above 0.70 for each construct, with the overall alpha value being 0.774. In essence, items who's alpha coefficient did not exceed 0.70 was dropped, due to it failing the reliability test. Based on the reliability statistics, the questionnaire used was well-articulated, and the data herein is reliable since the values are higher than the recommended 0.7, acceptable level. Furthermore, the correlation statistics between sustainability advancement and the measures that represent environmental performance, from the application of greening strategies and techno innovation showed that there exists a growing interest among small and medium enterprises to improve their manufacturing processes by applying new methods that positively affects their social and environment performance.

Table 2: Reliability Test

Constructs	**Cronbach's Alpha**
Technical preparedness	0.733
Financial contingency	0.856
Technological maturity	0.713
Governance	0.795

4.3 Regression Statistics

We analysed the significance level of the impact the independent variables have on the dependent variable. As such, the model summary is presented in table 3, showing the statistics from ANOVA where the R-value is 0.991. Thus, it indicates a high degree of correlation. The R-square value (0.982) specifies that the dependent variable; sustainability advancement, can be explained by the independent variables. I.e., technical preparedness, financial contingency, technological maturity and governance by 98.2 percent (goodness fit). Consequently, the overall variance explained by the four motivators was 98.2%. In this study, the F-test (ANOVA) has been presented at a significance of 0.000 ($p< 0.05$). The F value is found to be high (253.274) and justify the reason to reject the null hypothesis.

Table 3: ANOVA

R	R Square	Adjusted R Square	F	Sig
0.991	0.982	0.982	253.274	.000

Table 4: Regression Coefficient

	Standardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Technical Preparedness	.327	.001	.865	54.317	.000
Financial Contingency	4.100	.001	.441	13.684	.000
Technological Maturity	.119	.001	.411	1.462	.000
Governance	.081	.001	.227	3.113	.000

Based on the items that define the variables in this study, the significant values show less than 0.05 at 95% sustainability advancement. Proactive measures like the "technical preparedness dimension," supports environmental performance. The "financial concern due to operations and return on investment cost, and technological maturity concerns' were found to have a high significance in impacting sustainable advancement through green manufacturing and lean strategies. Lastly, the dimension of governance which is linked to policy constructions and struggle over intellectual property, whether or not to dominate a particular technology solution were all found to have a significant value of less than 0.05 at 95% sustainability advancement assurance (Table 4). The inference implication of the study is that companies that apply green strategies to advance their sustainability capability to improve materials handling, wastes management and energy or emission performance can have significant influence to expand their capital investment preparedness. This would give them a competitive advantage to consult with the government on secure green and advance technologies for future business. This corroborates the factors that have significance with environmental performance. Based on the regression findings, the following null hypotheses have been found to be rejected.

$H_0$1: There is no significant relationship between sustainability advancement and technical preparedness.

$H_0$2: There is no significant relationship between sustainability advancement and financial contingency.

$H_0$3: There is no significant relationship between sustainability advancement and technological maturity.

$H_0$4: There is no significant relationship between sustainability advancement and governance.

5 CONCLUSIONS

From observation, existing manufacturing enterprises are fast embracing the concept of greening their operations and rely on the financial consequences to be favourable to their business while trying to contribute to sustainability. The implementation of green strategies backed by the introduction of new governmental requirements and customer demands has inspired the proliferation of innovative techniques and technologies in the manufacturing sector across the Sub Saharan African region. This is more obvious in the food and dairy/beverage production companies, converting wastes to other benefits and products through a sustainable process for environmental/sustainable solutions. The majority of the employees are happy to report the green strategies and sustainable measures or the lean/wastes management practices that are being used in their organization. They believe (general opinion) that the organization's manufacturing strategies of greening their operations have put in place the required technologies and capabilities to ensure sustainable improvement. It is recorded that more training and government regulations to inform about environmental protections have helped to create more awareness in all work experience cadre based on the study. While the obvious concern of the lack of guaranty on return on investments frustrates business owners and managers to transform their production operation, a newer method to evaluate this issue is been researched to bring redress to the unease faced by manufacturers.

There is a growing increase in consumers awareness over the use of conventional products as the focus is more on green products. Therefore, most organizations must identify the trend of consumer interests and move along with the perspectives and demands of the consumers. In the same context, it is crucial to develop a lean-green model. Researchers have investigated the implementation of lean and green manufacturing approaches from different perspectives [53,54]. However, there is still much research to be conducted regarding their integration into a single approach. The present study has evaluated the propagation of green strategies and lean innovation or practices in manufacturing. Four concentrated proactive measures were tested. The research infers that the measured components (technical preparedness, financial contingency, technological maturity, and Government), which are in line with the green-lean activities would promote the environmental performance of the company and advance sustainable manufacturing. An investigation into the lean and green similarities and differences to better evaluate the sustainable practices to be implemented together with the potential benefits is required. A new level of training for lean-green practitioners should focus on the possibilities of integration, eliminating the barriers, and ensuring its implementation in future manufacturing approaches to accelerate the development of a sustainable portfolio.

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ON ACHIEVING BIODIVERSITY AND THE SUSTAINABLE DEVELOPMENT GOAL – REVIEWING AFRICA'S ROLE

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ABSTRACT

The gathering of one hundred and ninety four delegates in Japan (2010) to endorse the 2020 strategic plan for biodiversity, and the 20 Aichi conservation targets that allay the 2030 Sustainable Development Goals (SDG), draws attention to what is achievable in 10 years. This exploratory research reviews sustainable practices and discusses different perspectives and strategies through the lens of biodiversity that supports the sustainable development agenda. The article is prospective to inform ways towards the contributions of biodiversity to achieve some or part of all SDGs, emphasising influence, impact, and assessments of the benefits for economic, social, and environmental gains. The research draws a correlation of biodiversity importance with relevance to urbanisation from the African context. The study concludes on how improving knowledge on ecological conservation, clean energy production, and effective governance may become consequential to drive biodiversity and deliver sustainable development amongst developing nations.

Keywords: Biodiversity, clean energy production, effective governance, sustainable development goals

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1 INTRODUCTION

A forecast by the Food and Agriculture Organization (FAO), predicts the average food production to rise above 40% by 2030, and above 70% by 2050. This will mitigate the growing population trend and double the value of current energy and water demand by 2050 globally [1]. The essential production and consumption style to improve food security and waste management is, therefore envisaged for human survival in the years to come, as such, encourages an ecologically focused long-term approach for managing wastes. Feeding styles need to change, and product design also needs to be revolutionised to meet the eco-friendly biodegradable requirement [2]. Cost-effective, high-performance techniques and technologies are what is needed to service municipalities and cities, while focusing on the low-income and developing countries, as per agro-waste management and biodiversity projects. Exploiting the economic importance of agro-wastes is beneficial and promotes profitability, societal and social satisfaction, and environmental protection [3]. Coupled with the obvious, regarding urbanisation and population increase, and the threat of increased consumption and production that conversely ascribe to high risk of waste generation, authorities must devise sustainable means to manage what is considered as waste. Meanwhile, emerging technologies and techniques are springing up, and old methods of waste management are being reconsidered to ensure value creation [4].

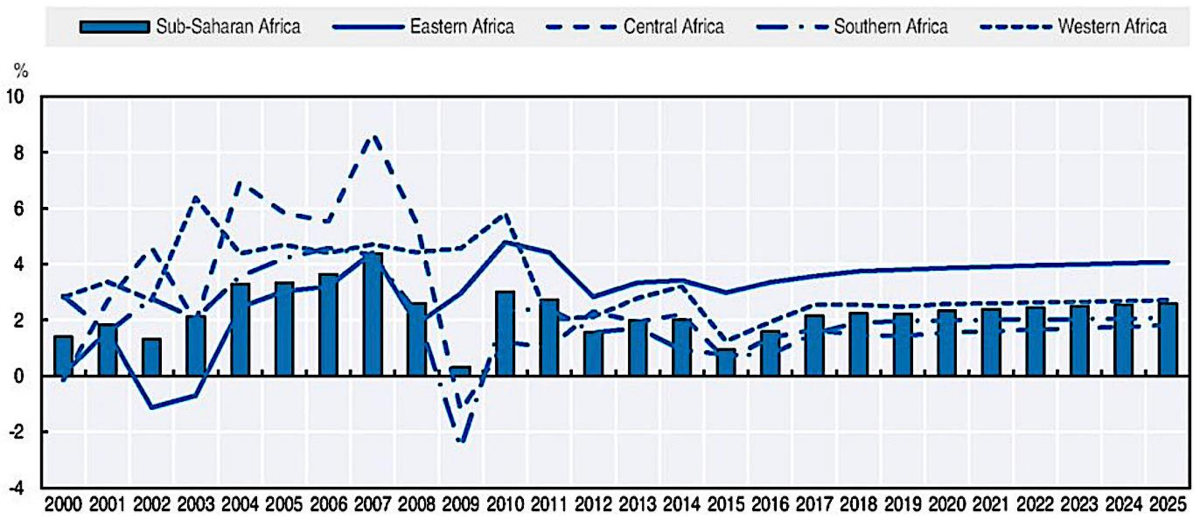

Figure 1: GDP growth per person in Sub Saharan Africa [5]

Importantly, based on the key underlying factors for agricultural development outlook in the Sub Saharan African region, the economic pretext to increase the chances for production, domestic demand, and trade-off in agricultural commodities needs reviewing. The projection by "FAO" presents a stagnated growth (2020 to 2025) in per capita GDP over the next five years resulting in a significant slowdown in the region (Figure 1.3). This, in turn, affects the decision for investment and optimal resources management. As such, the more likely reason to intensify agricultural resource diversity for sustainable solutions. In essence, stimulates agricultural biomass research to meet alternative, renewable energy, and sustainable material demand for the future. Accordingly; advances made in science that can transform agriculture business, making it profitable while assuring sustainability has been discussed [6,7].

Previously, the agriculture sectors did not receive so much attention and consideration, based on controls or mitigation of wastes disposal. These wastes were either heaped and burnt, allowed to dry and decay, or buried. Unfortunately, these practices are continued in most remote developing African localities. Nonetheless, waste quantification exercises and regulations that support agricultural waste management frameworks are being patronised and prioritised for future consideration, especially for income generation and as a sustainable energy option [8]. The National waste management and strategy for implementation in Africa began since early 2006. Although the initiative was first discussed in South Africa [9], it gradually gained popularity through the efforts of different agencies that subscribe to conservative approaches for farming, thereby, furnishing the government in their reports. These reports were based on investigations conducted to have a well-organised agro-waste management scheme. The impetus is more on developing nations to obliviate poverty and find a 'level ground' where the transformation of old practices conform to new standards. The proliferation of new technologies and operational strategies is well received and guided by governmental and public sector support through incentives that promote the course of less waste, more productivity.

1.1 Biodiversity Potential in the Agriculture and Food Industry

Biomass conversion to either gaseous or liquid fuels through the biological routes, or thermochemical process, has drawn research attention globally and aims to manage agricultural waste through careful waste disposal strategies and planning [10]. Bioenergy is defined as material directly or indirectly produced by photosynthesis. It can be utilised as feedstock in the manufacturing of petrochemical and other energy-intensive products [11]. The production and development of bioenergy and materials are based on the utilisation and application of biorefinery [12]. The biorefinery concept can be thought of as the equivalent of an oil refinery where different materials are derived from petroleum. The use of biomass as an alternative clean energy source compared to non-renewable resources involves a series of processes, including preparation and processing into products of interest (Figure 2 a, & b), with inference to how much waste is produced.

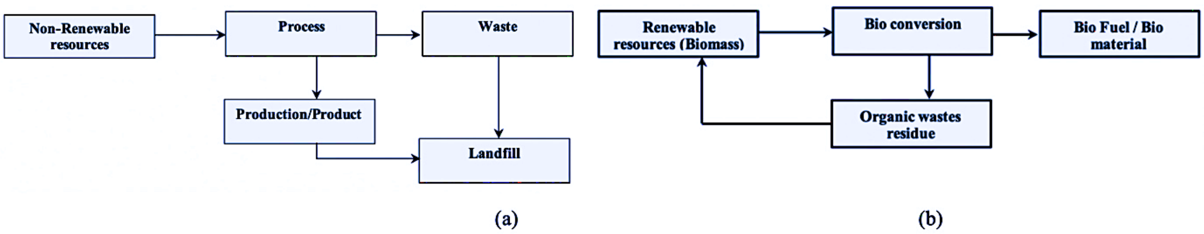

Figure 2: Potential for Sustainable Production from Renewable Resources versus non-Renewable Resources, (a) and (b) Respectively.

The conversion of Agricultural waste-biomass feedstock, i.e., organic or cellulosic materials to yield biofuels, is carried out in a process known as a biorefinery. Biogas, biohydrogen, bioethanol, biodiesel, bio-oils, and bio-char, all form part of the constituent of the beneficial outcome of agro-waste diversity from biofuels development [13]. The Republic of South Africa in her biowastes exploits is leading the campaign sustainability in Africa. The city of Johannesburg's transport system, recently acquired hundreds of dual-fuel buses, to support harmless emission-release in the transport sector [14]. The Euro-V-DDF brand of buses run on natural gas and diesel with up to 80% substitution, thus, to promote cost-saving on diesel and a reduction in the environmental impact. The contribution through the use of biofuel technology and other initiatives as such as electric and fuel cell buses to promote sustainable living in the city of Johannesburg – South Africa, forms part of the Government initiative to encourage biodiversity and advance climate change mitigation.

1.2 Biofuel Production and Areas of Application

Biomass conversion to fuels is summarised into three main techniques. It encompasses the physio-chemical, biochemical, and thermochemical conversion processes involved in derived vegetable oil, ethanol, biogas, bio-oil, syngas, and other forms of fuels (solid) [15,16]. Several operational principles are followed in the process, and the techniques vary depending on the desired end product. For example, the anaerobic digestion process which takes place in a reactor during the formation of methane gas (bio) can be used for different purposes, like in heating, cooking, and in more recent cases, to produce welding flames. This process effectively supports the act of composting, especially of food and agricultural products, thus, resolving the discomfort from the foul smells in open-air disposal [17,18]. Similarly, the thermochemical liquefaction process is one that promotes the yield of bio-oil. However, the cost of the technology poses a challenge to the technique. The pyrolysis process yields bio-oil, syngas, and charcoal from biomass conversion with the help of a catalyst to facilitate the operation and promote increased production [12].

2 SUSTAINABLE DEVELOPMENT AGENDA AND THE INTERPLAY OF BIODIVERSITY

The concept of sustainable development has been primarily discussed and adopts an acceptable definition [19,20], which was first published by the United Nations commission. According to the Brundtland report of 1987, the development meets the needs of the present generation without compromising the ability of future generations to meet their own needs [21]. The report draws particular interest to three pillars; economic growth, environmental conservation, and social equality [22,23]. While the agricultural, food, and beverage processing industries have been identified as substantial energy consumers [24], they are also significant contributors of unwanted wastes in the environment [25]. As such, it is crucial to promote industrialisation for sustained growth, by contributing to biodiversity, regarding agro-waste conversion for its value [26].

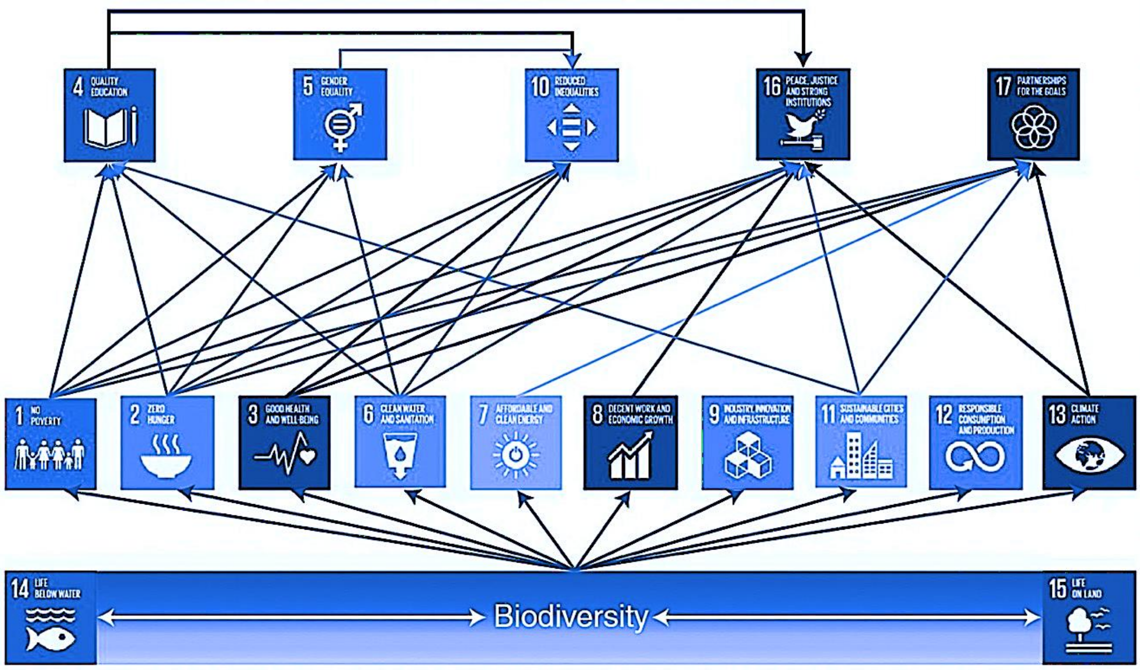

Figure 3: Biodiversity's contributions to sustainable development [27].

Consequently, the interlink between sustainable agricultural waste diversity and the need to foster global partnership for sustainable development must be committed to collaboration on natural resources conservation, social approaches, and policies [20]. Liu [28], termed sustainability to be the most active component besides the uncertainty of Renewable Energy Systems (RES) integration, to drive corporate strategies on environmental pollution reduction, and promotion of climate mitigation. Moreover, the deliberation on green initiatives, policies, and technologies that will align biodiversity with the sustainable development goals is pertinent, for the sake of addressing key perspectives that affects the business of biodiversity in developing countries and Africa in particular. The present research corroborates with the assertions of Blicharska [27], that; biodiversity is not only relevant to SDGs number 14 and 15 but is linked to the actualisation of the ten SDGs as shown in Figure 3. In essence, there are linked to the actualisation of SDG-1,2,3, and 6, all of which indirectly affects SDG-4 and SDG-16 the most.

3 METHODOLOGY

This exploratory research is based on a systematic review of the literature indexed in the Scopus database. A search was carried using the Title-Abs-Key search query: (biodiversity AND sustainable development goal), (agro* OR food wastes) AND (bio* OR energy AND technology). The investigation was a limited search from 2010 to 2020 and found 289 research articles. Eight external communications, announcements, and newspaper publications on Africa's sustainability were considered. 34 duplicates were removed, as the research focussed on scientific and technical contents. The author arrives at a total number of 263 records on the subject matter. Following further scrutiny, review articles that do not directly reference the African context were excluded, leaving a final sixty-four research articles which were used to draw inference on the study. The concept of biodiversity and sustainable development goal actualisation that is linked to the techniques and considerations that ensure land conservation, clean water and oxygen (carbon emission reduction), and sustainable ecosystem services for livelihood was explored. The author's focus is on the sustainable use of the components of ecosystem diversity to meet environmental protection and sustainable clean energy production. Thereby ensuring conservation in farming and exploitation of the wastes (agriculture) involved therein for the preservation of the environment and positive human impact.

4 EMERGING OPPORTUNITIES, CHALLENGES AND PROSPECTS OF MODERN BIO-ENERGY DISPOSITION

The need for clean and efficient energy systems development and a sustainable approach to enhance the techniques for biofuels production is to ensure energy security. From the perspective of the utilisation of wastes from farming and food production activities, different parameters can significantly affect the outcome of biofuel production [29]. These include, but are not limited to the quality of feedstocks, free-fatty acids, and water content, temperature condition (effective reaction), time of response (availability), and type of catalysts required, among others. The aforementioned is focused on the Waste to Energy (WTE) actualisation, applying nascent strategies and technologies to maximise energy and minimise harmful emissions [30]. Separate from the biochemical and thermochemical processes to achieve WTE, other emerging technology prospects exist, these include; Microbial Electrolysis Cell (MEC), and Microbial Fuel Cell (MFC). From the expectations, that is based on the effective operation of any chosen techniques, comes a new requirement for performance measure with regards to operating temperature and energy consumption.

The two most popular routes to achieve WTE include the biochemical and thermochemical processes. The biochemical process considers anaerobic conversion and fermentation of biodegradable biomasses for the production of biogases. The thermochemical approach includes the incineration, pyrolysis, and gasification process [31]. The thermochemical procedures are characterised by different features and requirements, which make one option more preferable for wastes remediation over the other.

4.1 Techniques in Bio-fuels Production

4.1.1 Biological Conversion of Biodegradables

- Anaerobic Digestion: The conversion phases are as follows: Hydrolysis (carbohydrates, fat, fat and protein present), Acedogenesis (fatty acid, sugar, and amino acid present), Acetogenesis (a form of volatile fatty acid), and the final stage - Methanogenesis (methane, carbon dioxide, and other trace gases). The digestion process is essential to meet cleaner energy production, environmental pollution, and wastes volume reduction, and recycling of nutrients [32]. Certain challenges that impede the success/proliferation of bio-digestion include a lengthy period and waiting time, which lasts up to 40 days. The characteristics of the feedstock, based on the occurrence, and the percentage composition of Carbon to Nitrogen (C: N), contained in the biomass substrate, being fed into the digester [33]. As such, a higher proportion of protein-based feedstock, leading to the production of ammonia will cause an imbalance in the digestion process, and reduce the rate of methanogenesis [34].

- Fermentation: In this process, organic wastes, mixed in a fluid, is acted upon by different microbes, so that carbohydrates are converted to sugar. The hydrolysed sugar is acted upon by bacteria (Clostridium and Enterobacter) responsible for the production of hydrogen and short-chain fatty acids [26]. One of the most promising and emerging technology for biohydrogen production is through the dart fermentation process. In this process, the production yields can be increased to a theoretical value of 4 mol/mol of glucose according to [35]. However, this value appears to be lower than the actual yield, as such, is said to be constrained by the sensitivity of the bacteria strains, affected by different operational conditions, such as pH, hydrogen accumulation, and the presence of short-chain fatty acids.

4.1.2 Thermochemical Conversion of Biodegradables

The process can facilitate value creation in energy and chemical production from wastes, and dried agricultural discards (wood, husks, fruit backs, etc.). As such, the process is completed in the absence of limited, or no oxygen at elevated temperature to yield char, hydrocarbon oils, and gases as eco-friendly fuels (Table 1). The process also recovers energy from non-biodegradable wastes, which is a waste to energy advancement through the same thermal process, which, in the long run, contributes to the general reduction of waste [36].

- Incineration: The terminology "Incineration" is the measure of decomposition of waste at high temperatures. It is considered to be one of the most effective thermal conversion approaches for waste beneficiation. As can be seen in Table 1, the incineration processes do not require cumbersome pre-treatment operations like other techniques. The application of incineration technology is suggested for handling biomedical wastes disposal. Moreover, residues and by-products from incineration (bottom ash) can also be processed or converted to

Approach	Parameters						
	Operation Principle	Operating Condition	Operating Temperature (°C)	Pre-treatment requirement	Product Yield		
					Solid	Liquid	Gas
Incinerator	Full oxidative combustion	Presence of sufficient oxygen	850–1200	Not necessary	Bottom ash, fly ash, slag, other non-combustible substances like metals and glass	-	CO_2, H_2O, O_2, N_2
Pyrolysis	Thermal degradation of organic materials in the absence of oxygen	Absence of oxygen	400–800	Required	Ash, char	Condensate of pyrolysis gas (pyrolysis oil, wax, tar)	–
Gasification	Partial oxidation	Controlled supply of oxygen	800–1600	Required	Ash, slag	-	SYNGAS H_2, CO, CO_2, CH_4, H_2O, N_2

materials for road and building construction, and soil amendment before resorting to the last option of disposal via landfill. Thus, promoting biodiversity.

Table1. Features of Thermochemical Process

- Pyrolysis: The theory behind the thermal treatment of waste is based on the restricted control of oxygen supply to control the burning and monitoring of the temperature at which decomposition occurs. Pyrolysis, unlike the incineration and gasification process, takes place in the absence of oxygen (Table 7.1), producing different proportions of gases, vapour, and char. Modelling of the process design to improve the pyrolytic technique has also been conducted [37]. The technology has also been researched, to perform favourably with the composting plastic waste [38–40]. It is a slightly ineffective process, allowing the conversion of about 70%, compared to the incineration technique where up to 90% of the feedstock can be decomposed during the combustion. Although, from popular saying: "no waste is a waste", the residues from this process can be transported to nearby farms for soil enrichment [37].

- Gasification: In this process, the conversion of feedstock is possible under intense heating, up to 1600 °C, without the use of a catalyst (Table 1). Researchers [41], have sought means to produce sustainable fuel from biomasses without leaving any wastes (char). The development of the gasification technology is dependent on reactor design, categorised accordingly: moving or fixed-bed, entrained flow, and the fluidised bed gasifier and has been extensively researched through time [42]. However, it is worth noting, that the pyrolysis and gasification conversion technology/systems are still within their experimentation stages and have not yet attained technological maturity for commercialisation. Several considerations have led to the above resolve: not enough data, and operational strategy to develop the technologies beyond the pilot stages.

5 SUSTAINABLE SOLUTION IN AGRICULTURAL WASTES DIVERSITY AND INNOVATIONS

The nature of innovativeness and intervention required to advance sustainability and proffer solutions about environmental challenges or issues linked to agro-wastes seeks support from all the private and government parastatals [43]. Researchers are relentless about drivers for the adoption of eco-innovation and what may guide the decision of different organisations to make a move on what innovative approach to take [44]. More so, the dichotomy between sustainable, environmental, and eco-innovation has received continuous research [45]. The innovation conception comprises of the technology/technical, service/process, and the business perspective for performance improvement and implementation [46–48]. Technology innovation from the perspective of agricultural sustainability solutions adopts nascent technological strategies for green products creation and development of renewable energy systems [23]. Hence, the concept would continue to evolve for effective service deliveries while transforming the agricultural sector [49].

The inclusion of the industry 4.0 components in agricultural development is critical to ensure improved operational activities. This will promote the adoption of advanced technologies, such as mobile internet, smart sensors, cloud computing, the Internet of Things, 3D printing, and much more, as effectively as possible [50,51]. The nature of the technology to be used, therefore, ought to permit sustainability across the agriculture supply chain, while fostering interconnection between the customers, retailers, and suppliers [52]. The agricultural industry can approach the industry 4.0 advancement with the perspective of not just wanting to digitise some sector (food production and processing, dairy farming, crop cultivation, etc.), but contemplate how the operations can become smart and sustainable. The prospect nowadays is towards smart wastes management and agriculture diversity as a functioning Industry 4.0-based agricultural development, which goes beyond the training of personnel. As such, it is essential to identify risks and opportunities, to ensure a credible approach to agricultural development and biodegradable wastes management progress [53].

6 WHERE IS THE SUB-SAHARAN AFRICA IN ALL OF THIS?

Amongst the fifty-five (55) countries in Africa, the Sub-Saharan region is made up of forty-six states. These regions are multi-culturally diversified and comprising of some of the notable low income generating economies globally. At the same time enlist some of the most mineral-rich, and agriculturally endowed nations on earth. Agricultural operations in the rural settlements, and even in the urban areas of some developing countries, are unsustainable, not monitored, regulated, or legally informed, which has led to detrimental environmental, health, and social implications [10]. The focus, therefore, is on the necessary interventions to salvage the imminent danger or energy and food security. In essence, what is the most sustainable approach to address the already existing saddening situation of poverty; health and wellbeing; decent work and economic growth; life on land; and peace and justice, and strong institution (SDG-1,3,8,15 and 16), in the Sub-Saharan African region. Collaboration between nations of the region can promote the expansion of agricultural resources for joint development, thus, sharing knowledge for excellence, and risk operations. Similarly, capacity building and infrastructural financing within the areas of agricultural wastes conversion to collectively strengthen waste management activities can lead a good start.

The derivatives from the collective inter-boarder projects (bioenergy from agro-wastes plants), can be used to sustain the poorer countries. For example, supply of electricity to the neighbouring border, villages, and islands would be on the bases of the who suffers access to electricity the most. Additionally, sharing of information and technological capabilities within the region can increase the focus on coordination to track progress and inform the decision that will further lead to the setting-up of the necessary mechanism and implementation of the required policies for extensive agriculture diversity. As such, the cleaner production and alternative energy development strategies to support sustainable development via the framework that benchmarks satiable standards in achieving agro-waste diversity vary from one place to the other depending on the law of the region. The recommendation is to have sustainable strategies that look beyond traditional practices, and crude methods, and pertains to effective resources-processing, and distribution, that conforms to energy-efficient routines [54,55].

The growing "managerial strategies" to make aware, consumers, through informative workshops, training programs, and awareness campaigns organised to enlighten small groups have been proposed [56]. Also, a gradual incentivisation process that promotes innovation and improvement on waste reduction at farms up to the final stage of product consumption is advised. Africa can learn from the standardisation, regularisation, and implementation of green innovation strategies identified by notable interest groups, and international bodies that are bent to promote positive socio-economic, and environmental achievement [57].

7 TOWARDS INTEGRATED WASTE MANAGEMENT SYSTEMS FOR SUSTAINABLE ENERGY SOVEREIGNTY IN SUB-SAHARAN AFRICA

The outlook on agricultural diversity soon draws interest to effective management techniques. This may lead to catastrophic challenges of preparing landfill to accommodate the different types of wastes (based on toxicity and bio-degradability), dealing with smells and the adverse effect of greenhouse gas emission, and toxic run-off which affects useful fertile lands and water ecosystem [58]. A very high degree of risk related to a specific kind of hazardous waste comes from sensitive mining operations and projects involving the use of radioactive material which affects the ecosystem. These radioactive elements have a significant effect on human health and environmental stability, over a lengthy period, impacting generations. In most cases, they are discharged-untreated in the open fields, leading to increasing causes of death/harm to the living and severe implication on the world's ecology [30]. There is good news, however, as environmental safety practitioners and experts around the world continue to search and identify high risks project regions, municipalities, and cities with increasing waste generation tendencies to roll out the mechanism and technological imperatives to curtail the awaiting menace without compromising on servitude [59].

Different innovative approaches exist: educate and implement new technology, improve old infrastructure to feet new design requirements, and cultural indifference to gainful utilisation of the agricultural wastes [60,61]. In the long run, feeding styles need to change, and if possible, revolutionise product design to meet eco-friendly biodegradable standards. Conveniently, by-products of agro-wastes/ashes can be utilised in the development of composite materials to lead zero wastes operation [62,63], or as raw materials for clean energy production. The mapping process of sustainable development agendas in comparison with some of Africa's national development plan targeting ecological infrastructures, critical for the socio-economic growth and development are continually being reviewed [64–66]. From our observation, we learn that the global drive towards the optimisation of energy systems and the implementation of conservative practices to mitigate climate change and resolve anthropogenic technicalities within energy-intensive industries have shown great potential. The option for safe, reliable, and utterly green technological innovation for heat and electricity generation to the rural and urban settlement must, therefore, explore the agro-waste conversion pathways.

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QUALITY MANAGEMENT PRACTICES AND INNOVATION PERFORMANCE: A THEMATIC ANALYSIS OF A MINING RESEARCH ORGANISATION IN SOUTH AFRICA

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ABSTRACT

Previous studies regarding Total Quality Management (TQM) practices have predominately been influenced by the manufacturing sector. Service sectors more especially research organisations are lagging in terms of the effective deployment of operational and strategic goals. Given the paucity of TQM literature in the research sector the objective of this article is to examine the influence of total quality management (TQM) practices on innovation performance in a South African research organisation. Ten face-to-face semi structured in-depth interviews with executive management participants were conducted. The article analyses inductively the management perspectives of TQM practices implemented in a research organisation. The results indicate that: leadership, customer focus, people management, and strategy have a positive influence on innovation performance. More importantly, this study underscores management's responsibility and how to effectively build on innovation capacity within research organisations.

Keywords: innovation, performance, total quality management, customer focus, research organisation

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1 INTRODUCTION

The global environment of research is expanding and evolving, changing the composition of research focus, strategy, investment, innovation and support [1-4]. Developing countries such as South Africa are now more concentrated on scientific and technology based research and innovation in order to build knowledge capacity, infrastructure, partnerships, resources in order to sustain and build business and innovation capacity for the Fourth Industrial Revolution Innovation capacity within research organisations need to be enhanced, productivity improved and a knowledge based economy built to utilise global competitive advantages through science, technology and innovation [2]. In recent years, extant literature has shown a positive correlation with total quality management (TQM) practises and innovation, with both components widely recognised for improving organisational performance, increasing profit and gaining competitive advantages [5-8]. Although, research has been done empirically on the correlation between TQM and innovation within the manufacturing and service sectors of industry, extant literature on the impact of TQM practices on innovation performance within a research context in South Africa is very limited or absent. Applying a positivist research philosophy [9], the research study will aim to enhance the limited knowledge gap in this sector and further examine the effectiveness of select TQM practises and innovation in the context of a research environment.

2 RESEARCH OBJECTIVE

The primary objective of the study will attempt to determine the influence of TQM practices on innovation performance in a research organisation with a primary focus on four TQM constructs namely; leadership, strategic planning, and customer focus and people management. In addition, the paper will also attempt to establish which TQM practices promote innovation performance in a research organisation.

3 LITERATURE REVIEW

3.1 Total Quality Management

TQM is defined as a holistic philosophy of management directed towards the continual improvement of the processes and products aimed at meeting both customer satisfaction and improving business performance and sustainability [5], [10]. First introduced by quality gurus Deming, Feigenbaum, Juran, and Crosby Foster [11-12], TQM employs a set of guiding practises or principles to develop organisations and improve profitability through enhanced productivity [5]. In the early 1950's Japanese firms adopted the practises of TQM to improve business performance through quality products and services, leading the changes in quality products and enhancing their competitive positions within markets globally [11-12]. Employing strategy, communication, and data, TQM enables quality management to be effectively integrated into an organisation's culture and operations. This ensures participation from all employees, which is important for TQM to be effective and successful.

3.2 TQM Dimensions

The Malcolm Baldrige National Quality Award (MBNQA) Foster [11] framework was utilised to identify the TQM dimensions to be researched for this study. According to Foster [11] the current MBNQA framework consists of six interrelated recognised practices of TQM: leadership, customer focus, information and analysis, people management, operations, knowledge management, strategic planning. The quality award model provides a valuable outline for organisations, and aids the adoption of TQM and the assessment of organisational performance. This study therefore focuses on establishing the impact of TQM on innovation performance in a research organisation based on the following TQM practices: leadership, strategic planning, and customer focus and people management to study the impact of TQM on innovation performance.

3.2.1 Leadership

In the context of TQM, the term leadership embodies support from executive management and is focused on the style of leadership, rather than the behaviour of the leader [13]. Effective implementation of TQM will ensure customer satisfaction and improved organisational performance and sustainability that will ultimately benefit all employees in an organisation. However, the involvement and participation of both employees and executive management are critical to the success of TQM [14]. Therefore, it is imperative that executive management should strive to provide the necessary leadership to ensure the successful implementation of an effective quality management system in the organisation [11]. Within a TQM context, leadership plays a critical role in the effective and successful implementation of TQM in an organisation [11], [15-16].

3.2.2 Strategy

In a TQM context, strategic planning refers to the growth and successive implementation of organisational strategic objectives, plans to build stronger relationships with customers, industry partners and suppliers, as well as the implementation of an effective quality management system. Al-Damen [17] defined strategic planning as an approach that systematically defines the long-term business goals. The implementation of proper systems of strategic planning enhances and improves the product quality, leading to increased customer satisfaction and enhanced organisational performance [18]. Therefore, strategic planning is vital to observe how an organisation progresses, implements and cultivates its strategic policies to attain enhanced operational performance.

3.2.3 Customer focus

Ogbari and Borishade [19] posited that dimensions of TQM significantly impact customer satisfaction whilst Panuwatwanich and Nguyen [20] concluded that organisations can exhibit better performance when TQM is implemented and attributed to improvements in both the work quality and satisfaction of customers. Yeng et al., [21] define customer relationship management as a continuous effort by an organisation in “maintaining a close relationship with customers” by acquiring continuous feedback on customer needs and requirements. Similarly, Yusr et al., [22] stated that an organisation should determine the wants of customers and provide consideration of such requirements towards improved organisational performance and satisfaction and loyalty of customers.

3.2.4 People management

People management is critical to the successful implementation of TQM practises. The integration of people management practices fosters the improvement of quality management systems within an organisation, as well as employee performance, productivity and engagement towards achieving the strategic objectives and quality goals. Usrof and Elmorsey [23] state that the success of any organisation depends on the organisation’s strategic management practices and how the strategy is implemented, designed, and controlled through the involvement of its employees.

3.2.5 Innovation

The Organisation for Economic Cooperation and Development (OECD), Oslo Manual [3-4], defines innovation as the application of new or enhanced products or processes, or as an innovative organisational technique in business practice or workplace organisation. Innovation can be regarded as the compromise of an organisation's ability with the conversion of ideas into new products, processes, and services, thus enabling the sustainability and growth of the organisation [24-32]. Innovation enables businesses to develop and introduce new or improved products to the market before their competitors and thus increase their market share [29], [33].

In many OECD countries, organisations currently finance the knowledge and intellectual capital that drive innovation R&D, resources and the capabilities of skilled employees and organisational capital, to the same extent as they do in human resources, manufacturing, safety and other sectors of the organisation. According to Pisano [24], one of the biggest challenges with efforts to enhance innovation are a lack of an effective strategy for innovation. A good innovation strategy will aid the promotion and alignment of the strategic direction of the organisation [24].

3.2.6 The relationship between TQM and innovation

Extant literature [5-6], [8], [20], [34], [35] have indicated that a significant relationship between implementation of TQM practices and innovation, as well as the implementation of TQM practices, in relation to overall organisational performance. Although studies between TQM and innovation are more recent, they are, however, not as extensive as those conducted on the connection between TQM and organisational performance [6]. The element of continuous improvement is very similar between TQM and innovation [6]. González-Cruz, Clemente and Camisón-Haba [36] suggested that successfully implemented TQM practices help an organisation to build innovation capacity and provide capabilities that are key for innovation performance.

Research organisations need to focus their efforts, TQM practices and implementation to gain insight into improving product and process innovation and gain competitive advantages. TQM practices may provide research staff with opportunities for applying TQM practices in their research and innovation where opportunities enable them to identify customer needs and wants. Therefore, the adoption of TQM within the research and innovation sector may indeed assist research organisation to improve in terms of customer needs, people management, management and strategic planning, as well as lower product development time and costs. TQM may also generate improved customer satisfaction, innovation, and improved business performance.

3.2.7 Leadership role in organisational innovation

Changing global markets, increased competition, and high client demand have involuntarily tasked leaders to pursue and achieve higher organisational growth, research, and develop new products and services. Within organisations of today, innovation is regularly peddled as the key to an organisation's future success and the catalyst that develops and promotes new business initiatives. Slimane [37] posited that leaders help to shape employees and provide a platform for people to come together and achieve their individual objectives and goals in an organisation.

3.2.8 Strategic planning in the innovation context

The capacity for innovation starts with the organisational strategy [24]. According to Pisano [24], without an innovation strategy, different functions of the organisation will follow conflicting priorities, even with a well-defined and clear business strategy. Bouhali, Mekdad, Lebsir and Ferkha [38] state that strategic planning is essentially a tool of leadership that aids an organisation to make intended decisions regarding a road map on “in what way” and “at what time” an organisation will be able to effectively meet its strategic objectives, as well provide an explanation of such activities in the future.

3.2.9 Customer focus with involvement

Philipson [39] state that innovation can be done using the customer involvement approach of creating tailored or specifically designed solutions or products that compete with products designed using uniform components that can be combined to offer customers cost effective, semi-original solutions or products. According to Fernandes et al. [40], customer focus has a positive impact on levels of product innovation. In addition Manders et al. [15] and Fernandes et al. [40] support the idea that a focus on the customer’s existing, future needs and wants fosters product innovation within an organisation [16].

3.2.10 People management in the innovation context

Employees are the heart of any organisation. For an organisation to flourish toward higher levels of innovation performance, the involvement of both employees and management is required. Effective management of employees can foster improved innovation performance and enhance the research and development of new products and services. For this to be successful; however, employees need to be motivated, involved, supported by management, engaged and invested in the innovation process and culture. According to Kahn [28], innovation is a state of mind that speaks to the internal process of innovation by individual employees and the fostering of a supportive organisational and innovation culture throughout the organisation. Innovation prospers when both the organisation and employees create a culture and environment that is conducive for innovation, which in turn establishes the occurrence of positive innovation characteristics [28].

4 EXPERIMENTAL METHOD

4.1 Data collection

The results of this research study were generalised for a South African mining research organisation. This study attempted to gather wider perceptions of TQM and innovation by from a South African context requesting participation from general management, supervisors, technical specialists and consultants, to respond, where possible. This study therefore attempted to focus on the employees specifically at a senior to mid management level in a research organisation and their perception of TQM practise in relation to innovation performance within their organisation, which is relevant to the success of the study. Table 1 indicates the demographic information relating to participants in terms of academic qualification, designation, age group and gender.

Utilising an exploratory design approach of a smaller sample size, information was derived from 10 semi structured, face-to-face interviews conducted with each participant contributing to the qualitative research part of the study where data was collated, observations derived, and inferences made towards the study. The semi-structured face to face interview process was conducted using a set of predetermined interview questions that related specifically to the topic of interest. Information derived from the interview process contributed to the qualitative research part of the study where observations and inferences could be made. The interview questions aimed to gather information regarding the participant's organisation and perceptions.

The total averaged length was between 60 minutes per participant. Employing purposive sampling allowed for judgmental selection by the researcher in the selection of participants representing diverse perspectives for purposes of this study [41].

The unit of sample required for this study is made up of general management, head of divisions, supervisors, technical specialists and consultants, scientists and engineers (Table 1). Participants responded positively to participating in the semi-structured interviews. Data derived from each interview was transcribed from field notes and subsequently transferred.
The age group of the participants ranged from 35-60 years of age at different management levels in the organisation. The educational qualification of the participants showed a highly qualified group of experts or technical professionals, with qualifications ranging from Honours to PhD qualifications.

The designation profile of each participant comprised of managers, head of divisions, technical specialists, consultant and research and commercial coordinators.

4.1.1 Interview context

The interview was conduct at the mining research organisation based in Johannesburg, South Africa at the selected participant's office. Meeting requests were set up prior to the interview being held and signed letter of permission to conduct the interview were also completed prior to each interview being conducted.

Participants were confident and provided a diversity of answers and perspective in terms of TQM and innovation within the context of their research organisation as well as their area of expertise as technical researchers within a science and engineering specialist fields of study.

Participants were very much interested in the research being conducted for the study and were eager to provide solutions and relate current challenges in terms of improving the overall organisation in terms of research and innovation within the context of the selected TQM constructs.

Table 1: Demographic information of participants and interview context

Participant No	Designation	Qualification	Age Group	Gender
1	Technical Specialist	Masters	50-55	M
2	Commercial coordinator	Diploma	55-60	M
3	Manager	Masters	40-45	M
4	Head	PhD	40-45	F
5	Research coordinator	Masters	35-40	M

Participant No	Designation	Qualification	Age Group	Gender
6	Manager	PhD	50-55	M
7	Consultant	PhD	55-60	M
8	Head	Honours	40-45	M
9	Technical specialist	PhD	55-60	M
10	Head	Honours	35-40	F

5 DATA ANALYSIS AND INTERPRETATION THROUGH THEMATIC ANALYSIS

Qualitative research allowed participants and the researcher to offer a fresh perspective where there was a gap in knowledge regarding a particular topic, or information [41].

The interview data was analysed using a thematic analysis. According to Braun and Clark [42], 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.

Utilising Braun and Clark's [42], Moira and Delahunt [43] (Table 2) recommended criteria for conducting a thematic analysis, data derived from each interview was transcribed from field notes and subsequently transferred into an appropriate level of detail and aligned for accuracy to the original interviews using coding. The coding utilised was based on commonalities in terms of interview answers amongst participants.

For this study, seven categories of distinctive and consistent themes were identified and aligned to the research question and the objective of the study. The interview data was interpreted, analysed in great detail rather than paraphrased and subjected to coding. Moreover, the interview questions aimed to assess the impact of the following TQM practices: customer focus, leadership, and strategy and people management on innovation performance.

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 following themes based on a thematic analysis approach emerged in relation to the research conducted consisting of 7 themes.

Theme 1: TQM understanding and perceptions
In terms of an understanding of Total Quality Management and it dimensions, the majority of participants had a somewhat vague idea and understanding of TQM. Only one participant was not aware of TQM, indicating that employees within the research organisation are aware of the concept of TQM and have an understanding thereof. With regards to practises or dimensions of TQM, only a few participants managed to articulate some form of understanding of the TQM practices or dimensions, while the majority of participants were not aware of any TQM practices or dimensions. More awareness, training and effective management needs to be done to ensure the practices or dimensions are correctly and effectively implemented.

In terms of having an effective quality management system in place or not, the majority of participants agreed there is a quality management system (QMS) in place; however, it is not effectively implemented within their organisation. Alluding to the notion that participants, particularly those in management roles, are not equipped with accurate information, training in quality management systems or its relevance to research and development and innovation performance. The researcher attempted to assess participants' views regarding whether the research organisation is ISO9001 accredited, its role, and an understanding of the accreditation within the organisation. Although the data indicated that the research organisations are ISO9001 accredited, the majority of participants related their understanding of ISO9001 to quality of work.

Theme 2: Role of leadership in research
In terms of leadership and its role in innovation, the participants were in agreement and felt strongly that leadership is responsible for development and implementation of an effective research and innovation strategy, steering the direction of the organisation, and fostering an innovative culture towards an environment conducive for employees to innovate. Collectively, participants were in agreement that leadership is one of the most critical constructs to ensure that innovation and TQM practices are supported, harnessed and driven within a research organisation.

Theme 3: Strategy in research
Analysis of the data indicates that the majority of participants concur that strategic planning plays an integral role in fostering innovation performance. Additionally, the majority of participants were of the opinion that innovation strategy should be aligned to the overall business strategy of the research organisation to enhance and foster innovation performance. The data tends to indicate that employees whom are more involved in the creation of their organisations research and innovation strategy are more likely to be invested, aspire to innovate and develop new products and processes.

Theme 4: Customer focus in research
The participants were in agreement that customer focus plays a significant role in aiding researchers in this organisation to identify areas to innovate new products, processes and services that are aligned with customer needs and requirements. It was felt that this would enhance innovation performance within a research organisation and ensure both its financial and operational sustainability.

Theme 5: People management in research

Collectively, participants felt strongly that the effective management of people, communication, regular engagement and the fostering of learning and innovation by leadership plays a significant role in the performance of innovation within a research orientated organisation. Participants felt more likely to innovate and develop new products and processes when rewarded, recognised, inspired, appreciated and engaged by leadership.

Theme 6: Innovation understanding and perceptions

In terms of innovation, its definition and understanding thereof, the majority of participants had a fairly good understanding of innovation and what it encompasses. The data demonstrates that although there no single definition of innovation amongst participants, there was general agreement of the nature of innovation. From an innovation strategy perspective, all participants except one were in agreement and stressed that an effective research and innovation strategy is critical to enhancing innovation performance and enables a research organisation to develop a clear vision and direction to do so.

Theme 7: Innovation challenges

An assessment of current challenges or obstacles faced in the research organisation in terms of building and sustaining innovation capacity and improving performance within their organisation revealed the following obstacles:

- An absence of an effective research and innovation strategy;
- A decline in scientific, engineering, and technology skills and experts at organisational and country level presents a critical challenge to the organisation's ability to build on their innovation capacity;
- Poor leadership support in fostering innovation performance;
- A lack of an innovation culture and an environment conducive to innovation;
- High levels of administrative duties, bureaucracy, procedures and protocols; and research divisions working in silos is an obstacle to building and sustaining innovation capacity within a research organisation
- A loss of experts and skilled professional,
- Poor team dynamics and integration of critical transfer of ideas, technological and industry experience

6 DISCUSSIONS OF FINDINGS

Theme 1: TQM understanding and perceptions

The majority of participants within the research organisation had some awareness of the concept of TQM and its relation to continuous improvement and quality. However, the majority of participants were not as confident in the implementation, practices and dimensions of TQM and its applicability to a research organisation. In terms of practices or dimensions of TQM, the data indicates that although the topic of customer focus, leadership, strategy and people management are discussed daily at this research organisation, employees in management roles are not always aware that these are types of TQM practices, or how TQM is implemented or practiced within an organisation. Moreover, this lack of awareness also indicates an ineffective quality management system. The findings suggest that TQM practices are not well implemented and practised within this organisation, particularly at a middle management and supervisory level. This is impacting on the quality of current research and innovation focused projects. Additionally, the findings of the qualitative analyses identified the following barriers to TQM practices and implementation: a lack of sufficient understanding, awareness and knowledge about TQM, lack of leadership support and engagement with employees, lack of basic leadership skills, training, and development amongst middle and senior management.

Theme 2: Role of leadership in research

Although the majority of participants are highly qualified scientists, engineers and experts in the research sectors, many have not undergone any formal management type training on leadership, strategy or people management. The research findings showed a strong consensus on the perspectives of participants that customer focus plays a critical role in the innovation of products and processes and innovation performance. Participants' feedback was consistent with the work done by scholars. According to Manders et al., [15] and Fernandes et al., [40] product innovation within an organisation is supported by focusing on the customer requirements to actualise the "right" products and processes to research, develop and innovate.

Theme 3: Strategy in research

Qualitative data findings indicate that an ineffective research, development and innovation strategy inhibits the ability of the research organisation to build its capacity to innovate. It also impedes the development of new products and services to clients and the financial performance of the organisation. This assumption is supported by the work of Pisano [24] and Antunes, et al., [27]) who posited that an organisation's ability to develop and implement an effective innovation strategy is critical to the overall success of innovation in an organisation and to the strategic direction in terms of what products and process to develop. The data tends to indicate that involved and inspired employees are more likely to innovate and develop new products and processes.

Theme 4: Customer focus in research

Participants in this study stressed that customer focus, potentials and necessities are often well attained when a research organisation develops innovative and quality products. Some participants asserted that a customer centric organisation fosters innovation, inspiration and creativity amongst scientists and engineers to enhance the innovation performance and enhance both customer and employee satisfaction.

Theme 5: People management in research

The overall perception of innovation by employees is positive and employees are constantly innovating and thinking of new ideas and concepts. Participants are in agreement that innovation sparks creativity and passion amongst scientist, engineers and technical experts, young and old. Additionally, the data demonstrated that effective management of people at an R&D organisation is critical to the successful implementation of TQM and its practices also improves innovation performance and plays a significant role in gaining a competitive advantage over competitors. Uslu [44] posited that strategic and effective management of employees positively influences job satisfaction and fosters an innovation culture in an organisation.

Theme 6: Innovation understanding, perceptions and challenges

Scientists, engineers and technical experts working in this R&D sector are well versed with the concept of innovation, its implementation and associated challenges and barriers. TQM in innovation is therefore perceived as the strong catalyst that facilitates R&D organisations to be creative, nurturing the development of new technologies and futuristic ideas that benefit the organisation, its employees, industry, the customer, and ultimately society. Participants felt strongly that a lack of effective leadership, support in the creation of an effective total quality management system, innovation culture, and innovation strategy inhibits a research organisation in its ability to build on its innovation capacity, retain or hire skilled scientists or engineers, sustain investment and funding of research projects or develop strategic objectives that are well aligned to the overall business strategy for the organisation. Ooi [14], asserted that positive engagement between employees and top management is vital to the successful application and practice of TQM and innovation in an organisation and as well as the satisfaction of both customers and staff. A poor innovation philosophy and a non-conducive environment tend to inhibit the ability of employees to innovate and come up with new ideas or products.

Table 3: Categories of themes and participant responses

Category of Theme	Code	Participant response
TQM understanding	**T1**	*"Standards are adhered to on an entire project lifecycle… it needs to be governed by quality standards, including reporting at a high enough level…." (Participant 1)* *"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)* *"TQM cuts across everything in the organisation from product to processes to technology and quality" (Participant 3)*
TQM practices	**T1**	*"Customer monitoring of quality management and continuous improvement" (Participant 5)* *"Implementation of quality standards and maintain it" (Participant 7)* *"TQM practices include procedures, policies and quality control" (Participant 10)*
Quality Management System	**T1**	*"…..quality management system in place… Not very effective only at a divisional level not organisational, quality accreditation, not sure how it's implemented" (Participant 2)* *"….Strong SHEQ and customer focus, others aspects of monitoring and continuous improvement and work."(Participant 5)* *"….quality of processes and activities in relation to product and processes, client interaction and staff job description…" (Participant 8)* *"….continuous improvement only, not sure what it entails or aware of how it is implemented at my organisation…" (Participant 10)*
ISO 9001	**T1**	*"… Organisation is ISO9001 accredited, to assess quality system in organisation but ISO9001 not effectively implemented…." (Participant 1)* *"…….is ISO9001 accredited. Quality accreditation role is to evaluate how we do our work and procedures and ensure quality work…." (Participant 2)* *"….. ISO9001 system in place to ensure quality consistency in services, continuous process…" (Participant 6)*

Category of Theme	Code	Participant response
Role of leadership in research	T2	*"Leadership is responsible for the innovation culture and creating a conducive environment for innovation" (Participant 1)* *"Role of leadership is to correct environment and headspace for staff to innovate too much red tape" (Participant 2)* *"Leadership can enable or disable innovation, set directs, enable environment that is conducive for innovation. Fostering physical infrastructure to innovate, tolerate risks and failures, critical is that leadership should foster freedom to create ideas within industry" (Participant 6).*
Strategy in research	T3	*"Yes, the right strategy will direct the thinking to innovate, empowerment of staff to try new things" (Participant 6)* *"Yes strategy aligns organisation with innovation, creates a directional focus for innovation" (Participant 7)*
Customer focus in research	T4	*"Very Important, because if the customer has to use your innovation in reality it might stop work… there has to be a customer to use the innovation … Need to identify customer, is innovation financially sound... Even though its sounds good academically, does it meet the needs of the customer?" (Participant 1)* *"Extremely important… Need to understand customer needs in order to innovate, new things to assist customer needs, product and services" (Participant 3)*
People management in research	T5	*"Yes, inspired and engaged employees, foster innovation performance" (Participant 1)* *"Most definitely...The more motivated and engaged employees; the more they innovate and create" (Participant 4)* *"Engaged and motivated employees think creatively and are motivated to innovate" (Participant 1)*
Innovation understanding and perceptions	T6	*"Innovation is a multi-component, novel ideas, novel applications, reorder of a recipe or completely new technique" (Participant 1)* *"Process of coming up with new ideas and that ultimately some impact on the industry for commercialization or benefit" (Participant 3)* *"Innovation is formally defined as the invention of an idea or the commercialization of an idea, a process that generates financial value from an initial idea" (Participant 7)*
Innovation strategy perspective	T7	*"…..organisation does not have an effective RDI strategy in place….not sure as yet direction of RDI" (Participant 1)* *"Organisation does not have a clear RDI strategy" (Participant 7)* *"Yes there is some form of a R&D &I strategy; …however there is much room for improvement …" (Participant 9)*

The categories of themes identified for the qualitative phase of this study and participant responses for each category is presented in Table 3.

7. MANAGERIAL IMPLICATIONS

The data tends to indicate that involved and inspired employees are more likely to innovate and develop new products and processes. Additionally, the data demonstrated that effective management of people at an R&D organisation is critical to the successful implementation of TQM and its practices. It also improves innovation performance and plays a significant role in gaining a competitive advantage over competitors.

8. CONCLUSION

The results of this study further emphasise the importance of leadership support and engagement, customer focus, strategy, and people management in a research organisation to promote innovation and enhance performance. If leadership engagement is active, and employees are included in the strategy development and implementation process, employees will feel engaged, invested and empowered, thereby improving the overall innovation culture and performance of the research organisation. Furthermore an effective innovation strategy may result in the appropriate allocation of research funding, budgets, and commercialisation of products, technologies, and intellectual property. Additionally, an effective innovation strategy will allow for the alignment of key research objectives to the business strategic goals, better overall management, and will foster the creation of centres of global research excellence and innovation.

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CAN THE INTEGRATION OF MANAGEMENT SYSTEMS IMPROVE ORGANISATIONAL EFFICIENCY?

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ABSTRACT

In the industry 4.0 era, the integration of management systems (IMSs) has become an increasingly important strategy to improve organisational efficiency. Despite the established need for IMSs, most research on IMSs has been undertaken outside of Africa. Research on how to carry out integration in Africa and more especially, South Africa has yet to be fully understood. The purpose of this study was to identify the factors that contribute to the IMSs. An online survey questionnaire was conducted among 220 respondents from four multi-national organisations who develop management systems for South African organisations. To validate the instrument confirmatory factor analysis and then structural equation modelling to determine the interrelationships between the factors. The results indicated that a strong relationship between IMSs' factors and organisational efficiency exists. The beneficiaries of this research are organisations that have two or more management systems and do not understand the IMSs' factors.

Keywords: integration, confirmatory factor analysis, structural equation modelling, management, organisational efficiency

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1 INTRODUCTION

Over the past two decades, organisations have been steadily implementing two or more management systems such as ISO 9001 and ISO 14001. With the increase of the use of management systems, 3% per year, ISO [1] and the need for organisations to reduce operating expenses, it is important to integrate more management systems effectively and efficiently to avoid additional overheads. Although integration of management systems is not a new concept, most work in the field has been limited to benefits of integration [2]; [3], the challenges [4]; [5], the levels of integration [6] and the models/frameworks [7]. These are only secondary why-factors and do not address the how of integration. Therefore this study will address this gap by developing a structured conceptual framework for integration, which can improve organisational efficiency. Finally, this study makes a novel and empirical contribution (conceptual framework) for organisations to implement IMSs.

2 RESEARCH OBJECTIVE

The primary objective of the study is to develop a conceptual framework by testing the statistical significance of the various factors on IMSs to improve organisational efficiency.

3 LITERATURE REVIEW

An IMS is a set of interrelated processes that share human resources, information, materials, infrastructure, and financial resources. The IMS is organised in order to meet goals related to satisfying different stakeholders [5].

The systems theory is based on an analysis of the concept of systems and system thinking [8]. This theory is preferred because the integration of management systems is a system of systems. This study seeks to understand how the elements constituting the system best can interact to produce the expected outcomes. Systems theory provides the basis for the development of the conceptual framework.

3.1 Factors that influence IMSs

The following factors have been identified that impact the IMSs in an organisation.

3.1.1 Leadership's influence on organisational efficiency

Leadership is the art of motivating a group of people to act toward achieving a common goal. In an organisational setting, this can mean directing employee with a strategy to meet the organisations' goals [9]. This leadership definition captures the essentials of being able and prepared to inspire others. Effective leadership is based upon ideas whether original or borrowed, that would not happen unless those ideas can be communicated to others in a way that engages them enough to act as the leader wants them to. The Honeybee leadership approach more recently, refers to a resilient and humanistic approach to organisational efficiency which builds on the sustainable Rhineland leadership practices [10].

3.1.2 Management as an influencer of IMSs

The behavioural theory of management enhances the list of matters invoking decisions and situations that appear when an organisation is engaged in organisational development [11]. The human being and his or her values and the compatibility of organisational processes are aspects of an organisation that the behaviourist investigates to determine whether decisions regarding organisational matters are required. Management has a significant part to play by enforcing managerial practices, promoting organisational trust, reciprocity, and a sense of organisational justice generating worker satisfaction, commitment, and effort [9].

3.1.3 The influence of policy on integration

Integration challenges emerge, particularly when complex societal issues are confronted with traditional forms of subsystem policymaking within hierarchic governance systems [12]. Policy matters, not only at the national level, but also at the regional and local levels [13]. Explicit integration policies are part of a normative political process in which the issue of integration is formulated as a problem, the problem is given a normative framing, and concrete policy measures are designed and implemented to achieve a desired outcome [13]. The desired outcome here will be measured in terms of efficiency and how it is related to policy. Policy is expected to improve organisational efficiency from the literature presented, which leads to the following hypothesis:

H_0^1 *There is no statistical significant relationship between organisational efficiency and policy.*

H_1 *There is a statistical significant relationship between organisational efficiency and policy.*

3.1.4 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 [14]. Workplace culture refers to the values, beliefs, norms, customs, and practices of an organisation [15]. Organisational culture is a set of norms, beliefs, values and vision that define, how employees and managers interact within an organisation [16]. A 2015 study by Deloitte University Press found that 87% of the organisations surveyed now cite organisational culture and employee engagement as their top challenges. Organisational culture also helps businesses to attract the best employees. Today, employees are looking for more than just a good salary. Generating profit is not enough. Millennials in particular are motivated by working environments that have a strong sense of purpose and values [17]. In addition, establishing an effective organisational culture in an organisation is an important strategy to advance organisational efficiency [17]. Therefore, from the theory the following hypothesis will be tested:

H_0^2 *There is no statistical significant relationship between organisational culture and organisational efficiency.*

H_2 *There is a statistical significant relationship between organisational culture and organisational efficiency.*

3.1.5 Employee motivation

Herzberg's two-factor theory holds that there are two types of motivators: extrinsic and intrinsic. Extrinsic factors include factors such as pay, supervision, working conditions and job security. Intrinsic motivation factors include achievement, recognition, and a responsibility for work. Intrinsic factors cause job satisfaction [18]. When employees enjoy their work (play), identify with the values and goals of the job (purpose), or when it contributes to their own professional goals (potential), performance levels increase [19]. Both organisational culture and motivation systems are related to the efficiency of an organisation, in that if an organisations' cultures are focused on throughput, then it is more likely that the organisation will make decisions based on the influence of local actions on global results, rather than attempting to optimise all resources locally [20]. Therefore, from the literature, the following hypothesis will be tested:

H_0^3 *There is no statistical significant relationship between organisational culture and employee motivation,*

H_3 There is a statistical significant relationship between organisational culture and employee motivation.

3.1.6 Management influence on organisational culture

When management is dealing with employees from different cultural backgrounds, it is important to educate your employees about how to approach any potentially delicate situations [16]. The perception and the understanding of emotional experiences are different among people from different cultures because culture influences which events trigger emotions and determines the norms of emotional expression [21]. Cultural differences cause communication problems, misunderstandings, and conflicts between the top management teams, which in turn can cause stress and negative attitudes among the acquired managers [22]. Therefore, from the theory the following hypothesis will be tested:

H_0^4 There is no statistical significant relationship between management and organisational culture.
H_4 There is a statistical significant relationship between management and organisational culture.

3.1.7 Innovation as an enabler of employee performance in an organisation

Innovation is defined as the commercialisation of all new combinations based upon the application of new materials and components, the introduction of new processes, the opening of new markets, and/or the introduction of new organisational forms [22]. Innovation is an idea, practice, or object that is perceived as new by an individual or other unit of adoption [23]. A crucial reminder is that an organisation’s innovation strategy does not have to be cast in stone. That is, managers can evolve the strategy in ways that make the most sense for their particular business. Therefore, from the theory the following hypothesis will be tested:

H_0^5 There is no statistical significant relationship between employee performance and innovation.
H_5 There is a statistical significant relationship between employee performance and innovation.

3.1.8 Innovation’s impact on organisational efficiency

An effective organisation operates like a well-designed, well-oiled machine. Its moving parts function smoothly to produce the results the business set out to achieve, with minimal wasted resources or time. There is a common understanding that the organisations need management and strategies not only for quality management, but also for innovation [24]. The findings suggest that innovation and quality management may be handled side-by-side and that it is necessary to identify exactly where quality management and innovation management strengthen or hinder each other. Quality is generally about conformance to standards with the ultimate purpose of amplifying organisational efficiency, while innovation is about breaking new ground [25]. However, it is unclear how organisations actually integrate quality and innovation into a coherent and powerful strategic package to improve organisational efficiency. Therefore, from the theory the following hypothesis will be tested:

H_0^6 There is no statistical significant relationship between organisational efficiency and innovation.
H_6 There is a statistical significant relationship between organisational efficiency and innovation.

3.1.9 Process standardisation and organisational efficiency

It is well recognised by regulators in many countries that standard setting among competitors can be procompetitive and good for consumers. Frameworks introduce standards used in each area [26]. Defined standards are designed to provide a clear definition of each business process for simplification of communication within the organisation and organisational communication with its surroundings. The most common definition standards are documents, established by consensus and approved by a recognised body that provides, for common and repeated use, rules, guidelines or characteristics for activities or their results, aimed at the achievement of the optimum degree of order in a given context [27]. As for the negative effect of standards, it has been shown that historical events are more important than an economic perspective, and standards can produce “lock-in effects” [28]. Therefore, from the theory, the following hypothesis was tested:

H_0^7 *There is no statistical significant relationship between organisational efficiency and standards.*

H_7 *There is a statistical significant relationship between organisational efficiency and standards.*

3.1.10 Standardisation and standardisation effort

Standardisation helps decrease variation, which increases quality and safety while reducing costs [29]. As an example, from a healthcare manager’s perspective, standardisation helps foster an environment of quality patient care. Standardisation, especially in healthcare, minimises the risk of errors, increases patient safety, and can actually improve the patient experience. Business processes cut horizontally across the organisation and create an interrelated organisational subsystem that forms a micro-structure of related tasks, technology, and people [30]. Therefore, business processes cover a wide range of activities within an organisation. The spectrum ranges from iterative and simple to creative, or knowledge-intensive, and unique business processes [31]. The main challenge during standardisation initiatives is to turn existing process variants into standard operating procedures that are obligatory for all employees in an organisation [32].

H_0^8 *There is no statistical significant relationship between standardisation effort and standards.*

H_8 *There is a statistical significant relationship between standardisation effort and standards.*

3.1.11 The theoretical framework for integration of management systems

According to Robson [33], developing a conceptual framework forces the researcher to be explicit about what he or she thinks he or she is doing. Therefore, conceptual frameworks introduce explicitness within research processes [34].

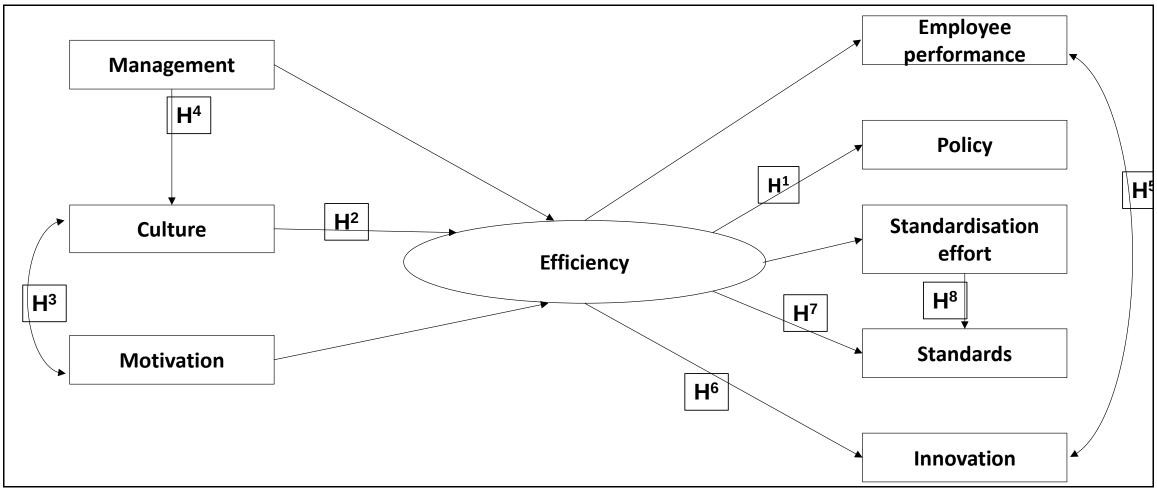

Figure 1: Path analysis framework of IMS

The theoretical framework for the study is presented in Figure 1 which has drawn on literature from systems theory, management theory, and leadership theory as the foundation for the path analysis development.

4 EXPERIMENTAL METHOD

Research approaches are the plans and procedures for research that span the steps from broad norms to detailed methods of data gathering, analysis and elucidation [35]. This study adopted the quantitative approach which made use of a survey questionnaire and was analysed through confirmatory factor analysis. Finally, the use of regression analysis was used to develop the structural model for integration.

4.1 Data collection procedures

The instrument used to gather the data was a self-administered, closed-ended, structured questionnaire that was posted online. An advantage of an online self-administered questionnaire, is it could reach a large sample in a short period of time [35]. The survey questionnaire used a seven point Likert-type scale (strongly disagree to strongly agree) to measure the responses. The questionnaire was subjected to a pilot study by experts familiar with the nature and scope of the research and principles of question construction.

4.2 Survey questionnaire development

The questionnaire contained statements and questions that adequately addressed the research objective - to develop a conceptual framework for the integration of management systems to improve organisational efficiency. There were a total of 10 factors, namely, leadership, management, organisational culture, employee performance, standards, standardisation, innovation, employee motivation, organisational efficiency and standardisation effort, which were aligned to the hypotheses from the literature review. Each factor had sub-questions that were aligned to each hypothesis. In this way the researcher ensured alignment and synthesis to the hypotheses were achieved.

4.3 Population and sampling

The population comprised of South African ICT organisations. No sampling was done in this study because the researcher conducted a census survey. The ICT sector was chosen, as this is a sector that is involved with development, management and continuous improvement of management systems. However, all South African ICT organisations could have participated so the research introduced the following selection 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 on at least three continents.

These strict criteria were introduced to ensure that only Multi-National Companies (MNCs) with extensive knowledge of IMS could be drawn as a sample. Table 1 is a summary of the population and sample.

Table 1: Summary of the population and sample size

Population	Targeted sample	Actual respondents
Organisation A	100	220
Organisation B	125	
Organisation C	125	
Organisation D	150	
	Total = 500	**Total = 220**

The link to the survey was emailed to the leader of the organisation once permission had been granted. Thereafter, the leader of the organisation forwarded the link to the survey to the employees. The following criteria were identified as respondents to the questionnaire (user, management or technical). In this way, the researcher succeeded in achieving an acceptable response from participating organisations. Of the targeted 500 participants, 220 responses were received. This is a response rate of 44.00%. Table 2 refers to the calculation on sample size acceptance [36].

Table 2: Sample size guide

Population	Percentage suggested	Number of respondents
20	100%	20
30	80%	24
50	64%	32
100	45%	45
200	32%	64
500	20%	100
1 000	14%	140
10 000	5%	450
100 000	2%	2 000
200 000	1%	2 000

According to table 2 for a population of 500, a response of 44.00% is deemed acceptable. It is therefore affirmed that the response rate was acceptable and the findings could be generalised over the community without reservation.

5. RESULTS OF THE STUDY

The purpose of this section is to explain the results of the study. The data presented is from the respondents who answered the online survey.

5.1 Reliability – Cronbach's alpha indexes of the constructs

Table 3 represents Cronbach's alpha indexes.

Table 3: Cronbach's alpha indexes of key constructs

Construct	Overall reliability
Management	0.965
Standards	0.931
Leadership	0.965
Policy	0.940
Performance	0.977
Standardisation effort	0.865
Organisational culture	0.952
Innovation	0.967
Motivation	0.909
Targets	0.809

Cronbach's alpha is a measurement of the variance within an item and the co-variance between a particular item and any other item on the scale [37]. All the alpha coefficient estimates were above 0.7, which implied that the data was reliable [38].

5.2 Analysis of the structural model

Structural equation modelling (SEM) is a multivariate statistical analysis technique that is used to analyse structural relationships [39].

Table 4: Model fit criteria and acceptable fit interpretation

Model fit criterion	Acceptable level	Obtained value
CMIN/DF (χ^2)	>1 and < 3	2.077
Goodness-of-fit (GFI)	0 (no fit) to 1 (perfect fit)	0.498
Root mean square error of approximation (RMSEA)	< 0.080	0.070
Normed fit index (NFI)	0 (no fit) to 1 (perfect fit)	0.998
Incremental fit index (IFI)	0 (no fit) to 1 (perfect fit)	0.999
PCLOSE	0 (no fit) to 1 (perfect fit)	0.261
HI 90	0 (no fit) to 1 (perfect fit)	0.149
CFI	0 (no fit) to 1 (perfect fit)	0.999
PCFI	0 (no fit) to 1 (perfect fit)	0.067

Notes: **PCLOSE** = test of close fit; **HI** 90 = test of fit indice; **CFI** = Comparative Fit Index

A model is considered a good fit if the value of the chi-square test is insignificant, and at least one incremental fit index (such as CFI, GFI, TLI, AGFI.) and one badness of fit index (such as RMR, RMSEA, SRMR) meet the predetermined criteria. The results of the SEM obtained for the proposed conceptual model revealed a ratio of chi-square value to the degree of freedom (x2/df) of 2.070, a GFI of 0.498, CFI of 0.999, NFI of 0.998, IFI 0.999 and RMSEA of 0.070.

Generally, fit statistics greater than or equal to 0.900 for GFI, NFI, RFI and CFI indicate a good model fit. Therefore, the model fit was acceptable.

6. HYPOTHESIS TESTING

Table 5 presents the results of hypothesis testing. All the proposed hypotheses are accepted. The values of r ranges from -1 to +1. The closer the value of r is to +1, the stronger the positive correlation between the 2 variables. The closer the value of r is to -1, the stronger the negative correlation between the two variables in question. Generally, for any values where $0 < |r| < 0.3$, this represents a weak correlation between the variables [39]. For any values $0.3 < |r| < 0.7$, this represents a moderate correlation [39]. For any values where $|r| > 0.7$, this represents a strong correlation between the variables.

Table 4 shows the regression weights

			Estimate	**P**
Culture	<---	Management	0.561	***
Motivation	<---	Culture	0.819	***
Efficiency	<---	Management	1.181	0.009
Efficiency	<---	Leadership	1.000	
Efficiency	<---	Motivation	0.040	0.774
Efficiency	<---	Culture	0.626	0.026
Standardisation effort	<---	Management	0.269	0.041
Standardisation effort	<---	Motivation	0.273	***
Standardisation effort	<---	Culture	0.065	0.293
Standardisation effort	<---	Efficiency	0.109	0.090
Standards	<---	Motivation	-0.329	***
Standards	<---	Effort	1.000	
Standards	<---	Efficiency	0.136	0.002
Policy	<---	Culture	0.062	0.681
Policy	<---	Efficiency	0.638	***
Policy	<---	Management	0.197	0.354
Policy	<---	Standards	-1.100	***
Performance	<---	Culture	0.247	0.171
Performance	<---	Efficiency	0.542	0.223
Performance	<---	Policy	-0.781	0.480
Innovation	<---	Motivation	0.019	0.889
Innovation	<---	Leadership	-0.386	0.160
Innovation	<---	Performance	1.000	-
Innovation	<---	Efficiency	1.000	-
Innovation	<---	Standards	-2.579	0.001

Table 4 shows the regression weights or estimated coefficients obtained in SEM. The table displays the unstandardised estimates of coefficients. The probability values associated with the null hypothesis that the coefficients are equal to zero are displayed under the probability (P) column.

Table 5: Regression weights for improving organisational efficiency

	Estimate	P value
Leadership	1.000	***
Management	1.181	0.090
Innovation	1.000	***
Policy	0.638	***
Organisational culture	0.626	0.026
Employee performance	0.542	0.223
Employee motivation	0.273	0.774
Standards	0.136	0.002
Standardisation effort	0.109	0.090

From Table 5 it can be deduced that the latent variable 'organisational efficiency' is influenced by three factors, namely leadership (B = 1.000), management (B = 1.181) and innovation (B = 0.638). This implies these factors have the highest influence on organisational efficiency when integration is concerned. These factors were used to develop the conceptual framework. To illustrate the confidence level, the p-value was used. The p value is the evidence against a null hypothesis. The smaller the p-value, the stronger the evidence that you should reject the null hypothesis

6.1 Path analysis

It is interesting to note in figure 2 that, of the three constructs (i.e. leadership, management, and organisational culture) which form the efficiency latent variable, from table 5, management (1.181) has the heaviest regression weight, followed by leadership (1.000). This supports the theory that management and leadership are key instruments in influencing the IMSs and improving organisational efficiency.

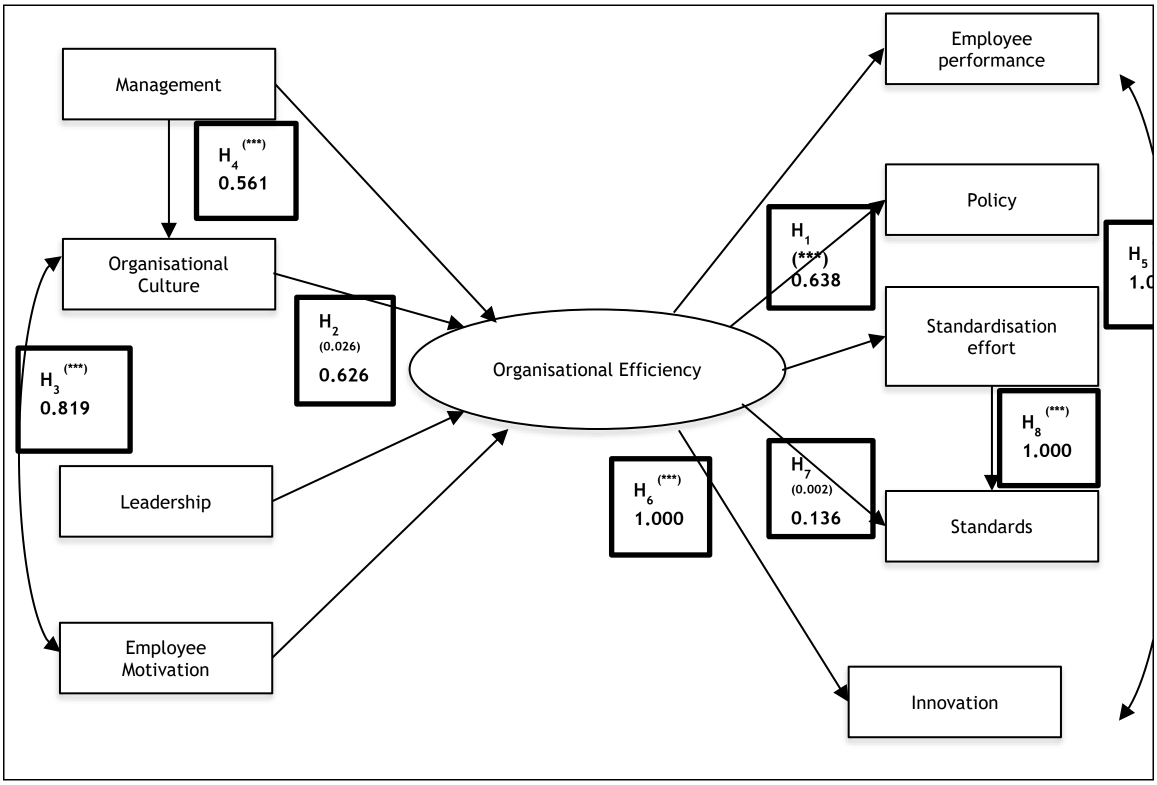

Figure 2: The structural equation model (SEM)

6.2 Hypothesis testing

6.2.1 Hypothesis 1 – relationship

Table 6 shows the CR probability of the CR for the relationship between organisational efficiency and policy was less than 0.010. This represents a significant relationship between the two variables at the 99% level of confidence.

Table 6: The relationship between organisational efficiency and policy

Variable	Mean	SD	Organisational efficiency
Policy	5.300	1.900	
Probability of CR			< 0.010

The decision rule was to reject the null hypothesis and accept the alternative.

6.2.2 Hypothesis 2 – relationship

Table 7 shows the CR probability for the relationship between organisational culture and organisational efficiency was 0.026, which is < 0.050, the level of significance. This represents a significant correlation at the 95% level of confidence between the two variables.

Table 7: The relationship between organisational culture and organisational efficiency

Variable	Mean	SD	Organisational culture
Organisational efficiency	5.300	1.800	
Probability of CR			0.026

The decision rule was to reject the null hypothesis and accept the alternative hypothesis.

6.2.3 Hypothesis 3 – relationship

Table 8 shows the CR probability for the relationship between organisational culture and employee motivation was 0.010 which is < 0.050, the level of significance. This represents a significant relationship at the 95% level of confidence between the two variables.

Table 8: the relationship between organisational culture and employee motivation

Variable	Mean	SD	Organisational culture
Employee motivation	5.300	1.800	
Probability of CR			< 0.010

The decision rule was to reject the null hypothesis and accept the alternative hypothesis.

6.2.4 Hypothesis 4 – relationship

Table 9 shows the CR probability for the relationship between management and organisational culture was 0.010, which is < 0.050, the level of significance. This represents a significant relationship at the 95% level of confidence between the two variables.

Table 9: the relationship between management and organisational culture

Variable	Mean	SD	Management
Organisational culture	5.300	1.800	
Probability of CR			< 0.010

The decision rule was to reject the null hypothesis and accept the alternative hypothesis.

6.2.5 Hypothesis 5 – relationship

Table 10 shows the CR probability for the relationship between employee performance and innovation was < 0.010, which is < 0.010, the level of significance. This represents a highly significant relationship at the 99% level of confidence between the two variables.

Table 10: the relationship between employee performance and innovation

Variable	Mean	SD	Employee performance
Innovation	5.300	1.800	
Probability of CR			< 0.010

The decision rule was to reject the null hypothesis and accept the alternative.

6.2.6 Hypothesis 6 – relationship

Table 11 shows the CR probability for the relationship between organisational efficiency and innovation was < 0.010, which is < 0.010, the level of significance. This represents a highly significant relationship at the 99% level of confidence between the two variables.

Table 11: the relationship between organisational efficiency and innovation

Variable	Mean	SD	Efficiency
Innovation	5.300	1.800	
Probability of CR			< 0.010

The decision rule was to reject the null hypothesis and accept the alternative hypothesis.

6.2.7 Hypothesis 7 – relationship

Table 12 shows the CR probability for the relationship between organisational efficiency and standards was 0.002, which is < 0.010, the level of significance. This represents a highly significant relationship at the 99% level of confidence between the two variables.

Table 12: the relationship between organisational efficiency and standards

Variable	Mean	SD	Efficiency
Standards	5.200	1.800	
Probability of CR			0.020

The decision rule was to reject the null hypothesis and accept the alternative hypothesis.

6.2.8 Hypothesis 8 – relationship

Table 13 shows the CR probability for the relationship between standardisation effort and standards was < 0.010, which is < 0.010, the level of significance. This represents a significant correlation at the 99% level of confidence between the two variables.

Table 13: the relationship between standardisation effort and standards

Variable	Mean	SD	Standardisation effort
Standards	5.000	1.800	
Probability of CR			<0.010

The decision rule was to reject the null hypothesis and accept the alternative hypothesis.

From the hypotheses testing, all 8 hypotheses null hypotheses were rejected and the alternative accepted.

7. FINDINGS

To make the model SEM identifiable, the regression weight of leadership was constrained to 1. All three variables – leadership, management, and organisational culture – influence efficiency positively. Management influences the IMSs and drives efficiency in an organisation.

From Table 4 it is clear that efficiency (B = 0.542, prob. = 0.223 > 0.100) does not influence employee performance of management systems. Efficiency affects standardisation effort (B = 0.109, prob. = 0.090<0.0100), standards (B = 0.136, prob. = 0.002 < 0.010), policy (B = 0.638, prob. = <0.000 < 0.010), and innovation (B = 1.000). This implies that leadership, management and organisational culture affect these variables indirectly. Innovation is to a high degree positively affected by performance (B = 1.000) and efficiency (B = 1.000), and negatively by standards (B = -2.579, prob. = 0.001 < 0.010).

Management also affects organisational culture (B = 0.561, prob. = 0.000 < 0.010) and standardisation effort (B = 0.269, prob. = 0.041<0.050) directly and positively. Management have a direct effect on the organisation, as managers are in contact with the employees and are directly involved with the integration of management systems.

Therefore, if management have adopted an organisational culture that aligns with the organisation, the employees will likewise adopt this culture, which will improve the IMSs and thereby improve the efficiency of the organisation.

Standards that are set will be to meet organisational objectives and the policy of the organisation will be implemented consistently in each department. Apart from organisational culture affecting employees' performance of management systems through efficiency, it also directly affects motivation (B = 0.819, prob. = 0.000 < 0.010) positively. Hence, the nature of organisational culture motivates employees of an organisation to achieve targets.

If the organisational culture is driven by management, then organisational culture drives efficiency in the integration of management systems. Employee motivation affects standardisation effort (B =0.273, prob. = 0.000 < 0.010) positively and standards (B = -0.329, prob. = 0.000 < 0.010) negatively, and does not affect innovation (B = 0.019, prob. = 0.889 > 0.100).

When employees in an organisation are motivated, the amount of effort they expend in the execution of their jobs will improve (B = 1), resulting in better performance and efficiency when integrating management systems. They will thereby become innovative in their effort for results and as a result drive organsiational efficiency. Standards strongly affect policy (-1.100, prob. = 0.000 < 0.010) negatively. The literature debates whether standards are highly correlated to policy which needs to be investigated.

8. DEVELOPED FRAMEWORK

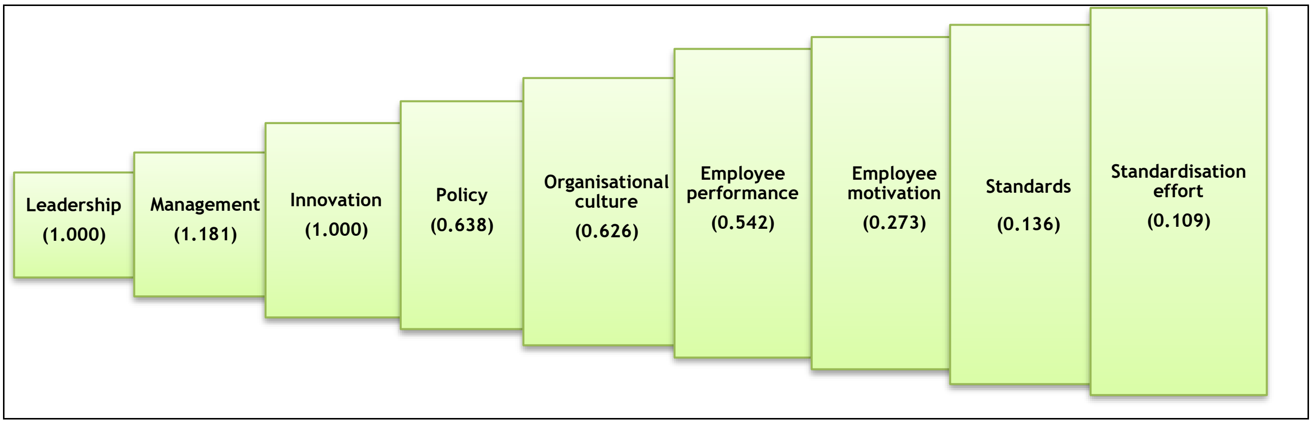

Figure 3: The developed conceptual framework for improving organisational efficiency

The literature review and the empirically tested factors (table 4) were triangulated to design the conceptual framework. A discussion of each factor is presented.

8.1 Leadership

Leadership was empirically tested as a factor of an IMS, and shown to positively and significantly be associated with IMS efficiency. The regression weight was 1.000 with a probability value of the critical ratio (CR) of less than 0.010 (<. 01). Leaders have a key role in strategy formulation and implementation [9]). In order to achieve this, leaders must be actively and visibly engaged in the organisation, displaying transformational leadership (leaders' effect on followers in that the followers feel trust, loyalty and admiration for their leaders and are motivated to do more than is expected of them).

8.2 Management

Management was empirically tested as a factor of an IMS and shown to be positively and significantly associated with IMS efficiency. The regression weight was 1.181 and the probability of the CR was 0.009 (< 0.01). The elements of organisational administration include planning, organising, command, coordination and control. Fayol also developed 14 general principles of management, namely unity of command, unity of direction, discipline, division of work, authority and responsibility, remuneration, centralisation, scalar chain, order, equity, stability of tenure and personnel, subordinate of individual to general interest, initiative, and *esprit de corps* [39].

8.3 Policy

Policy was empirically tested as a factor of an IMS and shown to be positively and significantly associated with IMS efficiency. The regression weight was 0.638 and the probability of the CR 0.010 (> 0.01). As was discussed in the literature [13], the effect of policy is translated into local-level practice, which is a crucial question for understanding whether integration programmes achieve their goals. Developing a policy provides a platform for improving the integration of employees and management systems into the fabric of the organisation.

8.4 Standards

Standards were empirically tested as a factor of an IMS and shown to be positively and significantly associated with IMS efficiency. The regression weight was 0.136 and the probability of the CR was 0.002 (< 0.01). It is evident that one of the rationales for the adoption of standards is that time spent [40]. Also on small decisions results in less time available to tackle bigger decisions [41]. The best way to initiate integration is to seek common points in the various standards and to ensure that the greatest possible number of procedures is shared among different IMSs.

8.5 Organisational culture

Organisational culture was empirically tested as a factor of an IMS and shown to be positively and significantly associated with IMS efficiency. The regression weight was 0.626 and the probability of the CR was 0.026 (< 0.01). Organisational culture involves a culture of learning, continuous improvement and stakeholder involvement [42]. Therefore, the current research concluded that organisational culture is one of the pillars of an IMS and if properly conducted, will lead to a competitive advantage, continuous improvement and increased sustainable financial performance.

8.6 Employee motivation

Employee motivation was empirically tested as a factor of an IMS, and was shown not to be positively associated with IMS efficiency. The regression weight was 0.040 and the probability of the CR, which was not significant, was p = 0.774 (> 0.1). Although the p-value was high, it can still be considered for the IMS framework as it affects standardisation effort positively. The contribution to management thinking is derived in part from his theory that two sets of variables, hygiene factors and motivators, together influenced worker motivation, and partly from his concept of job enrichment [18]. Extrinsic factors include such factors as pay, supervision, working conditions and job security. Employee motivation therefore has a significant bearing on employee performance.

8.7 Innovation

Innovation was empirically tested as a factor of an IMS and shown to be positively and significantly associated with IMS efficiency. The regression weight was 1.000 and the probability for the CR was less than 0.010. Innovation is defined as “the commercialisation of all new combinations based upon the application of new materials and components, the introduction of new processes, the opening of new markets, and/or the introduction of new organisational forms [22]. For successful IMSs, organisations should have knowledge sharing and dissemination processes designed for IMS to succeed.

8.8 Standardisation effort

Standardisation effort was empirically tested as a factor of an IMS and shown to be positively associated with IMS efficiency. The regression weight was 0.109 and the probability for the C.R was 0.090 (< 0.1). Although the p-value was high, it can still be considered for the IMS framework as it is positively affected by IMS efficiency. Standardisation is the process of developing and implementing specifications based on the consensus of the views of firms, users, interest groups and governments [30]. Organisations must use considerable effort to transfer knowledge, skill and when implementing an IMS. This will ensure all employees understand the integration process.

8.9 Employee performance

Employee performance was empirically tested as a response variable for an IMS. It was shown not to be associated with IMS efficiency. The regression weight was 0.542 and the probability for the CR was 0.223 (>0.1). Managers and their leadership establish goals as part of the performance management process and align the goals throughout the organisation. Alternatively, the organisation cascades goals down to the workforce. In either scenario, it is often the case that employees need specific training to achieve their goals. The performance factor is critical for organisational success [23]. Therefore, organisations that increase integration can realise competitive advantages and improve performance in a variety of economic performance dimensions, such as market brand and risk image.

All 8 empirically tested factors are accepted and were indicated as important for the IMSs.

9. MANAGERIAL IMPLICATIONS

This study benefits PR actioners and organisations by providing the important factors that need to be considered when management systems integration is concerned. The developed empirical framework provides a lens for the implementation process.\

10. CONCLUSION

An IMS requires the level of involvement and engagement from all levels in the organisation. The developed conceptual framework provides a good platform that there are other factors such as organisational culture and employee involvement which was traditionally overlooked. Whilst most studies on integration have shown the factors, benefits and challenges, however these studies have been conducted in isolation. The relationship between the factors of integration have received little attention if any, leaving a knowledge gap and from a practitioner perspective, in that, the relationship between the factors and how they jointly influence organisational efficiency is not known. This study addressed this gap successfully and concludes integration of management systems can improve organsaitional efficiency.

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MINIMIZING ENERGY CONSUMPTION IN A CEMENT MANUFACTURING: SOUTH AFRICAN CASE STUDY.

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ABSTRACT

Cement industry is one of the sectors that consume high energy. This high energy consumption is supported by the high demand of cement in developing countries such as South Africa. Cement is manufactured to build buildings that are strong and reliable for quality purposes. The major challenge with high level of energy consumption is that profit generated becomes minimum. The aim is to address the high energy consumption in the cement processes.

The financial energy consumption result was analysed through statistical technique. The results demonstrate that energy consumption can be reduced to the average of almost R59728,17 each month. The average consumption was used to control the cement process costs. Threats, opportunity, weaknesses and strength (TOWS) matrix was adopted to address high energy consumption in cement industry. This article focuses on energy consumption rate in the cement industry, concluding remark was addressed to assist the industry to reduce energy consumption.

Key words: Energy consumption, cement industry, quality, production, manufacturing, TOWS.

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1 INTRODUCTION

Cement production has increased in South Africa since construction is still developing and more infrastructures are to be built. Sustainable buildings rely on the quality of material used such as cement. All sectors depend on the buildings to perform their daily activities. For instance, a manufacturing company need cement to build its infrastructure such as manufacturing plant, offices and toilet among others. The high demand of cement brings the negative impact of energy consumption in the industry of cement as a whole. Cement manufacturing around the world is found to be 1.6 billion ton in each and every year Atmaca [1].

It was declared by Ansari [2] that cement industry is the second highest energy consumption industry after the steel industry across the world. This brings the new challenge of high energy consumptions in the sector of cement. This paper's concentrations are on the cement industry's energy consumption rate, to convey understanding on impacts caused during the manufacturing of cement such as high energy use. The number of processes available in production of cement contribute effectively in the industries negative energy consumption rate. Furthermore, Arfala [3] confirmed that cement industry has environmental impact through cement emissions as noticed with great interests in the past few years due to its contribution on the environmental pollution.

Cement construction is a constant process according to Atmaca [4], therefore stopping such production process for any reason such as tool changing can cause major damage to the cement industry. This discovery clearly tells us that energy consumption is very high in the cement sector for business purposes. However, there are loopholes that the industry of cement can take advantage of, for it to gain as business. This paper will analyse the energy consumption by the cement industry for the production of cement. The main aim of this article is to assist the cement department in reducing the energy consumption. One of the major objectives is to determine the impact caused by the cement process energy consumption through financial details.

As energy consumption showed to be the major financial attacker in the cement industries, controlling this financial major to limit the disadvantage of cement industry by the energy factor. If energy consumption cost is under control, benefits such as profit might double. This led the study to focus on controlling energy consumption in the cement industry. As much as there is high energy consumption in the sector, this article will be focusing on the energy consumed by the processes of producing cement.

Dealing with the process ineffectiveness will help improve productivity to the cement industry. But energy is the key component that increases expenses in cement industry, while its controllable expense among all other expenses (e.g. labour). The statistical method is employed to deal with the undesirable energy consumption seen in the cement industry.

This article is managed in the following manner: Section 2 contains literature review showing previous information of energy consumption in the cement industry. Section 3 outlines the research approach taken to conduct the study as whole from the start to finish. While, Section 4 presents results and discussion that shows better understanding of cement industry. Section 5 simply concludes the study outcome.

2 LITERATURE REVIEW

The literature review looks at the previous studies from as early as 2010 to 2019 on cement industry. The review looks at cement industry processes, cement energy consumption and cement impart on environment. The role of literature review is to outline the gaps caused by the cement manufacturing.

2.1 Cement production processes overview

The supply chain process is present in Figure 1 to demonstrate the processes that takes place during the production of cement from the start to the shipment of cement. Afkhami, Akbarian [5] confirm the processes of cement product by sketching the process flow of cement supply chain as shown in Figure 1. The cement process flow indicates eight processes namely, raw material extraction, raw material crushing and grinding, pre-heating, calcinating, kilning, clinker cooling, clinker grinding and cement shipment Akbarian [5]. All the processes are vital in the production of cement. Altun [6] Summary of cement processes manufacturing, Altun [6] defined cement engineering as a process which include raw material handling, pyrometallurgy and comminution.

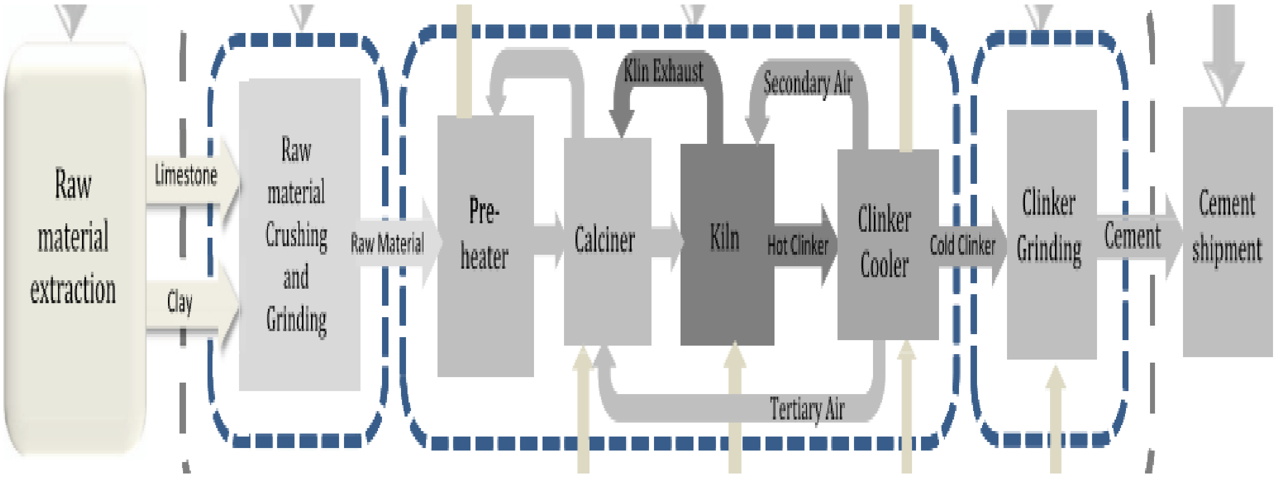

Figure 1: Cement production processes Akbarian [5]

One of the uses of cement is to build concrete which is the highly used cement material in buildings as well as construction sectors An [7]. Further explanation is that it is composed of ordinary Portland cement (OPC), water, aggregate and oftentimes, admixtures according to An [7].

2.2 Cement energy consumption

Altun [6] discovered that cement industry consumes a very huge amount of energy when taking consideration of the global energy consumptions. Figure 2 indicates the use of energy in the cement production processes. Among the cement process there are three high energy consumers such as cement grinding process which consume about 30% of energy in the production of cement, the material grinding process with consume about 26% and 24% consumed by the clinker burning/ cooling of the cement production processes [1].

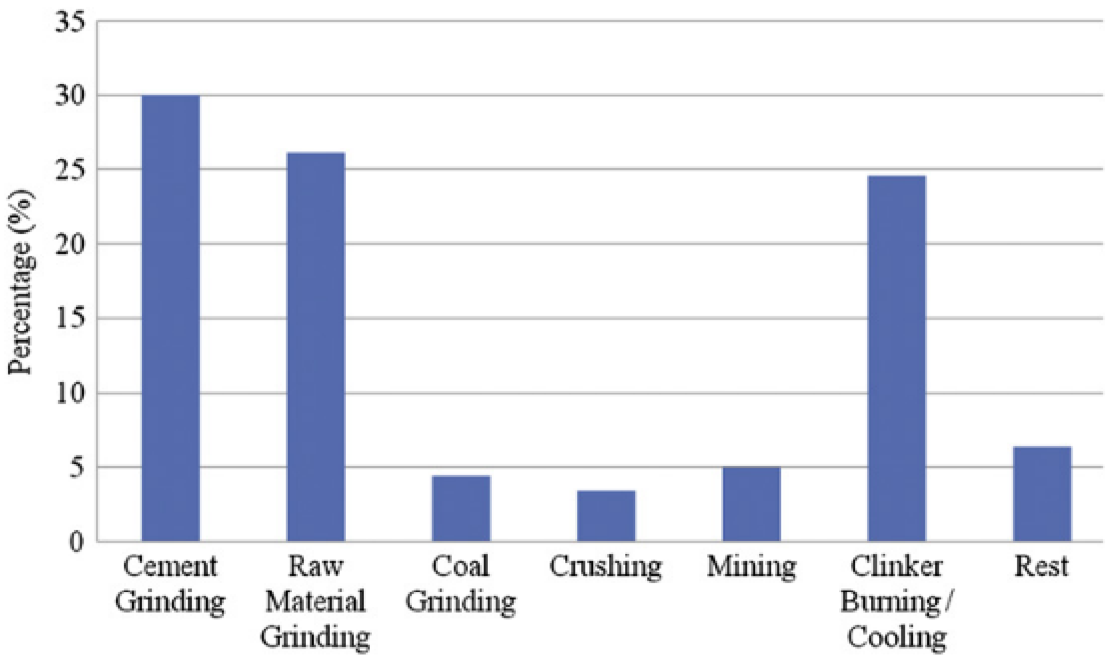

Figure 2: The use of energy in the cement industry Atmaca [1]

The cement industry use about 35.7% of energy of the industrial sector as whole, which made government of Thailand aim at reducing the use of energy in the sector by 37.5% by 2036 from the 2010 according to Assawamartbunlue [8]. The economic growth impression given by energy consumption and CO_2 continue to be dynamic to stimulate energy policy in all sectors Chakamera [9]. Energy consumption consist of two divided influencing factors. Namely external and internal factors, according to Atmaca [10] both external and internal are define as follows:

- External factors represent exterior conditions affecting the energy consumption such as climatological limitations.
- Internal factors refer to "inherent attributes, technical attributes, and management attributes of a building". Atmaca [10] summarized the parameters as:
    - *Inherent attributes are those features which maintain the normal function of the building (e.g. building area, air condition, operating time number of people).*
    - *Technical attributes present features which can be changed through technical means (e.g. equipment performance).*

2.3 Environmental impact caused by cement production.

There is significant collaboration that occurs among energy demand together with environmental contamination and both combination bring negative impact on the environment Adom [11]. Climate change is the major challenge facing world in our days which is caused by high level of CO_2 emission. The high non-renewable energy consumption has unswerving cause of increased carbon dioxide emissions Chen [12]. Chen [2] confirm that cement industry also contributes to climate change by producing most CO_2 emission during cement manufacturing process in the clinker production.

Cement production contribute approximately 5% of CO_2 emission across the world, 50% comes from calcinations processes and the other 50% comes from combustion processes Atmaca [1]. Furthermore, there is another element called sulphur dioxide which emit SO_2 into the air and this element causes the development of acid in the rain and smog [4].

Atmaca [1] clearly stated that cement industry is the utmost contaminant manufacturing discovered in the recent years.

3 METHODOLOGY

In this section, a research approach phase and techniques such as data gathering and data analysing to conduct the study are explained in detail. The data gathering was separately analysed for brief understanding of cement process data used and attainment of that energy consumption data. The statistical approach used to analyse the obtain data is also discussed thoroughly to give better understand on result analyses.

3.1 Data gathering

Data was obtained in the yearly financial statement of the cement industry of South Africa. The authors approached South African cement industry to obtain the necessary data (financial statement and energy consumption in cement industry) used for the study. Data for daily production was also used to analyse the energy consumption even further. Some of the daily production data used are production time, machine breakdown and tea-time. The data was taken from the previous financial statement of the cement industry during face-to-face interview with senior cement industry representative.

Senior cement industry employees and researchers selected the best information to be included in the study in order to obtain the energy consumption by the processes in the industry of cement. The cement representative assisted by emailing the required financial analyses utilising energy statement in the building to the researcher as part of study investigation and finance department also submitted their energy costs.

The other data was obtained in the past research papers that contain relevant information to the cement industry and energy consumption.

3.2 Analysis approach

The study focused on energy consumption and cost of energy in the cement industry. Prior analysing data graphically, an important stage of calculating the daily production in order to understand time cement industry use to conduct production. The formulae used to calculate daily productive time are presented as follows:

$$\mathrm{PT} = DT - TT_1 - TT_2 - Mb \quad (1)$$

Where,

PT – Productive time

TT - 1st Tea time

TT - 2nd Tea time

Mb – machine breakdown

Statistically model such as weighted average used to be the best way to present this study outcome for various reason such as easily understandable by readers. It is a useful tool which strongly allows the analyses of historical data. A further analysis led to creating the merging line by calculating the average cost of all monthly energy cost. The following formulae was used to calculate the merging line:

$$ML = \sum Mec/n \quad (2)$$

Where,

ML – merging line

Mec- monthly energy cost

n- number of months

The outcome of energy consumption in cement industry assisted in conducting the TOWS matrix which serves as controlling tool that can assist the cement industry to reduce the cost of energy in its processes, especially grinding, proportioning, blending and kiln processes.

Calculated cement energy figures were put into excel for better analysis techniques such as bar graph and pie chart. This kind of information is displayed in the result and discussion section. However, the data concerning other energy consumption (such as lighting) was little included because the study focus was on the processes of cement manufacturing.

4 RESULTS AND DISCUSSION

This section consists of results divided into two daily production data and cement energy performance. The cement industry normally works one shift which takes about 540 minutes each day. However, there are effective and ineffective time among the shift.

4.1 Overviewing daily data production

The energy consumption take place daily in the cement industry as it relies on it. Daily shift is as follows:

Total time available = 540 minutes

1^{st} Tea time = 15 minutes

2^{nd} Tea time (lunch) = 30 minutes

Total production time = 540 – 15 -30

= **495 minutes**

The above calculations assisted in obtaining each process operating time in the productive time for cement production. Figure 3 indicates the cement process together with time taken in each process step. The first process (Raw material extraction) which is very vital in the cement production takes 68 minutes. The highest leading process takes about 131 minutes and that is grinding, proportioning and blending. On the other hand, the lowest time-consuming process is the third process which is pre-heating that consume about 38 minutes in the daily production time. The fourth process of cement production is the second largest process (kilning phase) in the cement manufacturing by almost 118 minutes. The last process of cement production is packing and shipping all the produced product only take about 38 minutes of cement production processes.

4.2 Energy consumption overviewing

Figure 3 indicates the processing time on each cement stage. The process itself is multistage and takes different processing time as illustrated. Grinding, proportioning & blending, Kiln phase as well as cooling & final grinding processes consume almost 78% of the total processing time.

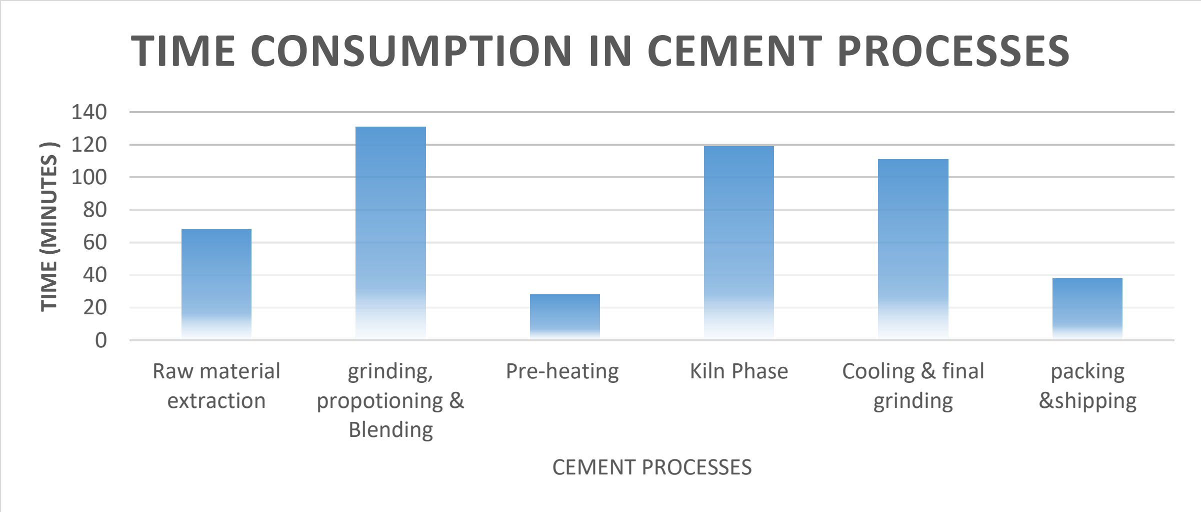

Figure 3: Time consumption in cement processes

The study focuses on energy consumption in the cement industry, that is why it is necessary to analyse energy consume in the cement production by using cement manufacturing times. Figure 4 simplifies the finding of energy consumption in the cement process for better understanding. The cement production processes flow as follows raw material extraction, grinding, proportioning and blending, pre-heating, kilning phase, cooling and final grinding as well as packing and shipping. The process consumes the following energy in each step 16%, 27%, 4%, 24%, 24%, and 5% respectively. The discovered trend between time and energy consumption is that, the more time the process takes there will be more energy consumed in that process.

The data presented in Figure 4 was developed from the energy consumption data received cement industry in order to see the process performance and understand the time-consuming process. The data presented illustrates average cement consumption in percentage. It was derived from the yearly energy consumption of all processes.

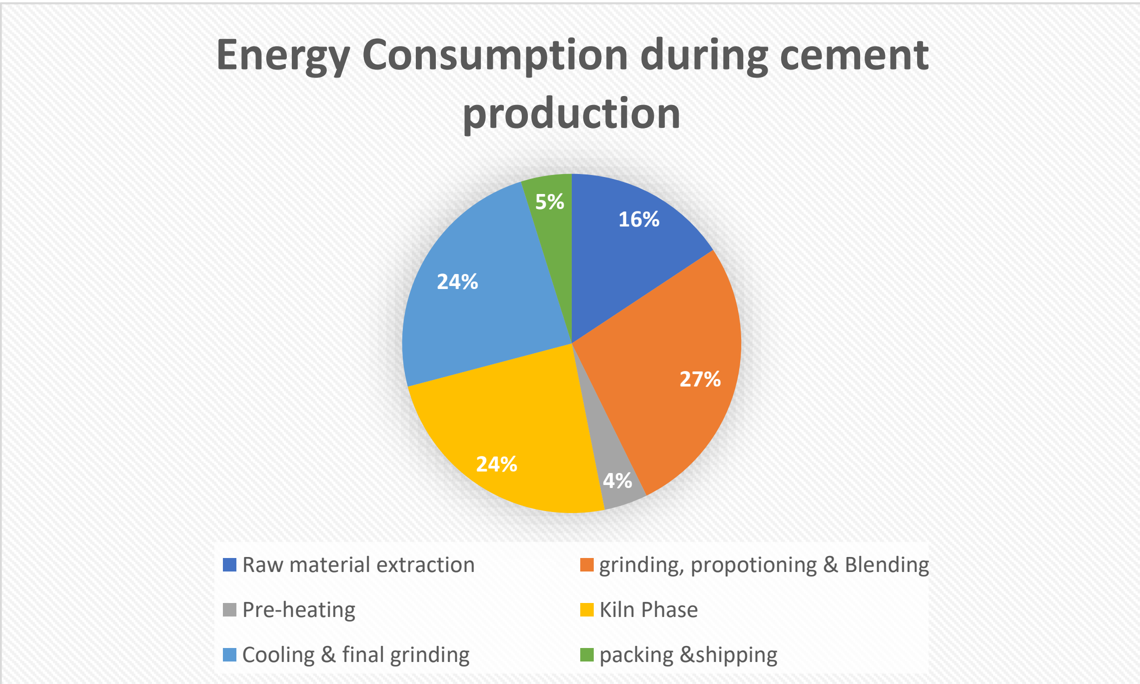

Figure 4: Summarised energy consumption throughout cement process

Figure 5 shows energy use in every month. The average cost of energy was conducted to merging line of the graph. The reason for conducting the merging line is that there is a high variation of energy consumption throughout the year from January to December. This line serves to guide the industry on energy use. Anything below the merging line indicates that energy use is expected as standard. While anything above the merging line indicates high use of energy in that month. Therefore, the cement industry needs to take measure to control that high use of energy. The merging line has an average cost of about (sum monthly cost/ number of months) R59728,17 presented in Figure 5 as a controlling measure.

Figure 5 shows energy consumption in January, February, September, October, November and December are below the merging line with a R54357, R52537, 54228, R59232, R56291and R31773 respectively. While, March, April, May, June, July and August consist of R60384, R61673, R65543, R67534, R76353, R768333 and R61673 respectively are found to be above the merging line. This indicate 50/50 situation between good and bad energy consumption in the cement processes.

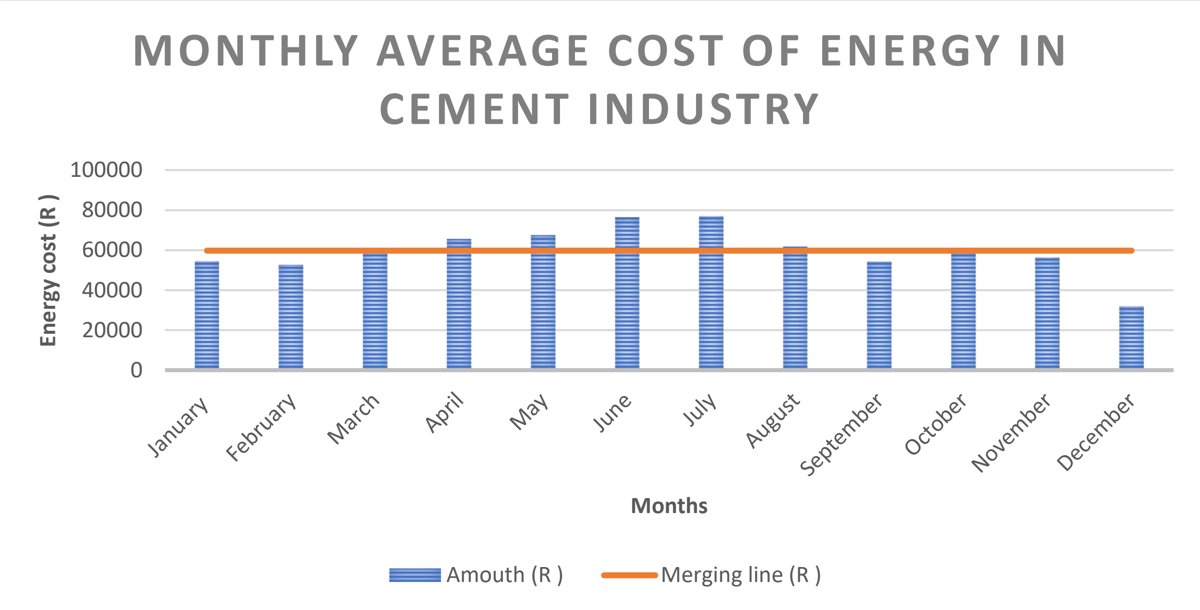

Figure 5: Monthly average cost of energy in cement industry

As energy consumption relies on time the process takes, then amount of cement produced each day was used to determine the average time for each process in order to meet the customer demand at less energy consumption. A daily target of cement industry to be produced each day is almost 406 bags of 50 kg. Each bag is produced by consuming almost 27 kilowatts. With this in mind, 406 bags of cement will be produced by consuming almost 10962 kilowatts.

4.3 Recommended technique

Dealing with high consumption of energy in the cement production processes, a threats, opportunity, weaknesses and strength (TOWS) matrix was developed with a purpose of decreasing energy consumption. This proposed strategy will assist in reducing the high energy consumption in the cement industry and bring sophisticated methods of producing cement.

Figure 6 shows us the processes or stages taken to deal with the outranging consumption cost of cement and direct the user to the solution if the cost is high above the margin line.

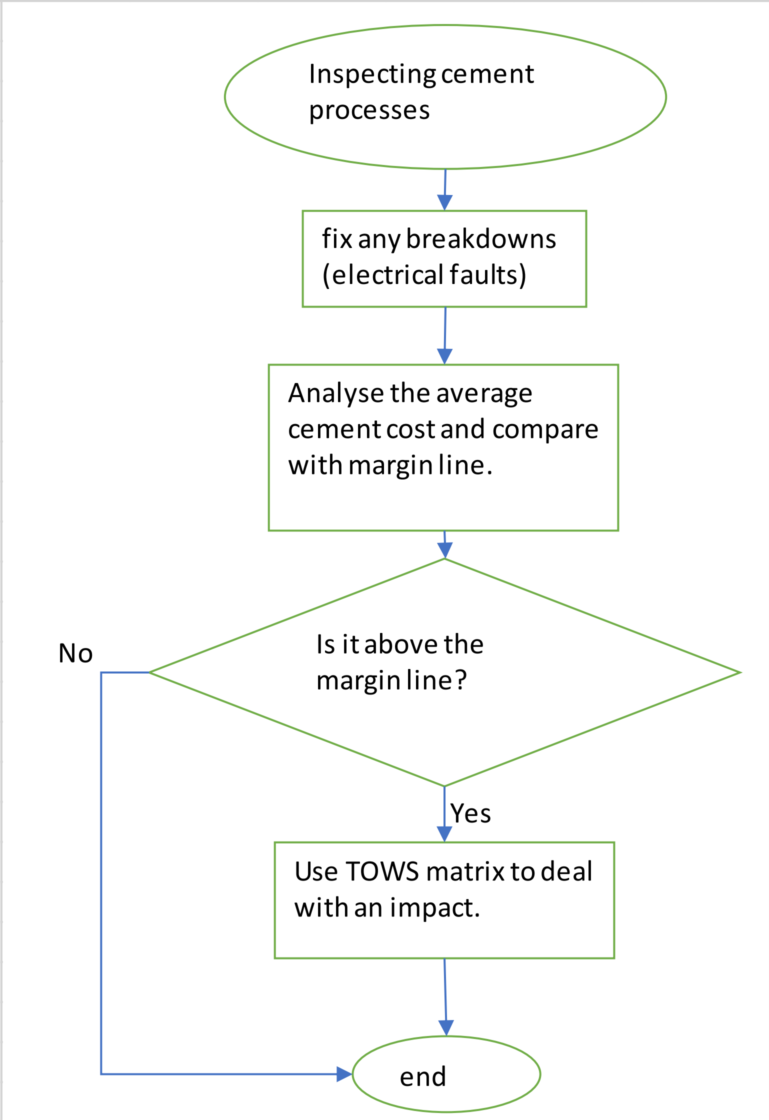

Figure 6: Dealing with the outranging consumption cost

Table 1 indicates the relationship the cement industry has towards TOWS matrix components. The first strategy is opportunity-strength (OS) strategy which overlooks at the relation between opportunity and strength strategy. In this strategy, a strength was applied to take advantage of future opportunities. The second strategy was opportunity-weakness (OW) to analyse available opportunities and addresses the cement industry weaknesses. The third strategy is threat-strength (TS) strategy. In this strategy an overview of future threat and deal with them using the strength such as less competition in the cement industry. While the last strategy is threat-weaknesses (TW) strategy, which deals with analysing available threats and improve their weaknesses to eliminate threat all together.

Table 1: TOWS matrix application on cement industry

	STRENGTHS	WEAKNESSES
	1. Less competition in cement production. 2. Less machine breakdowns and standardize processes 3. Strong financial muscle and hands on management 4.Good reputation of meeting customer demand	1.Minimum cement production time available 2. Produced cement cannot stay longer (6 months) in the warehouse. 3. Too much set-up time and cement rework to ensure quality
OPPORTUNITIES	**Opportunity-Strength (OS) Strategies**	**Opportunity-Weakness (OW) Strategies**
1. Cost savings on energy bills. 2.Easily increase daily cement productivity 3. Decrease energy cost in all cement production processes	1. Producing more cement at low cost by increase production time. 2. Decreasing energy consumption by eliminating reworks in cement production will give the opportunity of cost savings. 3. Developing policies that standardize cement processes.	1. Utilize the cost saving to deal with less cement production time by increasing production resources such as labor and maintenance team. 2. Using the forecasting to increase production and standardize supply chain processes.
THREATS	**Threat-Strength (TS) Strategies**	**Threat-Weakness (TW) Strategies**
1. Losing production time due to electricity breakdown/load shedding 2. Increasing of energy cost 3. Increasing cement production competition	1. Using the financial muscle to implement renewable energy in the cement production to avoid loss production time. 2. Producing more cement to take advantage of cement market.	1. Increasing cement production to take advantage of energy cost to minimize production set-uptime 2. Increase cement production quality to eliminate long stay of cement in the warehouse.

5 CONCLUSION

In the study of energy consumption in the cement industry, there is high energy consumption that has been discovered in the study using the cost of energy in cement industry. All processes are very important in the building of cement product. However, processes that consumed too much energy such as grinding, proportioning and blending, Kiln phase and cooling and final grinding are three processes that consume too much energy in cement making process.

A monthly analyses of energy consumption in the cement industry has been conducted and merging line was presented in the Figure 5. This merging line assisted the study to generate the controlling tool for cement industry for improvement purposes in the cement industry when it comes to energy consumption. This merging line consist of R59728.17 which presents energy that can be consumed as maximum.

The TOWS implementation will assist the industry to generate more savings and reduce electricity consumption by ensuring that all processes are monitored and are in line with the TOWS method. Processes such as Kiln phase and cooling are the one that need more attention according to the study result. These proses are the one that take more time compare to others. However, quality cement must be the major focus in production process for many reasons such as this product build structures that are used as shelter for human life. If quality cement is produced, less unnecessary accidents will be seen.

Savings can be easily achieved but, the proper cement quality study still need to be carried out in future studies, to ensure safety precaution are considered when dealing with reducing energy consumption in cement industry.

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UTILISING WORK MEASUREMENT TO MONITOR HOURLY OUTPUTS: EVIDENCE FROM A MANUFACTURING CONTEXT

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ABSTRACT

A work measurement investigation and the subsequent compilation of standard times will assist an organisation to monitor hourly outputs in manufacturing. Improvements in productivity based on work measurement investigations can be achieved by means of a simple, consistent monitoring system. Despite the ever-increasing importance of monitoring outputs and improving productivity, few large-scale empirical studies concern models, characteristics and indicators of monitoring systems. The primary objective of this paper is to use work measurement to set standard times for the assembly operations at Company A and display how efficiencies can be monitored on an hourly basis. The aim being to ensure that organisational performance is measured, and operations and employees are managed. The research design consisted of a mixed-methods approach. Many organisations lack a competently developed monitoring system to measure their outputs. The contribution of this paper is an output monitoring system designed and based on the universally accepted work measurement technique. The empirical results of the research instrument are indicative of the essential need for the system. The implementation of this system will ensure that organisational performance is measured, and productivity enhanced.

Keywords: Work measurement, time study, basic time, contingency allowance, rating, standard time

1 INTRODUCTION

Riddle [1] states that increasing employee productivity should be on the forefront of any managerial mind. In simple terms, a manufacturing organisation must develop a statistical and measurable way to measure each employee's actual production and then balance those numbers against the cost of each employee. Organisations have moved away from continuously supervising employees to ensure that set production targets are achieved. Work study and industrial engineering techniques allow management of organisations to compile realistic and achievable standard times for production processes. Herein lies the value of work measurement. As the name states, this universally accepted technique allows for the measurement of work to determine durations of processes and the subsequent compilation of standard times for all operational tasks.

Lavinsky [2] states that management guru Peter Drucker is credited with one of the most important quotes in management, namely: "If you cannot measure it, you cannot improve it." Simply, this states that only if one measures a task, will he/she be able to improve it. When you think about this quote, it should immediately become apparent how true it is, because, if you cannot measure something, and know the results, you cannot possibly get better at it. For example, it's impossible to set a customer delivery date, if one does not know how long it takes to produce a product. One can go so far as to add that "If you cannot measure, you cannot manage" [3]. Management need to know if production targets are being met and efficiencies attained, as this has consequences on customer delivery due dates and the subsequent profitability and sustainability of an organisation. The quest for lower operating costs and improved manufacturing efficiency has forced many manufacturing firms to embark on industrial engineering approaches to analyse and optimise their production [4].

This above information forms the basis of this paper as its main purpose is to show how a work measurement investigation can be used to design an hourly monitoring system for manufacturing organisations. During visits to various manufacturing organisations, evidence indicated a lack of properly designed monitoring systems for operational processes. Standards were not compiled by experienced work study and industrial engineering personnel. Most organisations used estimates to determine standard times. A work measurement investigation was undertaken to attain the objectives of this paper. Work measurement is the second technique of the concept "work study" [5] and is primarily concerned with the determination of the duration of tasks being performed [6]. Work study is the systematic examination of any type of work being conducted to effect improvements.

Joy [7] states that managing people within organisations involves relationships between jobs, systems and communication. To monitor outputs, performance must be compared against some kind of target. Work measurement would be used to develop these targets to assist management with monitoring outputs. The work measurement investigation was conducted in the assembly department of an organisation (Company A) which manufactures taps. An analysis of the present situation revealed that the assembly department did not have properly set standard times for their operational processes, some of which were highly labour intensive. A standard time is the amount of time it should take a qualified worker to complete a specified task, working at a sustainable rate [8]. There was no established method of measuring employee outputs, that is, no recording system.

The essential contribution of this paper is to use work measurement to set standard times for the assembly operations at Company A and develop a monitoring system to monitor efficiencies an hourly basis. Monitoring efficiencies on an hourly basis allows management to identify and immediately take corrective action should problem situations (bottlenecks) arise. This paper will report on the work measurement investigation that was conducted and the research methodology employed. This is followed by a discussion of the findings, the limitations and validity of the research. The paper closes with the conclusions and recommendations for further research.

2 PROBLEM INVESTIGATED AND THE RESEARCH OBJECTIVES

2.1. Problem investigated

When standard times are unrealistic, production schedules fail. Setting standard times for operational processes is a necessity for today's industrial engineer. Some operations require high-cost, high-tech, traditional work measurement, but one can often employ low-cost, low-tech, common-sense methods. The South African manufacturing landscape is littered with carcasses of organisations that have floundered without the ability to monitor their operational processes and outputs. Preliminary observations in the assembly department of Company A revealed that they did not have properly set standard times for the assembly operations. Company A used the costing of the product as a gauge to determine its efficiency, for example, if they produced one million rands of output per shift, they called this 100% productivity. They did not measure their daily outputs based on set standard times and did not have a monitoring system in place and hence could not manage their production outputs. Performance monitoring is critical to productivity improvement and the ultimate profitability and sustainability of an organisation.

2.2. Objective of the research

The primary objective of this paper is to use work measurement to set standard times for the assembly operations at Company A and display how efficiencies can be monitored on an hourly basis.

3 LITERATURE REVIEW

The theoretical framework for this paper consists of the definition, objectives, the nature, the scope and the procedure of work measurement. It also contains a review of "time study", which is a direct recording and most popular technique of work measurement. The review concludes with a look at the components of time study and a discussion of how these were used to obtain the standard times for this study.

3.1. The definition and objectives of work measurement

Work study consists of two techniques, namely, method study and work measurement, which are used in the examination of human work in all its contexts and which lead systematically to the investigation of all the factors which affect the efficiency and economy of the situations being reviewed to effect improvements [9]. Kanawaty [6] defines work study as "the systematic examination of the methods of carrying out activities to improve the effective use of resources and to set up standards of performance for the activities being carried out."

Work measurement is the second of the two principal techniques of work study. Kanawaty [6] defines work measurement as "the application of techniques designed to establish the time for a suitably qualified worker to carry out a task at a defined rate of working." Yusoffa, Jaffarb, Abbasc and Saadd [10] state that work measurement is mostly concerned with the investigation and reduction of any ineffective time associated with a job or operation. The Institute of Management Services (IMS) [11] states that work measurement is the process of establishing the time that a given task would take when performed by a qualified worker, working at a defined level of performance.

The primary objective of work measurement is to set time standards for a specific task [12]. Work measurement is concerned with investigating, reducing and subsequently eliminating inefficient time, that is, the time during which no effective work is being performed. The bjectives of work measurement are twofold, namely to determine the amount of work, mainly in terms of volume and quality; and how long it will take to complete the work.

3.2. The nature and scope of work measurement

Dagdevirena, Eraslanb and Celebic [13] state that it is not possible to be consistent and efficient, primarily in preparing manufacturing plans and programmes, short and long term forecasts, cost control, pricing and the other technical and managerial activities in an organisation with a time estimation that is not based on a standard time. Work measurement determines the duration of a task as well as helps to identify ineffective time with the aim of eventually eliminating it. Freivalds and Niebel [14] state that the nature of work measurement is based on establishing a time standard for carrying out a given task, taking the various allowances into consideration.

Work measurement is one of the most effective tools available to management and, when used in conjunction with method study, forms an excellent weapon when starting an attack on inefficiency in any organisation [9]. Similar to method study, work measurement can be applied anywhere where work is performed.

3.3. The work measurement procedure

Table 1 shows that work measurement has a basic procedure that must be followed when carrying out a work measurement investigation. To achieve success in a work measurement investigation, this procedure must be followed. The following steps represent the procedure of work measurement:

Table 1: Work measurement procedure [6]

STEP NUMBER	PROCEDURE	DESCRIPTION
1.	**SELECT**	The work to be studied.
2.	**RECORD**	All the relevant data relating to the circumstances in which the work is being done, the methods and the elements of activity
3.	**EXAMINE**	The recorded data and the detailed breakdown critically to ensure that the most effective method and motions are being used and that unproductive and foreign elements are separated from productive elements.
4.	**MEASURE**	The quantity of work involved in each element in terms of time, using the appropriate work measurement technique.
5.	**COMPILE**	The standard time for the operation, which, in the case of a stopwatch time study, will include allowances.
6.	**DEFINE**	The series of activities and method of operation for which the time has been compiled precisely and issue the time as standard for the activities and methods specified.

3.4. Time study

Time study is a direct recording technique of work measurement. This means that the investigator must be present at the place where the specific operation is being carried out in order to determine the duration of tasks. For the purposes of this paper, time study was used to set standard times and to set targets to monitor outputs. It allows the investigator to determine the time to be allowed for a suitably qualified worker, working at normal pace, to complete a specified task by using a specified method. Chisosa and Chipambwa [15] states that time study seeks to measure how long the average worker takes to complete a given task at normal pace. This "pace" is discussed under the heading "rating" below. Kanawaty [6] defines time study as "a direct work measurement technique for recording the times of performing a specific job or its elements carried out under specified conditions, and for analysing the data so as to obtain the time necessary for an operator to carry it out at defined rate of performance". Jacobs and Chase [16] state that time study uses a stopwatch to time the work, however, with the advent of technology, various new software tools are available to time operations. Time study is the most widely recognised work measurement method and the stopwatch study is still the most widely used time study method, [15].

3.5. The components of time study

In order to conduct a successful work measurement investigation, it is imperative that the steps of the work measurement procedure are sequentially followed. Table 2 displays the main components of a time study.

Table 2: Time study components

Name	Description
Observed time	In order to determine the standard time for a task, the task has to be broken down into elements. Kanawaty (1995) defines an element as "a distinct part of a specified job selected for convenience of observation, measurement and analysis". Thereafter, each element of the task is timed and a duration is determined. This is called the observed time.
Rating	Rating (also known as performance rating) is the assessment of the worker's rate of work, relative to the observer's concept of the rate corresponding to the standard rate [6]. Performance rating must be included during time study to normalise the job [11].
Basic time	Sarkar [17] states that basic time of a job is determined by multiplying the observed time by the rating factor. It is the time for carrying out an element of work at standard rating (100%). The example below shows the formula to calculate the basic time: ***Example:*** Element 1: Observed time is 1.45 and Rating is 80. $\frac{\text{Observed time x Rating}}{\text{Standard rating (100)}}$ $= \frac{1.45 \times 80}{100}$ = **1.16 centi-minutes.**
Frequency	The frequency refers to 'how often' each element occurs in a work cycle. Kanawaty [6] states that repetitive elements, by definition, occur at least once in every cycle of the operation; so, the entry to be made against a repetitive element will read 1/1 or 2/1, indicating that the element, for instance, occurs once in every cycle (1/1) or twice in every cycle (2/1).
Selected basic time	The selected basic time is obtained by taking the frequency into account. ***Example:*** Element 1: Basic time is 1.16 and the frequency is 1/1. Hence, the selected basic time is calculated as follows: 1.16 x 1 divided by 1 = **1.16 centi-minutes** If the frequency was 2/1, then the selected basic time would be: 1.16 x 2 divided by 1 = **2.32 centi-minutes**
Relaxation allowance	Relaxation allowance is an addition to the selected basic time to provide the worker with the opportunity to recover from the physiological and psychological effects of carrying out specified work under specified conditions and to allow attention to personal needs. The amount of allowance depends on the nature of the job. The relaxation allowance allocated to element 1 is 15%. Hence, the actual time for element 1 is calculated as follows: 1.16 + 15% = **1.33 centi-minutes**
Actual time	This is the time that is calculated after in inclusion of relaxation allowances as shown above. 1.16 + 15% = **1.33 centi-minutes**

Name	Description
Contingency allowance	Nikhila [18] states that this is an allowance of time to meet legitimate, irregular and infrequent items of work or delays which cannot economically be measured correctly. It is usually taken as less than 5%.
Standard time	The standard time is the total time, in which a job should be completed at standard performance. Figure 1 depicts the make-up of a standard time for a task. In Table 3, the contingency allowance is given as 4%. Hence, the standard time is calculated as follows: 0.899 + 4% = **0.935 centi-minutes.**

Further to the explanation of the time study components above, figure 1 provides a graphical representation of the "make up" of the standard time. It shows the calculation of the basic time and the subsequent addition of the necessary rest allowance and the contingency allowance which would be allocated to a given task. This should be seen in line with the calculations shown in table 3.

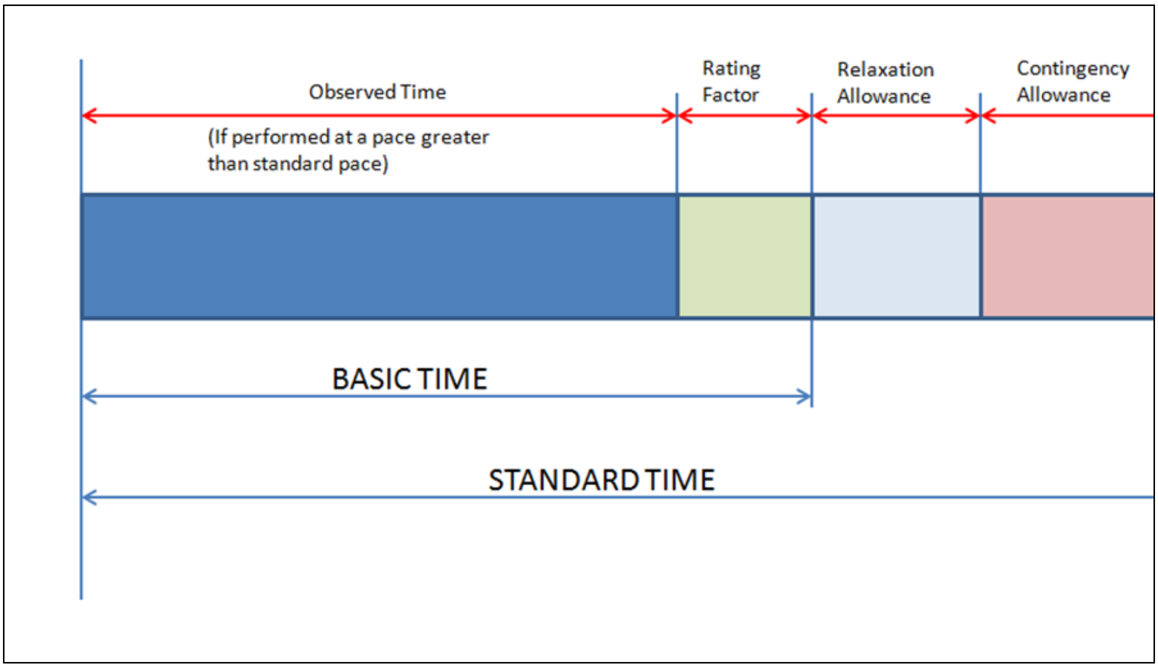


Figure 1: Make-up of standard time [16]

4 RESEARCH METHODOLOGY

4.1. The research design and instrument

The research design consisted of a mixed-methods approach which was used to gather data, which enabled the researcher to come to conclusions and to make recommendations regarding the development of the monitoring system. The data collection technique consisted of the work measurement investigation and a web-based questionnaire survey. The questionnaire was designed using the Lime Survey programme. A self-administered approach was followed, utilising a computer-aided web-based questionnaire. A dedicated uniform reference locator (URL) had been established on the website of the Bureau of Market Research (BMR) at the University of South Africa (Unisa). An e-mail message explaining the procedure to follow in order to complete the questionnaire was sent to respondents. The e-mail message included a hyperlink to the URL where the questionnaire had been hosted. The respondents were invited, by email, to visit the URL and complete the questionnaire. The online approach is appropriate, as surveys enable researchers to generalise their findings [19].

This questionnaire survey was found to be the most appropriate survey method as the respondents could easily be accessed [20]. The questionnaire consisted of fifteen questions and was sent out with a covering letter inviting the selected recipients to participate in the survey. It consisted of closed and open-ended questions. The purpose of the questionnaire was to gather critical responses as to the development and existence of monitoring systems in organisations.

4.2 The population and sampling in the study

The population of the study reported in this paper was composed of selected employees (n = 800) of organisations in South Africa. Their positions ranged from operators and supervisory staff to management. Purposive sampling was utilised to select the participants. Purposive sampling simply looks for people who can help build the substantive theory further [20]. Two hundred and thirty (230) respondents submitted their questionnaires online to the database and all were considered suitable for inclusion. The response rate was 28.75% and found to be acceptable for the purposes of this study.

4.3 Data collection and analysis

The work measurement investigation, which consisted of time studies, was used to collect data. The data were analysed using the set procedures of this technique. Relaxation and contingency allowances were allocated and the standard times for a specific product (Tap A) were developed. These standard times were used to develop the hourly monitoring system. Data were also collected by means of a structured questionnaire administered via a web-based survey which was sent to the participants. The questionnaire was utilised to elicit responses as to the development and existence of monitoring systems in their organisations. The questionnaire was pilot tested at two manufacturing organisations. A statistician from assisted the researcher with the amendments, the setting up of the database, and the analysis of the questionnaire.

Responses were automatically entered and saved on the online database. The questionnaire data were imported into the Statistical Package for Social Sciences (SPSS) in order to perform the statistical analysis. Basic frequencies for each question were performed. Descriptive analyses of all questions were performed to look at the distribution of the respondents. The researcher then selected certain questions that were relevant to the outcome of this study and requested cross-tabulations and Chi-Square tests to be performed. The aim was to see if there were associations between the selected questions.

5 FINDINGS AND RESULTS

5.1 Work measurement investigation:

During the work measurement investigation, the researcher conducted time studies using a stopwatch to determine the duration of each step of the assembly process of Tap A. The assembly of Tap A consisted of seven steps. In order to ensure accuracy, the researcher conducted time study on the same tap, but on different assembly lines. The aim here was firstly, to ensure that sufficient number of observations were recorded for accuracy. Secondly, to determine the standard pace of different operators and thirdly because Company A received the most orders as it is the most commonly used tap in households. This gives credence to the old adage “the greater the number of observations, the higher the level of accuracy". A total of 300 observations were recorded to improve accuracy of results. The researcher rated each operator conducting each element, based on his experience of rating. This was necessary to compile a realistic, reliable and achievable standard time.

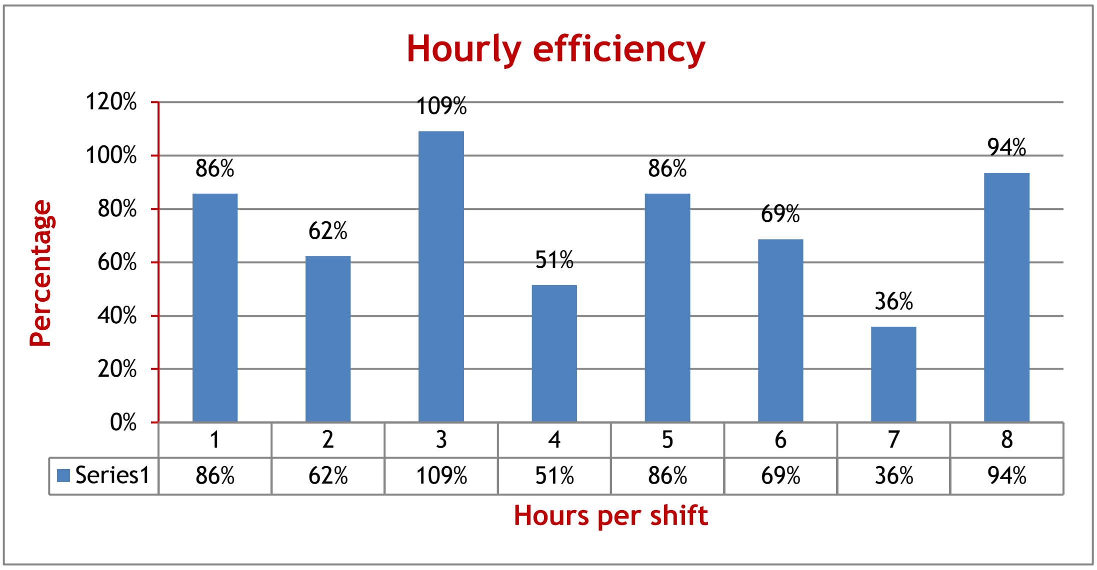
Thereafter, these time studies were analysed and a standard time for the assembly of Tap A was determined. The basic time, the selected basic time and the actual times for each element were determined. These were used to calculate the standard time for the assembly of Tap A as shown in Table 3. Table 4 shows the hourly performance of the assembly department.

Table 3: Standard time calculation Tap A

STANDARD TIME CALCULATION *(All times recorded in centi-minutes)*						
Step No.	**Element Description**	**Basic Time**	**Frequency**	**SBT**	**RA %**	**Actual Time**
1	Fit head part	0.153	1/1	0.153	12	**0.171**
2	Water pressure test	0.154	1/1	0.154	12	**0.172**
3	Fit back nut to tap	0.103	1/1	0.103	12	**0.115**
4	Fit cover and handle	0.096	1/1	0.096	12	**0.107**
5	Fit indice (cold)	0.129	1/1	0.129	12	**0.144**
6	Clean and polish	0.101	1/1	0.101	12	**0.113**
7	Packaging	0.069	1/1	0.069	12	**0.077**
					Total Actual time:	**0.899**
					Contingency allowance: 4%	0.036
					Standard time: *(centi-minutes)*	**0.935**

Table 4: Hourly performance

TapA **Date:** 12/06/2019	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Captured by: B. Sookdeo	08:00 to 09:00	09:00 to 10:00	10:00 to 11:00	11:00 to 12:00	12:00 to 13:00	13:00 to 14:00	14:00 to 15:00	15:00 to 16:00
Actual output per hour	**55**	**40**	**70**	**33**	**55**	**44**	**23**	**60**
Actual time per item	1.091	1.500	0.857	1.818	1.091	1.364	2.609	1.000
Cumulative output	1.091	2.591	3.448	5.266	6.357	7.721	10.329	11.329
Standard time per unit	0.935	0.935	0.935	0.935	0.935	0.935	0.935	0.935
Standard Cumulative	0.935	1.87	2.805	3.74	4.675	5.61	6.545	7.48
% Efficiency per hour	**86%**	**62%**	**109%**	**51%**	**86%**	**69%**	**36%**	**94%**
							Average efficiency per day:	**76.50%**



The system allows a clerk to input only the number of units (taps) produced for each hour worked. All other information is protected in the spread sheet. Upon this input, the system generates the percentage efficiency for that particular hour, as the standard time for this tap is linked to the hour under review. The cumulative output refers to the total time that the operator took to assemble x1 tap, that is, 60 minutes / 55 units = 1.091 centi-minutes. The standard time to produce x1 unit is 0.935 centi-minutes.

Therefore:

Standard time: 60 minutes / 64.17 units = 0.935 centi-minutes.

Then: 64.17 / 64.17 x 100 = **100%** efficiency

The output for "hour 1" (08:00 to 09:00) was 55, therefore that calculated efficiency is:

60 minutes / 55 units = 1.091 centi-minutes.

55 / 64.17 x 100 = **86%** efficiency

Figure 2 shows a graph which the system automatically generates to show the performance on an hourly basis. This can be done on an hourly or daily basis. The advantage of generating a graph on an hourly basis is that management will be able to identify inconsistences at an early stage and take subsequent corrective action.

5.2 Compiling time standards:

Time standards are necessary for costing purposes and for setting of output targets. After compiling the time standards, the work study officer must get "buy in" from the important role players. The standards must be accepted by all prior to implementation in a department. The standards need to be realistic and achievable and therefore need to be compiled by qualified personnel. Less than a quarter of the respondents indicated that their production targets were set by work measurement. Inaccurate time standards can be detrimental to employee morale which subsequently affects production outputs.

5.3 The monitoring system:

Almost 80% of respondents indicated that their organisations had a monitoring system in place. The quality of the system comes into question, as this contradicts the only 23.5% of respondents who indicated that their production targets were set using work measurement. Also, only 28.3% of respondents indicated that they monitored their production via a monitoring system.

Regarding the accuracy of the time standards, respondents were required to indicate whether the time standards were developed by a work study department, an industrial engineering department or whether the standards were developed by consultants. In response to this question, figure 3 depicts that 26.5% indicated that time standards were developed by their work study department,12.2% by industrial engineering and 23% by consultants.

The above responses provided justification for the necessity of monitoring systems in organisations. Respondents were also requested to indicate for what purposes the calculated efficiencies were utilised. Options differed from being “Discussed at production meetings” to “Staff are notified of the results”. The respondents indicated that the efficiency results were discussed at production meetings and it was also used to undertake corrective action. A total of 46.7% indicated that the results were used to show the performance of the department.

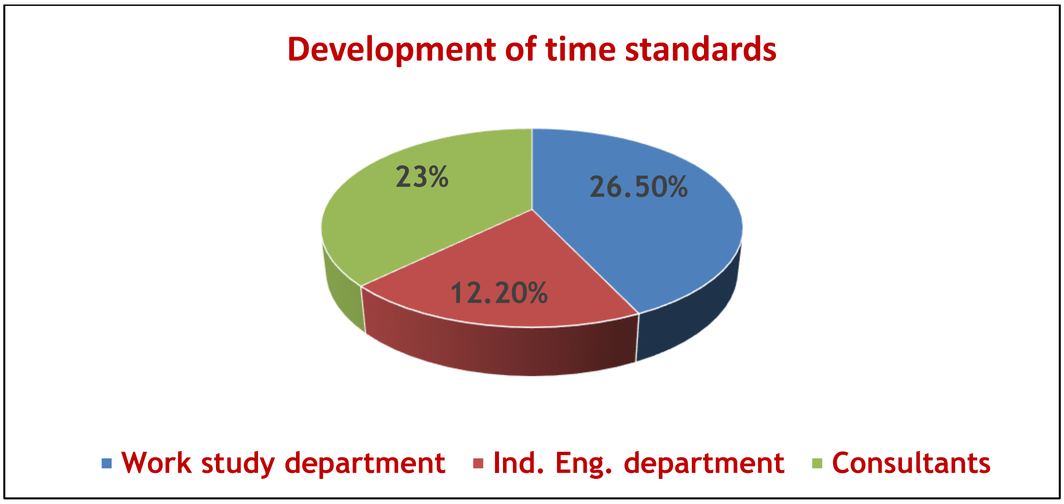


Figure 3: Development of standard times

Table 5: Statistics per question

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Work study department	61	26.5%	43.0%	43.0%
	Ind. Eng. department	28	12.2%	19.7%	62.7%
	Consultants	53	23.0%	37.3%	
	Total	**142**	**61.7%**	**100%**	**100%**
Missing	System	88	38.3%		
	Total:	**230**	**100%**		

6 LIMITATIONS OF THE RESEARCH

As with all research, this study was not without limitations [22]. The typical limitations of qualitative research apply [24]. A limitation of this paper is that this study was conducted at one manufacturing organisation and used only one product (Tap A) for the generation of the monitoring system.

Validity refers to the credibility or believability of the research. Credibility, (i.e. do the findings reflect the reality of the participants?) was enhanced by the use of a self-administered approach, utilising a computer-aided web-based questionnaire. A dedicated uniform reference locator had been established on the website of the Bureau of Market Research (BMR) at the University of South Africa (Unisa).

7 CONCLUSIONS

Singh and Garg [24] in [14] affirm that without work measurement, there can be no effective management, since work measurement determines standard times for operations, confirming its reliability as an effective measuring tool. It is imperative that management ensures that realistic and achievable standard times are set for all their manufacturing processes. This will allow them to determine hourly outputs and will assist with decision-making, costing and scheduling customer delivery dates.

It is common knowledge that the cost of every employee who interacts with the manufacturing of a product must be allocated to the cost of that specific product. Work measurement allows management to pinpoint areas of inefficiency and to easily identify ineffective elements in a process. The absence of monitoring systems results in management/supervisors failing to observe inefficiencies in operating processes and inefficient employees. Donovan [26] states that it is easy to fall into the common trap of having people busy with all kinds of activities but achieving few measurable results.

The benefits of implementing monitoring systems include: motivation to perform is increased, self-esteem is increased, managers gain insight about subordinates, the definitions of the job and criteria are clarified, organisational goals are made clear, employees become more competent, employee misconduct is minimised, there is better and more timely differentiation between good and poor performers, supervisors' views of performance are communicated more clearly, commitment, and intentions to stay in the organisation are enhanced and employee engagement is enhanced [27].

Industry liaisons by the researcher indicated a lack of properly-set standard times and monitoring systems in organisations. This was cause for concern as it affects decision-making at senior management level. The results of the questionnaire supported this as only 23.5% of the respondents indicated that their production targets were set via work measurement. This confirmed the necessity of monitoring systems to be developed. This paper explains the methodology to be used in the implementation of work measurement in order to compile standard times to develop monitoring systems. The paper succeeds in attaining the primary objective which was to use work measurement to set standard times for the assembly operations at Company A and display how efficiencies can be monitored on an hourly basis. The findings of this study will alert organisations to the value of monitoring systems to measure their outputs. It can be used as an important management aid in costing, control and in decision making.

It is recommended that organisations utilise this monitoring system to measure their daily outputs and to control processes and employees. Work measurement is not restricted to the manufacturing sector and as future research; the researcher intends to conduct a comparative study in the service sector.

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THE SELECTION OF RISK ANALYSIS METHODS IN LARGE SCALE PROJECT ORGANISATIONS IN SOUTH AFRICA

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ABSTRACT

The main steps of the risk management process are identification, analysis, evaluation, and resolution. Much attention is usually given to the identification of risk events, but the analysis step is often rushed. Three risk analysis methods are generally used, i.e. qualitative, semi-quantitative and full quantitative analysis.

The main objective of this research study was to investigate how project organisations select and utilise a risk analysis method and what measurement scales are applied. Data was collected by means of an online survey and through individual interviews with project managers.

The study indicated that a risk analysis method is often based on "ease of use". The decision is made at senior managerial level and the project teams must use the chosen method. There is fair distribution between the use of qualitative and quantitative risk analysis methods. The qualitative analysis method is mostly preferred, but the benefits of quantitative analysis methods were acknowledged.

Keywords: risk analysis, risk management, project performance

1. INTRODUCTION

1.1 Background

Over the past few decades South Africa, which is a developing country, has seen large infrastructure projects being executed. Prior to undertaking these large infrastructure projects, tasks teams are established to conduct a thorough risk assessment and analysis to determine the feasibility of performing the project. This was observed in the construction of the two Eskom power stations Medupi and Kusile, Sanral road network expansion and improvement, construction of 2010 soccer world cup stadia and construction of malls like the Mall of Africa in Midrand and Fourways Mall to mention a few. The biggest challenge that organisations experience is whether risk assessments are always performed in all projects.

Steyn et al. [1] says “a project is any unique endeavour undertaken to create a defined deliverable to meet requirements within a limited time scale and with limited monetary resources”. The success or failure of a project, as measured by these three criteria, is uncertain at the start of the venture [1]. All projects are risky, i.e. the outcomes are not the same as planned and risk management is therefore an essential component of project management (Nicholas and Steyn [2]). It is therefore included as one of the nine processes mentioned in the Guide to the Project Management Body of Knowledge (Project Management Institute (PMI) [3]). Many projects have high uncertainty due to compacted schedules, insufficient budgets, inaccurate scope, and poorly defined specifications that sometimes are not feasible to attain (Smith and Merritt [4]).

The International Standards Organisation (ISO) [5] defines risk as “the effect of uncertainty on objectives”. Our daily lives revolve around planning and managing risks, mainly because we want to achieve our daily and long-term objectives. Similarly, any project manager knows that managing risks is an essential and critical part of achieving project objectives (Steyn et al. [1]). The project risk management process comprises a number of steps or phases, e.g. risk identification, risk analysis, risk evaluation and risk treatment [4], [5]. This paper discusses the analysis step of the risk management process as applied in project management.

Risk management and analysis should not only be done during the execution of a project but should be also be considered as an integral part of deciding whether to do the project or not (Esteves et al. [6]). Risks related to politics, labour laws, financial viability, market niche and customer relations should be considered when organisations decide to initiate a project or not. Organisations in the financial sector consider risk as a major aspect in deciding whether to introduce a new product or not [2].

Various studies have been done on risk management, risk analysis and risk management tools, however the literature does not provide adequate guidance on how to select a risk analysis method amongst various options. Smith and Merritt [4] recommend the quantitative analysis method. Current literature also does not link the risk analysis method to the success of projects (Hillson and Simon [7]). As mentioned above, there are different methods/tools available to analyse project risks. Based on the evidence of project failure, organisations find it difficult to select an appropriate tools or methods for effective project risk management.

This study unpacked the methodology that organisations use to select risk analysis methods and how these methods contribute to the successful execution and completion of projects. The main objective of the study was to determine how project risks are analysed in large-scale project organisations in South Africa, how effective these methods are to contribute towards the successful completion of a project.

Based on the outcome of the research, recommendations were made on risk analysis method selection criteria and how organisations could apply these methodologies to ensure successful completion of a project.

2 LITERATURE REVIEW

2.1 Risk Analysis

Ward [8] suggests that the success of projects depends on the effectiveness of risk analysis methodology and tools used. He further echoes that organisations may decide to make risk assessment and analysis a paperwork exercise or to enforce risk assessment that it becomes an integral part and culture of project prioritisation, selection and management.

Three risk analysis types are used in risk management in industry, i.e. qualitative, semi-quantitative and full quantitative risk analysis (Radu [9]). The selection is determined by the time and resources available or the method used in the company for risk analysis in other departments, e.g. safety and environmental risk management.

2.2 Qualitative Risk Analysis

Risk analysis is a process of analysing and prioritizing risk based on the probability of risk occurring and the impact it would have on the project should the event occur. The qualitative risk analysis method uses descriptive scales to determine the probability and the impact or consequence of occurrence. Graves [10] suggests that qualitative risk analysis be used to identify areas in the project with greater risk exposure that could harm project completion date, budget, and scope. In project management, risk analysis informs the project manager on which risks money should be spent or which risks should be mitigated. This assists the project manager in determining the risks that require special attention and those that can be deferred the near future.

Qualitative risk analysis uses descriptive words like High, Medium, Low to define the consequences and probability of a risk event. The probability and consequence values are then combined by means of a risk matrix to determine a risk value for the event (Thomas et al. [11], Valis and Koucky [12]). Graves [10] suggests it is quicker and more affordable to use qualitative risk analysis and no specialised software is required. Korombel and Tworek [13] argued that qualitative risk analysis is mainly used for risk identification and prioritisation to enable the risk evaluation process. It is not considered for making conclusion/decisions on project risk. Qualitative risk analysis has some limitations as outlined by Elmontsri [14].

Cooper [15] suggests qualitative risk analysis uses ordinal ranking scales to describe consequence and probability of failure. It uses descriptive words for probability and consequence typically using 3-, 5-; 7- or 10-point scales.

2.3 Semi quantitative Risk Analysis

Valis and Koucky [12] define the semi-quantitative risk analysis as a technique that uses numerical rating scales for consequence and probability and then combine them mathematically to provide a risk value or level of risk. The general equation that is used to determine the risk value is:

$$Risk\ Value = Probability \times Consequence \quad (1)$$

Del Bianco et al. [16] suggest that a semi-quantitative analysis can lead to more accurate comparison of risks for easier prioritisation and better mitigation efforts. The use of semi-quantitative risk analysis increases project team efficiency in prioritisation of risks and to focus on the most critical/high priority risks.

Aven [17] says the semi-quantitative analysis forms a transition between quantitative and qualitative analysis. However, the semi-quantitative analysis output is also subjective like the qualitative analysis. He suggests the semi-quantitative analysis, compared with the quantitative analysis, is characterised by speed, simplicity of design, lower requirements on the input data and smaller demands on the resources.

Radu [9] suggests that the semi-quantitative analysis uses different scales to characterise the likelihood of adverse events and their consequences, e.g. 3-point, 5-point or 7-point scales. Aven [17] states that semi-quantitative assessment is advantageous when the quantification of risk is difficult to attain and qualitative interpretation is too subjective. The combination of qualitative and quantitative analysis can be advantageous and has more advantages than a single methodology.

Hallikas et al. [18] suggest the benefits of using the semi-quantitative approach when compared to using qualitative or quantitative analysis are:

- It provides a more consistent and rigorous approach to assessing and comparing risks than the qualitative approach
- It eliminates certain ambiguities and inconsistencies which can result from using the qualitative approach
- It requires at least the same substantial input data as qualitative analysis

The selection of semi-quantitative risk analysis balances the shortfalls posed by both the qualitative and quantitative risk analysis methods (Aven [17]). Most authors find the semi quantitative risk analysis as the option mostly chosen by small and medium organisations. The balance that semi quantitative provides to the organisation provides the assurance that the project risks are properly addressed.

2.4 Quantitative Risk Analysis

Quantitative risk analysis numerically analyses the impact of identified individual risks and sources of uncertainty on the project objectives. It quantifies project risk exposure, and it provides quantitative risk information to be used during risk response planning (Purnus and Bodea [19]). It is a more intensive analysis of high priority risks where an actual numerical probability rating is assigned to risk events and cost or duration values are assigned to consequence. (Bansal [20], Smith and Merritt [4]).

Valis and Koucky [12] define quantitative risk analysis as "estimating practical values for consequences and their probabilities which produces values of the level of risk in specific units defined during the risk management planning phase".Vose [21] suggest that the prerequisite in performing quantitative risk analysis is the past patterns of occurrence of risk events.

Bansal [20] suggests that quantitative risk analysis should only be conducted on high ranked risks identified during the qualitative risk analysis process and the focus should be on risks that affect project objectives severely. Vose [21] suggests that quantitative risk analysis provides a numerical estimate of the overall risk for the project objectives. It evaluates the likelihood of success and can be used to estimate project contingency reserves for money or a buffer for the duration.

Project managers constantly need to balance the three goals of project management, i.e.

- Schedule – will the project be completed within the agreed timeframe?
- Cost – will it be completed within the allocated budget?
- Performance – will the project deliver the desired deliverable?

Quantitative risk analysis uses numerical values that create a common understanding among stakeholders involved in the risk analysis of a project.

2.5 Simulation and other methods

Simulation, decision tree analysis, sensitivity analysis and other quantitative tools are often used as part of risk analysis (Shuyler [22], Munier [23]). Monte Carlo simulation is mentioned in the Project Management Body of Knowledge (PMBoK) guide (PMI [3]) as one of the quantitative risk management tools. A detailed discussion of cost and schedule risk analysis and simulation is provided by Cooper et al. [15]. Korombel and Tworek [13] also mention the importance of utilising quantitative risk simulation tools

3 RESEARCH METHODOLOGY

The intended outcome of this study was to understand how risk analysis methodologies are selected and how that benefits the management of projects. This study also investigated the benefits, advantages, and disadvantages of risk analysis methods. The research methodology and approach comprised 1) data collection by means of a survey, 2) data collection through interviews and 3) data analysis and evaluation.

3.1 Data Collection

Primary data for this research study was gathered through a quantitative online survey. The Questionnaires were sent to project team members within large scale project organisations such as power plants, municipalities, mining, and consulting firms. The target audience for the online survey was project workers that included project managers, coordinators, planners, construction managers, risk officers and project controllers. The survey determined the involvement of different project team members in the selection of risk analysis methods, which scales are used, and how effective risk analysis in projects is. Data was also gathered through semi-structured interviews with senior project managers, portfolio managers and senior project risk managers. The purpose of the interviews was to determine whether there is synergy between project teams and managers in the selection of risk and usage of risk analysis methods.

3.2 Survey Questionnaire and Structure

The online survey focused on experienced project team members, perspective on risk analysis methodology and how it links with successful execution of projects. The survey determined the involvement of project team members in the selection of risk analysis methods and benefits to projects they are managing and executing. The questionnaire had 4 sections with a total of 30 questions or statements. The questionnaire comprised the following sections:

- Respondent’s background - This section questioned the respondents’ experience in project management and basic training in risk management.
- Use of risk management in project management - This section referred to the risk management process applied in projects.
- Selection of risk analysis tools - This section identified the risk analysis method and tools used by organisations and how these methods are selected.
- Effectiveness of risk analysis methods - This section identified the effectiveness of risk analysis methods and the barriers to an effective analysis process.

3.3 Semi-structured Interviews

The semi-structured interviews focused on senior managers in the project management environment. The semi structured interview mainly determined the involvement of management in the selection of risk analysis methods. The semi-structured interview comprised 10 questions.

3.4 Data Analysis & Evaluation of Results

Only qualitative analysis was performed on the data that was gathered through a survey. The narrative from the interviews was transcribed and organised for comparison with the results from the survey. Some 25 responses to the survey were received and 5 managers were interviewed. The results are applicable to the four institutions involved in the survey and cannot be generalised for the total industry in South Africa

4 RESULTS

Due to sensitivity of data, the details of participating organisations are not revealed in this paper. The organisations are therefore just referred to as power, municipal, mining and consulting firms.

4.1 Demographics of Respondents

This section determined the demographics of the respondents, including experience in managing projects or participating in projects. The distribution of roles within projects and project teams were also requested.

4.1.1 Roles within project teams

Figure 1 below shows the number of respondents for different roles within project teams.

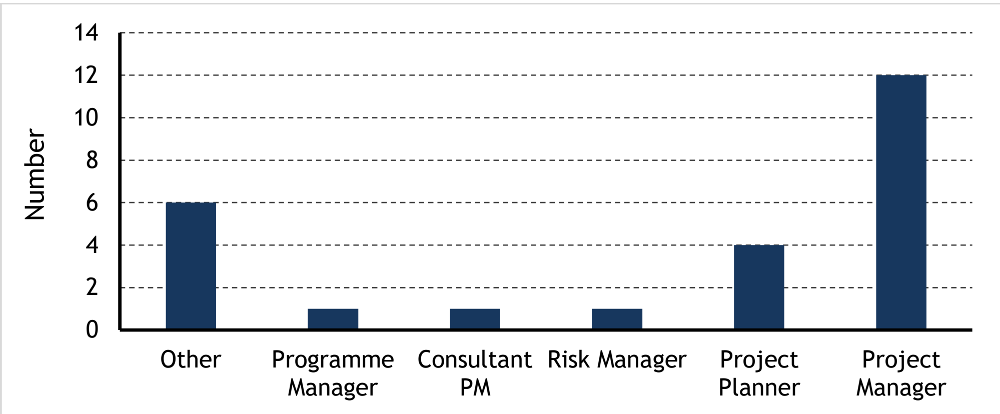

Figure 1: Project team roles

Most of the time the project manager will make the final decision regarding risk analysis methods and the scales that will be used. Nearly half of the respondents were project managers providing credibility of the results obtained.

4.1.2 Project team experience

The experience of respondents in project management is indicated in Figure 2. Four age categories were given as options in the questionnaire. The respondents were well experienced with 80% who had more than 5 years' experience in their current roles. Most of the respondents were involved in maintenance projects.

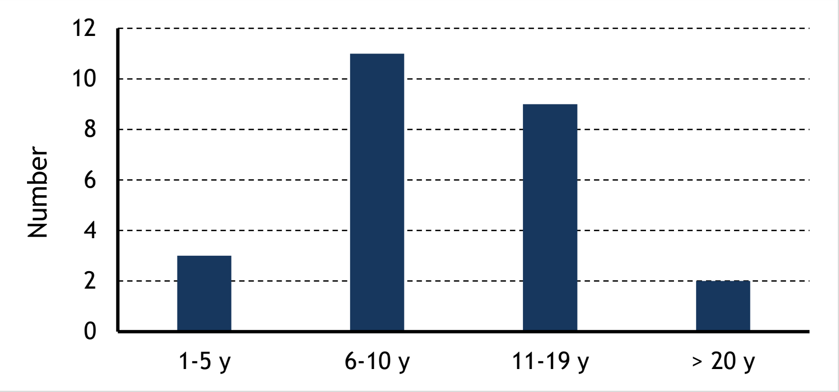

Figure 2: Experience of respondents

4.2 Risk Management in Projects

Respondents were questioned on their knowledge of risk management and how it is utilised in their organisations. The focus was on the integration of risk management and project management and the effectiveness of the risk management system. The results are shown in Figure 3 below.

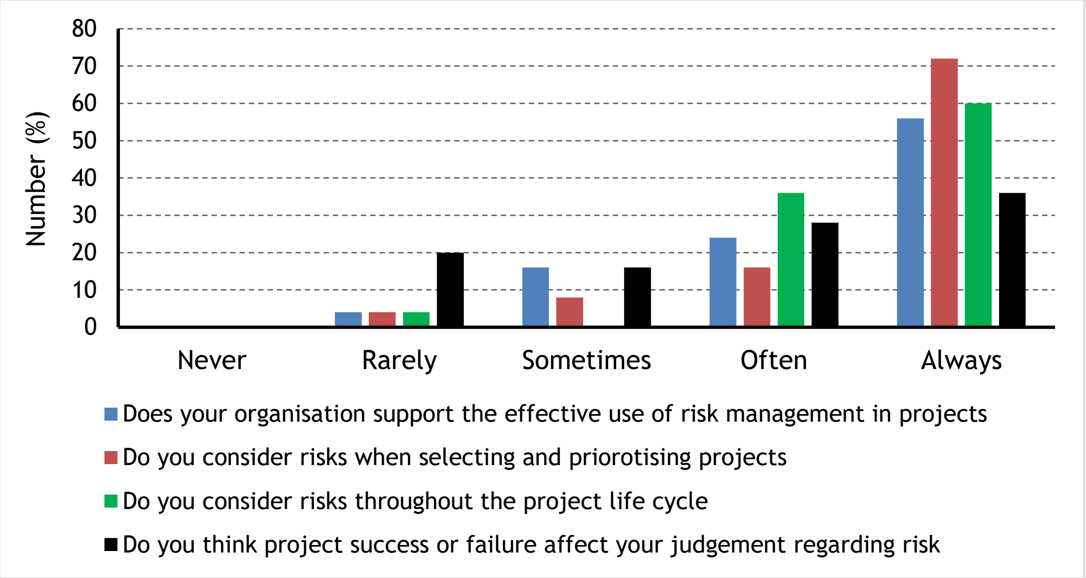

Figure 3: Risk analysis in the project lifecycle

It is encouraging that about 96% of the respondents indicated that risks are considered and managed throughout the total project duration. However, the respondents did not agree that project success or failure affect their judgement regarding risk.

4.2.1 Risk management effectiveness

The effectiveness of the project risk management process was evaluated, and the results are shown in Figure 4. Nearly 50% of the respondents felt that the risk management process in their projects are effective or highly effective. However, quite a large percentage said the process is only sometimes effective or not effective at all. For many organisations there is therefore room for improvement since the literature suggests that effective project risk management is a major contributor towards project success or failure.

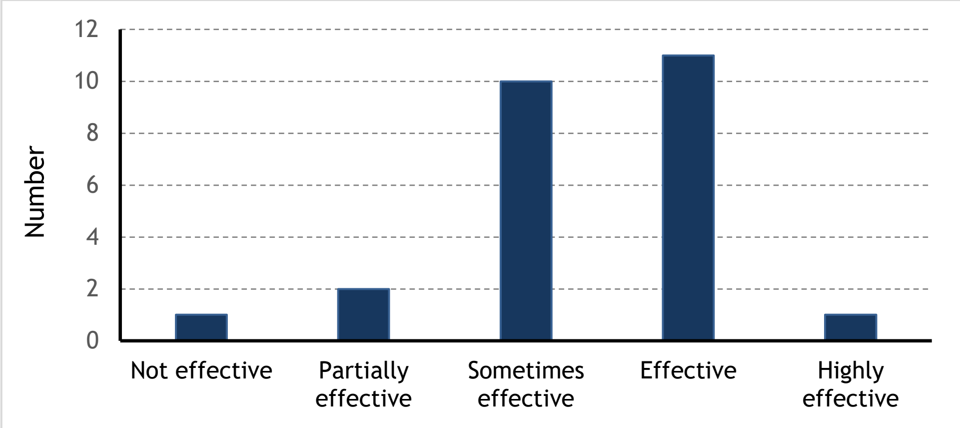

Figure 4: Effectiveness of project risk management

4.2.2 Project selection and prioritisation

Respondents were asked how projects are selected and prioritised in their respective organisations. The results for this question are summarised in Figure 5.

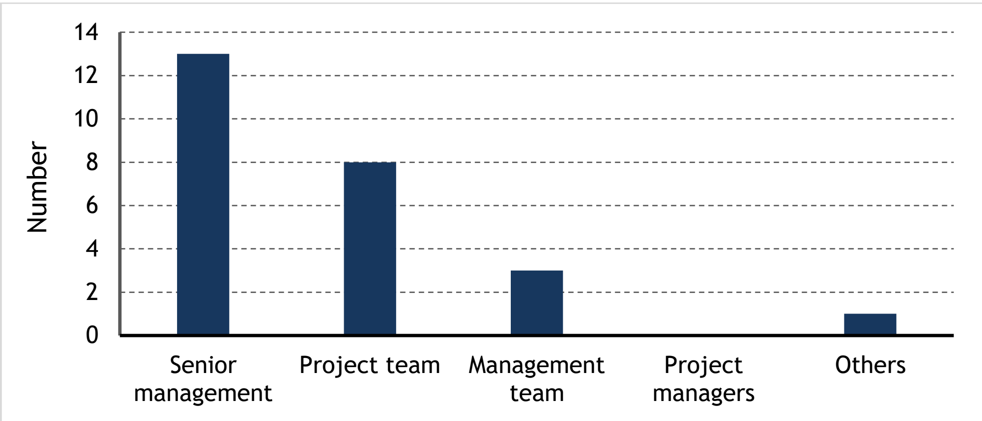

Figure 5: Project selection and prioritisation

Respondents indicated that mainly senior management and project teams are involved in the selection and prioritisation of projects within the organisation, i.e. 84%. None of the remaining respondents said that project managers are involved in this activity of selection and prioritisation of projects.

4.3 Risk Analysis Tools

4.3.1 Risk analysis method used in projects

Three risk analysis methods are mostly used to measure or quantify probability, consequence, and risk. These are qualitative, semi-quantitative and full quantitative. Figure 6 shows the respondents' responses on the risk analysis method used in their projects. Quantitative and semi-quantitative analysis methods account for 52% of the responses. However, the results indicate that qualitative methods are still popular with many organisations. This result is similar to what was found in literature (Steyn et al. [1]).

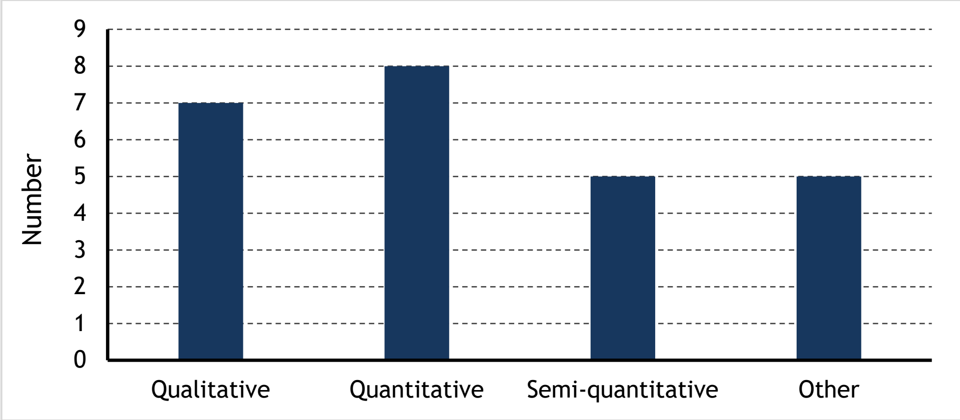

Figure 6: Risk analysis methods

4.3.2 Training on risk analysis methods

This question was posed to respondents to determine the depth in knowledge of the risk analysis methodology they are utilising. This includes the type of training they received in risk analysis methodologies. Fifteen (60%) of the respondents indicated they were trained in risk management and risk analysis and have a good knowledge of risk analysis methods while ten (40%) of the respondents were using risk analysis methods but never received any training.

4.3.3 Accountability for project risk analysis

Respondents were asked who is responsible for ensuring all project risks are continually analysed throughout the project life. Figure 7 summarises the responses.

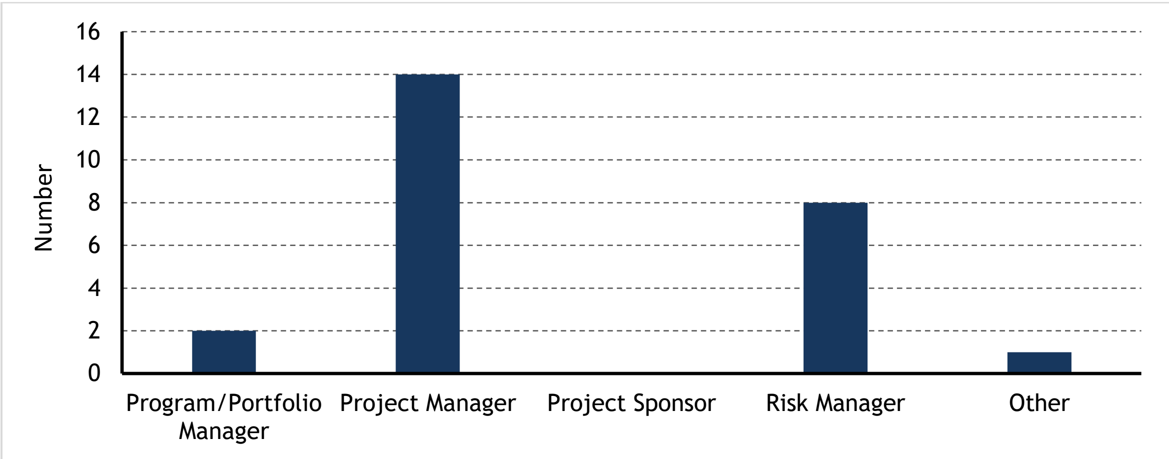

Figure 7: Project risk analysis accountability

A combined total of 88% of the respondents felt either the project manager or risk manager in a project is responsible for ensuring risk analysis is performed throughout the project's duration. Zwikael and Ahn [24] says project team members are responsible for identifying project risks.

4.3.4 Risk scales

Respondents were asked which risk scales are used in their project organisations. The options given were 3-point, 5-point, 7-point scales or probability estimates. The results are shown in Figure 8.

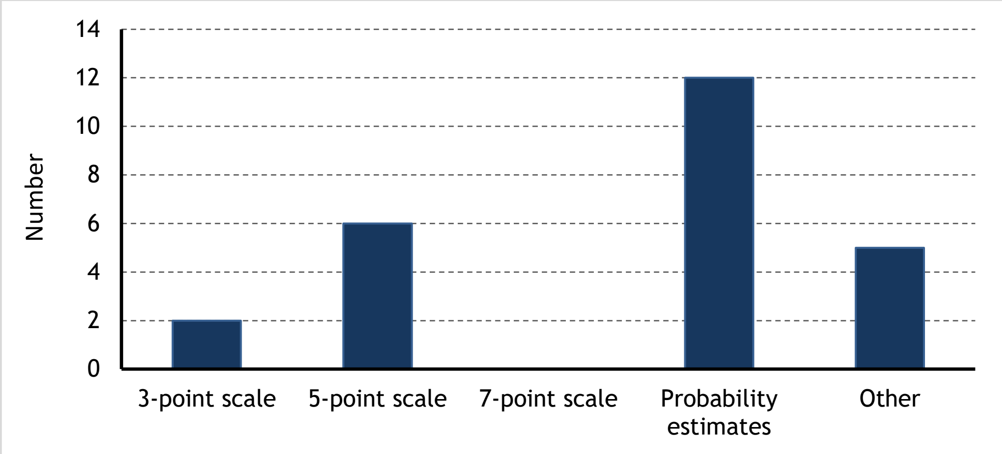

Figure 8: Risk analysis scales

Nearly half (48%) of the respondents indicated that probability estimates are used. This is also an indication that quantitative analysis is preferred over semi-quantitative and qualitative analysis in projects. A surprise result was that none of the organisations represented use the 7-point scale. It appears that project teams use parametric estimates (estimates based on events in historic projects of similar nature) to analyse and score the impact and probabilities of risks.

4.3.5 Risk analysis quantitative methods

Figure 9 shows to what extent the respondents use quantitative tools and methods in projects.

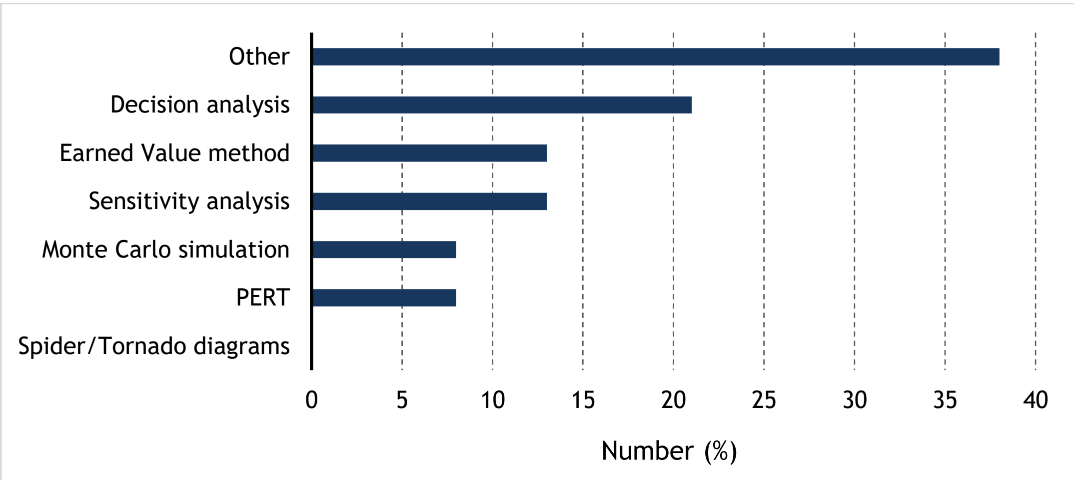

Figure 9: Quantitative risk simulation methods

Most of these tools are used to some extent but it was rather surprising that Monte Carlo simulation was mentioned by only 8%. Also surprising was that none indicated tornado diagrams which are quite useful to determine the relative contribution of uncertainties towards total risk in the project. The largest selection by the respondents was “other”. This could indicate that the respondents are not familiar with most of these quantitative tools or they do not have the necessary knowledge to apply them in practice.

4.3.6 Software and risk value

Respondents were asked if the risk analysis software is protected against human intervention and manipulation. This question was mainly directed at determining transparency and software integrity. 32% of respondents said the risk value is manipulated to favour a certain decision, while 32% indicated that occasionally risk values are adjusted and manipulated to favour certain decisions. 12% of respondents indicated that probability and consequences are “always” manipulated to achieve a certain risk value. Only 24% respondents indicated that risk value is never manipulated. 24% of the respondents indicated they do not use any specialised software application for risk analysis while 24% indicated there is a software application but it is seldom used. 24% indicated that they use risk analysis software regularly.

4.3.7 Data collection method

Respondents were asked to indicate how they collate input data that is used to perform project risk analysis, i.e. the data to estimate probability and consequence values. The results are shown in Figure 10. “Brainstorming” and “project history” were the most popular techniques for data elicitation although some project teams prefer focus groups that are formed from the expertise that is available in the organisation. Hender et al. [25] supports the finding that brainstorming is popular amongst project risk teams.

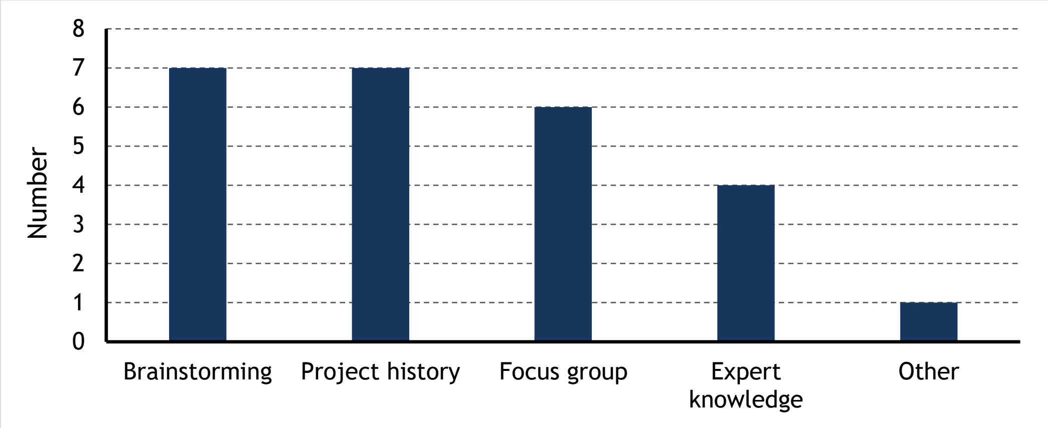

Figure 10: Data collection methods

4.4 Effectiveness of Risk Analysis

4.4.1 Effectiveness of data gathering method

Respondents were asked to comment on the effectiveness of data gathering and the input data used for risk analysis. 40% said the methodology used is effective and it assists the project team in analysing project risks. 28% indicated that the risk analysis method is “sometimes effective” while 24% indicated the risk analysis method is “partially effective”. Most teams are therefore satisfied with the approach but training in data elicitation could assist here.

4.4.2 Overall project risk analysis

The opinion on the overall project risks analysis methods utilised in their organisation was requested. Five questions in this section of the questionnaire aimed to determine how the project team members viewed risk analysis, how the methods are selected and how projects are prioritised. The results are shown in Figure 11.

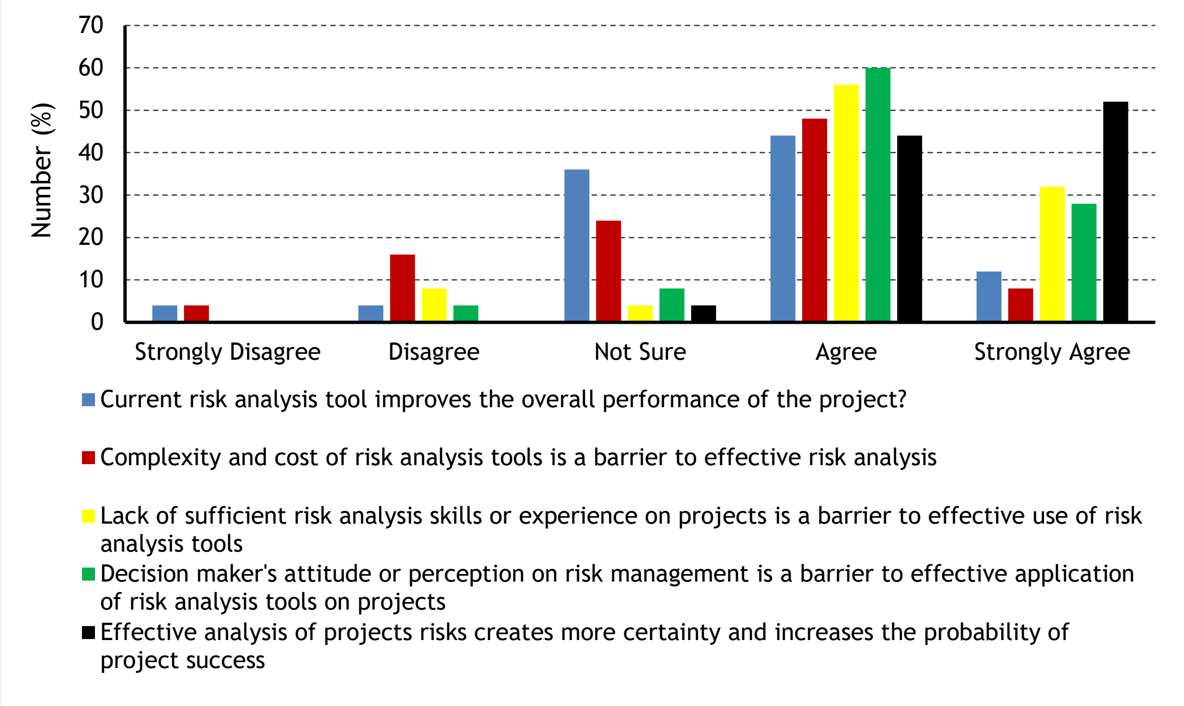

Figure 11: Summary of risk analysis

Nearly half (44%) of the respondents felt that the current risk analysis tool or method is not improving project performance. There is agreement on the other aspects that were questioned, particularly that effective risk analysis increases the chance of success for a project (96% agreed or fully agreed).

4.5 Semi-structured Interviews

4.5.1 Managers interviewed

Five respondents were interviewed, i.e. a senior project manager from power generating plant, senior risk manager from the same power generating plant, portfolio manager from the mining sector, portfolio manager from a large municipality in Gauteng and a senior project manager from a consulting firm.

4.5.2 Prioritisation and selection of projects

In power generation the risks are prioritised using quantitative risk analysis and a 5-point scale. The risks are then prioritised in terms of impact. The manager from the municipality cited that project prioritisation stems from the government service delivery plan. Qualitative risk analysis is used to select and prioritise risks. The consulting manager mentioned that selection and prioritisation use quantitative risk analysis where the projects are weighed on basis of return on investment (ROI), payback period, net present value (NPV) and resources required. The mining industry also uses a 5-point scale; however, projects are prioritised based on impact analysis and considerations are based on production, safety, and licence to operate.

4.5.3 Risk analysis and successful projects

All interviewees mentioned the importance of thoroughly analysing risks and not just doing a paper exercise. For risk analysis to be effective a “thorough analysis of risks” is essential. Hillson [20] supports this by saying “for risk analysis to be effective, a thorough analysis must be conducted, and all possibilities should be analysed”.

4.5.4 Perception on risk management

The interviewees were asked to comment on the general perception on risk management within their respective organisations. The general notion was that risk management is moderately effective within the context of projects. The mining sector and power generation shared the same sentiments that risk management was first introduced to the teams in the form of safety and health risk assessments. The municipality PMO Manager shared a rather disturbing view that they have the best risk management process but "on paper".

4.5.5 Selection of risk analysis method

From the survey it is evident that quantitative and qualitative risk analysis are equally popular in organisations. The interviewees differed in how a risk analysis method is selected in the different organisations they represented.

4.5.6 Stakeholder involvement during risk analysis

Interviewees were asked who is involved during project risk analysis. They mentioned that senior management is accountable for identifying relevant stakeholders and the project manager is responsible for coordinating stakeholder involvement. Senior project team managers in all four sectors mentioned that some project risk analysis aspects are discussed at executive level and require senior management to analyse the risks.

4.5.7 Effectiveness of risk analysis method

The interviewee from the mining sector mentioned the risk analysis process is highly effective. The member from consulting commented that "numbers cannot lie" and quantitative risk analysis is transparent, justifiable, and easy to follow.

4.5.8 Risk scales

The interviewee from the consulting sector commented that in their organisation they use the 5-point scale and the choice was based on the ease of use. Power generation also uses the 5-point scale for risk estimates.

4.5.9 Pitfalls in risk analysis methods

One of the major disadvantages cited was that the risk analysis process is lengthy and time consuming. The manager from power generation commented that the risk analysis process is always given less priority by the project team. It is then often done for compliance reasons and not to benefit the successful implementation and completion of the project. It was also mentioned that the analysis process allows for manipulation and adjustment of risks to minimise time to mitigate risks as the project should commence.

4.6 General notes from Interviews

Interviewees acknowledged that risk analysis is often not performed as documented and that pitfalls within their organisations hinder them from fully benefiting from project risk analysis. The municipality member mentioned the negative impact of political influence on project risk analysis. It was also mentioned that analysis session was sometimes treated as a war zone as well as a "paper exercise".

5 CONCLUSIONS

5.1 Selection of Risk Analysis Methods in Projects

The objective of this research was to determine how project risks are analysed in large scale project organisations in South Africa. The focus of the study was on the risk analysis method selection criteria and comparing different methods used to analyse project risks. It was also determined how risk analysis methods benefit projects, advantages and disadvantages of risks analysis methods, critical success factors and scale selection criteria.

5.2 Benefits of Risk Analysis Methods

Respondents were asked why a risk analysis method was selected and how the organisation benefits from the method. Most organisations cited advantage and benefits on the qualitative analysis as easier to understand, mathematical quantification is not necessary, and less time is required to conduct the analysis.

5.3 Critical Success Factors for Risk Analysis Methods

Critical success factors of the risk analysis method are linked to the successful completion of a project. Project success is usually measured as quality, cost, and schedule compliance. The study showed that risk analysis is often underutilised and executed as a paper exercise. This often leads to late completion of project and overspending on the budget.

5.4 Selecting Risk Analysis Scales

Like the selection of risk analysis methods, the study showed that the project team has minimal participation in the selection of risk analysis scales and this function is often left for organisation leadership to decide. The study also revealed that the 5-point scale for probability and consequence estimates is mostly used in projects in the four sectors.

5.5 Selecting Risk Probabilities and Consequences

This study showed that risk probabilities and consequences are determined at executive and board level. Categorisation may include operational, financial and company reputation. Senior organisation management determines what impact the risk could have on the organisation should the risk event occur. Organisations rate consequences of a risk in terms of the impact on the objectives of the organisation.

6 RECOMMENDATIONS

Only four sectors were represented in this study. It is recommended that further studies on risk analysis be done in more industry sectors, e.g. transport, manufacturing, processing, and telecommunications. This will enable comparison and to determine similarities and differences in risk analysis selection and application in projects. The study determined a lack of quantitative analysis methods like simulation and decision trees and training of project team members in these disciplines could be beneficial for project organisations.

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WORKING SMARTER, NOT HARDER: EVIDENCE OF PRODUCTIVITY IMPROVEMENTS USING METHOD STUDY INVESTIGATIONS

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ABSTRACT

Method study is the first technique of work study and looks at improving the methods of working. In the last century, the global manufacturing industry has been faced with various challenges including globalisation of markets and increased competitiveness. In spite of the ever-increasing importance for efficient operations, organisations have been reluctant to improve production systems to be responsive to customer demands. Improvements in productivity based on method study investigations can be achieved by systematically examining operational processes to develop more efficient ways of accomplishing tasks. The primary objective of this paper was to demonstrate that basic interventions using method study investigations can improve productivity in the workplace. A mixed-methods approach was used as the research design of the study. The essential contribution of this paper is a common-sense methodology which organisations can utilise to effect improvements. The empirical results indicate the essential need for method study investigations. It is concluded that the systematic implementation of this methodology will ensure that productivity is enhanced. Findings of this study may be extended to service industries.

Keywords: Work study; method study; productivity; process charts; efficiency; layouts; u-cell; manufacturing

1 INTRODUCTION

All manufacturing organisations aspire to be as efficient as possible in their operations, Chisosa & Chipambwa [1]. In this day and age, manufacturing environments are continually evolving and seeking efficient methods of working, [2]. This is owing to a number of factors, which include, intense competitiveness, the 4th Industrial Revolution, globalisation and the ever-expanding applications of technology in organisational processes, [5]. “So how do manufacturing organisations keep up with the above to ensure their sustainability?”

The answer lies in management stepping up to this challenge by continuously innovating and looking at improvements in any possible way to improve productivity. Frederick Taylor (1856–1915) proposed that the greatest loss owing to inefficiencies was not material, but indeed a waste of human effort, [6]. Put simply, he stated that people were working harder but not smarter. His “Motion Study” method sought to make processes more efficient by reducing the motions involved, thereby reducing human effort and producing more.

Improving productivity allows organisations to grow and increase their profitability. Productivity improvement measures output per unit of input, such as labour, capital or any other resource, [8] very aptly defines productivity as the transformation of available materials and workforce resources into essential goods and services within an organisation. Working smarter and working fewer hours may have a positive impact on productivity. Johnson [9] asserts that working longer hours does not necessarily result in increased productivity. Less fatigue occurs among employees when they work a shorter number of active hours, [12]. Organisations must attempt to reduce the consumption of resources, thereby reducing cost per unit output through utilisation of proper methods. Herein lies the benefits of method study. A method study investigation and the subsequent implemetation of the improvements can lead to significant productivity improvements with minimal financial outlay.

South Africa’s economic performance ranks 53rd out of 63 countries on the 2018 Institute of Management Development’s World Competitiveness Rankings (IMD), [13]. Compared to the United States (US), which has long enjoyed the world’s highest productivity, South Africa (SA) lags far behind their first-world counterparts. Improving productivity in individual organisations automatically leads to the overall improvement of productivity in a country. It is incumbent on organisations to improve their productivity, which also contributes to competitiveness and their sustainability, [14].

This paper reports on the method study investigation which was conducted in the assembly department of a selected tap manufacturing organisation (Company A). Method study is a technique of the concept work study and is primarily concerned with improving the methods of working. Work study is the systematic examination of any type of work being conducted in order to effect improvements, [15]. Continuous improvement of operational processes allows an organisation to develop its capabilities to keep it ahead of its competitors, [16]. The method study investigation in the assembly department will ensure this. The essential contribution that this paper makes is that it provides organisations with a universally accepted, user-friendly technique (method study) to improve organisational effectiveness and overall productivity.

If the assembly department achieved their daily target (one million rands - monetary output), they accepted this as 100% productivity. However, the number of resources that were utilised to realise this monetary output were not taken into consideration via a dedicated costing system. Management must be particularly interested in the relationship between productivity and efficiency as this speaks to managerial effectiveness, [17].

The results of the investigation will show the interventions that were implemented to improve the working methods of the operational processes, improve the layout of the work environment to ensure a smooth flow of work and the subsequent improvement in productivity. The structure of this paper consists of: an intensive method study investigation to improve working methods of the operational processes, improving the layout of the work environment, and reporting on the results of the research instrument. The overall aim was to improve productivity.

2 PROBLEM INVESTIGATED AND THE RESEARCH OBJECTIVES

2.1 Problem investigated

The researcher is a qualified work study officer, having spent sixteen years in the textile industry practicing work study and industrial engineering. Outputs in the assembly department of Company A were measured monetarily and referred to as daily productivity. Prior research into work study has largely focused on work measurement where the emphasis was on developing standard times for manufacturing processes – it has generally failed to explicitly consider the role of method study in firstly improving the methods of working to improve productivity, [18]. As stated above, direct observation of the assembly department indicated ineffective operational processes. Employees were content with the layout of their workstations, although it was evident that certain basic, common-sense improvements could have led to greater effectiveness in their working lives. Employees and management indicated that they were using the most efficient working methods and did not believe that it could be improved. This alluded to the concept of 'Resistance to change' or the "RTC factor" which is widely recognised as a significant contributor to this problem, [19]. Ineffective layouts and processes were not identified and hence, staff were content with their methods of working. Furthermore, it was found that the "deterioration effect" (of employees, tools and machines) which increases the time required to produce units, was prevalent in the assembly department, [20]. There was no prior method study investigation to identify inefficient working methods. This problem necessitated urgent interventions to improve working methods and the layout of the work environment, as the current methods of working had an adverse effect on the productivity of the assembly department.

2.2 Objectives of the research

The primary objective of the research on which this paper is based was to conduct an intensive method study investigation to improve working methods of the operational processes and to improve the layout of the work environment. The overall aim was to improve productivity in the assembly department.

3 THEORETICAL OVERVIEW

The theoretical framework for this paper contains references to certain textbooks that are rather old. However, these were considered as seminal works. The main reason for using these references is the limited availability of literature on this topic. Continuous references are made to the textbook by Kanawaty [21] as this is regarded as the 'Bible' of work study. The theoretical framework aims to bridge the gap between theory and practice. It consists of the definition and nature, the objectives and scope, and the procedure and recording techniques of method study.

3.1 Definition and nature of method study

Method study, as the name states, aims at improving the methods of working, towards making it more efficient. Chisosa and Chipambwa [1] state that method study raises the efficiency of production and can be used in all manufacturing as a scientific approach. Pycraft, Singh, Philela, Slack, Chambers, and Johnston [22] define method study as the systematic recording and critical examination of the existing and proposed methods of doing work, as a means of developing and applying easier and more effective methods and reducing costs, [16] underscore that method study determines the methods and activities to be included in jobs. Method study can also be seen as the systematic recording and critical examination of the factors and resources involved in an operation in order to develop more efficient working methods and to reduce costs, [21].

It can be seen from the above definitions that method study offers a systematic approach to problem solving. The objective is to make the work method or process more effective and to eliminate unnecessary and inefficient operations and movements. These are then simplified to determine the shortest possible route and the most effective sequence of operations. Method study is therefore constantly identifying problems to determine what caused them, what can be done to solve them and how to avoid them from recurring in future.

Overall, method study is concerned with the reduction of the work content of a job or operation. It speaks to how well the available resources such as worker-power, machines, materials, and money are utilised and compel manufacturers to rethink almost every aspect of their business operations, [23].

3.2 The objectives and scope of method study

The objectives of method study are: the improvement in the use of all inputs, developing better ways of doing things, and reducing costs in an organisation, [24]. It also contributes to improving efficiency by eliminating unnecessary work, delays and preventing waste. The objectives of method study mentioned above can be achieved through improvements in the utilisation of all inputs, that is: methods, employees, machines, materials, money, time, information leading to economy in human effort and reduction of uncessary fatique.

There is a traditional view that method study can only be applied to light work. This statement does not recognise the full potential of this technique. The scope of method study is much wider and it is explored briefly below, 24]. The application of method study in any organisation affects all hierarchical levels and must incorporate the employee, the environment and their interaction for optimal efficiency, [25]. This means that all levels in an organisation, from top management to the shopfloor employees, are affected by the application of method study. According to Freivalds and Niebel [3], method study is the careful analysis of body motions employed in doing a job. Seminal literature by Currie [26] postulates that method study can be applied anywhere and everywhere where people are engaged in work, since any method, process or procedure is open to improvements.

3.3 Method study procedure and recording techniques

Since method study is systematic, it uses a set procedure that must be followed in order to achieve success in a method study investigation. Seven essential steps of method study are identified, namely: select, record, examine, develop, define, install and maintain. These steps represent the procedure that must be followed when conducting a method study investigation, [16] . Although this linear representation shows the underlying simplicity of method study, in practice, the process is much more than repeated passes through the sequence of steps with each dominating at a different stage of the investigation, IMS, [27].

Method study utilises various techniques to record all the relevant information of an existing method. Among them are outline process charts, flow process charts, two-handed process charts, multiple activity charts, simo charts, flow diagrams, string diagrams, cyclegraphs, chronocyclegraphs, and travel charts. For the purposes of this study, flow process charts were used. A flow process chart is a graphical representation of the sequence of steps or tasks (workflow) constituting a process, starting from raw materials to the final finished product, [28].

4 RESEARCH METHODOLOGY

The research design for the study consisted of a mixed-methods approach which was used to generate data, enabling the researcher to come to conclusions and make recommendations regarding the method study investigation, [29]. The data-generation techniques consisted of the method study investigation and the distribution of a structured, self-administered, web-based questionnaire. This was found to be the most appropriate survey method as the respondents could easily be accessed, as noted by Alam, Hogue, Rout, and Priyadarshani [30] in Sookdeo [31]. The respondents were invited by email to complete the questionnaire. The online approach was deemed appropriate, as they are guaranteed to deliver results and surveys enable researchers to generalise their findings, [32]. The purpose of the questionnaire was to generate critical responses as to the use of method study investigations to improve productivity in organisations.

4.1 The population and sampling in the study

The population of the study reported in this paper was composed of selected employees (n = 800) of organisations in South Africa. Their positions ranged from operators and supervisory staff to management. Purposive sampling was utilised to select the participants. Purposive sampling simply looks for people who can help build the substantive theory further, [29]. Two hundred and thirty (230) respondents submitted their questionnaires online to the database and all were considered suitable for inclusion. The response rate was 28.75% and found to be acceptable for the purposes of this study.

4.2 Data collection and analysis

Data were collected via the method study investigation which consisted of process charting, and by means of a structured questionnaire.

4.2.1 Process charting

Flow process charts of the tap assembly process were compiled. The data were analysed using the recommended seven steps of the method study procedure. It is coincidental that the method study procedure and the tap assembly process consisted of seven steps each.

4.2.2 Questionnaire

The questionnaire was sent to the participants via email. It was pilot tested at two manufacturing organisations. A statistician assisted the author with the amendments, the setting up of the database, and the analysis of the questionnaire. Responses were automatically entered and saved on the online database. The questionnaire data were imported into the Statistical Package for Social Sciences (SPSS) in order to perform the statistical analysis. Basic frequencies and descriptive analyses of all questions were performed to look at the distribution of the respondents. The researcher then selected certain questions that were relevant to the outcome of this study and requested cross-tabulations and chi-square tests to be performed. The aim was to see whether there were associations between the selected questions.

5 DISCUSSION OF FINDINGS AND RESULTS

Preliminary investigations of the existing processes in the assembly department, by direct observation, revealed that employees used inefficient methods in their daily operational processes, some of which were highly labour intensive.

5.1 Method study investigation A: Process charting

The method study investigation consisted of intensive 'observation and recording' of the current method of working in the assembly department. Although there were a variety of taps being assembled, the most popular tap was selected for this study. Flow process charts were used to record the elements of each step of the assembly process. All the steps of each assembly process was recorded via direct observation. A description for each element of each process was noted and a symbol allocated to each element (see Table 1 for a description of elements and symbols). The flow process chart utilises the following symbols:

Table 1: Symbols used in process charting (Freivalds and Niebel, [3])

Symbol	Symbol name and description
○	**Operation:** Indicates the main steps in a procedure. Usually, the part, material or product concerned is modified or changed during an operation.
□	**Inspection:** Indicates an inspection for quality and/or check for quantity.
⇨	**Transport:** Indicates the movement of workers, material and equipment from one place to another.
D	**Temporary delay:** Indicates a temporary delay in the sequence of events.
▽	**Permanent storage:** Indicates a controlled storage in which material is received into or issued from a store under some form of authorisation.
⧇	**Combined activities:** When activities performed at the same time or by the same worker at the same workstation need to be shown, the symbols for those activities are combined.

Procedure Step 1: "Select" the work to be studied: The assembly department was selected.

Procedure Step 2: "Record" all the relevant information.

The assembly process consisted of seven steps. This means that on the assembly line, seven different operators were utilised to assemble this tap, hence seven flow process charts were compiled. The seven assembly steps (AS) were: AS1: Fit head part; AS2: Water Pressure Test; AS3: Fit back nut to tap (brass); AS4: Fit cover and handle; AS5: Fit indice (cold); AS6: Cleaning and polishing; and AS7: Packaging.

Procedure Step 3: Examine (critically), the recorded information.

Each of the flow process charts were subjected to a rigorous critical examination to eliminate inefficient operations, reduce transportation (movements) and limit the number of inspections. The overall aim was to "streamline" each step to make it more efficient. For example:

AS1: Fit head part to body of tap

AS1 consisted of 16 elements. Each element was described and a process chart symbol allocated to it (see Figure 1). A summary of the different symbols of the present method was completed. AS1 was critically examined and improved. The outcome is a proposed flow process chart for AS1 (see Figure 2). Total savings amounted to ten elements, indicating a significant improvement (62.50%) in the assembly process of AS1. A new summary was completed showing the comparison between the present and proposed methods (see "SUMMARY" in Figure 2). The rationale for the savings in the AS1 are as follows:

The ten elements which were eliminated (100% savings), will be conducted as "inside work". Kanawaty [21] asserts that inside work comprises those elements which can be performed by an employee within the machine (or process) controlled time. This means that all the preparatory elements leading up to AS1 must be conducted before AS1 starts. This helps to separate the setup times from the processing times. The goal is to find optimal sequences that minimise interruptions to the assembly process, Soroush, [33]. Hence, the time that it takes to complete AS1 is significantly reduced. A 100% saving in distance travelled (from 100 metres to 0) was also realised.

FLOW PROCESS CHART

LOCATION: Assembly Department	**SUMMARY**			
ACTIVITY: Assembly of tap	**EVENT**	**PRESENT**	**PROPOSED**	**SAVINGS**
DATE: 12-06-2019	**Operation**	**10**		
OPERATOR: Line 1 / **ANALYST:** B. Sookdeo	**Transport**	**4**		
METHOD AND TYPE:	**Delay**	**1**		
METHOD: Present **TYPE:** Operator	**Storage**	**0**		
	Inspection	**1**		
DESCRIPTION OF OPERATION: **Step 1:** Fit head part	**Time (mins.)**			
	Distance (metres)	**100**		

STEP NO.	DESCRIPTION OF ELEMENTS	SYMBOL	TIME (in minutes)	DISTANCE (in metres)	REMARKS
1	Prepare workplace				
2	Fetch jig from store			40	
3	Position at workplace				
4	Fetch head parts from storage			10	
5	Position at workplace				
6	Fetches body parts from storage			10	
7	Position at workplace				
8	Wait for other stations to set up				
9	Pick up body part and pos. in jig				
10	Pick up head part and pos. in body				
11	Screw on head part				
12	Pick up assembled head part				
13	Inspect head part				
14	Aside head part onto conveyor				
15	Remove and aside empty boxes				
16	Take jig back to store			40	

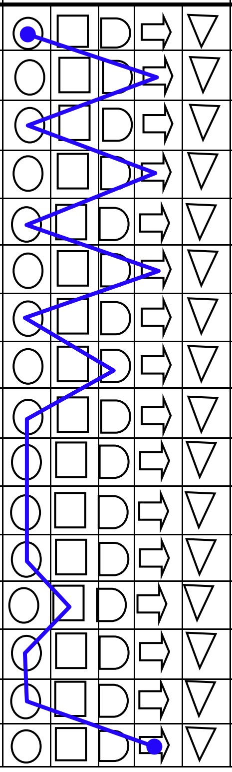

Figure 1: Present method: Flow process chart: Assembly Step 1: Fit head part

FLOW PROCESS CHART					
LOCATION: Assembly Department		**SUMMARY**			
ACTIVITY: Assembly of tap		**EVENT**	**PRESENT**	**PROPOSED**	**SAVINGS**
DATE: 12-06-2019		**Operation**	10	5	5
OPERATOR: Line 1	**ANALYST:** B. Sookdeo	**Transport**	4	0	4
METHOD AND TYPE:		**Delay**	1	0	1
METHOD: PROPOSED		**Storage**	0	0	0
TYPE: WORKER		**Inspection**	1	1	0
DESCRIPTION OF OPERATION:		**TOTAL:**	**16**	**6**	**10**
Step 1: Fit head part:		**Distance (metres)**	100	0	**100**

STEP NO.	DESCRIPTION OF ELEMENTS	SYMBOL	TIME (in minutes)	DISTANCE (in metres)	REMARKS
1	Pick up body part and pos. in jig				
2	Pick up head part and pos. in body				
3	Screw on head part				
4	Pick up assembled head part				
5	Inspect head part				
6	Aside head part onto conveyor				

Figure 2: Proposed method: Flow process chart: Step 1: Fit head part

Assembly steps 2 to 7:

The same process as AS1 was completed for the remaining six assembly steps. The flow process charts for these steps is not shown owing to paper space constraints. However, an explanation is provided.

AS2: Water pressure test: The tap was tested to determine whether there are any leakages. AS2 consisted of 15 elements. No improvements could be made as all the elements were compulsory.

AS3: Fit back nut to tap: A back nut was fitted to the body of the tap. AS3 consisted of six elements. No improvements could be made as all the elements were compulsory.

AS4: Fit cover and handle: A cover and handle were fitted to the body of the tap. A quality check was also conducted during this step. AS4 consisted of 11 elements. Elements 1, 4 and 7 were improved and a proposed method was compiled. Here, a savings of five elements were realised, which shows a significant improvement (45.45%) in the assembly process of AS4. The savings are shown Table 2.

Table 2: Summary of savings: Assembly step 4

Symbol	Present method	Proposed method	Savings
Operation	7	5	2
Transport	3	0	3
Delay	0	0	0
Storage	0	0	0
Inspection	1	1	0
Totals:	**11**	**6**	**5**

The rationale for the savings in AS4 is as follows: Elements 1 to 5 have been eliminated and similar to AS1, these elements should be conducted as 'inside work'.

AS5: Fit indice (cold/hot): A plastic fixture was attached onto the handle of the tap to denote a hot/cold water tap. AS5 consisted of six elements. No improvements could be made as all the elements were compulsory.

AS6: Cleaning and polishing: The tap was cleaned using a cloth and polish. A quality check was conducted and the tap was inserted into a plastic packet. AS6 consisted of five elements. No improvements could be made as all the elements were compulsory.

AS7: Packaging: The packaging box was made up, and 10 taps were placed into the box. The box was sealed and weighed. AS7 consisted of seven elements. One element (Aside box on table) was eliminated. Hence, there was a saving of one element (14.28%), which shows an improvement. The rationale for this was that the packaged boxes should be placed onto the pallet immediately after they had been closed.

Summary of improvements and savings

Table 3 shows a summary of the savings (24%) that had been realised from the method study investigation. This serves as an indication of the value of a method study investigation and how it can improve productivity in an organisation. The duration of each of the improved steps would also be reduced, thereby improving the capacity of the assembly process.

Table 3: Summary of savings

Assembly Step	Description	Number of elements		
		Present method	Proposed method	Savings
1.	Fit head part	16	6	10
2.	Water pressure test	15	15	0
3.	Fit back nut (brass)	6	6	0
4.	Fit cover and handle	11	6	5
5.	Fit indice (cold)	6	6	0
6.	Cleaning and polishing	5	5	0
7.	Packaging	7	6	1
	Total savings:	**66**	**50**	**16**

5.2 Method study investigation B: The present and proposed layouts of assembly department

At the time of the study, the assembly department utilised two types of layouts, namely, product layout (line manufacturing) and u-cell layouts. Stevenson [34] highlights that layout refers to the configuration of departments, work centres and equipment, with particular emphasis on movement through the system. Management were in a quandary about which layout would yield the greatest benefits in terms of manufacturing outputs. A study conducted by the author revealed that the u-cell layout was best suited for the assembly of taps. The proposed layout shows the elimination of assembly lines and the introduction of u-cells as the advantages of u-cell far outweigh those of the assembly lines. Moreover, unbalanced assembly lines create bottlenecks and problems in managing production, [35]. The u-cell assembly has been widely used in industry in recent years, [36].

During a method study investigation, it is imperative that the layout of a department is critically examined (Step 3 of the method study procedure) to determine if it allows for the efficient and smooth flow of work. It was evident from the beginning of the study that the layout of assembly department was not done appropriately. Raw materials were not stored according to customer orders and in close proximity to the assembly lines. Jigs and tools were stored in a toolroom and were only requested when the need arose. Travelling distances to source all requirements for the assembly process were lengthy. Company A had a large product variety which necessitated a higher degree of flexibility for handling components owing to the variations in the technical and functional aspects of the products, [37].

The present layout of the assembly department was drawn and critically examined. Thereafter, an improved layout was designed (see Figures 4 (present layout) and 5 (proposed layout). The aim was to show an effective flow of materials and employees within the assembly department in order to reduce transportation, eliminate delays and improve overall effectiveness. Heizer and Render [38] state that layout design needs to achieve the following:

- higher utilisation of space, equipment, and people;
- improved flow of information, materials or people;
- improved employee morale and safer working conditions;
- improved customer/client interaction; and
- flexibility (to be able to adapt to change).

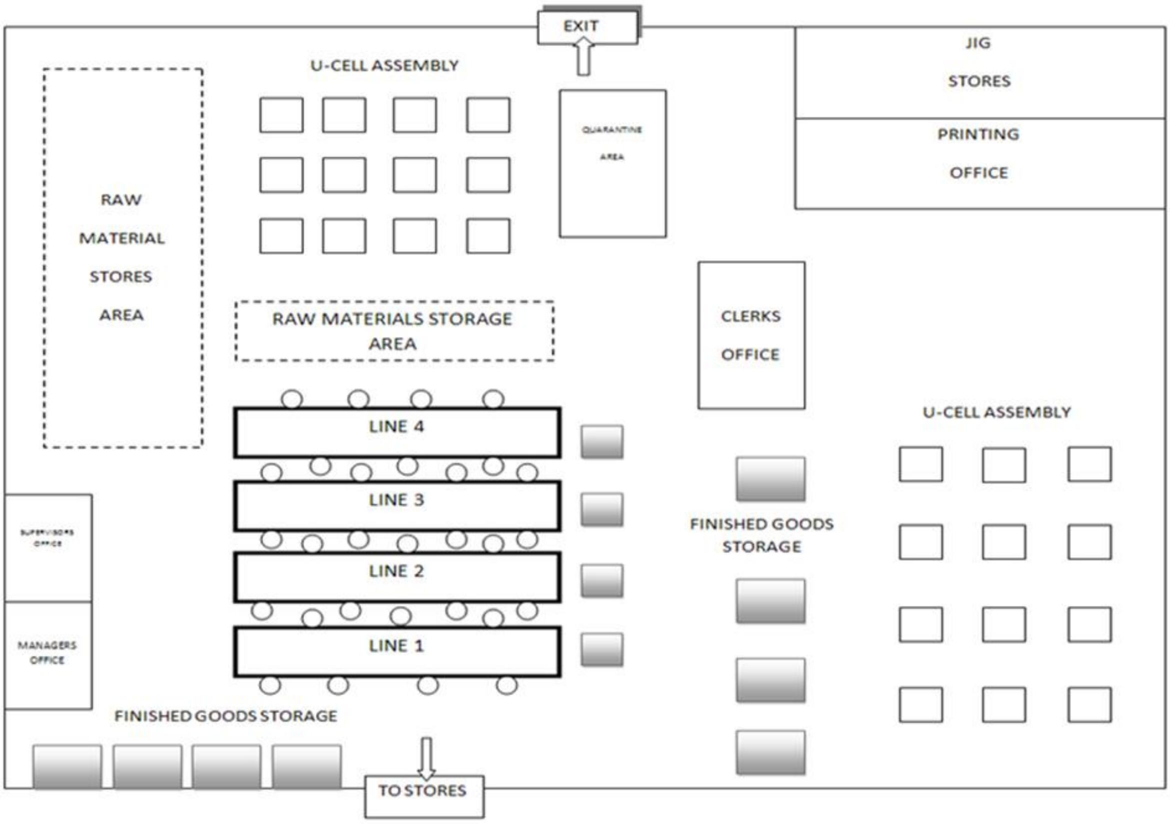

Figure 4: Present layout of the assembly department

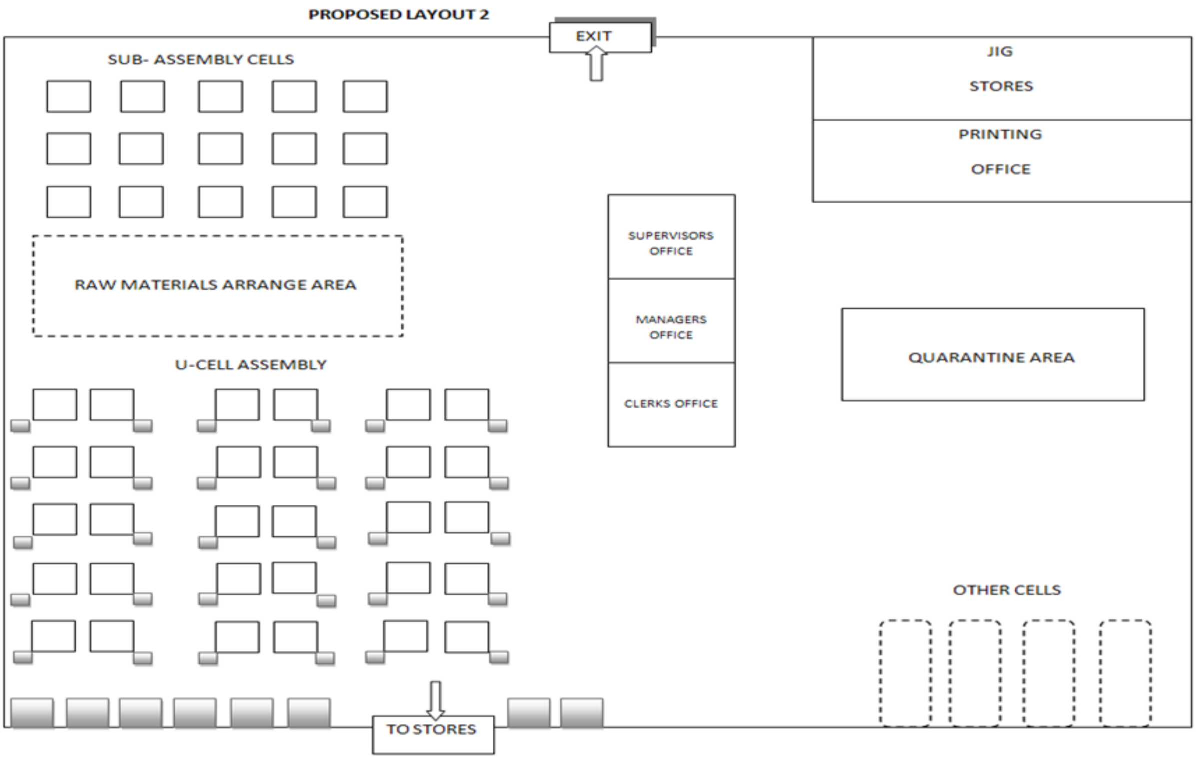

Figure 5: Proposed layout of the assembly department

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5.3 Qualitative results

Only significant responses related to the method study investigation are reported on in this paper. Poor working conditions and unrealistic working hours have a serious effect on morale and output. Pryce-Jones [39] states that employees who are most productive are also the happiest employees. Happy employees help their colleagues 33% more than their least happy colleagues; raise issues that affect performance 46% more; achieve their goals 31% more and are 36% more motivated.

A total of 54.8% of employees indicated that management do not motivate them to perform well. Management must ensure good working conditions in order to ensure job satisfaction. Employees need to be recognised for a job well done. As many as 29.8% of employees indicated that they were unhappy. There was, however, a very large percentage (14.3%) of missing answers. A very large percentage (48.8%) of employees indicated that they were not treated with respect by management. This is important for a healthy employer/employee relationships.

Employees were asked to indicate whether they understood the term productivity. The results revealed that 35.7% of employees indicated that they did not. This begs the question: "How does management expect employees to perform to their maximum and to look at opportunities for productivity improvement if they do not understand the basics of productivity?" It is imperative that management conduct training in the basics of productivity to inculcate a culture of productivity improvement in the assembly department.

During the method study investigation, five primary problems which hindered effective production were identified and employees were requested to indicate which of these problems they encountered the most. The results revealed that the major production problem was waiting for materials (63.1%). The assembly process was often held up owing to non-delivery of assembly components. Employees should not wait for raw materials as this causes bottlenecks in the operational processes which automatically, has a negative effect on the output.

6 LIMITATIONS OF THE RESEARCH

As with all research, this study was not without limitations (see Van der Merwe and Nienaber, [40], in Sookdeo, [41]. The typical limitations of qualitative research apply, Denzin and Lincoln, [42]; Marshall and Rossman, [43]. A limitation of this study was that it was conducted at one manufacturing organisation. Literature on method study was found to be limited and the researcher made significant references to Kanawaty [21]. Method study is not restricted to the manufacturing sector, and as future research the researcher intends to conduct a comparative study in the services sector.

7 CONCLUSIONS

As mentioned in the introduction of this paper, manufacturing environments are continually evolving and seeking efficient methods of working. They are continuously trying to outdo their competitors by producing quality products at the lowest possible price. Majumder [44] supports this by stating that in the current competitive climate, manufacturing processes are caught between the budding needs for quality, minimum production costs and short manufacturing times. This justified the necessity for the method study investigation to improve methods of working, ensure organisational effectiveness and improve productivity.

The objectives of the research were revisited to determine the extent to which they were achieved. The following noteworthy conclusions were drawn from this study:

Firstly, management need to implement method study investigations. The set procedure of method study must be followed during an investigation. Kanawaty, [21] asserts that method study must be conducted prior to work measurement in order to improve the methods of working before setting time standards. It is impractical to set time standards on inefficient methods of working. Process charts should be utilised to record all information of the present situation, to critically examine and develop improved methods of working. These must be defined, implemented and maintained by regular routine checks. The conclusion drawn from this is that if a method study is conducted systematically, the success of the investigation will be guaranteed.

The second objective concerns improving the layout of the work environment. During various industry liaisons, the author had observed many examples of employees working inefficiently. By conducting basic improvements using a common-sense approach, methods of working were improved. It is common knowledge that employees become very comfortable with their work environment over time and do not embrace change in a dynamic way. Continuous communication between management and employees could prevent resistance to change, [45]. Regarding the layout of the assembly department, it was recommended that only u-cell manufacturing be utilised in Company A.

The final objective of this paper reports on the results of the research instrument. The work environment must be conducive to working conditions which speaks to improved employee morale and job satisfaction. Management must treat employees with respect, motivate them to perform and then recognise their endeavours. In order to improve productivity, employees must be made aware of the positive impact of improved productivity. More importantly, management must conduct training in the basics of productivity to inculcate a culture of productivity improvement. Factors which hinder effective production must be identified and improved. In order to attain targets, all components for the assembly process should be readily available. Method study investigations ensure that employees do not wait for materials.

Managerial implications:

It is recommended that management instil a culture of efficiency. Senior management commitment is vital as it sets the example. The findings of this study may also be extended to the service sector. The essential contribution that this paper makes is that it provides organisations with a universally accepted, user-friendly technique (method study) to improve organisational effectiveness and productivity with minimal capital outlay.

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CHARACTERISTICS AND APPLICATIONS OF GEOTHERMAL WELLHEAD POWER PLANTS IN ELECTRICITY GENERATION

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ABSTRACT

The contribution of geothermal energy to the global electricity mix is very low and the growth in capacity is also limited compared to other renewable energy sources. This is mainly because of the long period it takes to develop a conventional power plant. Wellhead power plants can be used to realise early generation for investors by installing them on wells that have been tested and proven productive instead of being left idle during steam field development. This study concluded that wellhead can reduce the long wait to generate geothermal electricity and make some early return on investment. Although wellhead plants have lower efficiency and higher specific steam consumption than central plants, the use of combined cycle and cogeneration and optimum use of steam from a specific geothermal well make wellhead geothermal plants competitive. With a load factor of more than 0.7 and gestation period of six months or less, wellhead generation is a cheap and quick solution to base load electricity supply from geothermal energy and a means of developing geothermal electricity through decentralized generation.

Keywords: Geothermal wellhead power plants, central geothermal power plant, investment, load factor, geothermal electricity generation.

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1 INTRODUCTION

Electricity continues to account for over 40% of combined global energy demand and consumption [1]. Electricity generation alone accounted for 42% of global CO2 production in 2013 followed by transport which contributed 23% [2]. The rapid growth of electricity demand globally has led to more consumption of fossil fuels and increased discharge of greenhouse gases and other pollutants. Concerns over the environmental impact of fossil fuels have led to increased demand for renewable energy resources like geothermal [3, 4]. The word geothermal comes from two Greek words i.e. "geo" meaning earth and 'thermos' meaning heat [5]. The main advantage of geothermal in electricity is that it is renewable, it is ideal for baseload grid electricity supply and significant thermal applications [6, 7, 8]. With system reliability of 95% and even more, and a load factor of 90% and above, geothermal is what grids need for stability and reliability of baseload electricity supply [3].

Geothermal resources have significant untapped potential corresponding to 10,500 times known fossil fuels reserves [3, 9, 10]. Potential applications of geothermal are diverse and include geothermal heat pumps, direct heat/steam application and electricity generation [11, 12]. However, geothermal electricity contribution remains low globally with minimal annual growth compared to other renewable energy sources like solar and wind [13]. In the work of [3] about 100 GW capacity of geothermal remains untapped while annual growth in capacity globally is just 3-4% with a global share of electricity generation of just about 1%. According to [14] most geothermal electricity comes from central power plants whose capacity ranges 50-100 MWe and takes between 5 and 10 years to develop [3, 15].

This study seeks to highlight the characteristics of wellhead technology and propose their applications in the process of geothermal electricity project development and as an alternative technology in geothermal electricity generation.

2 PROBLEM STATEMENT

The total thermal energy content of the Earth is about 12.6 x 10^{24} MJ, while that of the crust is about 5.4 x 10^{21} MJ, which is over 100 million times more than world energy demand. In spite of this significant potential, only a small fraction of these resources are utilized. The growth of geothermal capacity is limited by the long period of time it takes to develop a central power plant and high risks involved [17]. Since a central power plant requires tens of production wells, with one well drilled after the other, a successfully drilled and tested well may wait for years to drill all wells requires for connection [3, 6, 7]. Though faster to develop, wellhead power plants seem to be inferior to central plants [21, 22]. There is a need to establish the potential of wellhead power plants as a feasible solution to challenges facing development and exploitation of geothermal resources which include long gestation periods and huge development costs and risks associated with project development.

3 GEOTHERMAL WELLHEAD POWER PLANTS

3.1 Description of wellhead plants

According to [15, 20] a wellhead power plant is "a modular miniature electricity generating plant that is installed within the confines of a geothermal well pad." Electricity generated from wellheads can be fed to the national or regional electricity grids or used in onsite power generation. Wellheads are small geothermal power plants that are installed at the well pad of a geothermal varying in size between 100kWe and 15 MW_e [23, 24]. According [16] wellhead plants assume the shape of a conventional geothermal power plant but on a smaller scale that use steam from a single well. The installation of a wellhead power plant can take 3 to 6 months after well drilling and testing. They are used to optimize production which is normally customized for a given well pad. This significantly overcomes the shortcomings of the traditional central geothermal power plant technology which takes up to 10 years for development and commissioning. Wellhead plants can be used in temporary or permanent mode [23].

Due to rapid expansion and high demand for geothermal electricity, the demand for wellhead power plants has significantly increased. Once the central power plant is constructed, the wellheads are removed and installed at other locations. According [15]. Wellhead units may be connected to geothermal wells with capacity up to 15 MW based on current technology using shorter steam lines as compared to central power plants. [14] noted that a wellhead generator is a road-transportable energy conversion systems of capacity 1-15 MWe but with a minimum practical size of 3-5 MWe based on economic considerations. Therefore wellhead power plants generally have a capacity of 0.1 MW to 15 MWe but cost-effective sizes vary with specific well characteristics and the technology adopted.

Wellhead technology involves using steam from geothermal wells that have been drilled, are productive but remain idle awaiting the development of a conventional geothermal steam power plant to generate electricity. In some cases, wellheads are built on a permanent basis on isolated geothermal wells which enables the investors to enjoy early electricity generation and cash flow before completion of a central power plant and continues generation from single or few production wells [19]. This uses idle geothermal resource between the time of successful completion of geothermal well drilling and construction & commissioning of the central or conventional geothermal power plant [3, 15]. In wellhead electricity generation, steam from a geothermal well is converted to electricity in a wellhead power plant unit that is installed just above or close to the drilled geothermal well. The plant has no steam field development except for brine and cooling tower blowdown disposal systems developed for a specific wellhead unit.

Wellhead power plants have much fewer permanent civil works and can be containerized or skid mounted for easy transfer from one well site to another [25]. This makes geothermal wellhead power plants simple and cheap to execute as compared to central power plants. Figure 1 shows an operating wellhead plant at Eburru in Kenya that was commissioned in January 2020.

Figure 1: Eburru 2.4 MW wellhead power plant [38]

3.2 Design and construction of wellhead plants

Wellhead plants are factory preassembled units and are generally supplied in 40ft ISO containers to the site with standardized key components to enable quick installation and dismantling [3.19]. According to [15, 20] the layout is comprises of various components like the steam gathering system consisting of steam pipes, valves, separator, used fluid level control and disposal, steam pressure control, flash water collection system and brine level control, the electric generator, steam turbine, non-condensable gas extraction system, electric power evacuation system and instrumentation and control systems.

Figure 2 gives a schematic illustration of a wellhead generating plant and shows the main elements of a wellhead power plant being cooling tower, generator, steam turbine, steam separator, silencer, simple steam piping, control containers and the production well.

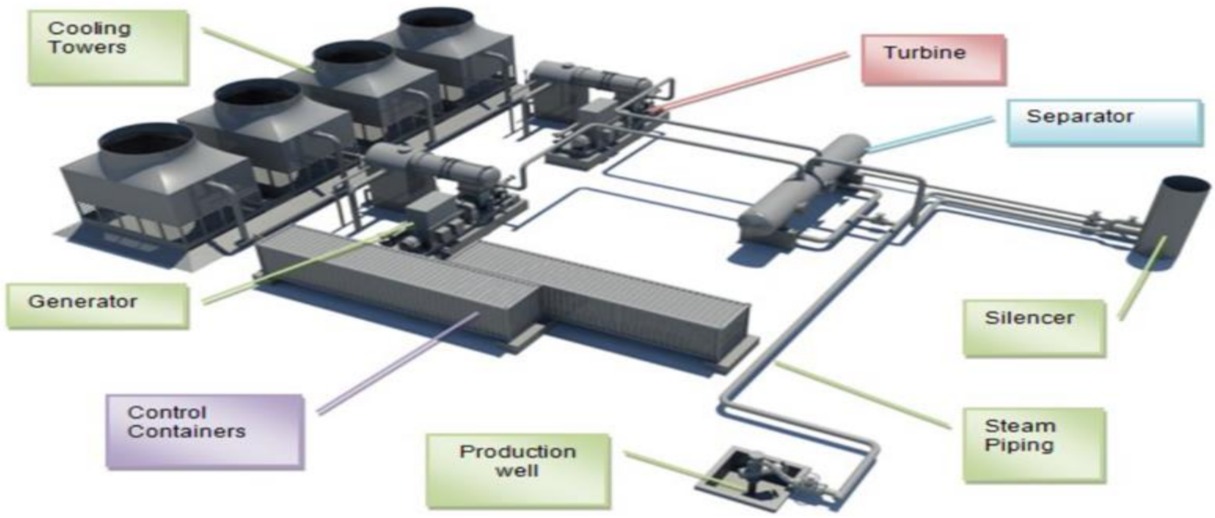

Figure 2: Wellhead generating plant [3]

4 GEOTHERMAL WELLHEAD VS. CONVENTIONAL PLANT

Larger equipment or plants enjoy economies of scale and are generally more efficient compared to smaller plants performing similar functions under the same operating conditions [23]. In this respect, Wellhead plants have a relatively lower efficiency and higher specific steam consumption than conventional geothermal power plants which is an indication that central plants are more efficient [15, 23].

4.1 Geothermal well characteristics and optimisation

For centralized power plants, steam separation pressure has an impact on the efficiency of the equipment. The selection of separation pressure involves analysis of characteristic curves of individual geothermal wells so as to select the optimal separation pressure that yields the highest total output. Since reservoirs according to [15, 23] are site-specific, power plants should be located just next to the specific reservoirs for optimum generation.

Steam from geothermal wells from the same steam field are rarely identical in characteristics. This means that the characteristics of each well need to be established separately for development of optimal power generation option. With a single pressure system for central power plants, wells operate at combined optimal pressure condition. As a result of this, some connected will remain underutilized at the separation pressure for having pressure above their closing pressure. This leads to lost generation that can be as high as 5-20 % of installed capacity [15, 23].

Therefore developing a field with wellhead instead of a large scale plant is an option technically worth considering. Since each geothermal field and geothermal well have different characteristics, it has to be analyzed separately before the design of the wellhead power plant. If the geothermal field has significant variation in individual well characteristics, wellhead power plants are more feasible option than central power plants. It is also practical to have, a mixed field development where both central power plants and wellhead plants are developed simultaneously [15, 23].

4.2 Geothermal fluid collection systems

Wellhead power plants are installed at the well pad or wellhead and therefore steam gathering system is minimal compared to central geothermal power plants. The effect is reduced cost of a piping system, pressure losses and visual pollution from pipe networks [3, 15]. Spent geothermal liquid needs to be disposed into the reservoir through re-injection wells which facilitate sustainable and environmentally friendly utilization of geothermal fluid. However, in wellhead power plants the reinjection fluid needs to be collected from each well pad and piped to the reinjection sites which is a drawback as it increases the cost of installation and operation cost [15, 23]. It also becomes uneconomical for an isolated well to have own reinjection well.

4.3 Control System for wellhead versus central power plant

Operations control in wellhead power plants is more complicated because the plants are widely distributed across the steam field with each wellhead plant having own control system similar to the large scale central plants and a group of wellhead plants will still need a centralized monitoring system making it comparatively more complex and expensive

4.4 Grid Connection System

In wellhead generation, often electricity evacuating is to a low voltage distribution grid which results in many trips of the plants and significantly reduce the capacity factor and other related operational and environmental challenges like in the case of Eburru power plant in Kenya where these trips also come with environmental pollution of surrounding human settlements [21]. The many wellhead power transmission lines interconnecting the plants and substations lead to visual impact just like the steam gathering system of large/central power plants. It is, however, optional to put the power lines underground resulting in some additional cost. Such an option is currently not considered feasible for steam gathering piping ([15, 23].

4.5 Non-Condensable Gas Emissions

Non-condensable gases mainly constitute of CO2 and H_2S and are well specific regardless of conversion technology of power plant configuration. There is however wider dispersal since it is well specific for wellheads [15, 23]. However, there is no impact on the quantity of emissions.

5 PERMANENT VERSUS MOBILE GEOTHERMAL WELLHEADS PLANTS

5.1 Application of Temporary and Permanent Wellhead Plants

Wellhead power plants may be developed as permanent power plants where it is technically difficult or is uneconomical to develop a central power plant. They can be developed as temporary generation units utilizing idle steam while awaiting the development of enough wells and steam for a central power plant development [3, 15]. Wellhead power plants can be used by investors to realize early electricity and revenue from discovered steam resources while steam field development is still progressing [3].

In this case, ease of shut down and relocation in terms of time is important. The downtime is influenced by the technology used and thus plant complexity. To minimize the downtime of the plants, civil engineering works for the new site should be ready before the dismantling of the plant takes place. During wellhead decommissioning and relocation in the case of temporary application, significant activities are undertaken. [15, 23, 27].

The temporary wellhead plants can be used for powering geothermal field activities and also supply power to the local or national grid. Permanent plants are used as a substitute for central power plants on a permanent basis normally in steam fields with significant wellhead characteristics and also where the wells are so widely spaced for steam interconnection (Kabeyi, 2020).

5.2 Differences between Temporary and Permanent Wellhead Plants

The differences between central power plants and geothermal wellheads can be summarized in Table 1. From Table 1, it is observed that it generally takes over 2 years to develop a central power plant upon the development of the steam field, but just 3 to 6 months to construct and commission a wellhead power plant depending on the technology used upon successful drilling of a steam well.

Table 1: Differences between central power plants and wellhead power plants [15, 35].

	PARAMETERS	CENTRAL POWER PLANT	WELLHEAD POWERPLANT
1	Set up period	Takes more than 2 years to set up	Takes between 3-6 months
2	Design& Customization	Not site specific.	Customized /specific site conditions
3	Well requirements	Use multiple steam wells.	Normally a well per plant
4	Plant Capacity factor	Higher capacity factor	Lower capacity factor
5	Efficiency	Higher efficiency	Lower efficiency
6	Electricity voltage	High voltage	Can use low voltage
7	Gaseous emissions	Well dependent or well specific	Well dependent or well specific
8	Operational Flexibility	Fixed	Flexible and portable hence mobile
9	Steam consumption	Lower per unit power	Higher per unit power

6 GEOTHERMAL WELLHEAD PLANTS AND SOCIO-ECONOMIC IMPACT

Geothermal power generation has some negative impact on the environment just like all other power projects arising from gaseous emissions, effluents and other undesirable audio-visual effects to levels that are dependent on the technology used. According to [15, 23]. Steam pipelines and power transmission lines have visual impacts. However, for wellhead power plants, the emissions are distributed over a wider area hence reducing the impact or intensity. Geothermal wellhead plants like the main plants have negative, environmental consequences. According to [21] one of the challenges of operating wellhead power plants is venting of geothermal fluid from production well as for the cases of Eburru EW-01 production well leading to silica deposits on neighbouring crop farms leading to protests and demand for compensation by farmers like in 2012. The main reason for frequent venting of wellhead well was:

1. High proportion of water in the steam from the production well
2. Frequent electricity power line tripping due to overload as the wellheads are connected to low voltage distribution lines hence subject to consumer trends.

7 OPERATIONAL AND ENVIRONMENTAL CHALLENGES OF WELLHEAD POWER PLANTS

Greenhouse gas emissions and global warming is the greatest environmental impact that should be considered in all power plants design and operation [32, 25]. Wellhead power plants just like conventional power plants come with several issues or challenges. Successful utilization of geothermal resources for electricity generation is dependent upon availability of almost zero emissions and efficient conversion technologies [29]. According to [30], unsustainable geothermal extraction practices previously caused several environmental issues like land subsidence and the disappearance of geysers in New Zealand. In Kenya blow offs occasioned by frequent trips of the Eburru Wellhead Plant have led to conflicts with local farmers due to deposits from geothermal well [23, 28].].

An extraction system is necessary to allow a condenser operate although CO_2 is often emitted to the surrounding, but an effort should be made to capture or isolate the non-condensable gases which pose an environmental pollution threat [29]. Though good for the environment, it becomes an economic burden for temporary wellhead plants. In the study by [22, 32, 33] on the environmental impact of Eburru wellhead power plant, it was established brine effluents composition exceeds acceptable limits, H_2S emissions exceeded the allowable limit of 0.0355 ppm why noise levels exceeded tolerant levels of 35dB [A] as far as 100 m away from the power plant. Of serious concern to the generation reliability and safety or security is that between 2014 and 2015, Eburru wellhead plant experienced 383 trips which are usually followed by venting and blow offs to the environment.

Therefore the operation and maintenance of geothermal wellhead power plants bring environmental challenges which must be addressed by developers in close collaboration with stakeholders. These challenges are brine effluent, noise pollution and repugnant smell from H_2S, and deposits on crops. Investment in technology to trap the non-condensable gases is important while reinjection besides managing pollution leads to sustainable resource management. The several trips raise concerns on the technical viability of the geothermal wellhead technology.

Although there are several environmental challenges of wellheads as mentioned above, the wellhead power plants have a positive net cash flow and generates positive revenue and profits for investors. Although the technical plant performance is lower than the central power plants which have over 95%, the wellhead plants at Olkaria in Kenya have plant capacity and availability of more than 70%, hence acceptable reliability. A Performance analysis of Eburru and Olkaria wellhead power plants showed that with tax and financial incentives, the payback period for wellhead plants is generally between 3.4 and 4.4 years for the plant and equipment alone while the ratio of profit after corporate to revenue ratio was between 0.643 and 0.686 between 2013 and 2016 depicting low operation and maintenance cost per unit power [15]. This is a positive contribution to the national grid supply and the investor technical and economic sustainability.

8 ECONOMIC/FINANCIAL BENEFITS AND FEASIBILITY OF GEOTHERMAL WELLHEAD PLANTS

Wellhead generators have several advantages which include acceptance for use in geothermal suites with strict size limitations like Japanese national parks which limit plant size to 7.5 MW, ease of transportation, ability to connect to lower voltage distribution lines, application in well testing while at the same time generating electricity, operation without auxiliary power source hence reduced installation cost, proving of quick return on investment, optimized power generation based on specific well conditions, ease of operation and maintenance, high degree of flexibility and low capital requirement [15, 25, 21,34].

8.1 Wellhead Power plant Revenue Analysis

Table 2 shows the revenue and operating profits for Eburru and Olkaria wellhead power plants in Kenya.

Table 2: profits for wellhead power plant [15].

YEAR	2013/2014	2014/2015	2015/2016
Gross Revenue (USD)	2,488,395.29	6,592,900.73	6,397,391.31
Annual budget expenditure	(201,312.52)	(134,655.18)	(429,085.93)
Gross Income	2,287,082.77	6,458,245.55	5,968,305.38
Provision for Tax at 30%	(686,124.83)	(1,937,473.67)	(1,790,491.61)
Net profit	1,600,957.94	4,520,771.88	4,349,292.83

Table 2 shows that wellhead power plants generate significant revenue for investors at lower operating costs. Therefore the return on investment is relatively high and attractive as permanent power plants.

A profitability assessment model showed that the payback period based on profit after tax is 4.4 and 3.4 years without corporate tax which indicates financial feasibility with a quick return on investment, reduced financial risk and early electricity ahead of the development of a central power station which often takes many years to complete Technically, wellhead plants have a capacity factor of over 70% which is acceptable as a baseload plant though operational challenges may threaten their sustainability [15,38].

8.2 Limitations/Disadvantages of Wellhead plants

The use of geothermal wellheads faces a number of challenges which include:

1. Each wellhead plant is complete with its own generator hence many similar equipment are needed for many wells in a steam field and this increases operation and maintenance costs.
2. Wellhead power plants have challenges of handling brine and effluents since most plants have no reinjection wells and this brings environmental concerns
3. Wellheads need many electrical transformers and transmission networks from a given geothermal steam field which can cause negative visual impact.

4. The long-term viability is yet to be established since for now they are commonly used for short term applications during the steam development stage.
5. There are queries on reliability and long-term economic viability of geothermal wellheads power plants due to several missing parts or equipment like reinjection systems although some are designed with these systems.

8.3 Application of Wellhead plants

Geothermal wellhead plants have a number of applications. Based on their characteristic technical and physical features, their applications include:

1. Powering of new geothermal field development operations mainly by temporary wellheads.
2. Use as auxiliary plants or stating power for the main geothermal plants
3. Wellhead plants can be used as permanent plants to supply electricity to the grid.
4. Used for onsite industrial applications where the wellheads can supply power to rural or remote industries located next to the plants.
5. Wellheads power plants can be used as peaking units for large installations where they supply peak power or excess demand.
6. Can be used as standby plants for the central plants where they supply electricity for auxiliaries during start-ups or when the main power plant is are down for maintenance.
7. The wellhead power plants can be used as a geothermal resource testing tool during geothermal development to prevent waste of steam during well testing.
8. Can be used as off-grid power plants for remote and isolated areas without grid power like military bases, remote villages, mines, isolated towns, tourist hotels and lodges in parks etc.

9 SUMMARY OF RESULTS AND FINDINGS

9.1 Results of the study

The results of the study can be summarized as flows for wellhead power plants and other small geothermal power plants. Table 3 shows that geothermal wellhead power plants are attractive and competitive geothermal electricity generation facilities and so can be used to accelerate geothermal electricity generation.

Table 3: Results of the study [15, 36, 37].

	PARAMETER	FEATURES/ CHARACTERISTICS	REASONS
1	Total Cost	Cheaper and simple	Fewer and smaller parts, systems compared to central power plants
2	Size	Smaller in size	Meant to produce electricity from a well or few hence limited capacity and size of plant
3	Sustainability of resource use	Less sustainable	Missing features like reinjection systems for many plants affecting sustainability of resource use
4	Generation Efficiency	Low	Wellhead plants are less efficient compared to central plants and have higher specific steam consumption. This

			is because they don't enjoy economies of size
5	Optimal resource use	Optimum in resource use	Wellhead plants are designed for specific well characteristics hence better resource utilization
6	Environmental impact	Better	Use of wellheads in a steam field may not reduce emissions but improves on dispersion compared to central power plants.
7	Technical feasibility	Feasible	Wellheads plants generate electricity although at a lower capacity factor and availability but the level is competitive and acceptable compared with other modes of electricity generation.
8	Investment risks	Low	Risks involved in resource development are lower since they are gradually introduced in small scale and can be dismantled and relocated easily.
9	Application	Permanent, & temporary	Wellhead plants can be used as permanent plants for wells that are too far apart hence uneconomical to develop steam gathering system and , for wells with too low or too high pressure within a given steam field
10	Electricity use/application	Grid and off grid generation	The flexibility and remote location of the plants can make them ideal for off grid application which the higher load and capacity factor and continuous generation make them ideal for base load supply.
11	Capacity	Up to 15 MW	Current technical capacity enable up to 15 MW wellhead generator capacity

9.2. Research Findings

The study showed the following findings about geothermal wellheads and small power plants:

1. The specific steam consumption is relatively lower in central power plants than the geothermal wellhead power plants hence more steam economy and power output per unit steam output.
2. Where a geothermal field has significant variation in well characteristics, wellhead plants becomes more feasible option than a central power plant.
3. It is technically feasible to have, a mixed field development where both central power plants and wellhead plants are used based on the varying characteristics of geothermal the geothermal steam field and individual wells.
4. The cost of backpressure wellhead power plants is lower than the condensing power plant, but the available power form the well is not as efficient in condensing or ORC plant meaning backpressure option is list efficient though cheaper technology option in wellhead power generation.
5. The CO_2 and H_2S emissions from geothermal wells is the same regardless whether they are connected to wellheads or central power plants. However for wellheads, these gases are dispersed over a wider area hence reducing the intensity and impact.

6. For geothermal field with significant variation in well characteristics, wellhead power plants as permanent installations can be used to ensure optimum generation from a geothermal steam field by optimizing generation from specific wells based on well's unique prevailing characteristics.
7. The central geothermal power plant has higher efficiency than the wellhead power plants and enjoy economies of scale in operation and maintenance.
8. The specific steam consumption for central power plant is lower than specific steam consumption of wellhead power plants for steam with similar properties.
9. For countries with stringent environmental regulations like Japan having significant geothermal resources in protected national parks, the use of wellhead power plants is recommended as opposed to central power plants since they have less environmental impact from pipelines and well emissions which are dispersed.
10. Reinjection of used geothermal fluid is a challenge with geothermal wellhead plants and a solution is to pipe the fluid to a reinjection well which is a cost especially where only one well exists.
11. The operation and control for several wellhead plants in a geothermal field is more demanding than a central plant since each wellhead has to be separately operated and controlled in addition to a combined monitoring system for all wellhead plants in a field.
12. A geothermal field with several wells leads to a network of several transmission lines in the field which can cause visual impact similar to the one caused by streamlines in a case of central power plant.
13. Transmission from wellheads is often done at low voltage distribution network/grid which is associated with overload trips and other operational challenges associated with operations of a single wells. This can cause related environmental challenges like blow off as the case of Eburru wellhead plant in Kenya.
14. Wellhead plants can be used as temporary or permanent plants. Where they are used as temporary plants, relocation time is an important consideration with backpressure turbine plants being the quickest and binary plants being slowest to relocate as they are more complex in construction.
15. The operation and maintenance of geothermal wellhead power plants brings environmental challenges which must be addressed by developers in close collaboration with stakeholders.
16. Atmospheric venting occasioned by wellhead plant trips, hydrogen sulphide gas odour, noise pollution and brine effluents disposal are the leading environmental concerns of geothermal wellhead power plant operations.
17. Most wellhead and small geothermal power plants do not use reinjection wells. Whereas this reduces costs, it compromises the overall sustainability of resource use in the long term.

10 CONCLUSION

Wellhead units can be connected to geothermal wells having output of up to 15 MW using current technology and steam resources, using less steam lines compared with conventional plants. The plants are standardized, easy to operate, move or transport, easy to operate, easy to maintain, fairly high reliability making them ideal for use as electricity source for field development operation, use as auxiliary plants for main plant, off-grid electricity application for remote areas. The plants are popular owing to their modularity and simplicity hence faster construction leading to short lead times compared to conventional central power stations. The simplicity of the wellhead power plant affects its efficiency and ultimately the utilization of the available geothermal resource as they are relatively less efficient. Wellhead plants can be designed for temporary or permanent applications and this may influence the selection of appropriate technology used. Since a portable geothermal wellhead plants are assembled on a common base then shipped to the site, the effect is reduced installation and adjustment work making it cheaper and faster to install and commission wellhead generators. Adoption of wellheads significantly reduces the time between completion of drilling and revenue generation from the steam or wells and minimizes wastage of drilled resource and shortens the period for return on investment (ROI) for drilling expenses making the investment attractive with reduced failure risks.

Wellhead plants use the same technologies like the big central power station but on a smaller scale leading to lower efficiency and higher specific steam consumption (SSC). To compensate for reduced efficiency and availability combined heat and power application is encouraged. Geothermal heat application includes agriculture, industrial processes like distillation and district heating. In geothermal project execution, Wellheads can be used as predecessors of central power plants for early generation revenue generation hence temporary application or permanent application where limitations like environmental regulation and too much variation in wellhead characteristics in a steam field. However, for long term investment decision, there is need to carry out technical, financial/economic and environmental feasibility although preliminary analysis shows significant economic returns from wellhead power plants besides early generation and mitigation of greenhouse gas emissions.

11 RECOMMENDATIONS

The biggest impediment to the development of wellhead generators is uncertainty concerning long term economic and technical viability. Whereas a straight economic comparison between wellhead power plants and central power plants indicate that wellhead plants may not compete favourably, they possess unique and desirable characteristics which can offset the economic disadvantages for certain applications. These desirable characteristics include reusability, low capital investment, portability, and rapid power production ability. Studies into the economic viability of wellhead power plants need to be done to quantify the benefits.

Further investigation into the long term environmental and technical sustainability of geothermal wellhead power plant needs to be done. The wellhead power plants design need to take care of noise pollution, reinjection of noise the hydrogen sulphide repugnant smell which is a major environmental concern for operating wellhead plants like Eburru in Kenya. More studies needed to determine the long term effect of this pollution on the environment to guide future investment in geothermal wellhead power plants.

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PERFORMANCE ANALYSIS OF DIESEL ENGINE POWER PLANTS FOR GRID ELECTRICITY SUPPLY

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ABSTRACT

Diesel engines play a critical role in stabilizing the electricity grid and provision of emergence and peak load supply. This study analyzed the role of diesel power plants in generation and supply of grid electricity with performance analysis of Kipevu I power station. The study established that the main challenges of diesel power generation is low plant use factor, low capacity factor, low plant availability and high cost of operation and maintenance and hence high cost of power. Long procurement procedures and low technical capacity are responsible for the high plant downtime and hence low availability while high operation and maintenance costs including cost of heavy fuel oil are the main reasons for high electricity cost. The study recommends cogeneration, contract management and efficient procurement system for spares.

Keywords: diesel engine, diesel powerplant, diesel power generation, engine maintenance, powerplant operation.

1 INTRODUCTION

Electricity is a very important resource for all economies globally. The global electricity demand is expected to grow at an average of 2.11% between 2019 and 2040. The growth between 2010 and 2018 was much faster which puts pressure on transmission and distribution infrastructure. The challenge facing electricity market is that generation and demand grow faster than transmission and distribution networks, leading to reliability issues such as power outages and surges hence the need for back up and emergence power. Diesel generators are commonly used to fill these deficit [1]. The global energy consumption as in 2012 stood at 104,426 TWhr with fossil fuel being the largest contributor. Electricity accounted for about 18.1% of the total energy consumption in 2012. In 2013 the world electricity generation was about 23,322 TWhr of which 41.3% was from coal, 21.7% from natural gas, 16.3% from hydro, 10.6% from nuclear, 4.4% from oil and 5.7% from renewable sources such as geothermal, wind and solar [4]. In 2004, between 10% and 15% of global electricity production, came from diesel engine power generation whose main application globally is use as standby and emergency applications by hospitals, airports, hotels, industry, and most utilities that need reliable power throughout [6]

Power generating stations in which diesel engines are used as the prime movers for electric generators are known as diesel power plants [3]. The diesel burns inside the engine and the products of this combustion act as the working fluid to produce mechanical energy by expansion action on engine pistons. The diesel engine drives alternator which converts mechanical energy into electrical energy. Diesel power generation costs are significantly high because of the cost of diesel fuel and are therefore suitable for short term small generation [2]. The main challenge of diesel power is environmental impact due to emissions and high cost of power which is 2 to 3 times the cost of power from renewable energy sources. Diesel engines also have a lower thermal efficiency of about 35% [1, 20]. The continued use of diesel power plants for electricity generation is often prompted by seasonal variability of hydropower due to drought. Due to this, diesel power plants are still used to supply peak and base load electricity for public grids in many developing countries [4, 2, 3].

This study examines diesel power generation to establish its feasibility in supplying reliable and cost effective electricity to the public grid by carrying out a performance analysis of Kipevu I power station in Kenya to determine challenges facing diesel engine power generation for grid electricity.

1.1 Problem Statement

Energy is a critical ingredient for sustainable development making it necessary to have secure, adequate, and competitively priced supply while maintaining the environmental integrity [7]. Electricity supply and consumption directly support economic activities, with energy being an input in almost all major economic activities in all countries [8]. Although diesel power plants play a significant role in stabilization of the grid and supply of peak power and emergency power, they are the major cause high electricity cost, because the consumer has to fully meet the fuel cost in addition to the actual energy cost. Diesel power generation costs about $0.35 per kWh, while the cost of geothermal ranges from $0.08 to $0.09 per kWh, according to the government of Kenya [10]. This high unit cost can be attributed to high maintenance, operation, fuel oil and lubrication costs typical of diesel plants. The price of power from diesel power plants consists of the fuel element and the electricity or energy part unlike other power plants like geothermal and hydro where the price consists of just the energy or electricity portion. This study targeted Kipevu I power station because it has the worst performance among diesel power plants in terms utilization and capacity factors [5, 3, 4].

2 DIESEL POWER GENERATION

2.1 Global And Regional Status

Diesel power plants are quick to develop and are cheaper per kW capacity compared to renewable energy and low carbon sources and high degree of operational and expansion flexibility, wide fuel use, high reliability and generally higher efficiency at part load and part capacity as well as black start capability. However they are expensive to operate and maintain due to high fuel costs and more repair costs, overall making them more expensive and polluting to the environment [23].

Unreliable supply from power utilities have forced many investors to install backup generators mainly as diesel generator sets for own electricity generation while utilities higher emergency generators to meet shortfalls in generation and quality of power [23]. On average, emergency power constitutes 6% of total installation capacity for Sub Saharan Africa making it about 750 MW. In some sub-Saharan countries, emergency power has contributed a very big proportion of installed capacity at its peak for example Uganda realized 47.7%, Rwanda 48.4% and Angola 18.1 % [22]. This shows that diesel power plants contribution to electricity grids of many developing countries.

2.2 Power Plant Performance Indicators

Fossil fuel power plants dominate electricity generation globally contributing 65% of the total electricity supply, with coal alone accounting for 40% of the total. The average efficiency of all thermal power plants running on fossil fuels (coal and gas) is around 33% [20] and for diesel power plants about 35% [21, 24]. The best performing fossil fuel power plants have efficiency of 47-49% with coal and over 60% for natural gas. Various power plant performance indicators are used to measure performance of different power plants with no simple way to measure overall plant performance. Power plants are expected various objectives which reliability economic, environmental, societal and other. The objectives differ from one power plant to another [20, 21].

2.2.1 Efficiency

Overall efficiency of a thermal power plant is defined as the ratio of heat equivalent of electrical power output to the heat of combustion supplied [24]. Design heat rates vary significantly based on plant type. Within each category, actual heat rates may vary by as much as 10-15% from factors including base or peaking load, load gradients, normal degradation, fuel source, how well the plant is operated and other indicators [20,25]. Therefore efficiency of a plant is a factor of both design, operation and maintenance.

2.2.2 Availability

Availability is the percentage of energy the unit can generate over a given period of time, relative to its design capacity over same period usually a year i.e. 8760 hours. Availability is affected by all outages and restrictions due to both planned and unplanned events. It is not however affected by dispatch requirements by the utility company with maximum availability possible being 100% [20, 25].

2.2.3 Capacity factor

Capacity factor is the ratio of actual output over a period of time, to its potential output if it were possible for it to operate at full nameplate capacity indefinitely. It is ratio of energy the plant produced during a period of time to expected production at nameplate capacity for the entire period being considered. Capacity factor is influenced by design, type of fuel and operational regime. Capacity factor is reduced by both planned and forced outage and load limitations [20, 25].

2.2.4 Reliability

Reliability of a power plant is the probability that it will operate for a given period of time without failure for prevailing operating conditions. Power plant reliability is a function quality of design, plant endurance, consistent quality, maintainability and dependability of the power plant systems. The highest possible reliability is 1 or 100% and depends predominantly on quality of operation and maintenance [24]. Therefore

Reliability = (Expected running hours - Downtime)/Expected or planning running hours.

2.3 Diesel Power Generation in Kenya

Kenya’s electricity mix was dominated by hydropower for quite some time which is affected by drought and seasonal availability of rainfall. In the year 2000, hydropower capacity dropped from 501 MW to just 104 MW due to severe drought just between July and December. These lead to a massive deficit of about 126 Gwhr equivalent to 173 MW average load capacity and peak deficit of 370 MW hence the urgent need for huge power rationing across the country creating huge demand for emergency electricity supply [16, 21].

As of June 2017, Kenya's total installed electricity capacity stood at 2,333 MW with 69% amounting to 1610 MW coming from publicly owned KenGen’s. Independent Power Producers (IPPS) supplied the rest of the electricity mostly from diesel power plants. Of the total installed capacity, 12.2% came from thermal/diesel sources [7, 15].

2.4 Diesel Power Plants in Kenya

The electric power sector was earmarked as an important sector by the national development plan of 1994- 1996 but it heavily relied on hydroelectric power for about 77% electricity supply. With prolonged drought and continued growth of electricity demand, Kipevu 1 diesel power plant was installed followed by [12, 13, 15].

Table 1: Plant Capacity of Diesel Plants [12, 13, 15].

Power Plant	Installed Capacity (MW)	Effective Capacity (MW)	Capacity Factor	Ownership
Kipevu 1	73.50	52.30	0.71	GOVERNMENT/PUBLIC
Kipevu 3	120.00	115.00	0.96	GOVERNMENT/PUBLIC
Iberafrica	108.50	108.50	1.0	PRIVATE
Tsavo	74.00	74.00	1.0	PRIVATE
Rabai	90.00	90.00	1.0	PRIVATE
Thika	87.00	87.00	1.0	PRIVATE
Gulf	80.32	80.32	1.0	PRIVATE
Triumph	83.00	83.00	1.0	PRIVATE
TOTAL/AVE	**716.32**	**690.12**	**0.96**	

3 COST OF ELECTRICITY

The cost of diesel power is divided into fuel cost and cost of energy. Table 2 below shows the cost of electricity from various power plants in Kenya.

3.1 Energy Cost For Various Types of Power Plants

Table 2: Electric Cost for Different Power Sources [11].

Station	Energy Cost A (Ksh/Kwh)	Fuel Cost B (Ksh/Kwh)	Total Variable Cost A+B (Ksh/Kwh)
Major hydros	0.080	0.000	0.080
Olkaria 2	0.099	0.000	0.099
Orpower4-plant 2	0.417	0.000	0.417
Orpower4-plant 3	2.829	0.000	2.829
Orpower4-plant 1	2.829	0.000	2.289
Olkaria 1-AU	3.017	0.000	3.017
Olkaria 4	3.017	3.017	3.017
Olkaria 1	3.087	0.000	3.087
Imenti tea factory	6.131	0.000	6.131
Wind(Ngong)	6.162	0.000	6.162
Sangoro hydro	6.628	0.000	6.628
Small hydros	7.899	0.000	7.899
Rabai power 2	0.942	7.140	8.081
Kipevu diesel 1	0.298	7.900	8.198
Kipevu 3 diesel	0.806	7.609	8.414
Rabai power 1	0.942	7.535	8.476
Wellhead(ow37& 43)	8.686	0.000	8.686
Eburru hill	8.686	0.000	8.686
Gikira hydro power	10.219	0.000	10.219
Iberafrica-additional	1.076	9.410	10.485
Iberafrica-existing	1.162	10.051	11.213
UETCL (tie line)	6.875	9.393	16.628
Thika power 2	1.167	15.230	16.397
Thika power 1	1.167	16.455	17.621
Tsavo power	1.061	17.239	18.300
Triumph power 2	1.013	17.307	18.319
Triumph power 1	1.013	18.082	19.094

Gulf power	0.771	18.424	19.195
UETLC (Requested)	6.875	13.346	20.221

3.2 Energy Cost for Diesel Power Plants

Table 3 below shows the energy cost, fuel cost and total variable cost for Kipevu 1, Major hydros, Olkariia 2, Kipevu 3 and Rabai power stations for comparison.

Table 3. Energy Cost for different Diesel Power plants [10].

Station	**Energy Cost A KSH/kWhr**	**Fuel Cost B KSh/kWhr**	**Total Variable cost**
Kipevu 1	0.298	7.90	8.198
Major Hydros	0.08	0.00	0.08
Olkaria 2	0.099	0.00	0.099
Kipevu 3	0.806	7.609	8.414
Rabai Power 2	0.942	7.140	8.081

Figure 1 shows the fuel cost in red and energy cost in blue for the above power stations

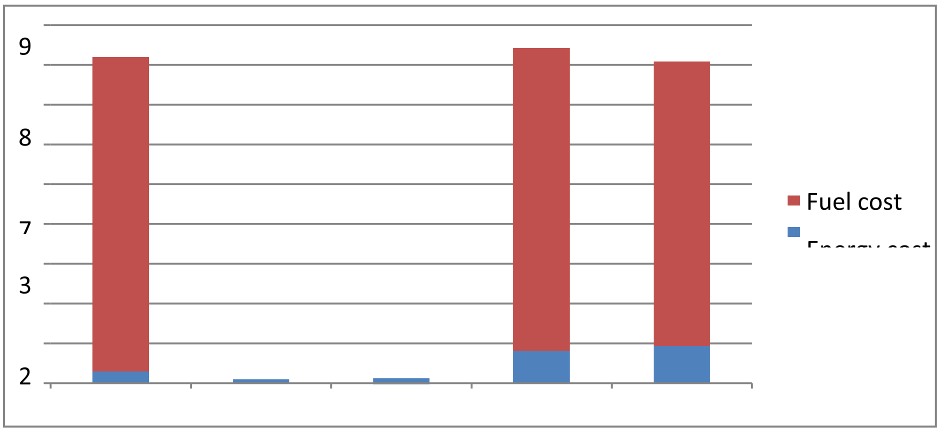

Figure 1: Variable Unit Costs Of Power [11,13, 14].

4 DIESEL ENGINE POWER PLANT COMPONENTS AND LAYOUT

4.1 Layout of Components

For a complete diesel power plant, several components and systems are assembled together with the engine and generator being the primary equipment. Figure 2 bellow illustrates the basic components and systems in a diesel engine power plant

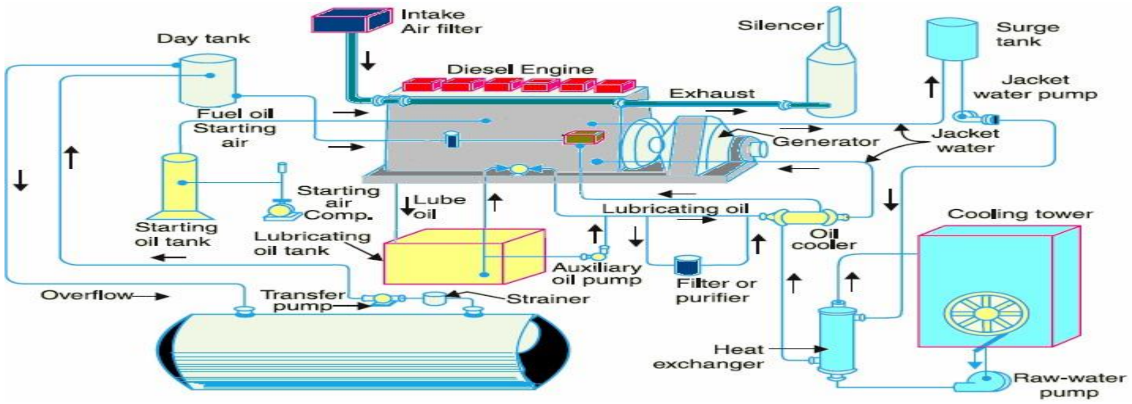

Figure 2: Components of a Diesel Power Plant [18].

From figure 2, the main systems include fuel oil handling and heavy oil treatment systems, fuel storage and treatment tanks, fuel heating seating, instrument compressed air system, engine starting compressed air, black start generator, lubrication system, engine cooling system, exhaust system, air intake system among others [2, 3].

4.2 Performance parameters

4.2.1 The Diesel Engine

The prime mover for diesel power plants is the diesel engine running on IDO or HFO Kipevu 1 engines are started on Industrial diesel oil (IDO) but change over to heavy fuel oil (HFO) before full load and vice versa[19].

4.2.2 Engine Performance Criteria

Performance of an engine is determined by a number of indicators or criteria, namely indicated power, fuel power, brake power, brake thermal efficiency and indicated thermal efficiency, specific fuel consumption among others [2, 3].

4.2.3 Brake power

$Bp= 2\pi NT/60$

Where: T is the torque in Newton-meter (N-m)
N is the angular velocity in revolutions per minute (rpm)

4.2.4 Indicated power

This is the power developed by combustion of fuel in the engine cylinder. It is given by; $Ip= PVNK/60$
Where: P is the mean pressure
V is the displacement volume of the piston K is the number of cylinders

4.2.5 Friction power ($F_{.P}$)

This refers to the difference between indicated power and brake power. It represents all the losses of the engine mainly due to friction, leakages and incomplete combustion. $F_{.P}=Ip-Bp$

4.2.6 Mechanical efficiency (η_M)

It is given as the ratio of brake power to indicated power as a percentage. η_M= Bp/Ip *100%

4.2.7 Indicated thermal efficiency (η_i)

This is the rate of indicated power to thermal input.

η_i= Ip/fuel power
Fuel power= m_f*C_V where mf is mass flow rate and C_V is lower calorific value

4.2.8 Brake thermal efficiency (ηB_p)

This is the ratio of brake output to thermal input. ηBp=Bp/mf* C_V

4.2.9 Specific fuel consumption (sfc)

It is a measure of the fuel used to generate a kWh of power. It is given by the ratio of brake power to the product of mass flow rate and volume flow rate.

Sfc= Bp/mf*Qnet

5 MATERIALS AND METHODS

5.1 Data Collection and Analysis

Data collection was coordinated and purposefully done by two research assistants with guidance from the first author who worked in the power station between 2016 and 2012 as both operations and maintenance engineer. Interviews, document analysis, and questionnaire were used to collect both qualitative and quantitative data. Documents accessed include daily operation reports, monthly and annual reports, as well as machine operation and maintenance manuals with authority of the company (KenGen). Data collected was analyzed and presented using both quantitative and qualitative techniques.

5.2 Construction of Kipevu 1 Diesel Engine Power Plant

Kipevu 1 was commissioned in 1999 and is government owned though KenGen. The power from the plant is used to stabilize the voltage of power in the coastal city. [16]. Kipevu 1 has six MAN B&W 9L58/64 engines each with a capacity of 12.25MW bringing the total capacity installed at the station to 73.5MW. The effective capacity of the plant is 52.3MW.

Figure 3: Kipevu 1 Power Plant [15].

6 RESULTS AND DISCUSSION

6.1 Engine Data

The power plant has 6 engines with a capacity of 12.25 MW each thus an installed capacity of 73.5MW. The effective capacity of the plant is 52.3 MW. Currently, the plant has five running engines due to a total failure in one of the engines. Table 4 below shows the engine parameters.

Table 4: Engine capacity

Parameter	Value (MW)
Engine make	MAN B&W 9L58/64
Indicated power	12.5384
Effective capacity	8.72
Brake power	10.4595
Thermal effciency	83.7%
Friction power	2.07897

Table 5 below shows other engine design specifications.

Table 5: Engine Specifications (Engine Operation and maintenance manual).

PARAMETER	**VALUE**
Number of cylinders (N)	9
Bore diameter	580mm
Length of stroke (L)	640mm
Engine speed (N)	428 rev/min
Fuel consumption	0.214kg/kWh
Fuel's calorific value	42000kJ/kg
Mean effective pressure (Pme)	23.1bar
Ignition pressure	150bar
Compression pressure	135bar
Mean piston speed	13.2m/s
Compression ratio	9.1
Sense of rotation	anticlockwise

Calculations:

6.1.1. Indicated power (Ip)

$$\text{Ip} = \frac{Pme.LAN.K}{60 \times 1000 \times 2}$$

$$= \frac{23.1 \times 0.64 \times 0.58^2 \times 9 \times \pi}{1000 \times 4 \times 2 \times 60}$$

=12538.4212 kW.

6.1.2. Brake power

$$Bp \ = \frac{2\pi NT}{[60*1000]}, But\ torque, T = P * 9.5488/N$$

Year	Power generated (GWh)
2010/11	223
2011/12	256
2012/13	185
2013/14	220
2014/15	157
2015/16	129

$$= 10460 * \left[\frac{9.5488}{428}\right]$$
$$= 233365.53 N.m$$

$$Bp = 2\pi * 233365.53 * \frac{428}{[60 * 1000]}$$
$$= 10459.4559 KW$$

6.1.3. Mechanical efficiency

$$\eta = \frac{\text{bp}}{\text{ip}}$$

$$= 10549.4559/12538.421$$

$$= 0.834 = 83.4\%$$

6.2 Electricity Generation Data

Table 6 below shows the electricity generation data as extracted from company generation reports

Table 6: Power Generated At Kipevu 1 over the Last Six Years (KenGen, Annual Generation Reports)

The power used domestically within the plant is 3% of the total power. The number of engines running per day depends on demand.

6.2.1 Load factor

Load factor is a measure of generation realized against effective or maximum capacity of the power station. Effective capacity is less than the design or nameplate capacity due to various operational and technical factors including fuel condition and environmental conditions.

$$\text{Load factor} = \frac{Average\ load\ of\ the\ power\ station}{Maximum\ load\ of\ the\ powr\ station}$$

$$= \frac{50.731}{60}$$

$$= 0.85$$

This implies that 85% of the effective capacity of the power plant is utilized in loading the plant.

6.2.2 Capacity factor

Capacity factor is an indicator of how much of name plant or design capacity of the diesel engines is loaded. High capacity factor shows excellent loading of the engines with respect to capacity.

$$\text{Capacity factor} = \frac{Average\ load}{Rated\ capacity\ of\ the\ powerplant}$$

$$= \frac{50.731}{73.5}$$

$$= 0.69$$

6.2.3 Plant use factor

$$\text{Plant use factor} = \frac{Actual\ power\ genenarated\ \ for\ the\ year}{Installed\ capacity \times Dutation\ of\ the\ year}$$

Table 7 below shows a summary of plant use factors between 2010 and 2016 as shown by company generation data.

Table 7: Plant Use Factor for a Period Six Years

	Year	**Plant use factor**
1	2010/11	0.346
2	2011/12	0.398
3	2012/13	0.287
4	2013/14	0.342
5	2014/15	0.244
6	2015/16	0.200
	Average	**0.30**

The plant use factors calculated over the last six years have been low and continue to go lower with an average of 0.3. The reduction of availability may be partly due to aging of the plant hence more downtime and reduced use of diesel power as Kenya increased its use of geothermal electricity for base. Therefore, based on loading characteristics, the power plant is ideal for peak and emergence applications.

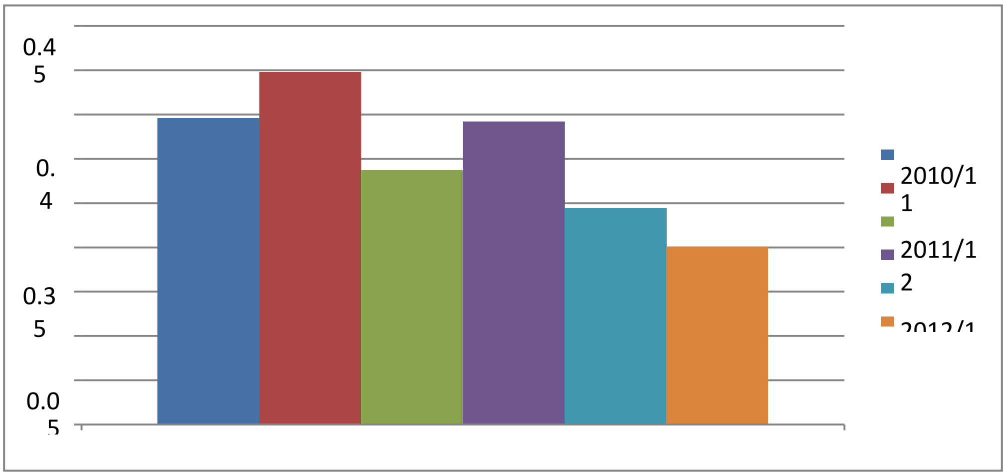

Figure 4: Plant Use Factor Trends

6.3 Operation and Maintenance Data

Kipevu 1 has a low and declining availability and reliability mainly due to low quality maintenance which has ensured that the machines breakdowns are relatively many and it takes long and occasionally years to avail an engine after a major failure. Planned maintenance has often delayed and omitted due to lack of spare parts.

6.4 Plant maintenance

The power plant applies different types of maintenance namely preventive, predictive and corrective maintenance

6.4.1 Preventive maintenance

Preventive maintenance is conducted to keep the plant and equipment in working condition or to extend the life of plant and equipment. This include planned maintenance as recommended by the manufacturer and condition based maintenance. These include routine maintenance after 200 hrs, 1500 hrs, 4,000 hrs, and, 8,000 running hours, as specified in the engine operation and maintenance manual. Preventive maintenance applies to the engines and auxiliary equipment since their performance also affects availability and reliability [25]. Common preventive maintenance practices included lubrication and greasing, gland packing adjustments, oil change, topping up of water, tightening loose bolts, vibration monitoring, temperature monitoring etc. Therefore condition based monitoring is a form of preventive maintenance.

6.4.2 Predictive maintenance

This refers to measures put in place to identify a failure risk and managing it before failure or the plant reaching critical state. Specific indicators could be used to predict a potential failure. Instrumentation plays a critical part in predictive maintenance. For Kipevu 1 predictive maintenance activities include laboratory analysis of fuel and lubrication oils for contamination and quality, vibration sensors for the turbochargers, cylinder temperature monitoring, cylinder peak pressure monitoring, lube oil levels and quality to determine any water leakages. Exhaust gas monitoring can also be used to determine the quality of combustion, but these system is was not operational. Combustion quality influences engine thermal efficiency and output and so should be monitored [20, 23].

6.4.3 Corrective maintenance

Corrective maintenance is also called repair or breakdown maintenance and as the name suggests, it is maintenance done ones the equipment has failed and so cannot continue running or operating. The main challenge facing Kipevu 1 is long procurement procedures for spares and technical services from manufacturer and third parties for quick and quality repairs. Contract management and exemptions from the public procurement act which slows down the process may help [23, 25].

6.5 Plant Availability

Plant availability is a function of plant operation and maintenance. Table 8 below shows a summary of plant availability between 19999 and 2016 as extracted from generation reports. Plant availability is a function of plant quality of maintenance and operation of plant and equipment hence the need for availability of quality spares, and qualified, well trained and competent operation and maintenance personnel in an enabling environment.

Table 8: Plant Average Percentage Availability [15]

	Year	**Average Availability (%)**
1	1999/1999 (commissioning year)	90.9
2	1999/ 2000	81.9
3	2000/ 2001	78.04
4	2001/ 2002	69.78
5	2002/ 2003	60.32
6	200/2004	64.74
7	2010/2011	74.78
8	2011/2012	66.18
9	2012/2013	94.02
10	2013/2014	85.38
11	2014/2015	77.42
12	2015/2016	76.95
	AVERAGE	**76.75**

It is noted from table 8 that availability was between 70 and 91 between 1999 and 2003 when engine No.2 governor failed rendering the engine unavailable for two and a half years until August 2005 [16].

6.6 Legal and Policy Framework

As a government institution, KenGen must adhere to the public Procurement Act which stipulates procedures for procurement of spare parts and other critical inputs. This long tendering process makes it impossible to urgently access spare parts that are needed. This is experienced in Kipevu 1 and other government owned diesel plants but is not the case for the independent power producers. The IPPs have supply contracts from specific suppliers making the acquisition of required parts easier and faster. These private entities are not required by law to be subject to the Public Procurement and Asset Disposal Act 2015.The procurement process is summarized below;

Figure 4: Procurement plan at Kipevu I

6.7 Power Purchase Agreements

Power purchase agreements are the agreements signed between any power producer and the power distributer to whom they sell their power. In this case a power purchase agreement exists between Kipevu 1 power plant and KPLC. The initial PPA was bulk power based where payments were based entirely on electricity supplied to the grid. Modifications are however done from time to time to accommodate changing times. These PPAs attract high penalties for unavailability which are usually paid by the plant. These penalties have no direct bearing on the cost of power but affect the plant's profitability.

7 CONCLUSION

Kipevu 1 power plant continues to face relatively poor performance compared to privately owned power plants. A combination of condition based, preventive and quick response to breakdown maintenance will improve the power plant performance in terms of capacity factor and availability. Adequate instrumentation of plant and equipment will enhanced condition based maintenance. However the delays in procurement of technical support services and spare parts have contributed to poor performance of Kipevu 1 power plant compared to privately owned and operated plants. Fuel costs are also high and are passed down to the consumers making cost of diesel power higher than geothermal and hydroelectric sources.

Long procurement processes in acquisition of spare parts and specialized service cause long downtime and reduce plant availability. With penalties for poor performance by utility company, the investor's income is negatively impacted compromising the power plants sustainability and continued operation. The poor performance makes the plant unsuitable for base load power supply to the grid. The privately managed diesel power plants have higher availability and capacity factor implying better operation and maintenance practices than the publicly owned Kipevu I. Ultimately contract management and overhaul of procurement and maintenance practices will effectively improve the performance of the power plant and reduce cost of generation and hence price of electricity.

8 RECOMMENDATIONS

Efficient and economical operation and maintenance of diesel engine power plants calls for technical, policy and legislative measures. Diesel power plant operators should overhaul their technical and operational systems to ensure quality and timely services to supplied quality, affordable and reliable power. Technically it is necessary to build the technical capacity in terms of skills and tools to ensure quality and timely maintenance. Delay in procurement of technical services can be reduced by contract management, subcontracting and exemption from the requirements of the public procurement act for critical spares and services. Fuel cost can be reduced by development of combined cycle plants while shift to gas from diesel or HFO is another fuel cost saving measure. These will also reduce environmental impact of diesel power plants. For off grid operations which often rely on diesel power plants for remote towns with no grid, it is recommended that hybrid systems are used. These systems combine diesel generators with renewable sources like wind, solar or both for 24x7 stable electricity supply.

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IMPLEMENTATION OF 5S PRINCIPLES IN MECHANICAL ENGINEERING LABORATORIES OF UNIVERSITY OF SOUTH AFRICA, SCIENCE CAMPUS, FLORIDA

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ABSTRACT

The 5S principles are used to establish and maintain a quality environment at university laboratories. This paper presents the implementation of the 5S principles in mechanical engineering laboratories of the University of South Africa in order to optimise the practical work, workspace and safety of the university laboratories. The outcome of this research study will be implemented in other faculties. A working model was developed to create a 5S structure and implementation process. Implementation of these principles improved equipment utilisation, created a clean workplace, improved safety in the labs, enabled equipment identification and created more space around the labs and machines.

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1 INTRODUCTION:

The rapid growth of university laboratories has led to the need for better management of these laboratories in order to provide a safe, clean and healthy environment. The statutory laws on health, safety and environmental protection have also assumed a bigger role today [1]. Housekeeping and workplace organisation should be among the first steps to improve organisation image. By practising the principle of a place for everything, and everything in its place, standardised operations will be developed [2]. Management by exception will be easily practised. Furthermore, people who take pride in their workplace will be more likely to produce high-quality products and services [2].

Researchers have found some differences in the methods used in Japanese car manufacturing, especially in Toyota. These methods are called lean. The model first gained ground in the car industry but nowadays it is the leading manufacturing philosophy in almost every field of operation [3]. 5S may be considered as a tool of lean as it reduces waste and adds value to the process. It is a low-cost technique used by organisations to clean, order, organise and standardise the workplace. In the early 1980s, the concept of 5S was developed by Takashi Osada. The techniques consist of five steps stated in Japanese as Seiri (sort), Seiton (set in order), Seiscou (shine), Seiketsu (standardise) and Shitsuke (sustain). It may be combined with other tools such as Kanban, Kaizen, total preventive maintenance and total quality management in addressing pertinent issues in the workplace [4]. It is a tool that allows control of the workplace visually [5].

With the intention of improving efficiency, eliminating waste and increasing process consistency [6]. In the simplest terms, lean manufacturing can be described as the elimination of waste [7]. These methodologies have proven that they are viable to increase the performance of production processes and obtain competitive advantages to remain on the market. The integration of 5S entails an intense process by which “system weaknesses are analysed to thus be able to determine the areas where lean could be applied” [8]. The significance of education in the development of a nation cannot be underestimated. It is education that develops expertise, excellence and knowledge, leading to the universal development of any economy [9]. Scholars state that 5S is a management method of the work area as a consequence of the application of the Kaizen culture [10].

Creating knowledge through insight gained by practical experience has become an integral part of undergraduate STEM education [11]. Universities and technical colleges aim to close the gap between theory and industrial practice using educational laboratories. These laboratories have technical resources and comparable functional characteristics with industrial facilities [12]. A neat and clean workplace can be a model of a good work culture. It reflects service quality and creates an image of excellence about the institution. Laboratories as one of the components supporting university services should be neat and clean workplaces [13]. Countless scientific articles have presented cases where the 5S methodology was implemented and produced extremely positive results. In the small-scale manufacturing industry, various authors have demonstrated that, at different intervention intervals, this practice generates several benefits such as better space management, increase in productivity, reduction in the time required to find objects and prevention of tool loss [14].

Problems are experienced relating to equipment settings for activities involving students. Examples of these problems are conducting experiments, space between equipment, as well as movement of people due to space limitations at mechanical engineering laboratories of the University of South Africa. This study implemented the 5S principles to solve these problems. Using 5S, the laboratories were expected to improve equipment utilisation, produce a clean workplace, improve safety in the labs, enable equipment identification and create more space around the labs and machines.

2 METHODOLOGY

In this study, 5S principles were implemented to solve various problems at the mechanical engineering laboratories of the University of South Africa. The 5S methodology was applied in four laboratories: Strength of materials lab, thermodynamics lab, mechanics of machines lab and fluid mechanics lab. The total time taken to implement these 5S principles was 4 weeks and the distribution is shown in table 1. Broken equipment and unnecessary tools, parts, materials and boxes were removed from the laboratories and disposed of in the dustbin. Lab equipment and other essential items were kept in the labs.

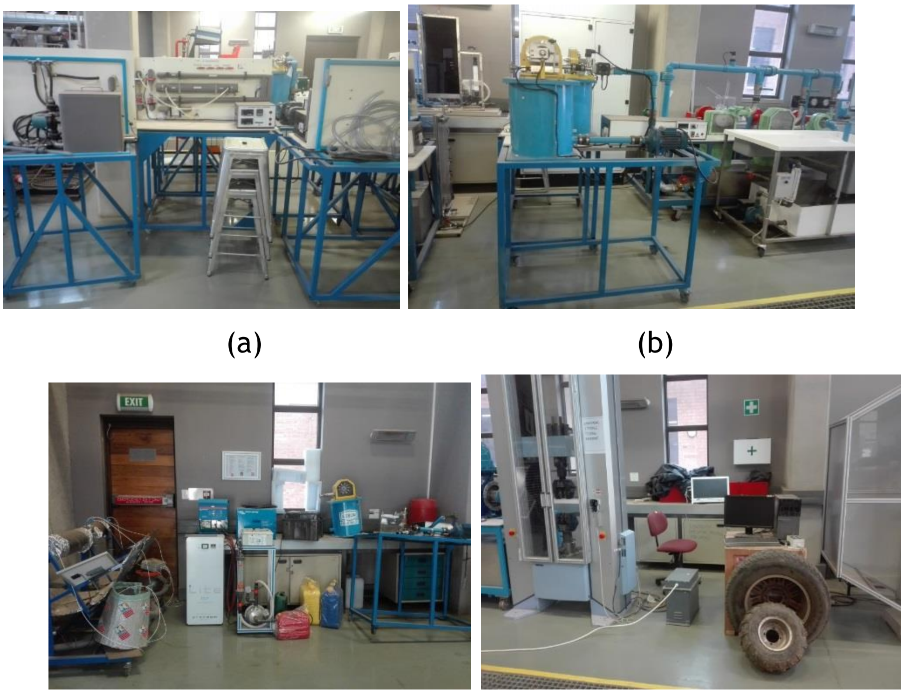
Machines were arranged in such a way that there is adequate space between the equipment and free movement of students in the labs. Equipment used in the same module and level were placed in one area. Laboratories and all equipment were cleaned to keep them clean and tidy for the next group of students. Standard operating procedure notices for all equipment were attached to each machine, and occupational health and safety regulations, safety signs, fire extinguishers and first aid kits were hung on the walls. Lab technicians or academic staff members accompany the students when they enter the labs to perform practical experiments to ensure their adherence to the rules and procedures of the lab.

Table 1: Total time to implement 5S methodology in four laboratories

Laboratory	Guide	Teamwork	5S
Strength of materials	8h/principle	6h/principle	❖ Sort 8h ❖ Streamline 5h ❖ Clean 3h ❖ Standardise 8h ❖ Sustain 1h
Thermodynamics	8h/principle	6h/principle	❖ Sort 7h ❖ Streamline 6h ❖ Clean 4h ❖ Standardise 7h ❖ Sustain 1h
Mechanics of machines	5h/principle	6h/principle	❖ Sort 4h ❖ Streamline 3h ❖ Clean 1h ❖ Standardise 4h ❖ Sustain 1h
Fluid Mechanics	8h/principle	6h/principle	❖ Sort 7h ❖ Streamline 5h ❖ Clean 2h ❖ Standardise 5h ❖ Sustain 1h

3 RESULTS AND DISCUSSION

The five essential principles were dealt with separately and in order. The first three principles are operational, the fourth principle maintains the state reached through the previous ones and the fifth principle helps to work for continuous improvement. Four people were tasked to implement these principles in four laboratories. The strength of materials, thermodynamics and fluid mechanics labs were each given 8 hours per task because they have a great deal of equipment and more work needed to be done in those laboratories. The mechanics of machines laboratory was given 5 hours per task since it did not have too much equipment. Due to teamwork the hours were reduced to 6 hours per principle. As shown in table 1, more hours were spent on sorting and standardising. It took a week per laboratory to implement all 5S principles. sort

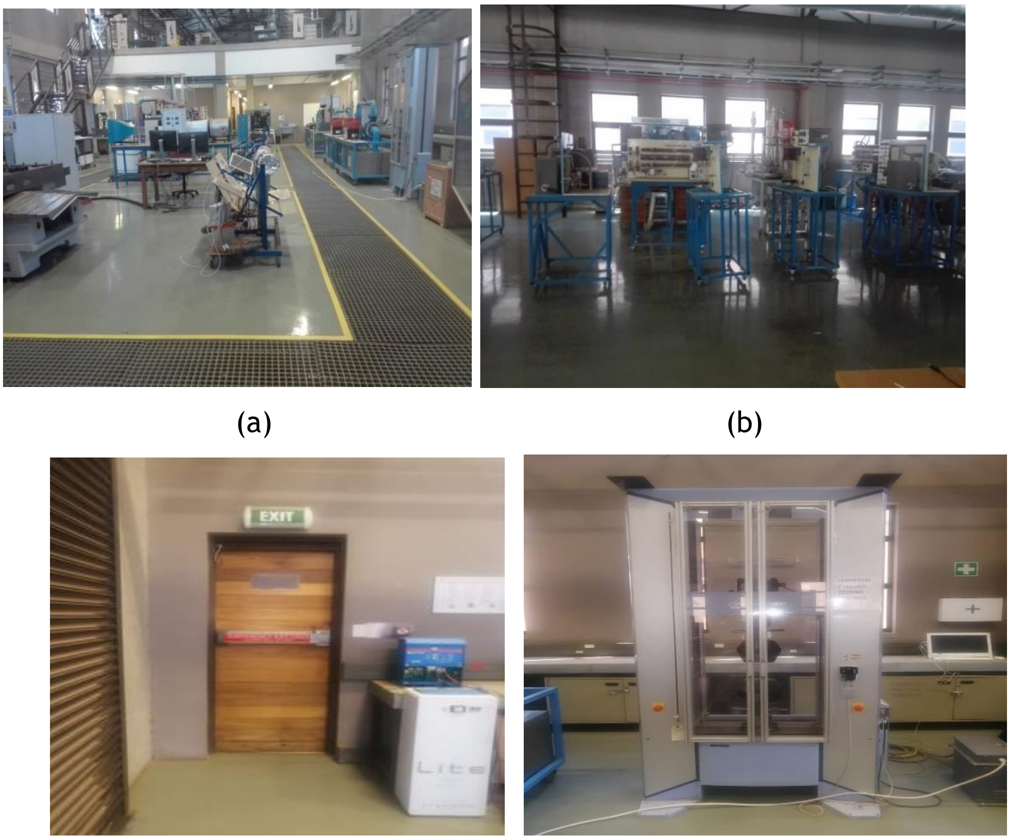


(a) (b)

(c) (d)

Figure 1(a-d): Conditions in laboratories before implementation of 5S principles.

Figure 1(a-d) presents the conditions in the laboratories before implementation of the 5S principles. It can be seen from figure 1a that equipment was packed closely together and there was no space for students to access it. Equipment of different disciplines was placed in one area. This created confusion among students during practical sessions (figure 1b). It can be seen from figure 1(c-d) that broken equipment and unnecessary materials were kept in the laboratories. These unwanted items made the laboratories untidy and filled up the space. Also, the figure shows that some of the equipment was blocking the emergency exit door, which was not safe for students or staff members.



(a) (b) (c) **(d)**

Figure 2(a-d): Conditions in laboratories after implementation of 5S principles.

First principle, equipment were separated according to discipline which took more hours as shown in table 1. The equipment was arranged in such a way that there is enough space in between them and to make sure students can walk freely around the machines. All the equipment was cleaned as well as the laboratories floor. The longest cleaning time was taken on thermodynamics lab and it was reported to be 4 hours as the lab have quite a number of equipment. The machines were labelled and a standard operating procedure was attached to each machine as well as the safety signs. Lab technicians make sure that students and academic staff follow the rules and requlations of the laboratory at all times. Laboratory safety presentation given to students last for an hour. Figure 2(a-d) shows the laboratories with well-arranged equipment, which was packed according to discipline. Enough space was created between the equipment to allow movement during practical sessions. A 35% reduction in practical preparation time has been achieved. More space has been created in the laboratories. Students of different modules and levels can be accommodated at the same time without disturbing each other. Equipment can be easily identified and accessed by students and staff members. Machines and the floor can be cleaned in less time. Students can conduct experiments freely and can easily detect equipment failure. The emergency exit door is freely accessible without any obstacles as shown in figure 2c.

4 CONCLUSION

In this study, the 5S principles in the laboratories of the Mechanical Engineering Department at the University of South Africa were implemented. These techniques related to the students, teaching and learning as well as practical activities. The implementation of these principles improved equipment utilisation, resulted in a clean workplace, improved safety in the labs, enabled equipment identification and created more space around the laboratories and machines. It has also improved the morale of the students and staff, improved the working environment and has developed a new culture in the university that motivates students and staff members. The 5S principles have helped to reduce accidents, develop a systematic working procedure and increase the development of the university.

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EVALUATION OF COMPUTERIZED TOMOGRAPHIC SCANNER PREVENTIVE MAINTENANCE: A CASE STUDY

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ABSTRACT

Preventive maintenance (PM) is commonly practised in the Maintenance of a computerized tomography scanner (CT scanner) used in hospital. Considering the fundamental observation, no machine is 100% efficient, as most mechanical/electrical appliances are used beyond manufacturer’s recommendation. The PM procedure on the CT scanner at a hospital in South Africa was investigated based on questionnaires answered by the technicians of the company that conducts maintenance and the radiographers working in the radiology department of the specific hospital. The result of the study revealed that a regular PM on the CT scanner can improve the performance and reliability of the CT scanner. The result also revealed that efforts geared at decreasing the equipment downtime also decrease the associated maintenance and repairs costs. The whole situation with respect to the overuse of the CT scanner and its regular maintenance needs to be balanced through the introduction of a sustainable management plan.

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1 INTRODUCTION:

Maintenance is an effort to ensure that the assets of a company continue to provide a service, which will then ensure that the company can provide its designated service [1]. Scientific Literature has defined maintenance into two main types: corrective maintenance that occurs after a system failure, and preventive maintenance, that is performed before systems failure in order to maintain the equipment in working condition by providing inspections, detection and prevention of incipient failures [2]. Maintenance provides critical support for heavy and capital-intensive industries by keeping the productivity performance of plants and machineries in a reliable and safe operating condition [3].

There has been a paradigm shift in the concept of maintenance over the years, from a reactive and pure technical support to facilities to an operational but very strategic function [4]. Medical equipment management is a fundamental part of managing a clinical engineering department. It includes the business processes used in interaction and over-sight of the medical equipment involved in the diagnosis, treatment and monitoring of patients [5]. As medical device becomes more sophisticated and plays a more crucial role in modern healthcare, maintenance issues demand ever-increasing attention. The most critical problem facing the medical device is the downtime [6]. Equipment should be properly maintained in order to fulfil their objectives. The signs of equipment's failure may not be apparent to clinical staff [7]. Operational failures in healthcare can hinder employees, potentially decreasing both productivity and quality of care [8].

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 [9]. Maintenance impact on business performance aspects such as productivity and profitability has increased. A day's output lost because of an unplanned stoppage will never be recovered without additional costs being incurred, like overtime work [10]. Patients in a healthcare facility are often fearful and uncertain about their health, their safety, and their isolation from normal social relationships [11]. The performance of hospital buildings and their components depends to a large degree on continuous and planned periodical maintenance [11]. Excellent maintenance management may reflect well on various sectors of a company, and even boost companies to the extent that, through planned maintenance, they will obtain a competitive advantage [12]. The maintenance organization is confronted with a wide range of challenges that include quality improvement, reduced lead times, set-up time and cost reductions, capacity expansion, managing complex technology and innovation, improving the reliability of systems and related environmental issues [12].

The effective maintenance management of medical technology influences the quality of care delivered and the profitability of healthcare facilities [6]. The costs of maintenance and the potential effect on maintenance costs from adopting predictive maintenance techniques is not well documented at the national level[13]. An effective medical equipment maintenance programme consists of adequate planning, management and implementation. Planning considers the financial, physical and human resources required to adequately implement the maintenance activities [14]. Machines must be maintained to ensure adequate levels of safety and quality. There should, similarly, be a regular maintenance and testing program for hospital and workshop equipment [15].

The passing into law of the Medicines and Related Substances Amendment Act 14 of 2015, and the subsequent establishment of the South African (SA) Health Products Regulatory Authority (SAHPRA) by the SA government, are milestones for the health sector [16]. The CT scan is a radiographic process that produces a photon attenuation map of the patient based on the variable attenuation of a beam of X rays as it passes through a patient. there are numerous indications for performing CT-based exams, including evaluation of cerebrovascular disease, intracranial haemorrhage, sinusitis, pulmonary embolism, aortic dissection, fractures, and many tumours [17]. Planned preventive maintenance is regular, repetitive work done to keep equipment in good working order and to optimize its efficiency and accuracy [18]. Lack of preventive measure is currently the problem that implicates poor maintenance performance of CT scanner [19]. The CT scanner is a vital piece of equipment for the hospital as it assists doctors to diagnose internal injuries such as internal bleeding, broken bones etc. This hospital is the only one with this type of equipment in the entire region. There is a high demand as other hospitals around the region send their patients with internal injuries to the hospital under study. Therefore, it is imperative to make sure that the equipment is reliable, to minimize downtime and to maintain the equipment based on its usage rather than calendar maintenance to increase its life span so that it can serve the community at all times. The objective of the study is to evaluate the existing preventive maintenance of the CT scan and to recommend effective preventive maintenance to minimize equipment downtime to improve its reliability and prolong its life span.

2 METHODOLOGY

In this study, the descriptive research survey method was used. Descriptive research can be either quantitative or qualitative. The goal of descriptive research is to describe a phenomenon and its characteristics [20]. The primary data collection method used in this study was through a structured questionnaire. The questionnaire was designed on Microsoft word format. It was organized and worded to encourage respondents to provide accurate, unbiased and complete information. There were two different questionnaires send to these two different disciplines, but there were some similar questions. The questionnaire that was sent to Radiology staff Members consisted of two sections. Section one describes the objective and importance of the questionnaire, contact person, and the duration to complete the questionnaire. Section two was a list of multiple-choice questions to be answered by the chosen group of people. The questions were divided into three parts. However, part 3 was directed to technicians only. Part 1 consists of general questions about the CT scanner, part 2 had questions relating to Quality assurance performance on the CT scanner and part 3 had Maintenance related questions. The questionnaire that was sent to the technicians had two sections also but with the inclusion of part 3 which was maintenance related questions.

Twenty hard copies of the questionnaire were sent to the radiology department staff members of the hospital under study and four electronic copies were emailed to the technicians of the company that conducts the repairs and maintenance under study CT scanner. The distribution of participants in the study is shown in Table I. Within a week, a telephonic reminder was made to recipients of the questionnaire for quick response. After a week, 16 hard copies were collected from Radiology staff members of the hospital under study. Two weeks later, three E-mails were received from three Technicians assigned to maintain the CT scanner.

A limitation of the study was the small sample available. This was the result of the limited number of personnel employed in the radiography department of the hospital and the small number of technical maintenance personnel working on the CT scanner of the hospital under study. The collected data from the questionnaire was analyzed using Microsoft excel software to generate the descriptive statistics.

Table I: Questionnaire distribution

People involved	Data collection method	Number of questionnaires
Radiology staff members	questionnaire	20
Technicians	**questionnaire**	**4**
Total		**24**

3 RESULTS AND DISCUSSION

3.1 Response to Questionnaires

From the twenty hard copy questionnaires sent to the radiology staff members at the hospital, sixteen were answered and returned within the stipulated time. Out of the four electronic copies sent to the technicians at the support company, three answered copies were received through emails after reminding them telephonically. The distribution of the questionnaires received is presented in Figure 1.

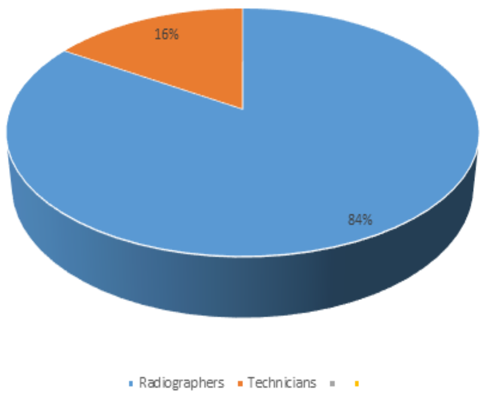

Figure 1: Distribution of respondents

From figure 1, it was found that 84% of the respondents were radiographers at the hospital while 16% were technicians at the company that conducts the repairs and maintenance. All the respondents were professionals in their fields and revealed valid information about the CT scanner. In addition, they had an interest in responding to the questionnaire because they knew that it would have a positive impact on the maintenance culture, efficiency and the performance of the CT scanner. Moreover, it would provide a better service to the community that the hospital serves. Figure 2 shows the distribution of the recommended number of patients that should be scanned in a day.

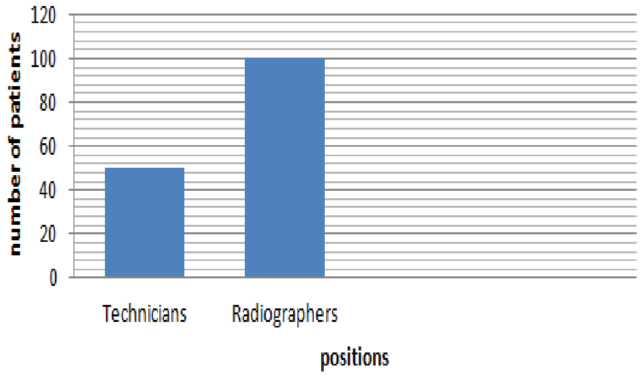

Figure 2: Daily recommended limit to scan patients in a day using the CT scanner.

The results show that the radiographers scan 1to 100 patients per day, while the technicians recommend that 1to 50 patients should be scanned in a day, which is in line with the manufacturer's recommended rate. The obtained results indicate that the machine is used beyond manufacturer recommendation. The equipment is over used and this could result to machine breakdown. Therefore, a special maintenance procedure needs to be implemented to suit the current usage of this equipment. It will be appropriate to embark on special PM to improve the efficiency, life span and reliability of the equipment since it is operating under abnormal conditions due to the demand of the community. It was observed that the CT scanner operated twice as much as the design abilities catered for. That means the planned maintenance needs to be done twice as often as recommended by the manufacturer. Figure 3 shows the distribution of the type of maintenance performed on the CT scanner at the hospital.

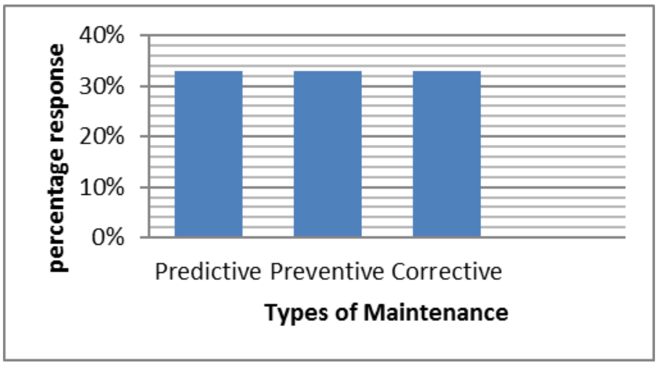

Figure 3: Type of maintenance carried out on the CT scanner.

The result shows that on the average 33% of the maintenance being done for each of the above-mentioned maintenance procedures on the CT scanner. This revealed that the PM must be upgraded to meet the growing demand. Corrective maintenance is very costly and delays the use of the equipment. This shows that this equipment is maintained while broken. PM needs to be done on this equipment to prevent failure before it occurs. It saves time and minimizes the cost of repairs and maintenance. Figure 4 shows the distribution of whether the technicians are based at the hospital or not.

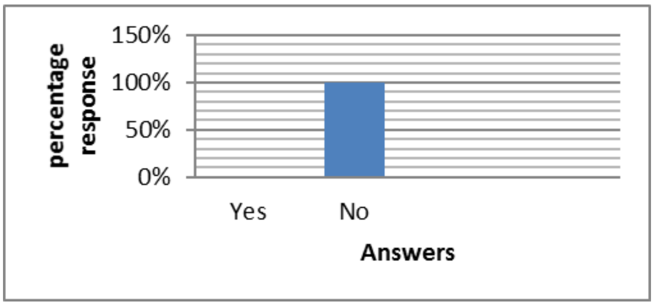

Figure 4: whether the technicians are based in the hospital.

The result shows that the technicians are not based at the hospital; they are about 80 km away from the hospital. They also offer maintenance services to different hospitals, this leading to a longer response time. This could exacerbate the duration of downtime when it occurs. It shows that there is no daily maintenance-taking place on this equipment, which includes inspection, lubricating and cleaning of the CT scanner. Routine maintenance is an important part of keeping equipment up to date and functional. Figure 5 is a presentation of the frequency of maintenance on the CT scanner.

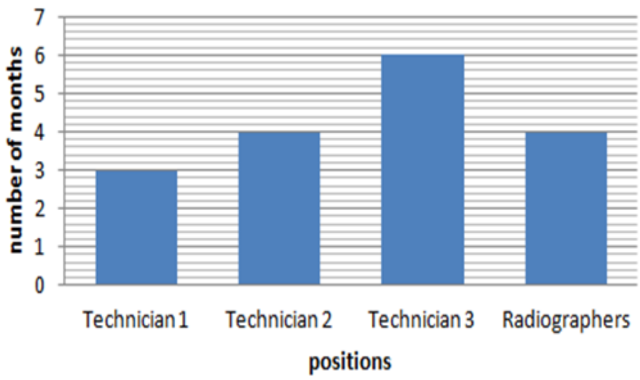

Figure 5: Distribution of how often maintenance is conducted on the CT scanner.

The result shows that technician 1 indicated that the planned maintenance is done every three months, technician 2: every four months, technician 3: every six months, whereas all the radiographers indicated that planned maintenance is done every four months. As in the equipment manual, planned maintenance should be done every four months. From figure 5, it is seen that the maintenance percentage varies between the radiographers and the technicians, which indicates a high level of irregularity. It was observed that the technicians were not consistent in their responses, which is an indication that they are not doing PM but were instead doing corrective maintenance on the equipment. This indicates that more training by the supplier must be done with the target group the technicians as well as the radiographers. The drawing up of a set of standard operating procedures for the maintenance of the scanner should be considered. The distribution of the number of times that the CT scanner breaks down in a year is presented in Figure 6.

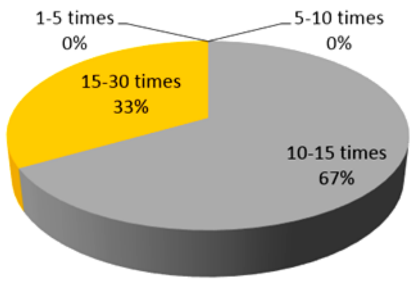

Figure 6: Number of times that the CT scanner breaks down in a year.

The result shows that most of the breakdowns take place for about 10 to 15 times per year with a percentage of 67%, followed by 15 to 30 times or a percentage of 33%. From figure 6, the results revealed that the equipment downtime is between ten and fifteen times per year. Breakdowns increase maintenance costs and reduce service to the community. Data from the survey on how maintenance reports are kept at the hospital is presented in Figure 7. The results show that 66% and 33% of the maintenance reports are kept in the file and external server respectively. This is dangerous because files can be lost or misplaced.

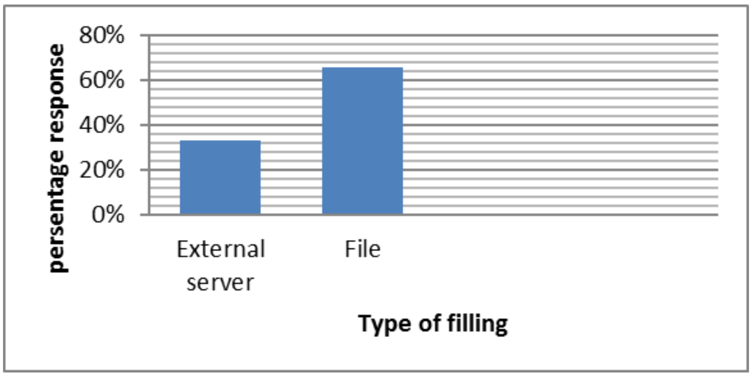

Figure 7: how maintenance reports are kept.

Effective PM thus needs to be implemented to minimize downtime of this critical equipment. Accurate management statistics need to be kept providing a clear view of the situation with respect to breakdowns. This must be made visible to the hospital manager to enable the correct officials to take timeous decisions and make funds available. The serviceability of the CT scanner does not in total lie in the field of responsibility of the radiographers, they are the users. The distribution of how much time is spent on periodic or scheduled maintenance is presented in Figure 8.

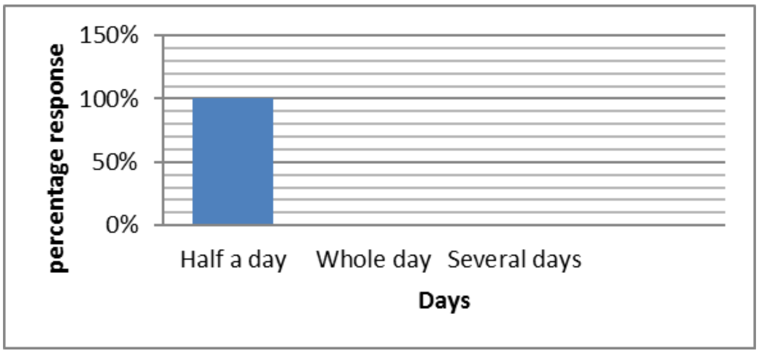

Figure 8: Duration of Periodic/scheduled maintenance.

The results indicated that periodic or scheduled maintenance takes half a day (4.5hours) to be completed. This implies that no service is given to the patients for half a day on that day of scheduled maintenance. More hours spent on maintaining the equipment, meaning no service to patients. This is very dangerous because some patients' condition becomes worse, which can lead to loss of life if there are patients with internal bleeding. That is why an effective preventive maintenance needs to be proposed to reduce this downtime of CT scanner.

3.2 Proposed Maintenance Procedure

From the results obtained and analysed, we propose that the hospital needs to have an in-house maintenance department and must have skilled personnel to conduct PM procedures when due. Furthermore, the result revealed that most of the maintenance documents are being stored manually. A computerized maintenance management system needs to be installed to manage all the maintenance activities. Which, will be managed by in-house maintenance department. In addition, the following is recommended:

- Daily quality assurance should be done by the radiographer together with a technician. If they do not get expected results, action should be taken immediately.
- Daily routine maintenance should be performed which include cleaning the dust, inspection and lubricating if necessary. If they see or suspect something wrong, action should be taken right there.
- At the end of every two months, planned maintenance needs to be performed instead of four months since the equipment is operating at twice the expected usability.
- The equipment must be tested after planned maintenance.
- Save the equipment history.

The proposed PM procedure flow chart is presented in Figure 9.

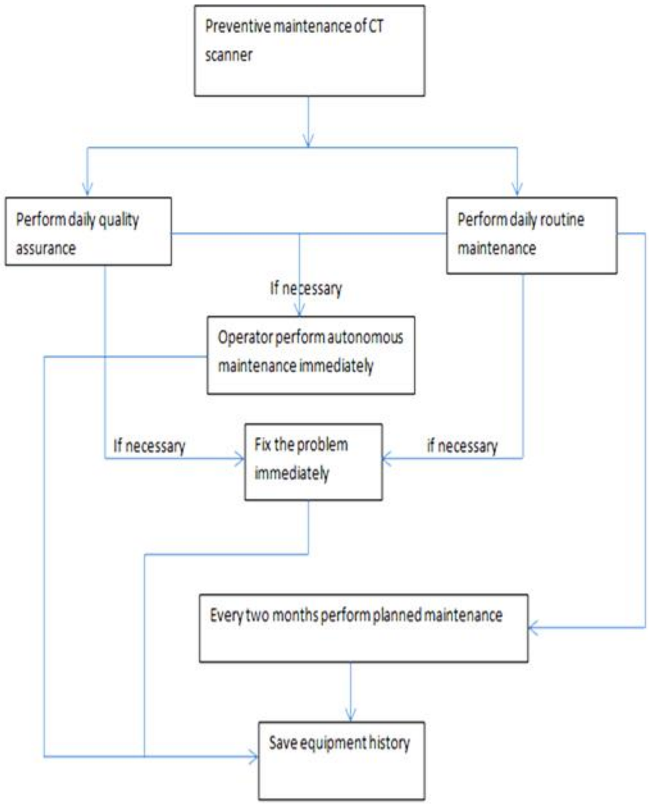

Figure 9: Proposed preventive maintenance flow chart.

4 CONCLUSION

The current study was aimed at studying and analysing the existing maintenance culture on the computerised tomographic scanner (CT scanner) in a radiology department of a hospital in South Africa with the aim of proposing a more effective PM procedure, which can improve the reliability and performance of the CT scanner. This was achieved by designing a suitable questionnaire to sample the opinion of the radiographers and the maintenance technicians. It was observed that the machine is used against the manufacturer recommendation. Therefore, a special maintenance procedure needs to be implemented to suit the current usage of this equipment. It was observed that the CT scanner operated twice as much as the design abilities catered for. It was observed that corrective, preventive and predictive maintenance procedures are being done on the CT scanner and the maintenance reports are being kept in the file for future reference. It was further observed that much time is spent on periodic maintenance that always lasts for half a day. In addition, there is an indication that daily maintenance, which includes inspection and cleaning, are not being performed on the CT scanner as recommended. The results obtained on the planned maintenance on the CT scanner differed between the technicians on the one hand and the radiographers on the other. Despite this, it is clear that the whole situation with respect to the overuse of the CT scanner and its regular maintenance needs to be balanced through the introduction of a sustainable management plan. To reach this point more training by the supplier must be done with the target group the technicians as well as the radiographers. The drawing up and implementation of a set of standard operating procedures for the maintenance of the scanner should also be considered. Accurate management statistics need to be kept providing an accurate view of the situation with respect to breakdowns to the relevant officials to enable them to make timeous decisions and make funds available. A follow-up study on this initial research should ideally involve all the management personnel in such a hospital who take decisions, which affect the maintenance of the equipment being researched. This could overcome the limitation of the small sample present study.

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FACTORS THAT INFLUENCE THE IMPLEMENTATION OF WAREHOUSE MANAGEMENT SYSTEMS IN SELECTED SOUTH AFRICAN COMPANIES

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ABSTRACT

Some global studies estimate that around 50% of IT-related projects fail. However, there are several success stories where both local and international organisations have reaped great rewards after such implementations. The purpose of this study is to explore the factors that influence the implementation of warehouse management systems (WMS) in warehousing operations in South Africa. Previous work, from other parts of the globe, has identified such critical factors and this study aims to interrogate such factors in the South African context. A conceptual framework was built through the literature review. Research data was collected from selected supply chain organisations in Gauteng through qualitative semi-structured interviews and analysed using thematic content analysis. Several factors such as non-availability of local software, the need for local technical support, change management and the relationship with external consultants were cited as some of the key factors that influence such implementations.

Keywords: WMS, systems, implementation

[*] Corresponding Author

1 INTRODUCTION

According to the 10th State of Logistics report of 2013, South African supply chains have moved beyond survival mode where costs, inventories and lead-time have been minimised within individual supply chain functions [1]. Viljoen [2] defines survival mode in his seven-stage model as the phase where organisations operate independently with little planning, control and no regard to the threats and opportunities around them. End-to-end integration of supply chain functions is the next major shift required in South Africa to make organisations more customer-centric and competitive [1]. One of the major keys to the success of effective supply chain management (SCM) is the use of integrated information systems that enable visibility of product demand and stock levels through the full length of the supply chain. This has only become a possibility with the ongoing advances in information systems technology [3]. One of the major components of the supply chain technologies that organisations are implementing is the warehouse management systems (WMS). WMS are software applications that manage the flow of materials into and throughout the storage facilities.

> *"A typical warehouse management system can provide detailed directions for receiving, storing, bin selecting, picking, and shipping tasks required in all warehousing operations. By shifting some of the decision making from independent human operators to a centralised planning system, measurable benefits can be achieved. These planning systems support warehouse workers through standardised processes, instructions, rules, and parameters established during system implementation" [4, p. 71].*

Often, the implementation of such complex systems requires expertise and involves a wide range of stakeholders both within and outside the implementing organisation [5]. The successful implementation of WMS varies across organisations. For example, in early 2016, Finish Line, an American company that sells athletic shoes and apparel, recorded disappointing results where sales dropped by 3.5% with their stock price falling by 11% [6]. The same misfortune befell other organisations like Adidas, Foxmeyer Drug and Hershey Foods [7] and these seem to represent the end of the spectrum of how "not to implement" a WMS. On the other hand, there are success stories of numerous organisations that have also implemented similar systems. Cambridge Foods, a subsidiary of Massmart in South Africa managed to increase inventory accuracy, outbound order accuracy and picking productivity [8]. Barloworld Logistics South Africa deployed a WMS in five months. The project was completed within the projected go-live date and the system implemented without customisations [9]. While some research specific to WMS has been done around the world and generally for system implementations in South Africa, this research paper seeks to explore more on the factors that influence the implementation of WMS in warehousing operations in South Africa.

2 LITERATURE REVIEW

2.1 Principles of Warehousing

Warehouses are an integral part of the supply chains. According to Rushton et al. [3], the main objective of warehouses is to facilitate the movement of goods throughout the supply chain. Warehouses are involved in various stages of the sourcing, production and distribution of goods, from the handling of raw materials and work-in-progress through to finished products as well as being the dispatch point serving the next customer in the chain. Typical functions of a warehouse are receiving, reserve storage, order picking, value-added services, marshalling and dispatch [3].

2.2 Warehouse Management Systems (WMS)

A WMS is computer software that can handle operations in the warehouse such as receiving stock with receipt documentation, put away labels, generating pick instructions and replenishing pick locations [10]. According to Schmeltzpfenning, et al.,[11], the core functions of a WMS can be categorised into three, namely; managing incoming goods (receiving), inventory management and managing the despatch of goods (outbound) to customers or consumers. Figure 1 below outlines the core and additional functions of a fully-fledged WMS.

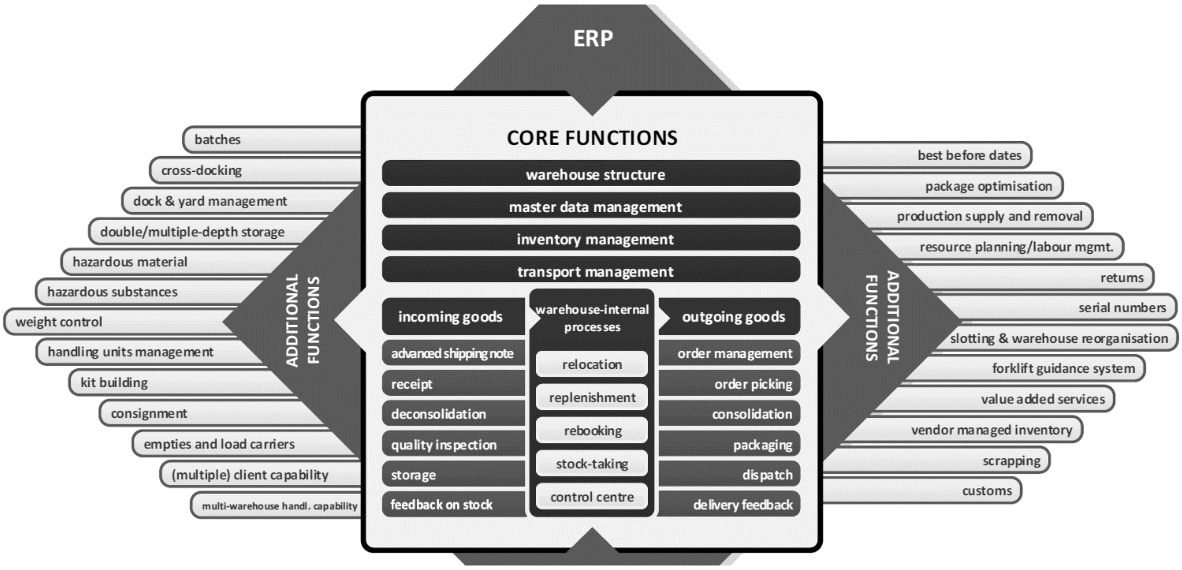

Figure 1: Functional Scope of a WMS [11]

A WMS can be either stand-alone or can be part of Enterprise Resource Planning (ERP) systems [12]. Many ERP vendors are increasing the capabilities of their system's functionality while most WMS vendors are adding supply chain visibility and other management capabilities. As customers constantly ask for further functionalities to realize the possibilities of cutting the costs for their warehouses, vendors of WMS constantly enlarge the scope of their software systems, thus WMS nowadays increasingly offer functionalities, which have their origin in ERP software [13]. Most common ERP systems like SAP actually have WMS modules as part of the extended SAP suite [14]. Therefore, the implementation of ERP and WMS continues to be closely tied due to the continuous integration and interfacing between these two.

2.3 Factors that affect a WMS implementation

Several authors have suggested a range of factors that influence WMS implementations. These aspects vary from business, technological, human resource, infrastructure, planning to change management. Emmett [10] argues that a visible and involved top management is key to a successful implementation. Further to that, the management needs to put "its money where their mouth is" by ensuring that the same commitment is cascaded down the lower ranks of the organisation [15]. As well as to intentionally involve all stakeholders at the earliest stage as far as possible to ensure that all stakeholders are involved [10]. All large technology deployments involve changes in processes that affect people who must cope with them for successful implementations [16].

Change management is a comprehensive, cyclic, and structured approach for transitioning individuals, groups, and organisations from a current state to a future state with intended business benefits. This helps organisations to integrate and align people, processes, structures, culture, and strategy [17]. Similarly, Gourley [17] emphasises that participation of the warehouse staff in the implementation process is a factor critical to success. He cites that for a company to succeed, it must actively encourage the involvement of staff in decision-making and welcome input from suppliers to identify improvement areas. Project planning with realistic timescales needs to be managed internally and not left to an external software vendor, who really has no idea of the fine complex details of the user's business [10]. Similarly, the program needs to be flexible where necessary [15]. Coupled with the project planning is the development of contingency plans if there are deviations from the initial plans [10]. Sehgal [16] also contends that aligning the processes with the solution being deployed is a critical success factor for any technology deployment project. He also argues that a solution can be custom developed to support a business function to suit the process exactly as required but such a solution can become a liability when the underlying business process changes by constraining the business's ability to adapt. Such solutions are also difficult to upgrade to newer evolutions of the software, as the customisations would have to be re-developed into the newer versions. Master data is the base data that provides the basic references to the organisational transactions. The consistent use of such data provides a structure to the transactions so that these transactions can interact with each other, as well as consolidating for creating meaningful corporate-level metrics. This consistency is more critical when there is integration and interfacing with other enterprises systems as the data and transactions need to be uniform across the various systems. A system implementation will likely fail if there is unclean master data [16]. Collaboration within the supply chains will lead to greater consolidation and an increase in shared-user operations [12]. Running supply chains, more often than not, involves interacting with other enterprises and entities; hence, the relationship with other stakeholders will affect the implementation of a WMS [16]. However, Emmett [10] contends that the ownership of implementation should remain within the organisation, especially with software vendors as at some point, they will not be there and the local teams should continue to provide support. RectechSolutions [18], through years of research, have developed a framework of what they consider critical success factors in system implementations. They have classified and summarised these factors as shown in Figure 2 below.

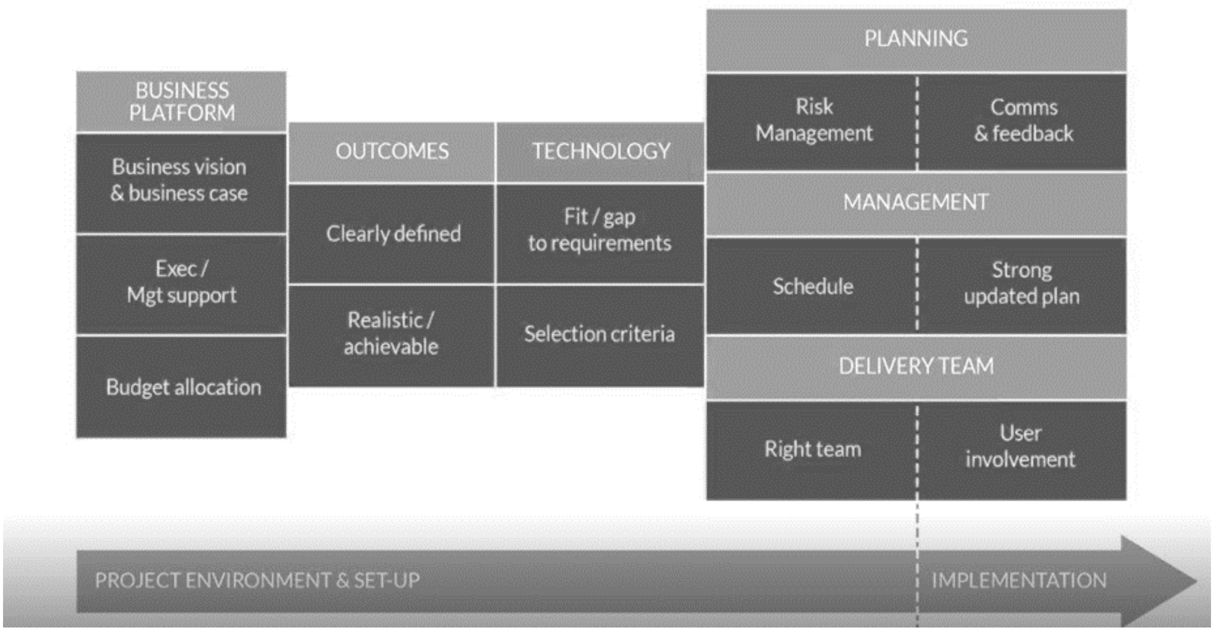

Figure 2: System Implementation – Critical Success Factors [18]

Garg et al., [19] group the factors that influence the implementation of ERP, which has similarities with a WMS, into the following categories; Strategic, People, Technological, Project Management. Figure 3 below shows a cause-and-effect diagram for each of these categories.

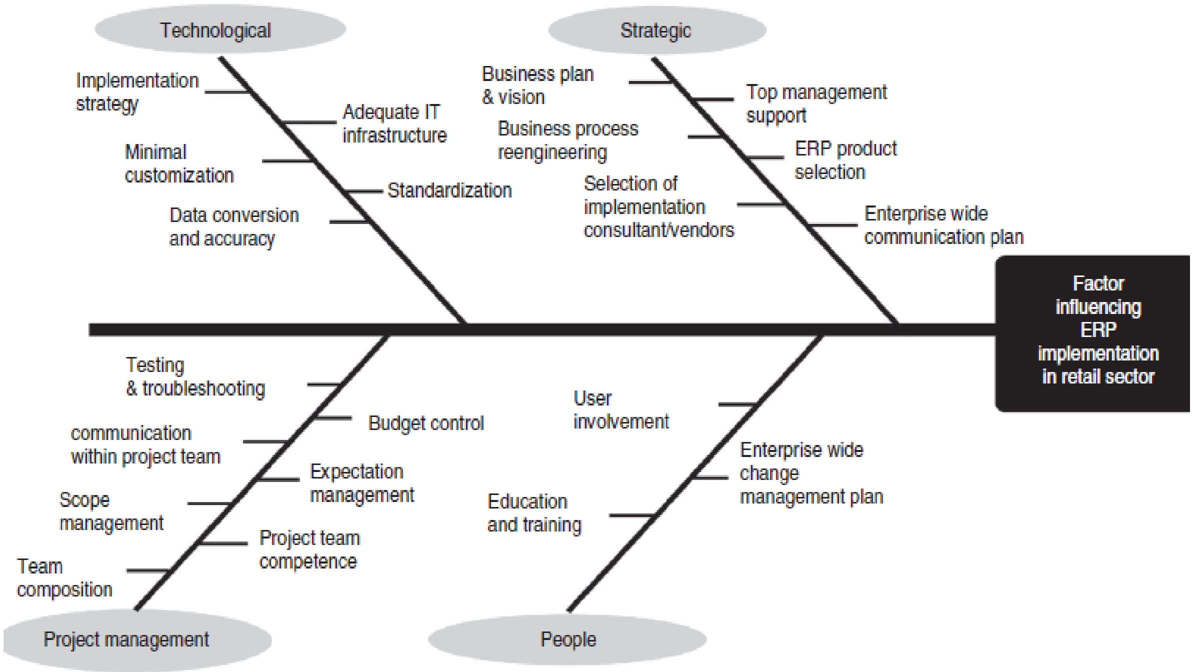

Figure 3: Items Influencing ERP implementation [19]

2.4 Trends within South African supply chains

According to the 10th State of Logistics survey of 2014, many South African companies have been working from severely disjointed ERP and SCM systems that have been designed for an individual company and offer little opportunities for integration; trend to a globally connected world [1]. However, organisations continue to adopt some of the technologies as South Africans increasingly look to online digital platforms to carry out activities such as banking, shopping and trading [20]. One of the technologies that have gain traction is the "as-a-service channel offerings" where partners used on-demand platforms where they pay for usage as opposed to on-premise systems where you have to pay for the infrastructure as well [20]. This is also enabled by the fact that excellent cloud data centres are becoming more available to South African organisations with Microsoft and Amazon setting up their data centres in the country [21]. It is expected that the adoption of automation will increase in South African organisations [20]. The same trend was observed by Schreuder [22] in which South African and African organisations have begun to implement automated storage solutions in warehouses. One example of such is the most automated pharmaceutical distribution facilities in the Southern Hemisphere [23], which is a testament that South Arica organisations are prepared to, invest in such technologies.

2.5 Conceptual Framework for factors that affect WMS Implementation

Below is a conceptual framework for the factors that affect the implementation of a WMS as identified in the literature review.

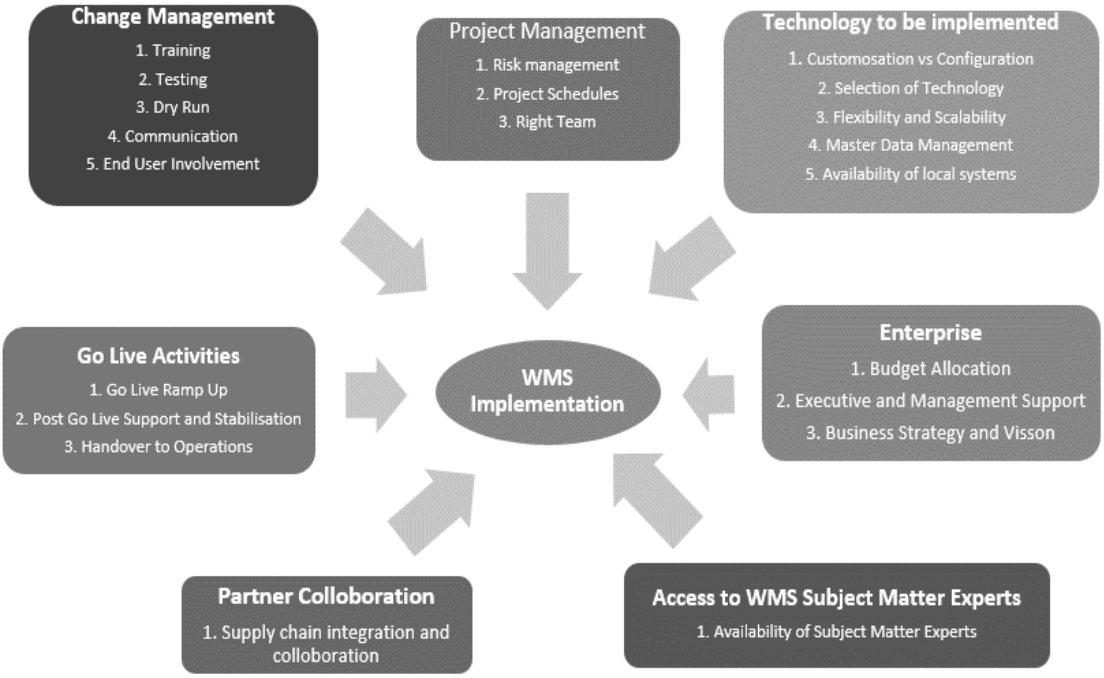

Figure 4: Conceptual Framework for factors affecting WMS implementations

3 RESEARCH METHOD

3.1 Research design

In this research study, a qualitative approach using semi-structured interviews and thematic content analysis was used to explore the factors that affect the implementation of WMS in South Africa. Qualitative research is a more appropriate approach to this research because it provides a complex textual description of how experts that have vast experience in this field have encountered [24].

3.2 Sampling

The research was targeted at South African warehousing enterprises that have implemented WMS. Purposive sampling was used to select several organisations that have done such implementations. Purposive sampling involves choosing people whose views are relevant to an issue because it is believed that their views are particularly worth obtaining and typify significant varieties of viewpoint.[25], The process includes establishing the participant profile, identifying a possible list of participants and finally seeking specific individuals from this list to participate [26]. For this study, the participants chosen were the project champions who led in the various implementations of WMS. The participants were chosen from various industries, summarised in Table 1 below.

Table 1: Respondent Demographics

Company	Industry	Number of years in Operation	Location	Designation of Interviewee
Company A	IT equipment distributor	>30 years	Gauteng	Supply Chain Executive
Company B	Food Retailer	About 30 years	Gauteng	Senior IT Manager: Supply Chain Systems
Company C	Third-Party Logistics (3PL)	>30 years	Gauteng	Supply Chain Implementation and Improvement Manager

3.3 Instrumentation

Semi-structured interviews were used to gather data from the identified participants. Jankowicz [25]) explains that this technique involves asking open-ended questions whose content and sequence are not fully specified in advance. Interview questions were developed using the Wengraf model [27]. An example of the application of the model is shown in Figure 5 below.

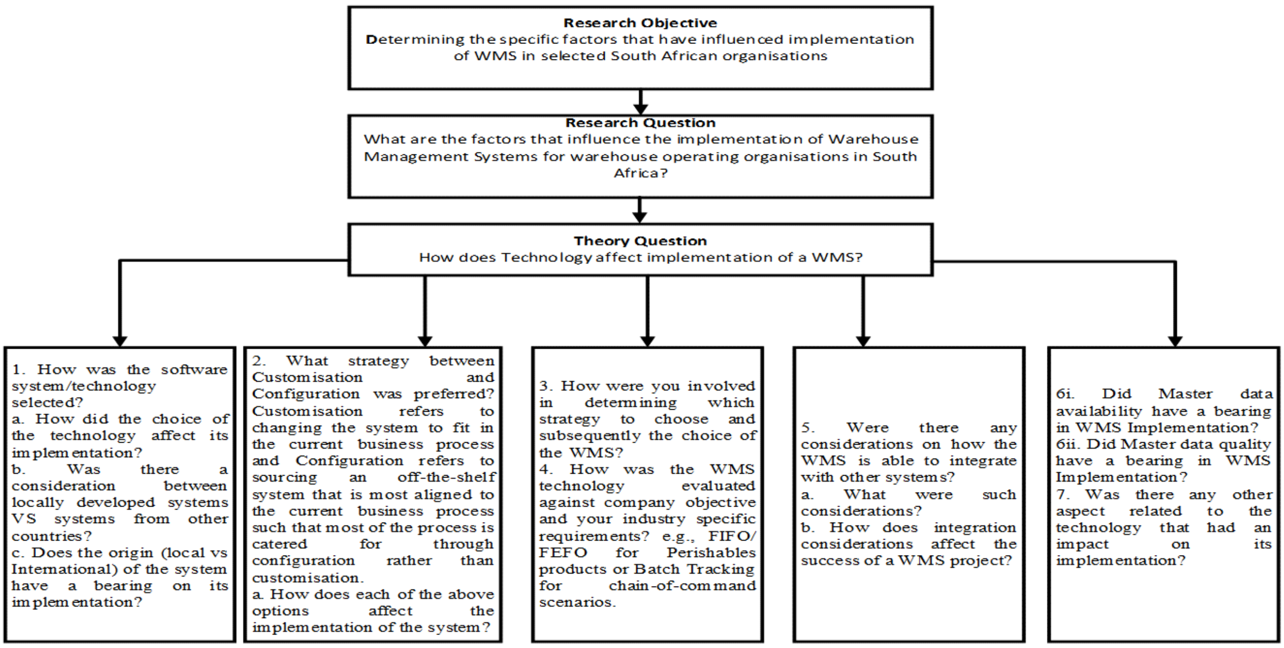

Figure 5: Example of application of Wengraf pyramid model

3.4 Data Collection and Analysis Procedures

Data were collected through interviewing identified participants. Each participant was required to sign a consent form as proof having agreed to be interviewed. This was essential for ethical reasons. The participants were informed of the nature of the study and participant consent was sort. Data collected will be anonymous [28].

The gathered data was analysed through content analysis. Content analysis is a detailed and systematic examination of the contents of a particular body of material for identifying patterns, themes, or biases [28]. This type of analysis categorises the answers to semi-structured questions so that the meanings expressed in the data can be classified, coded, and tabulated. Saldana [29] defines coding as a method that enables one to organize and group similarly coded data into categories or "families" because they share some characteristic.

3.5 Validity and Reliability

According to Salmon & Fargotstein [30], researcher bias occurs when some aspect of the research design and/or how the research is conducted, generates a description or a conclusion, which is not accurate. Leedy & Ormrod [28] suggest triangulating multiple data sources, intentionally looking for outliers, continuing to collect data until data saturation point, or seeking feedback from both participants and professional colleagues about your findings and interpretations. In this research, an experienced industry expert reviewed the interview questions before the interviews were conducted to address some of the bias. The feedback from the expert was incorporated into the interview questions. After completing the thematic content analysis, the same industry expert was interviewed to discuss the results to seek feedback and validation.

4 RESULTS

The results are presented below are in line with the seven major topics which were developed in the conceptual framework and were used as guidelines to develop questions that were posed to the participants during the interview processes. These topics are Enterprise, Technology, Partner collaboration, Project Management, Change Management, Go-live activities and Access to WMS experts. As part of the process to assure the validity and reliability of the research results, an interview was done with the same expert who reviewed the base questions that were used for the interviews. In the interview, the expert was taken through the initial themes that had been drafted comments and feedback was given for each theme. The emerging themes for each code and sub-code are summarised in Table 2 below.

Table 2: Emerging themes from thematic content analysis

Code	Sub-code	Emerging theme
Enterprise	Corporate Support	Senior management involvement was highly important in the implementation of WMS projects for the companies surveyed.
	Alignment to Corporate Strategy	It emerged that corporate business strategy and vision had an influence on the implementation of WMS concerning the systems and processes to implement for the organisations surveyed.
Technology	Technology Selection	Companies surveyed first relied on already available software or technology options within their organisations. If they needed to go to market competition, the prominence of the software and whether it is fit for purpose were major factors.
	Configurability versus Customisation	Most organisations interviewed preferred a more configurable system with the flexibility of some customisation if required.
	Local versus international brand	The local presence of a software brand, in both an implementing partner and support services, were cited as critical for the organisations interviewed.
	Integration capabilities	The capability of the system to easily integrate with other systems was raised important, especially in the 3PL environment where external partners are involved.

Code	Sub-code	Emerging theme
	Ease of deployment	The ease of deployment was raised as an important consideration when implementing WMS in 3PL organisations for clients where the process is pretty much a standard with little exceptions.
	Master Data	The availability and quality of master data were described as the "oxygen" of a WMS implementation. It also emerged organisations must not entirely reliable on master data supplied by external stakeholders as such master data often does not meet their needs.
Partner Collaboration		For all the entities researched on, partner collaboration was significant to enable a successful implementation of a WMS and they needed adequate processes to ensure such collaboration is a reality.
Project Management	Project Planning	The importance of an independent Project Management Office (PMO) was underscored by most of the respondents. In a 3PL setting, it emerged that there are broader considerations in project planning.
	Risk Management	Most organisations involved in this research conceded that they had to consider risk management in the early stages of the project. The areas covered for risk management were wider than the WMS project itself.
	Project Team	All studied organisations emphasised that a dedicated team that has the representation of all the stakeholders, affected by the project or the solution, needs to be set up and there must be co-operation between the team as led by the PMO office.
	Project Documentation	All researched organisations had internal processes to manage all project documentation. It emerged that project documentation must be kept and updated always, as it is essential for continuity and future reference.
Change Management	Change Management	For all the researched organisations, change management emerged as the biggest concern in implementing a WMS and that it was poorly handled in their respective implementations.
	Stakeholder involvement	The results show that stakeholders were not involved early enough in the projects. Early stakeholder involvement was raised as critical to achieve success and avoid resistance to change by most organisations researched.
	Training	Most respondents conceded that little training was conducted in their implementations and that, whilst training will provide a good foundation to prepare users for the new system, they still expected some exceptions on the go-live day, which may not have been covered during training.
	System Testing	All respondents carried out system testing and highlighted the importance of the various phases of system testing; namely analyst testing and user acceptance testing, with one respondent raising the shortcomings that often arise in these processes, which become a reality during the go-live.
Go Live Activities	Go Live	All participants faced a great deal challenges in their respective implementation go-lives with the reasons

Code	Sub-code	Emerging theme
		including poor project planning, inadequate training and insufficient change management.
	Cutover Plan	Some organisations did not have a cutover plan while others did have. A cutover plan is a plan with details of all the activities that will need to be done over the go-live period.
	Roll Back Plan	Only one respondent cited the importance of a rollback plan as a contingency measure in case of an unsuccessful go live attempt while the other two organisations did not have such a plan.
	Business Intelligence Availability	One of the respondents mentioned the impact of the availability of appropriate business intelligence tools (reports and dashboards) at the start of go-live activities to capacitate the operational team to understand better the new systems and make decisions quicker.
	Handover and Stabilisation	All respondents stressed that a period of handover and stabilisation is necessary to handhold and ease the operational teams into the new system to a point where they can operate with minimal involvement from the project team. A formal evaluation and sign-off of the project were done at the end of such a period.
Access to WMS Experts		All respondents attempted to transfer knowledge to their internal resources and some had challenges in getting the WMS experts transferring knowledge to their internal resources hence it is necessary to have a process in place to ensure that such knowledge transfer happens.

5 DISCUSSION

5.1 Key factors that contribute to the effective implementation of WMS in SA organisations

The discussion seeks to address the research question on what the factors that affect WMS implementations in some South African organisations are.

5.1.1 Enterprise

The findings on the enterprise showed a consensus amongst the interviewees that the corporate structure must lay a conducive environment within the organisation for a WMS implementation to succeed. Such support includes the availability of resources and financial backing since such implementations often need a lot of capital expenditure. The research also found that availability of funds was not an issue because such funds would have been allocated for beforehand as such; projects are planned for due to the CAPEX required. To facilitate and link the Executives to the project, Patton & Coombs [31] suggest a role of a project champion who will need to influence the executives to continue to support the project and simultaneously encouraging “self-ownership” by all the other stakeholders in the project. Corporate strategy was also raised as a key characteristic. This was further evidenced by one organisation changing their WMS approach they had initially implemented when the organisation moved to become a 3PL business as well as from the global 3PL organisation whose approach is grossly influenced by the global strategy from the global offshore head office.

5.1.2 Technology

The choice of technology was found to be mostly influenced by the business where a preferred software is chosen across all the businesses. Implementing and choosing a business application should be all about solving business problems improving business processes [32] and should never be an IT project. This was evident throughout the research where respondents stressed the importance of putting business or operations at the forefront and the IT becoming an enabling department. There was also a varied finding from the 3PL environment where the client dictates the organisation which software to use, thus an organisation is forced to implement systems in their premises to accommodate their different client. This means that the organisation must be technically equipped on these various systems as well as the support expertise.

It also emerged that there was not many South African developed WMS and organisations end up using international brands. However, there was overwhelming agreement amongst that the international brand must have a strong local presence, in the form of an implementation partner, to ensure readily available support when it is needed as opposed to relying on support from offshore organisations. The concept of user groups has been widely adopted in other continents where users from different organisations meet, either in conferences or online, and share experiences on how they are using technologies from vendors and also to benchmark on how they are performing amongst each other as well as against industry best practices. Only a handful such meetings seem to have been done in South Africa, mainly by the software resellers trying to be visible and hopefully make a sale. It is important that South African organisations consider such communities in order to share expertise and cooperate with each other.

Regarding configurability or customisability, it emerged that a configurable system is mostly preferred, while some degree of customisability is required in instances where exceptions arise A configurable system is ideal because there is less development required to set it up and it is easier to deploy system upgrades, as there are no previous diversions from the base system from the vendor. Gartner [33] also confirms this notion that available WMS's generally offer similar functionalities, even though they can differ in usability, adaptability, intelligence, scalability and life cycle costs.

The research also revealed the following to be critical factors in WMS implementation

- The system must facilitate easy integration with other systems. This was more evident in the 3PL business where organisations need to interface with other customers' systems or other internal systems.
- The system must be easy to deploy to allow easier reproducibility especially in the 3PL business where the lead-time to onboard a client is critical in getting and retaining business.
- When selecting which technology or software, the specific industry or customer needs must be prioritised. While the benefits of selecting an off-the-shelf software have been outlined above, there are instances where a bespoke software must be chosen or multiple systems must be used.

5.1.3 Partner Collaboration

The relationships between the implementing organisation and all stakeholders, such as suppliers, customers and implementation partners were identified to have an impact on a successful implementation. Through collaboration, partners work as if they belong to one enterprise, to increase competitive advantage and achieve mutual benefits [34]. Similar research has been done in South African organisation and results show that collaboration can enhance response customer needs and streamlining distribution and operating costs [35].

5.1.4 Project Management

A designated Project Management Office (PMO) was cited by most of the interviewees. Therefore, it can be concluded that the existence and involvement of such an office is a critical success factor in a WMS implementation. The project management must be organisation-wide and the project should not be considered only as an IT project. The IT department must be a support department to the business to implement the project as opposed to them leading the implementation [36]. A dedicated team that has the representation of all the stakeholders must be setup. A robust risk management program was identified as a critical success factor and must be reflected in the project management activities. The organisation must look out for any risks from the earliest stages of the project through the various engagement they will have with the stakeholders. Proper project documentation also came out as an important consideration. This is a reinforcement of the importance of project documentation as stated by Lientz & Rea [36] who also underline that business or operations people must formulate the bulk of documentation of the project and only leave IT team or external consultants to work on the technical documents.

5.1.5 Change Management

All the participants remarked that they had not executed well enough the change management in all their respective projects and this negatively affected the success of their projects. It can be concluded from the responses of the interviewees that change management is one of the major critical success factors in the implementation of WMS in the organisations that participated. The other aspects that were identified as important in achieving successful change management included

- An effective communication platform or forum must be set up where all stakeholders can raise any issues related to the implementation without fear of victimisation.
- All stakeholders must be involved as early as possible in the project to avoid resistance to change at the advanced stages.
- Instituting an effective communication platform or forum where all stakeholders can raise any issues related to the implementation without fear of victimisation.

Training

The aspect of training was also, overwhelmingly, identified as a key factor in such an implementation. Two points can be concluded from the research;

- All system users must be adequately trained before the go-live date.
- Whilst training is important, it will not cover all aspects that will be encountered during the actual use of the system, therefore, proper handholding must be planned for once the project has gone live.

All the organisations studied still carried out their training through traditional methods of theoretical training, desktop training and in exceptional cases practical hands-on training. Organisations should now consider using new technologies such as Virtual Reality (VR) to conduct their training. Several organisations in developed countries have already adopted this method of training [37]. The benefits of using such technology include no need to set up a physical training space since the training is virtual thus training will not disrupt the current warehouse operations and little involvement of experienced personnel, mostly, external consultant which come at a high cost.

System Testing and Go-live readiness

All participants highlighted the importance of conducting several iterations and levels of such testing as an important factor in achieving a successful go-live. Organisations could also consider using automation-testing methods to do all tests. Automation testing helps to reduce the regression testing effort and improves the test coverage consequently improving the quality of the software as well as reducing the time-to-go-live. However, the cost of developing such a system and training their staff may be a deterrent in some organisations. Automated testing should not completely replace manual testing but must be used as a complementary tool, especially for those processes that are relatively difficult to test through automation.

5.1.6 Go Live Activities

The critical factors pertaining to go-live activities that influence the success of WMS implementations that emerged from the experiences of the studied organisations and were confirmed by the interviewed industry expert are:

- Preparation for the go-live day must begin from the day the project is initiated. All project activities should culminate to the go-live date. A go-live readiness checklist must be formulated with all milestones that must be met before a go-ahead is granted. The checklist should be the basis for any go or no-go decision.
- A detailed cutover plan must be drawn up and be used as the guide to all go-live activities. The plan must also have all actions assigned to specific people and mention the timeframe within which each action must be started and completed.
- Relevant business intelligence tools, including reports and dashboards, must be provided to assist the organisation in the go-live transition. When taking-on stock onto the new WMS, the teams need readily available reports to measure progress as well to compare with stock levels from the system or report before the switchover to the new system.
- Handholding and on-site support will be required during the go-live period until the system is stably implemented. Therefore, suitably trained super users and the project team must be readily available so assist the users with any queries and there must be sign-off to officially handover the project to the operations after which any queries and requests will be done through the agreed support channel.
- Only one participant mentioned that a rollback plan was a requirement when implementing a WMS. This is at odds with the best practice specified in the ITIL deployment management practice, which recommends such a plan [38]. A detailed rollback plan must be in place as a contingency if a go-live is not successful.

5.1.7 Access to WMS Experts

The research revealed that there is limited local WMS software and organisations often have to implement international brands that are usually brought into the country through implementation partners or through the consultants in the case of organisations with headquarters that are outside of South Africa. To have a successful implementation, organisations need to build internal capacity to both implement and support their implementations. This is also confirmed by Somers & Nelson [39] who emphasises that, while the experts are important, organisations should not delegate key project aspects to them and should be used as partners and not drivers of the project. External consultants often come at a high cost and it is cost-effective to use more of internal resources for future work.

6 CONCLUSIONS AND RECOMMENDATIONS

This research was conducted to determine what the factors that influence the implementation of WMS for warehouse operating organisations in South Africa are. To answer this question, a conceptual framework was developed, through the literature review, which then acted a basis for conducting qualitative research on three participants that were selected. Semi-structured interview questions were posed to the participants. Their responses were analysed through thematic content analysis. The research shows that the factors that affect WMS implementation in South Africa are quite comparable to other research already done and the factors that were identified for WMS are similar for other business enterprise systems such as ERP. It also emerged that there are specific areas that South African organisations were struggling with and hence they need to focus on. These include executing effective change management, embracing technology for training, adhering to IT-related best practices such as implementing roll back plans as part of the go-live processes.

6.1 Limitations

This research was only limited to three organisations in the Gauteng province of South Africa. While the results showed converging themes, as well as some divergent views amongst the participants, more participants would have reinforced the findings that emerged from the research. Given that only organisations within Gauteng, the economic hub of the country, were part of the research, perhaps other factors would have emerged had other organisations in other localities were involved.

6.2 Recommendations for future work

Below are some of the recommendations for future work that can be conducted to further understand the subject that was under study.

- Increasing the size of the participants in the study to capture as many views as possible.
- Extending the study to other organisations in other provinces as they may be other factors that could emerge, for example, the impact of infrastructure availability as well as access to labour.
- Carrying out a quantitative study to determine the criticality of each of the factors based on data gathered.
- Understanding the impact of technology absorption in the South African context and its impact on warehousing and supply chain in general.

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BANKING 4.0 - THE IMPACT OF INDUSTRY 4.0 ON CURRENT BUSINESS BANKING BUSINESS MODELS IN A BIG SOUTH AFRICAN BANK

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ABSTRACT

Financial technology (known as Fintech) is an Industry 4.0 reality for the Finacial sector. Fintech provides a platform for the improvement and automation of the delivery and use of financial services. It also introduces competition in the from of new entrants to the market who have embraced Fintech from the start. With the dawn of Fintech, banks need to ensure that their business models enable them to adapt and scale their product offerings with the rapidly changing technologies of Industry 4.0. This raises the challenge as to how banking business model need to evolve to accomodate this inevitable change. This study employs a qualitative approach to investigate this through the lens of Kolber's Banking Business Models of the Future framework. An adapted framework is finally proposed.

Keywords: Industry 4.0, 4th industrial Revolution, Fintech, banking, business, business models

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1. INTRODUCTION: BACKGROUND AND CONTEXT

According the Schwab[1], the term, Industry 4.0 was coined at the Hannover Fair in 2011. The previous three industrial revolutions all created major social change and opportunity, but today's revolution is unique in the velocity at which the new ideas and technology spread around the world [1]. In this fourth industrial revolution, also known as the digital revolution or mostly referred to as Industry 4.0, the lines between physical, digital and biological spheres are blurred. According the Schwab [1], Industry 4.0 is characterised by rapid development and advances in technology and can not only change industries, but entire systems, countries and society. This is the combination of internet of technologies and future-orient technologies which leads to a paradigm shift in industrial production according to Lasi [2], and it is the revolution in the underlying technology. Liang[3]. Industry 4.0 will change the design, manufacture, operation and service of products and services. The connectivity and interaction between parts, machines and people will make production systems 30% faster and 25% more efficient, while enabling mass customization. Ganzarain & Errasti [4]. Disruption is imminent yet Industry 4.0 enables companies to venture into other industries at amazing speeds. Moreno [5].

Although there are themes around rapid development in technology, speed and velocity of change, digitization and inevitable change, there is no one formal definition or understanding around Industry 4.0. For the purpose of this paper Industry 4.0 is defined as the rapid advances in technology and how these impacts the current ways of work.

The focus of this study is then on how these rapid advances are impacting the business models in the banking industry. A business model is a company's plan for making a profit and it identifies the products or services the business will sell, the target market it has identified, and the expenses it anticipates. This is the strategy of the business. Investopedia [6]. Thompson[7], describes strategy as the things that managers and organizations do i.e. "this is how organizations copes with the world, which is dynamic and emergent".

Banking is no exception. It is driven by the strategic framework that the executives put in place and drive. From Thompson's [7] definition of strategy, one can conclude that business models are a basis of how business is done and how they adapt to the changing business environment to ensure relevance and sustainability. In the light of the change that comes with the development of Industry 4.0, it would seem feasible that banking business models would need to incorporate these anticipated and inevitable changes. Thompson[7]. Since Industry 4.0 is inevitable, banks need to ensure that business models enable them to adapt the way they do business and be ready scale their product offerings in line with the rapid changing technology. This raises the challenge as to how banking business model need to evolve to accomodate this inevitable change.

This research explores the impact of Industry 4.0 on the banking industry and more specifically on the business models that banks use to do their business. It finally proposes a new Industry 4.0 framework for banks. For this research the banking industry is defined as financial institutions that accept deposits from the public and creates credit from this. The emphasis of this research is specifically on a large established financial institution and it focus on a particular bank within South Africa.

2 LITERATURE REVIEW

2.1 Traditional business banking models

Stephan Bird, CEO of Global Banking at Citigroup, described the current traditional banking models at a stage of extinction and added that banks should either swiftly adapt and

Create new competitive positioning or gradually perish. Chen [9]. He added that internet based financial enterprises are cutting directly into traditional financial industry. New business models and internet-based finance companies have the following characteristics: flexible organizational structures, they are formed by joint ventures or small equity investments, financial products are innovated through the mobile internet, and new products can be introduced quickly, processes are evolving continuously. Chen [9] . In the new models, trade can be conducted anytime and anywhere though online transactions Itonics[10].

In traditional business models, all financial transactions occur over the counter, in fixed places or fixed facilities, customers were expected to go to the branch to execute their banking. This is further complicated by complex processes and structures and thus, time consuming for even simple transactions like, cash withdrawals, deposits, balance enquiries.. Legacy systems are also a problem to most large organizations and the bank is no exception. As described by Bennett [11], "Migrating and updating this baggage (referring to legacy systems) from our past has technical and nontechnical challenges, ranging from justifying the expense in dealing with outside contractors to using program understanding and visualization techniques." This then increases time and effort that must be spent on getting historic legacy systems on par and does not enable companies to focus on their core business execution.

2.2 Established vs new banks

Established businesses have greater customer confidence than new innovative businesses. They also have excellent market access, reliable and established products, established brands and customer confidence. Itonics [10]. An example of this is African Bank (AB), that was placed under curatorship in 2014. It would be expected that AB would lose customer confidence, yet after the a new banking licence was obtained, their customer advances grew at 9% and group profit after tax was up by 19% according to the 2018 annual financial statements. Annual Financials African Bank[12]. One can conclude that established banks have an advantage over new entrants to the market when it comes to customer confidence and new business. These established major banks still have the ability to grow in an unfavourable economic climate. This is demonstrated by the combined headline earnings for the four major banks being up by 8.7% from 2017 to 2018 according to a PwC report. Natsas and Roopnarain [13].

When expenditures are considered, however, the major banks have a few concerns they need to address. The combined cost-to-income ratio of the top four banks in South Africa, Nedbank, FNB, Absa and Standard Bank, is 55.1% according to Temkin[14], in comparison to a newer entrant, Capitec, with a ratio of 39%. Annual Financials Capitec[15]. While the actual numbers are not available at the time of this publication, the expected cost-to-income ratios for the new digital banks are expected to be between 25% and 30%. Withers[16]. This is due to the fact that they have fewer employees, less administrative costs and no legacy systems to maintain which leads to lower back office technology costs. Withers[16].

Therefore, with the dawn of Industry 4.0, major banks will need to carefully consider how they will be doing business differently going forward and continuously improving processes.

2.3 Conceptual Framework

The conceptual framework from Deloitte in their article on Banking Business Models of the future from Kobler [17], was used as the basis to look at the readiness to enable Industry 4.0

in the Big Bank, South Africa. This article identified 5 pillars that banking must incorporate in their business models to be ready for Industry 4.0. These pillars are gamification, blockchain technology, biometric technologies, digital investment and process automation (Figure 1).

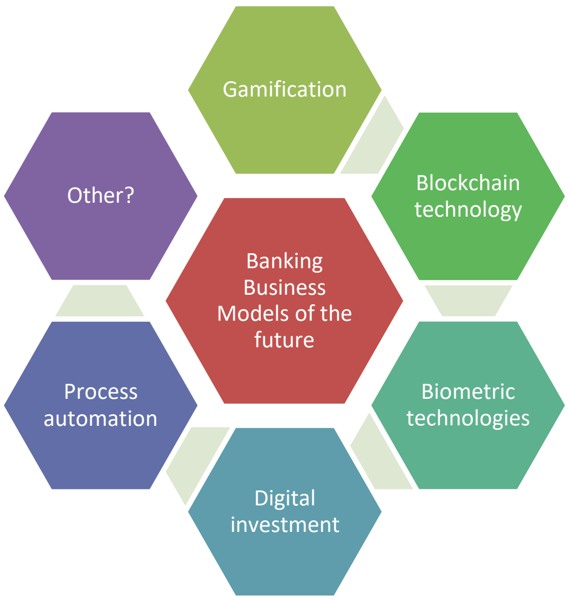


Figure 1: Banking Business Models of the future Kolber[17]

Each pillar is described briefly below:

2.3.1 Gamification

According to Kolber[17], gamification ensures “a more enjoyable experience for the customers.” Yazdanfard [18] defines gamification as the use of game mechanics in non-game environments. This includes reward levels and a competition element. deCos [19] explains that, in a broad sense, gamification is understood as a way to support user engagement, enhance user activity, social interaction and improve overall user experience. The desired effect is achieved through activating intrinsic motivation and incorporating game design elements. deCos[19]. Baptista [20] explains that there is a direct and strong relationship between gamification and the interaction in using banking services, and when implemented properly customer experience is more enjoyable, thus, increasing customer acceptance, engagement and satisfaction. Yazdanifard [18] points out that gamification is still in its infancy stages and it is hard to predict its effectiveness in the long run. Currently gamification strategies mainly focus on reward systems to engage customers. Marketers are only beginning to scratch the surface of the potential gamification has to offer in the service industry.

2.3.2 Blockchain technology

Blockchain is a real time global payment network enabling payment to anyone, anywhere, thus, simplifying payments and transaction flows. According to Accenture[21], the adoption of Blockchain technology will enable banks to process payments more quickly and more accurately, reducing transaction processing costs. Blockchain is currently a concept that has received significant attention in financial technology (FinTech). It combines several
computer technologies, including distributed data storage, point-to-point transmission, consensus mechanisms, and encryption algorithms and is a disruptive innovation of the iInternet era. As blockchain is a major breakthrough in data storage and information

transmission, it might fundamentally transform the existing operating models of finance and economy, which might lead to a new round of technological innovations and industrial transformation within the FinTech industry, Liang[3]. The main reason for resistance to blockchain technology is regulatory, compliance and security. Accenture[21].

2.3.3 Biometric technologies

Biometric technologies allow for seamless and secure digital authentication and reduce identity theft. These technologies are voice recognition and touch indentification (ID) fingerprint sensors, and will enable the ability to move away from passwords. Grant[22]. Biometric technology is defined as, automated methods for identifying a person or person's based on physiological or behavioural characteristics. Vacca[23].

2.3.4 Digital investment

Digital investment is described as robo-advisors, that enable automated investment advisory services. Kobler [17]. According to Forbes, these investment services promise to make investing easy, inexpensive and even fun. Berger[24]. Advanced machine interfaces, including machine learning, Artificial Intelligence (AI) and the idea of platform thinking also form part of the definitions. The latter entails a collection of capabilities (or services/functions), to enable the brands, segments and product houses to create and deliver contextual solutions. This is also an interface for customers, partners and employees to interact and communicate.

2.3.5 Process automation

Process automation offers large scale cost reduction, in combination with increased flexibility and accuracy of back office tasks. Kobler [17]. Business process automation is the use of technology to execute recurring tasks or processes in a business where manual effort can be replaced. It is done to achieve cost minimization, greater efficiency, and streamlined processes. Kissflow[25]

These five pillars form the Kobler [17] framework used to establish the requirements for big South African banks to ensure that they are ready for the impact of Industry 4.0. The framework was used to evaluate how a specific big South African bank is adapting to this new way of doing business.

3 RESEARCH METHOD

This research was exploratory as the phenomenon of Industry 4.0 is still relatively new in banking worldwide.

3.1 Research Instrument

Semi-structured interviews were chosen, as the concepts tested from the framework which wereused as the basis for this research, needed explanation and the oral testimony of subject matter experts was required. The interview questions were developed based on the pyramid model as presented by Wengraf [26]. These progressed from the critical research question to theoretical questions and then to the particular interview questions. To test these interview questions, a few non-formal interviews were held with trusted colleagues. The way the questions was posed were tested and slightly adapted.

3.2 Sampling and respondents

Purposive, non-probability expert sampling was used as Industry 4.0 in banking is a relatively new area of study and expert opinion are required to draw conclusions. For this study it was decided that at least one person per business unit working actively on the topics in the

conceptual framework would be interviewed. Originally, eleven respondents were identified for interviews. But as the research progressed, it became apparent that more participants would be required to validate certain findings and obtain clarity for some pillars. Clarifications and the impact on risk and current implementation were interrogated. For the five pillars investigated, thirteen subject matter experts were interviewed. Gamification was the exception. For the gamification pillar, an additional participant was interviewed, resulting in fourteen respondents for this pillar.

3.3 Data Collection

The ethics process as prescribed by the University of the Witwatersrand Ethics Committee, was followed for the data collection process. Interviews were done within a big South African bank. Permission was obtained from the business unit manager to conduct the interviews. The interviews lasted about 40 minutes on average and were recorded and then transcribed.

3.4 Data Analysis

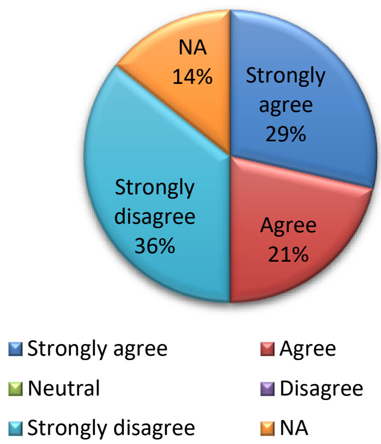
Coding was done in three main stages. Interview transcripts were pre-coded. As described by Saldana [27], this is to highlight, jot down and underline things and ideas that strike you. It also included reading the transcripts from different perspectives. For this research, all interviews were conducted recorded and then transcribed by the researcher. This ensured that the interview was listened to when conducted, then listened to again while transcribing and then captured. Once this was done these transcribed interviews were read a few times to ensure there was understanding of what was presented. Level 1 coding was then done with the first participant's data, identifying words and phrases that represented the main idea or ideas presented by the participant. This then progressed to the second participants data and so on. It was found that as coding progressed, the subsequent sets of data influenced and affected the coding of the interviews from the previous participant's data. Saldana [27] refer to this as "Coding contrasting data" (p18) and indicates that this maximizes the potential for variety. In vivo coding was done on the data where descriptions and explanations were given and hypothesis coding was done on inputs of numbers based on the Likert scale, for implementation, relevance and timing. After the first very granular level of coding, pattern coding was done, to collate the data into clusters and meta-data, which lead to the themes identified. Once the first and second levels of coding were completed, the data was ready for analysis. Themes were identified and pie charts and histograms of the data collected were drawn. This assisted in understanding the effect of the implementation, relevance and timing of the topics researched as well as the themes that emerged from the data.

To ensure that the research was valid and reliable, construct validity and reliability judging criteria was used.

4 RESULTS

4.1 Evaluating the implementation of Industry 4.0

To evaluate the implementation of Industry 4.0 in the business banking environment of the investigated South African bank, the following was found:



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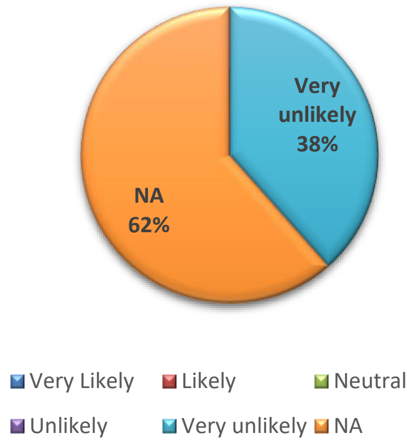
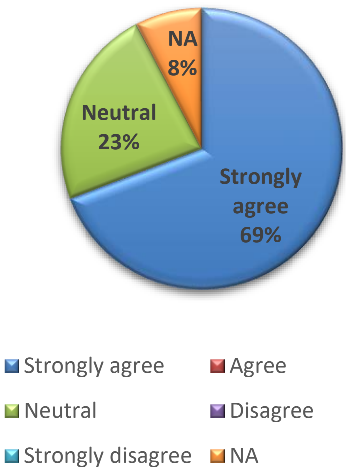


Figure 3: Implemented - Blockchain

Figure 2 indicates that Gamification implementation had a 50/50 ([29%+21%]/[36%+14%]) split between implemented and not implemented, while Blockchain was not implemented at all (62%+38%) (Figure 3).



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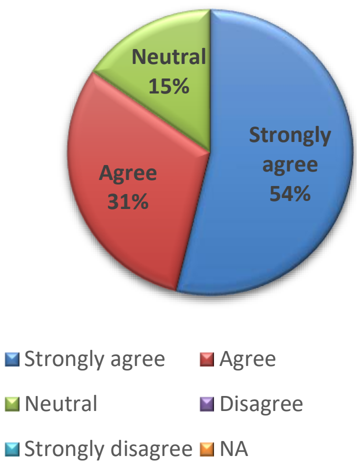

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Figure 4 indicates that Biometric technologies had a 70% implementation rate and that Digital investment were implemented at 85% (31%+54%) of business units (Figure 5).

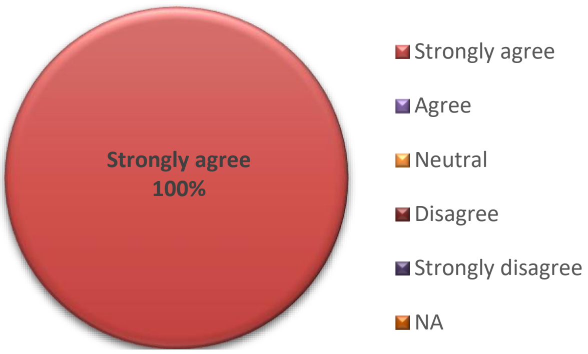

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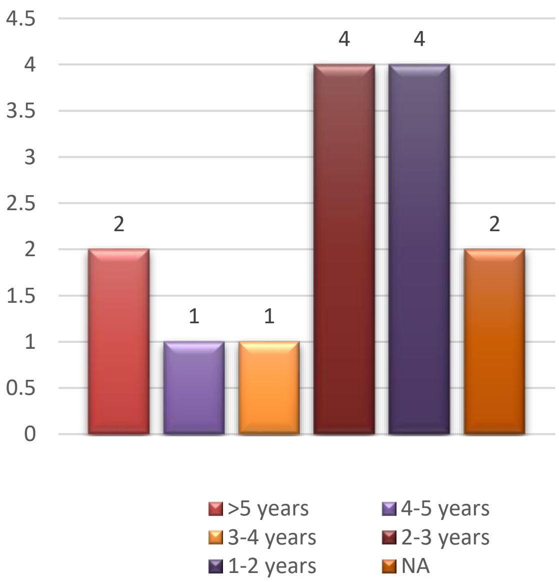
Figure 6 indicates that all business units are implementing process optimization.

From the above, the bank is currently implementing all these game changing pillars in the organization to a more or lesser degree.

4.2 Identifying the impact of the changes due to Industry 4.0, (2015 to 2019)

The results showed that, except for blockchain technology, all the other pillars are either investigated and/or implemented for the last 5 years, even though some might have been limited to 1 or 2 business units, e.g. gamification and digital investment.



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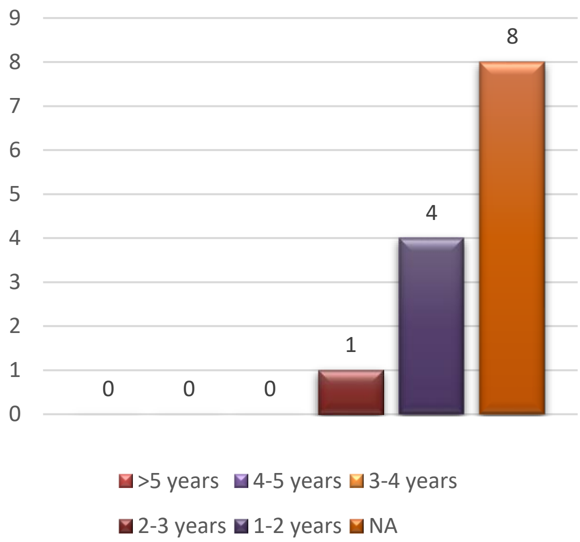

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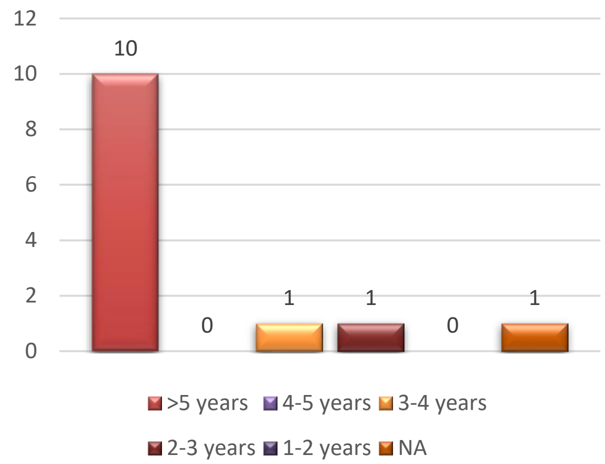
Figure 7 shows that only 2 respondents indicated that Gamification was investigated their areas in the last five years.10 respondents mentioned that they were investigating this in their areas in the last 1 to 4 years and 2 respondents do not believe thatgamification is applicable in their business unit. , Only 5 respondents indicatedthat they were investigating blockchain technology actively, while the other 8 b that this is not applicable or relevant in their business units (Figure 8).



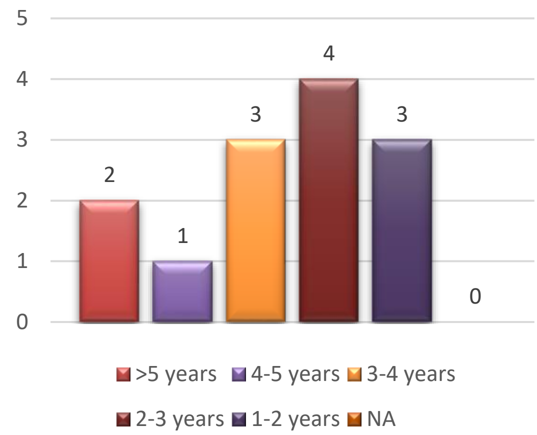


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Figure 9 indicates that Biometric technology has been used in most areas for the past 5 years. Only one area indicated that this is not relevant to them, while Digital investment is implemented in all areas (Figure 10)

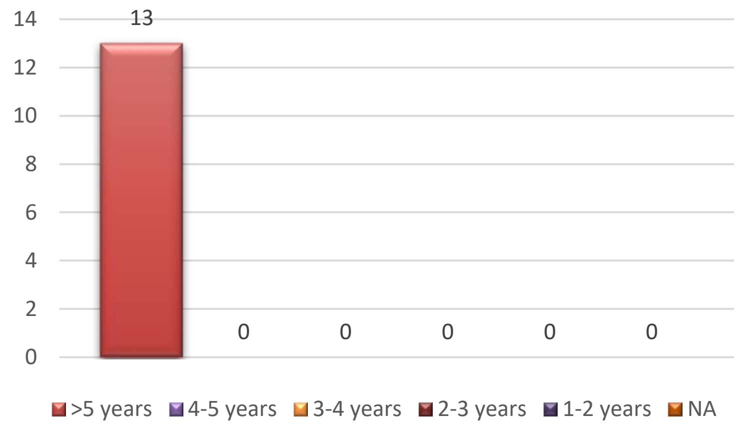

Figure 11: Timing of usage - Process Automation

Process automation is actively implemented in all areas, as indicated in figure 11.

The change in business models and strategic focus are evident in the presented results. The majority of the participants only started looking at gamification as part of their business models in the last 3 years. This has a significant impact on the way business models and strategies are formulated. Blockchain technology, however, only started impacting business models in the last 2 years, and the impact is still in an exploratory phase. Biometric technologies and process automation have had an impact on business models for the last 5 or more years. This impact is increasing as the focus on this is becoming greater. Digital investment is gaining momentum and has had a major impact on the business models in the last 5 years.

5 DISCUSSION

5.1 Gamification

Gamification was described as enabler for a more enjoyable and richer customer experience. Through the study this definition has changes slightly to also include the fact the game mechanics are used to modify customer behaviour. Training and development emerged as important applications of gamification, i.e. to ensure that compulsory regulatory training is done in a more enjoyable way. Additionally, ensuring a more enjoyable customer experience is important, and elements of gamification should be used in the design thinking for training. Respondents, however, felt that this is not a core banking function. It was revealed that gamification is immature in banking as well as worldwide and still needs to be explored more holistically. One aspect that is receiving traction in banking is the creation of a more enjoyable user experience, where banks are actively driving this in their process thinking as well as customer interfaces.

5.2 Blockchain technology

It was concluded that blockchain technology had limited applications and is a technology that must still be developed to a more mature stage before banking can consider this. Although use cases of cross border transactions and easy flexible payments came through strongly, the risk and regulatory frameworks are not mature enough to incorporate this as an active product of the bank. An important consideration is that the key currency of banking is trust. Since blockchain technology is still a new technology, the questions arise as to whether the bank should incorporate this as a key product. It may be perceived by investors and customers as a gamble, jeopardising the trust element of the bank. Lastly, the technology is not widely adopted as yet. Once there is a wider adoption within the industry, closed networks (permission blocks) might be considered. The low volumes compared to current systems (e.g. VISA), that blockchain technology can handle, are also still a significantbarrier for adopting this technology widely.

5.3 Biometric technology

It was established that the use cases for biometric technologies are vast. There are major opportuniies within call centres to utilise voice recognition and finger prints as signatures for contracts, and verification and authentications of customers. There are, however, a few challenges. Regulation, for example, require signatures to be in wet ink for some contracts. Secondly, the advancement of digital infrastructure i.e. artificial intelligence and robotics using natural language processing, to enable the processing of the bulk of the call volumes is not at the required level of advance yet. With the necessary digital investment and security implementations, these challnges may be overcome and enable biometric technology to be used to enhance efficiencies and possible use cases.

5.4 Digital investment

The original framework included digital investment as a pillar on its own. From this research, it is established that digital investment should rather be changed to digital investing and become a supporting, or base pillar. The reason for this is that digital investment is much more than robo-advice in the investment space. Digital investing is required for the enablement of all the other pillars. To establish a more enjoyable customer experience, digital investment is required to ensure that customer and user interfaces are rebuilt. The enablement of blockchain technology also requires vast digital investment to enable platforms to build and support this. Biometric technology must be integrated into current systems and processes. To ensure this is done as effectively as possible, digital investment is required. Process automation cannot be done without investment in digital technologies and systems. The only reservation is that robust legal frameworks must be in place to ensure that, where the lines are blurred between man and machine, the required legislation is in place to protect where necessary and prevent fraud.

5.5 Process automation

Process automation is a key component of Industry 4.0. Without process automation, there will be no "straight through" processing and manual processes will persist. Currently, this hinders efficiency, in that vast data capturing is required, in and between systems. This not only causes bottlenecks and increased time to execute the process, but it also introduces problems like typing errors, for example. It is, however, clear that process automation goes hand in hand with process optimization and the establishment of process relevance. If a process is not optimised but automated only, this may mean that possible other integration points were not considered and wastes were not identified. The optimization and identification of the relevance of processes is sometimes lacking. It was concluded that not just process automation but also process optimization is a continuous improvement activity. System integrations should be managed efficiently and effectively on an ongoing basis.

5.6 Timing of framework

The timing of the implementation required for each pillar was also investigated. An order of implementation was established, as follows:

i. Process automation and optimization was established to be highly relevant and widely implemented throughout the organization. The recommendation is that this is the first step to ensure that the bank is ready for Industry 4.0.
ii. Biometric technologies have vast benefits once implemented appropriately. This is the second pillar that must be implemented to ensure alignment and readiness for Industry 4.0.
iii. Gamification and a more enjoyable customer experience are an important aspect to consider. If systems and processes are hard to use, customers and users will try to avoid these where possible and avoid them. This is placed third on the list of timing and importance because, if the basics are not right, i.e. process automation and optimization and biometric technologies, there are limited use cases to enable gamification and more enjoyable customer experience. These will then be limited to learning and development and not imbedded in the bank's DNA.
iv. Blockchain technology is last on the list for timing and implementation importance. because this is a new technology.. Banking, in general, is not associated with being market leaders in cutting edge technology. They prefer to use established proven technology. Blockchain technology is still in its infancy stages when it comes to regulatory aspects, volumes and adoption. This is thus currently not a technology that should be in that front line of implementation for Industry 4.0. As some of these aspects, however, fall into place, blockchain technology can change banking significantly. This should be consistently monitored.

5.7 Supporting pillars to the framework

Four supporting pillars were identified as part of the research, namely, human resources, digital investing, big data and security.

5.7.1 Human resources

Buy-in from employees and customers are important to execute any strategy. Without the hearts and the minds of the people imbedded in the strategy, no strategy can be implemented. A transformative purpose is required for employees and customers to support the Industry 4.0. journey. This means that all should understand why is this required and why is this necessary. It is also important employees to understandhow they are impacted. If these questions can be answered efficiently and effectively, the implementation of the strategy for Industry 4.0. will be successful. People do, however, need to understand that change is inevitable. If they are unwilling to change and adapt, this will impact them significantly. It is, thus, important for the bank to continuously update all employees of the latest developments and changes that happen and the progress that has been made. Additionally, the bank needs to establish ways for employees to avail themselves for growth opportunities.

5.7.2 Digital investing

As discussed earlier, digital investing is a core supporting pillar to ensure the success of Industry 4.0. Investment in digital infrastructure across the board is required to enable processes and technologies. Vast investments are required to ensure that systems and processes are optimised, legacy systems are replaced and that there is still a good customer experience. To enable biometric technology, gamification and blockchain technology, digital investing is required and thus identified as a base pillar.

5.7.3 Big data

Big data is also established as a base pillar for all other pillars. This is because data is required to understand which processes must be optimised, it is also used to enable biometric technologies and gamification. Data is also used for the execution of blockchain technology use cases. Data can assist the bank to enable better understanding of their customers i.e. to enable customers to get the correct and required products. Data enrichment is also required and has various applications. Data impacts the strategy and inform management decisions.

5.7.4 Security

Security underpins all of the pillars. The best process automation and optimization should be executed, using maximum security. This is the same for all the other pillarsAs mentioned before, the key currency of banking is trust. The privacy of customers must be valued, and risk must be minimized. With exceptional security the bank will continue to draw more customers and expand their foot print and enhancements required for Industry 4.0.

5.8 Proposed New Framework

The proposed new framework, based on the discussion in sections 5.6 and 5.7 above, is depicted in Figure 12 below. The four main pillars are process optimization and automation, biometric technologies, gamification and blockchain technology. The four supporting pillars that underpins these are human resources, digital investment, data analytics and security. This is encompassed by a customer centric approach, i.e. what will be customer think, experience or do.

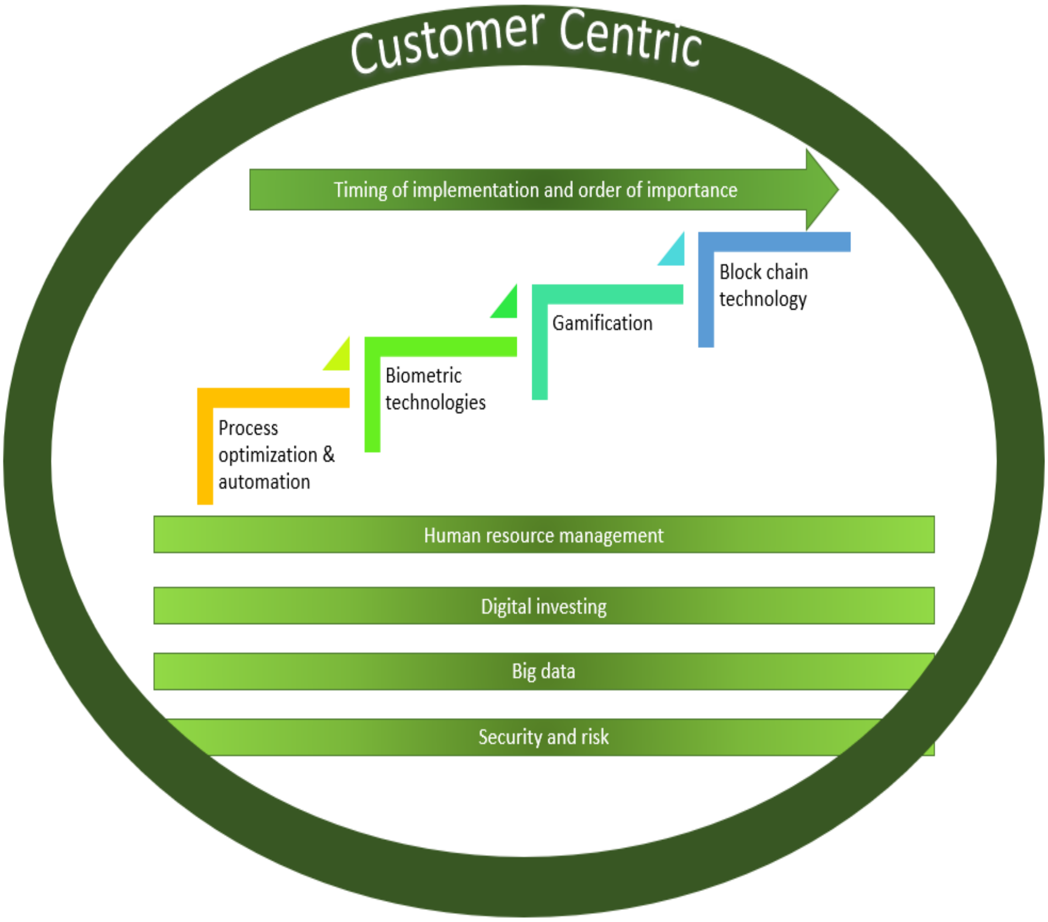

Figure 11: Industry 4.0 Readiness Framework (HM Bohmer, 2020 ©)

6 CONCLUSIONS

The impact of Industry 4.0 on business models is significant. While traditional banking models include branch banking, maintaining legacy systems and operating within complex structure, future banking business models are based on digital banking capabilities or Fintech, and self-run centres of excellence, which included systems to support these and are ideally self-maintained systems. These also include machine learning and lean efficiency processes that are optimised to ensure complexity and is only incorporated were absolutely required. These will enable banks to re-invent themselves and keep up with the increasing competition on the financial industry. This should be done by leveraging t current industry advantage, i.e. as an established bank with thousands of current customers who already trust the bank, and by continuing to innovate,grow and use thexisting big data lakes to extract the information and reports required.

In summary, gamification was not a topic that was even considered 5 years ago within the banking context, yet now the bank has large projects and initiatives that investigate s and seek implementations of this pillar. This pillar will in turn be part of the enablers to ensure a smooth, customer centric customer experience and will continue to move the branch banking, or brick and mortar model of banking, to a digital bank. It will also have an impact on the complex structures of the bank as these structures will be questioned and optimised where possible to implement gamification.

Biometric technologies have also shaped the focus of business models. Call centres and branch banking can be done more effectively if implemented correctly. With regards to this pillar, the bank is actively implementing this and investigating new avenues to implement. Branch banking will be revolutionized by this as customers can be identified without any physical documentation. This will also impact complex structures and processes.

Blockchain technology is still in the infancy stages of development with regard to regulation, legislation and adoption. As mentioned previously, the key currency of the bank is trust, meaning that only proven technologies are incorporated in their systems. The bank should, however, continue to monitor the progress of blockchain technology as this currently does not influence the business model per se. Once implemented it will, however, have an impact on branch banking as it will encourage digital banking models. Maintenance of legacy systems will be impacted as new systems and integration will be required and complex structures will be challenged through blockchain technology.

Digital investing will ensure that the current legacy systems are either decommissioned or enhanced in such a way that a large legacy bank will become a customer efficient, cost effective digital bank. This will enable self-maintained systems and capabilities or platforms to establish the centres of excellence. This cannot be done without optimised processes and structures. These changes will impact the business models and strategy to ensure that digital banking will become the bank of choice.

Process optimization and automation will impact branch banking as customers will be serviced more efficiently. It also impacts the maintenance of legacy systems, in the sense that, if processes are optimised some of the systems may not be necessary anymore or optimised to use new systems. Complex structures are also impacted when processes are optimised and automated. To be ready for the digital revolution, the bank should actively focus on optimising business processed throughout.

Human resource management, big data and security and risk are the new pillars identified through this research. These pillars will impact traditional banking models in that they support the main pillars to effectively operate and be implemented. They assist in identifying changes required.

So, are traditional banks ready for this transformation? From the above research done, the conclusion is that, if the bank continues on the current path, they are on a trajectory to be ready for the impact of Industry 4.0. All pillars are implemented or investigated actively and there is focus to drive this actively. Blockchain technology may be seen as the exception, but without a clear broader framework available to monitor it, this is currently sufficient.

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SUCCESS FACTORS OF TECHNOLOGY INNOVATION: AN ORGANISATIONAL PERSPECTIVE

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ABSTRACT

Technology innovation is a complex process and often results in low rates of commercialisation. To facilitate effective innovation management, this study aimed to identify success factors of technology innovation by a systematic literature review on 151 publications. A vast assortment of factors was identified and grouped into four categories deemed most suitable for organisational innovation management, namely interpersonal, intra-organisational, inter-organisational, and extra-organisational factors.

The results have important implications for innovation theory and practice. Theory is enriched with the representation of technology innovation success factors in an integrated manner, providing a holistic view of factors requiring attention during technology innovation. From a practical perspective, the factors in various categories will better enable innovation managers to enhance the process and improve the likelihood of successful outcomes.

Future research is suggested to focus on changes in the relationships between the factors at the various stages of the innovation process.

Keywords: technology innovation, success factors, organizational perspective, systematic literature review.

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1 INTRODUCTION

Innovation leads to economic growth [1] – while this was mentioned several decades ago it remains true today. Technology innovation is the progression from ideation to commercialisation, and is typically a difficult and slow process [2, 3]; however, several factors exist that contribute to successful technology innovation.

Technology, along with technological development and advancement, are imperatives for the economic growth and survival of any nation [4]. Hence, "a nation's prosperity is partly a function of its technology and partly the nation's ability to keep up with changes in technology" [4:932]. Similarly, the survival of many organisations depends on their ability to bring new products to the market effectively [5, 6]. Successful technology innovation is critically important for organisations to survive in the rapidly-changing environment within which they operate [7-10]. Moreover, technology innovation is a considerably challenging process [11-14], and it can take an "amazingly long period of time for new technologies to be adopted by those who seem most likely to benefit from its use" [15:604]. It is therefore believed that the identification of success factors of technology innovation would reduce the uncertainty and risk [16-20], along with improvement of the low success rate and extended timeframes that are often associated with the process [11, 12, 14].

The objective of this study was to identify success factors of technology innovation, along with the classification of these factors into categories pertaining to organisational innovation. When search phrases relevant to the technology innovation process and its characteristics, as defined for this study, were entered into a literature search database, a large number of publications along with a vast assortment of success factors were retrieved. Therefore, in an attempt to develop a more holistic view of the factors that contribute to successful technology innovation, and how they relate to various aspects of the organisation and its relationship to others and the market, a systematic literature review (SLR) was conducted. A descriptive, textual narrative synthesis was applied for this SLR and the work serves as background to an empirical study [21] that focuses on the dynamics and interrelationships of success factors across the technology innovation process.

To address the objective of this SLR, four research questions were formulated, namely:

1. Which publications identify factors that contribute to successful technology innovation?
2. Which publications suggest models or frameworks for technology innovation from which success factors can be derived?
3. What are the success factors of technology innovation from the collection of publications?
4. What common relationships exist between the factors to enable classification into categories?

As the basis for this study, technology innovation is defined as a non-linear, highly integrated process that encompasses four stages, namely concept development, research and development (R&D), product development, and implementation as illustrated in Figure 1 [22]. The stages of the technology innovation process are highly interconnected and interactive, with the arrows indicating the fluid nature of the overall process.

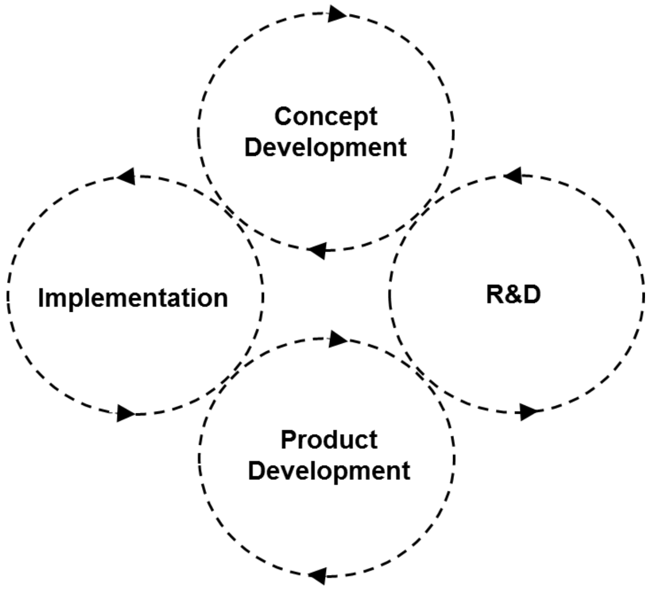

Figure 1: Depiction of the technology innovation process for this study [22]

Within each of the technology innovation stages, various and diverse activities occur. These might include the screening of options during concept development, experimentation during R&D, engineering during product development, and installation and commissioning during implementation. In addition to technology innovation activities, several other interactions occur. From an organisational perspective, an important internal interaction might be corporate entrepreneurship, which is a managerial strategy that focuses on the stimulation of entrepreneurial behaviour, aiming for enhanced innovation within the organisation [20, 23]. Another valuable organisational interaction, particularly with the external environment, is open innovation, which involves a collaborative network of external research partners [24].

2 REVIEW METHOD

The review method involved an SLR to minimise researcher bias and to ensure maximum coverage of relevant "intellectual territory" [25:207]. This rigorous process originated in the medical field decades ago and has been adopted widely in other subject areas due to the structure and transparency that such reviews lend to the literature review process [26]. The SLR was performed in three phases, namely planning, execution, and reporting [21].

2.1 Identification of search phrases

During the planning phase of the literature review, primary and secondary search phrases (Table 1) were formulated; these resulted from the cyclic technology innovation process and its embedded stages of concept development, R&D, product development, and implementation, as depicted in Figure 1. Accommodation within the search was made for the inclusion of terms that may be used to describe similar aspects, such as "ideation" to refer to concept development, as well as accompanying interactions with the innovation process, such as open innovation and corporate entrepreneurship. Primary search phrases related to technology innovation e.g. technology commercialisation, - development and – transfer were included for completeness.

Table 1: Primary and secondary search phrases in article titles

Primary search phrase	Secondary search phrase	Search No.
Innovation	Factor, success	1
	Framework OR model	2
Concept development OR ideate/ideation OR invent / inventive / invention	Factor, success	3
	Framework OR model	4
Research and development OR R&D	Factor, success	5
	Framework OR model	6
Product development	Factor, success	7
	Framework OR model	8
Technology development	Factor, success	9
	Framework OR model	10
Corporate entrepreneurship	Factor, success	11
	Framework OR model	12
Open innovation	Factor, success	13
	Framework OR model	14
Technology commercialisation / commercialization	Factor, success	15
	Framework OR model	16
Technology implementation	Factor, success	17
	Framework OR model	18
Technology transfer	Factor, success	19
	Framework OR model	20

All search phrases were specified to feature in the title of the publication, except for the term "success" that was selected to also feature in the abstract or keywords. This was done to capture publications involving *success factors* that were not captured from the publication title. As indicated in Table 1, ten primary search phrases were used, along with the specification of two sets of secondary searches, resulting in twenty separate searches.

2.2 Selection of relevant database

For this study, the databases of Scopus, Web of Science, and Google Scholar were compared. While Google Scholar is freely available, it lacks citation analysis tools and does not enable searches to be saved or search results to be exported [27]. The Web of Science database retrieved fewer articles when compared to the same search performed in the Scopus database, and the citation analysis of Scopus was faster than the former [28]. Scopus is updated daily, and covers around 60 million records, including abstracts of around 25 000 peer-reviewed titles, and also includes over 4 000 open-access journals [27]. Scopus was thus selected as the preferred database for this study.

3 IDENTIFICATION AND APPRAISAL OF LITERATURE

To provide structure to the analysis of the publications, a list of screening codes, shown in Appendix A, was prepared, including descriptive codes, such as year, journal, and primary search terms, as well as open-ended codes focusing on the findings of the review [21, 29].

During the execution phase of the literature review, the selection process, shown in Table 2, was used to screen the relevance of the research results [21, 30]. A total of 12 611 publications were retrieved from the twenty searches, which was refined in subsequent selection steps, resulting in a final collection of 151 articles.

The final sample of 151 publications, organised chronologically from the earliest publication to 2019, is shown in Appendix B.

Table 2: Literature selection process

SLR Stage	Identification	Screening					Eligibility				Inclusion	
Search No.	Potentially relevant unique hits identified for retrieval	Excluded based on refining subject category	Potentially relevant references in proper subject category	References excluded based on title	Potentially relevant articles for further review, combine all search results	Remove duplicates	Potentially y relevant articles for further review, check abstracts	Publications excluded based on abstract	Potentially relevant articles for further review, check full text	Publications excluded based on full text	Additional articles identified by forward and backward search	Total number of publications included in SLR
1	205	168	37	8	29							
2	5 464	5 344	120	82	38							
3	2	1	1	1	0							
4	1 503	1 415	88	77	11							
5	68	37	31	4	27							
6	2 216	1 701	515	447	68							
7	111	55	56	31	25							
8	1 251	793	458	387	71							
9	23	8	15	10	5							
10	791	610	181	165	16							
11	5	4	1	0	1	43	361	206	155	15	11	151
12	36	13	23	11	12							
13	25	20	5	4	1							
14	252	154	98	82	16							
15	10	2	8	4	4							
16	45	8	37	28	9							
17	27	8	19	13	6							
18	221	155	66	50	16							
19	20	18	2	0	2							
20	336	205	131	84	47							
Total	**12 611**	**10 719**	**1 892**	**1 488**	**404**							
Reason	As per primary and secondary search phrases	Publications screened for journal article, and (i) Engineering and (ii) Business, Management and Accounting subject areas		Screening exclusions based on irrelevant topics, e.g.: no model or framework, business model, technology road-mapping, risk assessment framework, benefits and cost framework, life-cycle assessment, and linear innovation processes			Non-eligibility exclusions based on irrelevant topics, e.g.: no model or framework, no success factor(s), business model, technology road-mapping, risk assessment framework, benefits and cost framework, life-cycle assessment, supply chain concept model, irrelevant to technology, process model/framework				Backward (reference list) and forward (citation) searches, adhering to primary and secondary search phrases	Final list

To check for proper inclusion of relevant literature in the selection of the 151 publications, the key literature sources of a previous study by the authors on the topic of technology innovation [22] were compared. It was found that all the relevant key literature sources from the comparative study were included, supporting that the literature selection process was appropriate.

The number of initial and final articles, per primary and secondary search phrases, is shown in Table 3. From the total number of articles that were retrieved as part of the first search result, only slightly more than 1% of articles were included in the final collection.

Table 3: Number of initial and final publications, based on search phrases

Search No.	Primary search terms	Initial search	Final selection
1 & 2	Innovation	5 669	24
3 & 4	Concept development OR ideate/ideation OR invent / inventive/ invention	1 505	1
5 & 6	Research and development OR R&D	2 284	26
7 & 8	Product development	1 362	36
9 & 10	Technology development	814	10
11 & 12	Corporate entrepreneurship	41	7
13 & 14	Open innovation	277	18
15 & 16	Technology commercialisation / commercialization	55	13
17 & 18	Technology implementation	248	3
19 & 20	Technology transfer	356	13
Total		**12 611**	**151**

An analysis of the journals in which the 151 articles were published revealed a total of 94 journals, which reiterates the diverse nature of technology innovation, as well as the vast assortment of journals that form part of the (i) Engineering, and (ii) Business, Management and Accounting subject areas.

Table 4 lists the journals within which three or more articles of the final list featured.

Table 4. SLR results: number of articles per journal (featuring 3 or more articles)

Journal	Number of articles
Technovation	7
European Journal of Innovation Management	6
Technological Forecasting and Social Change	5
IEEE Transactions on Engineering Management	5
International Journal of Technology Management	5
Journal of Product Innovation Management	4
Journal of Technology Transfer	4
Research Policy	4
Journal of Management Studies	3
Engineering Management Journal	3
Journal of Manufacturing Technology Management	3
R&D Management	3
Journal of Business Research	3
Research Technology Management	3

The final selection of articles originates from 36 countries. Figure 2 highlights the top five publishing countries for this study, contributing 45% of the total publications, namely USA (32 of 151), United Kingdom (13 of 151), Sweden (9 of 151), Canada (7 of 151) and Germany (7 of 151), with the overall percentage contributed by each country indicated. Of interest is the comparison of these countries with the Global Innovation Index 2019 rankings [31]. With the exception of Canada, which is ranked 17th of this global index, all countries are ranked within the top ten innovative countries worldwide.

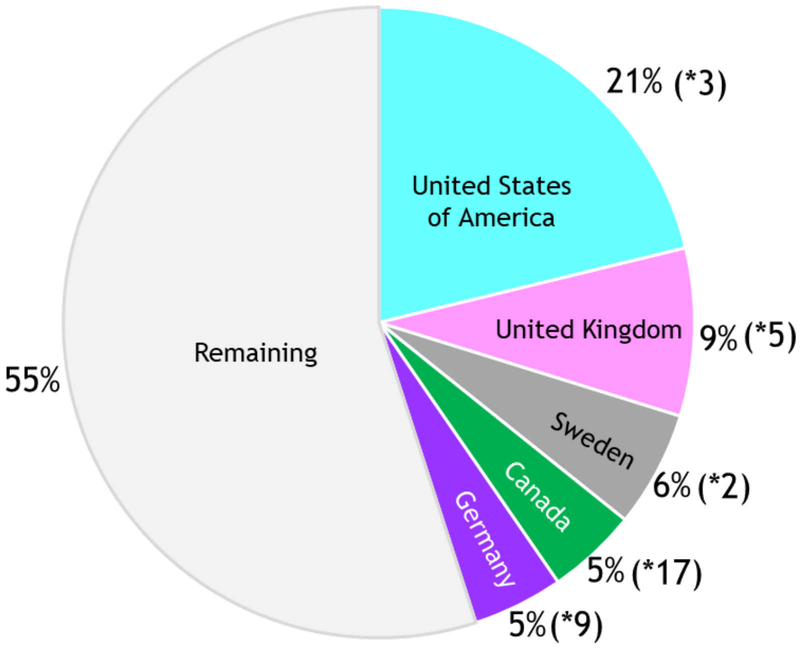

Figure 2. Top five publishing countries of this SLR (*Global Innovation Index 2019 rank)

4 ANALYSIS AND SYNTHESIS OF LITERATURE FINDINGS

4.1 Technology innovation success factor categories

For this systematic review, an organisational perspective was taken, whereby the organisation developing the technology formed the primary frame of reference, with success factors grouped into relevant categories that are interconnected with the organisation from various angles. Hence, the vast assortment of success factors that were obtained from the publications was distilled into four categories, represented holistically in Figure 3, namely:

1. Interpersonal: technical skills and personality traits of the members comprising the innovation team, along with productive utilisation of these qualities amongst the members through effective teamwork.
2. Intra-organisational: the immediate environment surrounding and influencing the innovation team, along with organisational structures, processes, and support.
3. Inter-organisational: interactions between the organisation and its innovation partners, suppliers and networks.
4. Extra-organisational: the customer and market influences that the organisation experiences from the external environment in which it operates.

Figure 3 provides a depiction of the interrelatedness of the technology innovation success factor categories within an organisational context. The directional relationships between the various categories are shown, starting from the smallest area of influence, the interpersonal factors between the team members, which extends to intra-organisational factors between the team and the rest of the organisation. The interrelatedness of the factors is further expanded by inter-organisational relationships with suppliers and partners and, finally, the extra-organisational factors indicate the relationship of the organisation with its customers in the market.

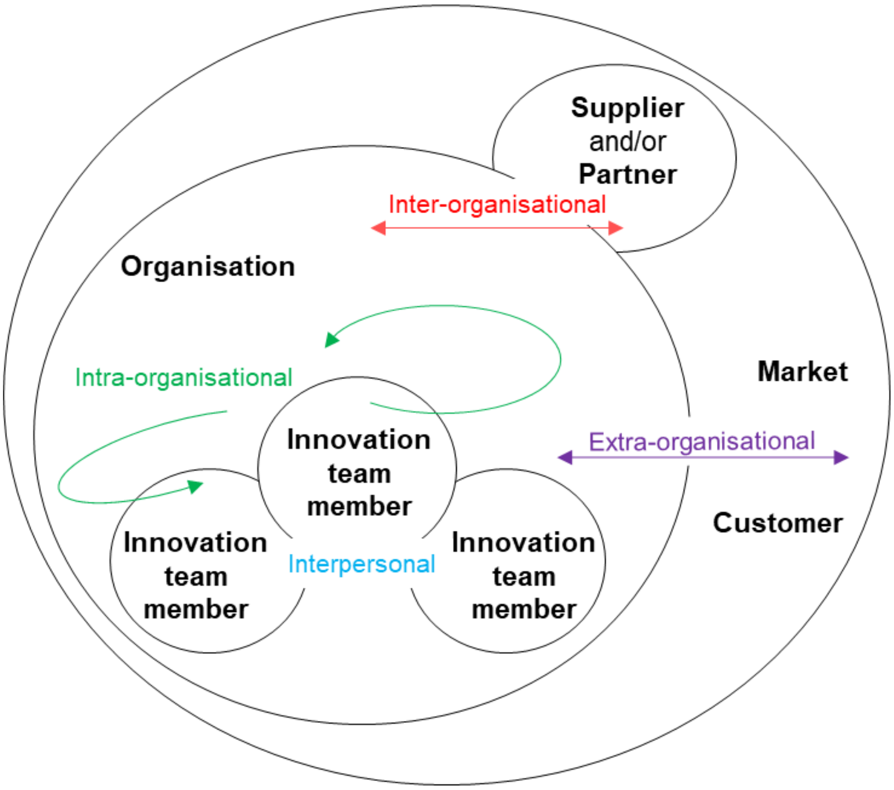

Figure 3: Integrated representation of success factor categories for technology innovation from an organisational perspective

Figure 3 shows the fluid nature of the organisational context, with success factors acting in an interconnected manner upon the other. However, to provide a proper analysis of the literature, an assumption is made that the identified factors do not change over time.

4.2 Contribution to innovation theory

The 151 publications of this SLR were compared in terms of the number of success factor categories that each publication covered.

Table 5 shows that 46 publications covered one of the four success factor categories, such as Freeman [32], Krishnan and Bhattacharya [33], and Azarmi [34] focusing only on intra-organisational factors, while McFadzean, et al. [23], Elkins and Keller [35], and Hayton and Kelley [36] focused only on interpersonal factors. Sixty publications, such as Zirger and Hartley [37] (interpersonal and intra-organisational), Alekseevna [38] (intra- and inter-organisational), and Balachandra and Friar [5] (intra- and extra-organisational) discussed two of the four categories. Thirty-nine of the 151 publications, such as Jolly and Creighton [39] (interpersonal, intra-, and inter-organisational), Kandemir, et al. [40] (interpersonal, intra-, and extra-organisational), and Evanschitzky, et al. [3] (intra-, inter-, and extra-organisational) covered three of the four categories.

Table 5: Success factor categories in the collection of SLR publications

Number of categories covered (out of 4)	Number of publications	Publications
1	46	[23, 32-36, 41-80]
2	60	[5, 15, 16, 19, 37, 38, 81-134]
3	39	[3, 4, 6, 7, 10, 12, 14, 18, 39, 40, 135-163]
4	6	[20, 164-168]
Total	**151**	**151**

Only six publications [20, 164-168] covered all four success factor categories. However, a few aspects concerning the objective of this paper, need to be highlighted for each study, and these are listed in

Table 6.

Table 6: Key aspects from publications that cover all four success factor categories

Authors	Key aspects
Shaw, et al. [20]	• The focus of this study is corporate entrepreneurship and innovation. • Two models are presented, a macro-model and a micro-model for corporate entrepreneurship and innovation, resulting in a potentially complicated representation of the content of the study. • This article was published 15 years ago; hence some of its content might be outdated.
Berkhout, et al. [164]; [165]; [166]; Ford, et al. [167]	• These publications are all based upon the Cyclic Innovation Model, which depicts the processes in innovation by a circle of change. • Only entrepreneurship is described as interpersonal factor.
Van Der Heiden, et al. [168]	• The focus of this article is on absorptive capacity concerning international technology transfer. • No specific interpersonal factors are highlighted; rather the focus is on knowledge and absorptive capacity. • The focus of intra-organisational factors deals with how absorptive capacity needs to be cultivated in an organisation. • Inter-organisational factors focus primarily on technology transfer mechanisms.

Even though these six publications (

Table 6) covered all four categories of organisational technology innovation, none of these studies provided such an inclusive view as is provided by this paper. Therefore, the primary contribution to innovation theory made by this study is the provision of a *holistic overview* of success factors of technology innovation, covering all four categories from an organisational perspective, namely interpersonal, intra-organisational, inter-organisational, and extra-organisational factors.

The success factors for technology innovation, grouped according to the identified categories, are discussed in the following sections.

4.2.1 Interpersonal factors

Interpersonal factors relate to the technical skills and expertise, as well as personality traits of the individual researchers comprising the technology innovation team [4, 169, 170].

The composition of the research team is critically important for successful technology innovation, ensuring the availability of the required technical skills [12, 14, 40, 79, 109, 111, 146, 151, 160]. Important skills include the formulation of accurate technical specifications, such as originality, fit-for-purpose, durability, functionality, aesthetics, and user-friendliness, amongst others [3, 10, 43, 59, 90, 91, 94, 121, 127, 129, 146, 152, 161, 171, 172]. A special skill set is also required to accurately articulate the purpose of the technology and the need that it will satisfy in the market [4, 34, 40, 109, 111, 146, 152, 154]. Technology management skills are also required, ensuring that the process of technology innovation is managed appropriately [72, 88, 98, 103] and that a holistic view is taken over all aspects that may influence the technology, its development, and its intended users [46, 78, 87, 106, 147].

Researcher attributes such as professionalism [90], creativity [170], leadership [35, 152, 154], and entrepreneurial behaviour [20, 36, 86, 105, 109, 128, 145, 168] contribute considerably to the success of technology innovation, along with the presence of a motivated and driven project champion leading the team [12, 14, 40, 75, 79, 90, 109, 146]. Moreover, effective communication is critical for successful technology innovation [117, 146, 154], which also involves the transfer of knowledge and skills between the team members, as well as between the various functions within the project, and the greater organisation [78, 87, 106]. It is illogical to expect a single researcher to possess all the mentioned personality traits and attributes, hence the importance of the composition of the innovation team, along with effective teamwork, is emphasised [36, 153].

4.2.2 Intra-organisational factors

Intra-organisational factors have an internal orientation, on the organisational level, and involve the provision of organisational support to the research team to facilitate successful technology innovation [45, 57, 61, 66, 76, 77, 169, 170]. Technology innovation within an organisation involves functional and support perspectives [49, 54, 65, 138], however, these perspectives do not act in isolation; rather, an integrated and interconnected environment exists within which technologies are developed [73, 107, 110, 113, 139, 147, 156, 157, 159].

Seemingly the two most important organisational factors for the facilitation of successful technology innovation are (i) top management support [6, 12, 18, 34, 50, 62, 79, 85, 90, 94, 103, 109, 130, 144, 146, 148, 162], and (ii) the provision of effective organisational structures and processes that facilitate technology innovation [6, 33, 37, 81, 83, 92, 109, 123, 146, 151, 153, 155]. Caution is provided against the overuse of excessive processes that might stifle innovation [42, 48, 51, 56, 64, 89].

The presence of an innovative organisational culture [6, 37, 84, 98, 108, 109, 123, 128, 148], including motivated and rewarded employees [111, 123, 148] is essential for successful technology innovation. Furthermore, the creation and maintenance of knowledge networks, with adequate sharing of knowledge within an organisation, contribute considerably to successful technology innovation [4, 87, 106, 109, 115, 119, 134, 150]. Moreover, effective communication throughout the entire organisation forms an essential component of the innovation process [46, 71, 93, 94, 117, 121, 130, 132].

4.2.3 Inter-organisational factors

Inter-organisational factors focus on relationships and interfaces between various organisations in the context of collaborative research partners, suppliers, alliances and networks [134].

When a technology is developed and marketed within the boundaries of an organisation, this concept is termed closed innovation [13, 24, 69, 102, 116, 173]. Over time, companies began to realise that internal and external ideas and inputs can be of considerable value to technology development efforts and that adequate skills and resources within a single organisation may limit successful technology innovation, which resulted in the evolution from a closed innovation approach to an open innovation approach being adopted by many organisations [60, 69, 70, 102, 158, 163]. Open innovation is a collaborative research approach where a network of research partners jointly perform technology innovation [80, 83] and enables the realisation of shared knowledge and benefits, as well as shared development costs and risks between multiple partners [95, 99, 125].

One of the most important benefits of open innovation is accelerated time-to-market of the technology [52, 63, 68, 82, 95, 102, 112, 114, 149]. Effective management of technology development activities between the various research partners across the open innovation network needs to receive considerable attention [7, 41, 47, 104, 120, 122, 132, 135, 152, 162, 174], with specific plans in place for the management of intellectual property [19, 68, 137].

Inter-organisational interactions, such as open innovation, require extensive networking, collaboration, and considerable engagement across multiple organisational boundaries, which often involve different cultures; hence, the nurturing of fruitful business relationships are critical [38, 58, 124, 140, 142]. This highlights the need for soft skills in addition to strong technical capability within the research team [41, 149, 170], with a particular focus on entrepreneurial behaviour [20, 23, 97, 164-167].

4.2.4 Extra-organisational factors

Extra-organisational factors have an external orientation and focus on the relationships between the entire innovation team and its macro environment [169]. The external environment, comprising the customers and their needs, existing in the market within which the technology is intended to be implemented, plays an essential, and often deterministic, role within the context of technology innovation [145]. Impacting factors within the external environment are typically out of the control of the research organisation, however, they have a considerable influence on the ultimate success or failure of the innovation [55, 131, 170].

For technology innovation to be successful, it is critically important for the research organisation to be in contact with its intended customers, ensuring effective flows of information between all stakeholders [32, 40, 67, 84, 93, 96, 99, 109, 113, 129, 136, 143, 152, 154].

A thorough market analysis is essential to ensure that the organisation has an accurate awareness of the market and its demands, needs, trends, and changes [12, 35, 40, 46, 74, 94, 103, 109, 118, 126, 127, 141, 146]. Market information, such as the size, position, growth prospects, substitutes, competition, and legal regulations need to be understood clearly for an organisation to position itself appropriately to remain competitive, relevant and sustainable, within its external environment [3, 34, 84, 85, 90, 143]. To ensure that technology development efforts are spent effectively, a thorough assessment of the business, the targeted market, and the customers is essential [35, 74, 94, 103, 127, 146], with the satisfaction of customers as one of the key performance measures [19, 71, 100, 110, 175].

4.3 Contribution to practice

Upon evaluation, the vast assortment of success factors from the 151 publications can be summarised and clustered into the particular organisational categories that were defined for this study. The collation of the success factors is presented in Table 7.

Table 7: Technology innovation success factors per organisational categories

Interpersonal	Intra-Organisational	Inter-Organisational	Extra-Organisational
[3, 4, 10, 12, 14, 20, 34-36, 40, 43, 46, 59, 72, 75, 78, 79, 86-88, 90, 91, 94, 98, 103, 105, 106, 109, 111, 117, 121, 127-129, 145-147, 151-154, 160, 161, 168-172]	[4, 6, 12, 18, 33, 34, 37, 42, 45, 46, 48-51, 54, 56, 57, 61, 62, 64-66, 71, 73, 76, 77, 79, 81, 83-85, 87, 89, 90, 92-94, 98, 103, 106-111, 113, 115, 117, 119, 121, 123, 128, 130, 132, 134, 138, 139, 144, 146-148, 150, 151, 153, 155-157, 159, 162, 169, 170]	[7, 13, 19, 20, 23, 24, 38, 41, 47, 52, 58, 60, 63, 68-70, 80, 82, 83, 95, 97, 99, 102, 104, 112, 114, 116, 120, 122, 124, 125, 132, 134, 135, 137, 140, 142, 149, 152, 158, 162-167, 170, 173, 174]	[3, 12, 19, 32, 34, 35, 40, 46, 55, 67, 71, 74, 84, 85, 90, 93, 94, 96, 99-101, 103, 109, 110, 113, 118, 126, 127, 129, 131, 136, 141, 143, 145, 146, 152, 154, 169, 170]

Interpersonal	Intra-Organisational	Inter-Organisational	Extra-Organisational
• Technical skills & expertise • Entrepreneurial behaviour • Leadership and championing • Communication • Motivation • Creativity • Teamwork	• Top management support • Organisational structures and processes • Organisational culture • Organisational strategy • Sharing of knowledge and soft skills	• Open innovation • Supplier/service provider network • Partner/alliance network	• Customer needs identification • Customer involvement • Market analysis

An important practical contribution of this study is that these factors can be used as a guideline for innovation managers to focus upon during the technology innovation process, to potentially increase the likelihood of successful innovation.

4.4 Future research

This study has shown that several factors contribute to the success of the technology innovation process. While the identification of particular success factors is considerably important for technology innovation, of further relevance is the role that these factors play during the various innovation stages. Hence, it would be of value to direct future research towards the identification of changes in the interdependencies and importance of these factors during the progression of the innovation process. This will guide innovation managers to focus on predetermined, innovation stage-specific factors, and further increase the likelihood of successful innovation.

5 CONCLUSIONS

Technology innovation is imperative to organisational survival and growth; however, this is a complex process, and often involves long timeframes and low success rates. Consequently, the objective of this study was to identify the success factors of the technology innovation process, which was accomplished through a systematic review of relevant literature. A total of 151 publications were reviewed and a vast assortment of success factors was identified, which were grouped into four categories deemed most appropriate for organisational innovation, namely interpersonal, intra-organisational, inter-organisational and extra-organisational factors.

From an organisational perspective, interpersonal factors of the researcher and the innovation team, along with the interactions that take place within the entire organisation impact the success of technology innovation. Moreover, intra-organisational factors, such as processes, structures, resources, and the provision of support by other departments also have a considerable influence on technology innovation. Inter-organisational factors, such as open innovation, collaborative networks of research partners, and suppliers play an important role in successful technology innovation, along with the satisfaction of customer demands and needs within the extra-organisational environment where the organisation competes for the favour of customers within the market.

The primary contribution made to innovation theory by this study is the provision of a holistic overview of success factors of technology innovation, from an organisation perspective, which was not prevalent in any of the publications that were reviewed as part of this research. Furthermore, an important practical contribution of this study is the identification of key success factors of technology innovation for each of the four organisational categories, which can be used as a guideline by innovation managers to potentially increase the likelihood of successful technology innovation within their organisations.

While it was not an objective of the study to perform applied thematic analysis for the categorisation of the success factors, it would be of interest to perform such an analysis for confirmation of the reproducibility of the results.

Clustering of the large variety of success factors into these specific categories might be of value during subsequent studies where interrelations of organisational aspects and technology innovation are sought. Of particular value would be to determine how the interdependencies between the factors change in importance across the different technology innovation stages.

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APPENDIX A: SLR SCREENING CODES

Adapted from [21] and [29]

Codes on Factors	Coding Options
Primary and secondary search terms	As per pre-defined terms for searches 1-20
Publication source	Peer-reviewed journal articles
Subject category	(i) Engineering (ii) Business, Management and Accounting
Publication year	Earliest up to 2019
Factor	Open-ended: factors claimed to contribute to success of each respective primary search term (1-20)
Framework	Open-ended: frameworks, from which factors are derived, claimed to contribute to success of each respective primary search term (1-20)
Codes on Findings	**Coding Options**
Success factor (category)	Open-ended: from an organisational perspective
Success factor (particular)	Open-ended: particular factor within organisational success factor category
Findings on success factor categories	If applicable, findings derived from categories
Findings on success factors	If applicable, findings derived from particular factors within organisational category
Findings details	Open-ended information on findings Thematic analysis for themes supporting findings

APPENDIX B: SELECTION OF PUBLICATIONS

Publications are listed chronologically from 1 to 151, with the corresponding number from the reference list indicated in square brackets.

No. & Ref.	Authors	Title	Year	Main search phrase
1 [39]	Jolly, C.	The technology transfer process: Concepts, framework and methodology	1977	Technology transfer
2 [94]	Cooper, R.G.	Process model for industrial new product development	1983	Product development
3 [117]	Lucas Jr., G.H., Bush, A.J.	The marketing-R&D interface: Do personality factors have an impact?	1988	R&D
4 [154]	Pinto, J.K., Covin, J.G.	Critical factors in project implementation: a comparison of construction and R&D projects	1989	Technology implementation
5 [155]	Romano, C.A.	Identifying factors which influence product innovation: a case study approach	1990	Innovation
6 [4]	Madu, C.N.	Prescriptive framework for the transfer of appropriate technology	1990	Technology transfer
7 [126]	Seaton, R.A.F., Cordey-Hayes, M.	The development and application of interactive models of industrial technology transfer	1993	Technology development
8 [18]	Emmanuelides, P.A.	Towards an integrative framework of performance in product development projects	1993	Product development
9 [37]	Zirger, B.J., Hartley, J.L.	A conceptual model of product development cycle time	1994	Product development
10 [156]	Saren, M.	Retraining the process of new product development: From “stages” models to a “blocks” framework	1994	Product development
11 [161]	Wei, L.	International technology transfer and development of technological capabilities: A theoretical framework	1995	Technology development
12 [32]	Freeman, C.	The greening of technology and models of innovation	1996	Innovation
13 [150]	Lynn, H.L, Reddy, M.N., Aram, J.D.	Linking technology and institutions: the innovation community framework	1996	Innovation
14 [5]	Balachandra, R., Friar, J.H.	Factors for success in r&d projects and new product innovation: a contextual framework	1997	R&D
15 [64]	Krishnan, V., Eppinger, S.D., Whitney, D.E.	A model-based framework to overlap product development activities	1997	Product development
16 [148]	Lester, D.H.	Critical success factors for new product development	1998	Product development
17 [123]	Rouse, W.B.	R&D/technology management: a framework for putting technology to work	1998	R&D
18 [71]	Matzler, K., Hinterhuber, H.H.	How to make product development projects more successful by integrating Kano's model of customer satisfaction into quality function deployment	1998	Product development
19 [84]	Balbontin, A., Yazdani, B., Cooper, R., Souder, W.E.	New product development success factors in American and British firms	1999	Product development
20 [115]	Liyanage, S., Greenfield, P., Don, R.	Towards a fourth generation R&D management model-research networks in knowledge management	1999	R&D
21 [19]	Niosi, J.	Fourth-generation R&D: From linear models to flexible innovation	1999	R&D
22 [121]	Nellore, R., Söderquist, K., Eriksson, K.-A.	A specification model for product development	1999	Product development
23 [135}	Barclay, I., Dann, Z.	Management and organisational factors in new product development (NPD) success	2000	Product development
24 [15]	Geroski, P.A.	Models of technology diffusion	2000	Technology transfer

No. & Ref.	Authors	Title	Year	Main search phrase
25 [152]	Nellore, R., Balachandra, R.	Factors influencing success in integrated product development (IPD) projects	2001	Product development
26 [108]	Jensen, B., Harmsen, H.	Implementation of success factors in new product development — the missing links?	2001	Product development
27 [6]	Connell, J., Edgar, G.C., Olex, B., Scholl, R., Shulman, T., Tietjen, R.	Troubling successes and good failures: Successful new product development requires five critical factors	2001	Product development
28 [110]	Lager, T., Hörte, S.-Å.	Success factors for improvement and innovation of process technology in process industry	2002	Innovation
29 [95]	Daniel, H.Z., Hempel, D.J., Srinivasan, N.	A model of value assessment in collaborative R&D programs	2002	R&D
30 [162]	Zahra, S.A, Nielsen, A.P.	Sources of capabilities	2002	Technology commercialisation
31 [33]	Krishnan, V., Bhattacharya, S.	Technology selection and commitment in new product development	2002	Product development
32 [136]	Brockhoff, K.	Exploring strategic R&D success factors	2003	R&D
33 [130]	Valle, S., Fernández, E., Avella, L.	New product development process: Strategic and organisational success factors	2003	Product development
34 [131]	van Egmond-de Wilde de Ligny, E.L.C., Kumaraswamy, M.M.	Determining the Success or Failure of International Technology Transfer: A Conceptual Framework	2003	Technology transfer
35 [35]	Elkins, T., Keller, R.T.	Leadership in research and development organizations: A literature review and conceptual framework	2003	R&D
36 [81]	Alexandre, T.M., Furrer, O., Sudharshan, D.	A hierarchical framework of new products development: An example from biotechnology	2003	Product development
37 [101]	Gembicki, S.A., VandenBussche, K.M., Oroskar, A.R.	Novel tools to speed up the technology commercialisation process	2003	Technology commercialisation
38 [16]	Åstebro, T.	Key success factors for technological entrepreneurs' R&D projects	2004	R&D
39 [105]	Hindle, K., Yencken, J.	Public research commercialisation, entrepreneurship and new technology based firms: An integrated model	2004	Technology commercialisation
40 [46]	Bout, L.Y., Lombaers, H.M., Fisscher, O.A.M., Constantinides, E.	Post-project reviews as a tool for stimulating commercialisation at TNO Industrial Technology	2004	Technology commercialisation
41 [147]	Lager, T., Hörte, S.-Å.	Success factors for the development of process technology in process industry: Part 1: A ranking of success factors on an operational level and a dynamic model for company implementation	2005	Technology development
42 [111]	Lager, T., Hörte, S.-Å.	Success factors for the development of process technology in process industry: Part 2: A ranking of success factors on an operational level and a dynamic model for company implementation	2005	Technology development
43 [157]	Schoen, J., Mason, T.W., Kline, W.A., Bunch, R.M.	The innovation cycle: A new model and case study for the invention to innovation process	2005	Innovation
44 [23]	McFadzean, E., O'Loughlin, A., Shaw, E.	Corporate entrepreneurship and innovation part 1: the missing link	2005	Corporate entrepreneurship
45 [20]	Shaw, E., O'Loughlin, A., McFadzean, E.	Corporate entrepreneurship and innovation part 2: a role- and process-based approach	2005	Corporate entrepreneurship

No. & Ref.	Authors	Title	Year	Main search phrase
46 [113]	Lee, J.-D., Park, C.	Research and development linkages in a national innovation system: Factors affecting success and failure in Korea	2006	R&D
47 [54]	Fleisher, C.S.	Assessing the tools and techniques enterprises use for analysing Innovation, Science and Technology factors: are they up to the task?	2006	Innovation
48 [40]	Kandemir, D., Calantone, R., Garcia, R.	An exploration of organizational factors in new product development success	2006	Product development
49 [36]	Hayton, J.C., Kelley, D.J.	A competency-based framework for promoting corporate entrepreneurship	2006	Corporate entrepreneurship
50 [129]	Suikki, R., Haapasalo, H.	Business impact of technology piloting - Model for analysis in different phases of development cycle	2006	Technology development
51 [106]	Hines, P., Francis, M., Found, P.	Towards lean product lifecycle management: A framework for new product development	2006	Product development
[77]	Ross, V.E.	A model of inventive ideation	2006	Ideation
52 [164]	Berkhout, A.J., Hartman, D., van der Duin, P., Ortt, R.	Innovating the innovation process	2006	Innovation
53 [127]	Slater, S.F., Mohr, J.J.	Successful development and commercialisation of technological innovation: insights based on strategy type	2006	Innovation
54 [119]	Mu, J., Peng, G., Tan, Y.	New product development in Chinese SMEs: Key success factors from a managerial perspective	2007	Product development
55 [50]	Cooper, R.G., Kleinschmidt, E.J.	Winning businesses in product development: The critical success factors	2007	Product development
56 [165]	Berkhout, A.J., Van Der Duin, P.A.	New ways of innovation: An application of the cyclic innovation model to the mobile telecom industry	2007	Innovation
57 [49]	Cooper, R.G.	Managing Technology Development Projects (Cooper)	2007	Product development
58 [141]	Hörte, S.Å., Halila, F.	Success factors for eco-innovations and other innovations	2008	Innovation
59 [59]	Iamratanakul, S., Patanakul, P., Milosevic, D.	Innovation and factors affecting the success of npd projects: Literature explorations and descriptions	2008	Product development
60 [145]	Kearney, C., Hisrich, R., Roche, F.	A conceptual model of public sector corporate entrepreneurship	2008	Corporate entrepreneurship
61 [100]	García-Valderrama, T., Mulero-Mendigorri, E., Revuelta-Bordoy, D.	A balanced scorecard framework for R&D	2008	R&D
62 [91]	Choi, J.K., Nies, L.F., Ramani, K.	A framework for the integration of environmental and business aspects toward sustainable product development	2008	Product development
63 [42]	Anand, G., Kodali, R.	Development of a conceptual framework for lean new product development process	2008	Product development
64 [70]	Markman, G.D., Siegel, D.S., Wright, M.	Research and technology commercialisation	2008	Technology commercialisation
65 [69]	Lichtenthaler, U.	Open innovation in practice: an analysis of strategic approaches to technology transactions	2008	Open innovation
66 [122]	Perry, N., Candlot, A., Schutte, C.	Collaborative knowledge networks emergence for innovation: Factors of success analysis and comparison	2009	Innovation

No. & Ref.	Authors	Title	Year	Main search phrase
67 [146]	Kulatunga, U., Amaratunga, D., Haigh, R.	Critical success factors of construction research and development	2009	R&D
68 [17]	Elmquist, M., Le Masson, P.	The value of a 'failed' R&D project: An emerging evaluation framework for building innovative capabilities	2009	R&D
69 [68]	Li, J., Kozhikode, R.K.	Developing new innovation models: Shifts in the innovation landscapes in emerging economies and implications for global R&D management	2009	Innovation
70 [72]	Miller, A., Radcliffe, D., Isokangas, E.	A perception-influence model for the management of technology implementation in construction	2009	Technology implementation
71 [88]	Cetindamar, D., Phaal, R., Probert, D.	Understanding technology management as a dynamic capability: a framework for technology management activities	2009	R&D
72 [149]	Lichtenthaler, U., Lichtenthaler, E.	A capability-based framework for open innovation: Complementing absorptive capacity	2009	Open innovation
73 [120]	Munsch, K.	Open model innovation: Culture, contract and competition embrace the practical issues that R&D leaders need to consider.	2009	Open innovation
74 [109]	Jyoti, Banwet, D.K., Deshmukh, S.G.	Modelling the success factors for national R&D organizations: a case of India	2010	R&D
75 [52]	DiAntonio, S.A.	New model for University research and Technology Transfer	2010	Technology transfer
76 [138]	De Waal, G.A., Knott, P.	Product development: An integrative tool and activity research framework	2010	Product development
77 [102]	Grönlund, J., Sjödin, D.R., Frishammar, J.	Open innovation and the stage-gate process: A revised model for new product development	2010	Product development
78 [166]	Berkhout, G., Hartmann, D., Trott, P.	Connecting technological capabilities with market needs using a cyclic innovation model	2010	Innovation
79 [114]	Lee, S., Park, G., Yoon, B., Park, J.	Open innovation in SMEs-An intermediated network model	2010	Open innovation
80 [82]	Almirall, E., Casadesus-Masanell, R.	Open versus closed innovation: A model of discovery and divergence	2010	Open innovation
81 [112]	Lazzarotti, V., Manzini, R., Pellegrini, L.	Open innovation models adopted in practice: An extensive study in Italy	2010	Open innovation
82 [158]	Spaeth, S., Stuermer, M., Von Krogh, G.	Enabling knowledge creation through outsiders: Towards a push model of open innovation	2010	Open innovation
83 [103]	Guimaraes, T.	Industry clockspeed's impact on business innovation success factors	2011	Innovation
84 [66]	Kunz, V.D., Warren, L.	From innovation to market entry: A strategic management model for new technologies	2011	Innovation
85 [104]	Hidalgo, A., Albors, J.	University-industry technology transfer models: An empirical analysis	2011	Technology transfer
86 [74]	Mudambi, R., Swift, T.	Proactive R&D management and firm growth: A punctuated equilibrium model	2011	R&D
87 [67]	Lazzarotti, V., Manzini, R., Mari, L.	A model for R&D performance measurement	2011	R&D
88 [133]	Wang, L., Ming, X.G., Kong, F.B., Li, D., Wang, P.P.	Focus on implementation: A framework for lean product development	2011	Product development
89 [14]	Meyer, A.D., Aten, K., Krause, A.J., Metzger, M.L., Holloway, S.S.	Creating a university technology commercialisation programme: confronting conflicts between learning, discovery and commercialisation goals	2011	Technology commercialisati on

No. & Ref.	Authors	Title	Year	Main search phrase
90 [125]	Schweisfurth, T., Raasch, C., Herstatt, C.	Free revealing in open innovation: A comparison of different models and their benefits for companies	2011	Open innovation
91 [93]	Closs, L., Ferreira, G.C., Soria, A.F., Sampaio, C.H., Perin, M.	Organizational factors that affect the university-industry technology transfer processes of a private university	2012	Technology transfer
92 [3]	Evanschitzky, H., Eisend, M., Calantone, R.J., Jiang, Y.	Success Factors of Product Innovation: An Updated Meta-Analysis	2012	Product development
93 [61]	Kang, H.-Y., Lee, A.H.I., Chang, C.-C., Kang, M.-S.	A model for selecting technologies in new product development	2012	Technology development
94 [99]	Frishammar, J., Lichtenthaler, U., Rundquist, J.	Identifying technology commercialisation opportunities: the importance of integrating product development knowledge	2012	Technology commercialisati on
95 [124]	Sandulli, F.D., Fernandez-Menendez, J., Rodriguez-Duarte, A., Lopez-Sanchez, J.I.	Testing the Schumpeterian hypotheses on an open innovation framework	2012	Open innovation
96 [86]	Burgess, C.	Factors influencing middle managers' ability to contribute to corporate entrepreneurship	2013	Corporate entrepreneurshi p
97 [85]	Barragán-Ocaña, A., Zubieta-García, J.	Critical factors toward successful R&D projects in public research centers: A primer	2013	R&D
98 [90]	Cho, J., Lee, J.	Development of a new technology product evaluation model for assessing commercialization opportunities using Delphi method and fuzzy AHP approach	2013	Technology commercialisati on
99 [107]	Horn, C., Brem, A.	Strategic directions on innovation management - a conceptual framework	2013	Innovation
100 [60]	Janeiro, P., Proença, I., Gonçalves, V.D.C.	Open innovation: Factors explaining universities as service firm innovation sources	2013	Open innovation
101 [128]	Soleimani, M., Shahnazari, A.	Studying effective factors on corporate entrepreneurship: representing a model	2013	Corporate entrepreneurshi p
102 [41]	Aarikka-Stenroos, L., Sandberg, B., Lehtimaki, T.	Networks for the commercialisation of innovations: A review of how divergent network actors contributte	2014	Innovation
103 [58]	Iamratanakul, S., F. Badir, Y., Siengthai, S., Sukhotu, V.	Indicators of best practices in technology product development projects: Prioritizing critical success factors	2014	Technology development
104 [48]	Commenge, J.-M., Falk, L.	Methodological framework for choice of intensified equipment and development of innovative technologies	2014	Technology development
105 [167]	Ford, N., Trott, P., Simms, C., Hartmann, D.	Case analysis of innovation in the packaging industry using the cyclic innovation model	2014	Innovation
106 [63]	Kondev, G., Tenchev, D., Vasileva, P.	An open innovation model in the context of improving the competitiveness of the chemical and metallurgical industries	2014	Open innovation
107 [38]	Alekseevna, M.A.	Evolution of the innovation process models	2014	Innovation
108 [137]	Cervantes, M., Meissner, D.	Commercialising public research under the open innovation model: New trends	2014	Open innovation
109 [143]	Jung, M., Lee, Y.-B., Lee, H.	Classifying and prioritizing the success and failure factors of technology commercialization of public R&D in South Korea: using classification tree analysis	2015	Technology commercialisati on

No. & Ref.	Authors	Title	Year	Main search phrase
110 [139]	Ehrenberger, M., Koudelková, P., Strielkowski, W.	Factors influencing innovation in small and medium enterprises in the Czech Republic	2015	Innovation
111 [144]	Kachouie, R., Sedighadeli, S.	New product development success factors in prospector organisations; mixed method approach	2015	Product development
112 [132]	Vega-Jurado, J.M., Juliao-Esparragoza, D., Paternina-Arboleda, C.D., Velez, M.C.	Integrating technology, management and marketing innovation through open innovation models	2015	Open innovation
113 [12]	Kirchberger, M.A., Pohl, L.	Technology commercialization: a literature review of success factors and antecedents across different contexts	2016	Technology commercialisati on
114 [10]	Meleloe, K.E., Walwyn, D.R.	Success factors for the commercialisation of Gas-to-Liquids technology	2016	Technology commercialisati on
115 [87]	Calcagnini, G., Favaretto, I.	Models of university technology transfer: analyses and policies	2016	Technology transfer
116 [118]	Milskaya, E., Mednikov, M., Loginova, N.	Development of the innovative technologies transfer conceptual model	2016	Technology development
117 [51]	De Souza, V.M., Borsato, M.	Combining Stage-Gate™ model using Set-Based concurrent engineering and sustainable end-of-life principles in a product development assessment tool	2016	Product development
118 [168]	van der Heiden, P., Pohl, C., Mansor, S., van Genderen, J.	Necessitated absorptive capacity and metaroutines in international technology transfer: A new model	2016	Technology transfer
119 [159]	Van Lancker, J., Mondelaers, K., Wauters, E., Van Huylenbroeck, G.	The Organizational Innovation System: A systemic framework for radical innovation at the organizational level	2016	Innovation
120 [45]	Botha, L., Grobbelaar, S., Bam, W.	Towards a framework to guide the evaluation of inclusive innovation systems	2016	Innovation
121 [34]	Azarmi, D.	Factors affecting technology innovation and its commercialisation in firms	2016	Technology commercialisati on
122 [43]	Barbieri, J.C, Alvares, A.C.T	Sixth generation innovation model: description of a success model	2016	Innovation
123 [79]	Salgado, E.G., Sanches da Silva, C.E., Mello, C.H.P., Samaan, M.	Critical Success Factors for New Product Development in Biotechnology Companies	2017	Product development
124 [89]	Chauhan, A.S., Badhotiya, G.K., Soni, G., Rathore, A.P.S.	Analysis of success factors for a new product development initiative in Indian automotive industry: An ISM approach	2017	Product development
125 [97]	Escobar-Sierra, M., Lara-Valencia, L.A., Valencia-DeLara, P.	Model for innovation management by companies based on corporate entrepreneurship	2017	Corporate entrepreneurshi p
126 [57]	Hilkevics, S., Hilkevics, A.	The comparative analysis of technology transfer models	2017	Technology transfer
127 [62]	Khan, J., Haleem, A., Husain, Z.	Barriers to technology transfer: A total interpretative structural model approach	2017	Technology transfer
128 [44]	Batabyal, A.A., Yoo, S.J.	On research and development in a model of Schumpeterian economic growth in a creative region	2017	R&D
129 [7]	Dincer, I.	Importance of research, innovation and commercialisation for technological success	2017	Innovation
130 [163]	Zobel, A.-K.	Benefiting from Open Innovation: A Multidimensional Model of Absorptive Capacity	2017	Open innovation

No. & Ref.	Authors	Title	Year	Main search phrase
131 [142]	Hosseini, S., Kees, A., Manderscheid, J., Röglinger, M., Rosemann, M.	What does it take to implement open innovation? Towards an integrated capability framework	2017	Open innovation
132 [65]	Kumar, R., Singh, H., Chandel, R.	Exploring the key success factors of advanced manufacturing technology implementation in Indian manufacturing industry	2018	Technology implementation
134 [96]	De Moortel, K., Crispeels, T.	International university-university technology transfer: Strategic management framework	2018	Technology transfer
135 [55]	Hamdan, A.R., Fathi, M.S., Mohamed, Z.	Evolution of Malaysia's technology transfer model facilitated by national policies	2018	Technology transfer
136 [56]	Hamel, N.M., Kowang, T.O., Fei, G.C.	A conceptual framework for lean research and development	2018	R&D
137 [98]	Florén, H., Frishammar, J., Parida, V., Wincent, J.	Critical success factors in early new product development: a review and a conceptual model	2018	Product development
138 [76]	Naveiro, R.M., de Oliveira, V.M.	QFD and TRIZ integration in product development: A Model for Systematic Optimization of Engineering Requirements	2018	Product development
139 [116]	Lopes, A.P.V.B.V., de Carvalho, M.M.	Evolution of the open innovation paradigm: Towards a contingent conceptual model	2018	Open innovation
140 [140]	Fisher, G.J., Qualls, W.J.	A framework of interfirm open innovation: relationship and knowledge based perspectives	2018	Open innovation
141 [83]	Asim Z., Teck T.S., Sorooshian S.	An expert-approved R&D model	2019	R&D
142 [47]	Capuano, C., Grassi, I.	Spillovers, product innovation and R&D cooperation: a theoretical model	2019	R&D
143 [92]	Chung B., Hyun B.-H.	Analysis of success factors for technology commercialization using meta-analytic structural equation modeling	2019	Technology commercialisati on
144 [73]	Miranda J., Pérez-Rodríguez R., Borja V., Wright P.K., Molina A.	Sensing, smart and sustainable product development (S3 product) reference framework	2019	Product development
145 [75]	Mumford, M.D., Mulhearn, T.J.	Leading creative research and development efforts: A literature review and proposed framework for the engineering domain	2019	R&D
146 [151]	Nanda, T., Gupta H., Singh T.P., Kusi-Sarpong S., Jabbour C.J.C., Cherri A.	An original framework for strategic technology development of small manufacturing enterprises in emerging economies	2019	Technology development
147 [153]	Pienaar C., van der Lingen E., Preis E.	A framework for successful new product development	2019	Product development
148 [78]	Sá, E.S., Pinho, J.C.M.R.D.	Effect of entrepreneurial framework conditions on R&D transfer to new and growing firms: The case of European Union innovation-driven countries	2019	R&D
149 [80]	Tan, L., Tang, D., Chen, W.	Dynamic model and simulation of open innovation in product development	2019	Open innovation
150 [160]	Vrontis D., Christofi M.	R&D internationalization and innovation: A systematic review, integrative framework and future research directions	2019	R&D
151 [134]	Zhang J., Jiang H., Wu R., Li J.	Reconciling the Dilemma of Knowledge Sharing: A Network Pluralism Framework of Firms' R&D Alliance Network and Innovation Performance	2019	R&D

MAINTENANCE STRATEGIES IN THE RAIL ENVIRONMENT

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ABSTRACT

Maintenance in the rail environment needs an innovative, integrated and proactive approach for its interoperability requirements for the improvements in safety, availability and reliability. Therefore, solutions for finding improved maintenance strategy frameworks are becoming important.

This study follows a deductive philosophy and uses secondary sources of data to analyse maintenance strategies. The systematic literature review methodology is employed to collate, review and synthesise the available scholarly studies and publications pertaining to the implementation of maintenance strategies in the rail environment. The study uses five phases to develop a comprehensive maintenance strategy framework that can be used in a rail environment

Keywords: maintenance strategy, framework, concept, implementation

1 INTRODUCTION

A maintenance strategy is a structured upkeep of equipment that involves the identification, researching and execution of repairs, the replacement and inspection decisions and formulation of the best life plan for each of the plant in coordination with other departments [1]. A maintenance strategy is made up of one or more maintenance techniques (also called maintenance types).

According to Vlok PJ [2] the terms, maintenance strategies and maintenance techniques are sometimes used interchangeably. However, in the context of this research, a maintenance technique is seen as a sub-task of a strategy. Thus, a strategy is seen as the overall direction an organisation wants to follow, consisting of one or more maintenance techniques. Maintenance methodology is seen as consisting one or more maintenance strategies. It involves tools that can be used in implementing the maintenance strategies.

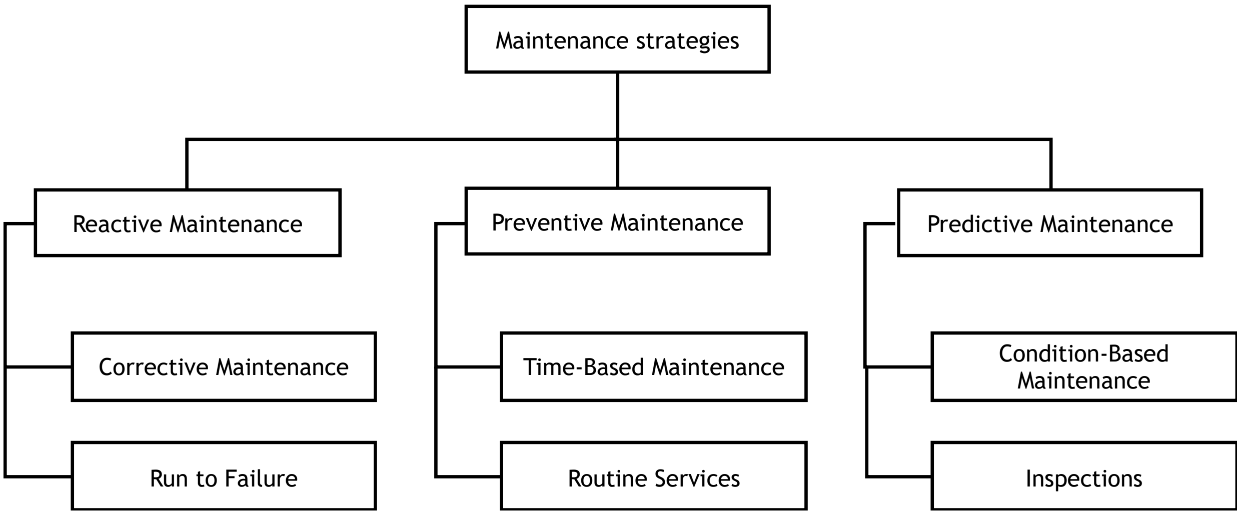

Figure 1 Maintenance Strategy Tree (adapted from [2], [3]**)**

In developing a maintenance strategy for implementation, an organisation has to go through three steps. These are work identification, purchase of resources and strategy implementation [4]. On assigning a maintenance strategy to specific components, failure mode and the failure rate of components need to be identified, goals of maintenance specified and nature of the equipment to be maintained analysed [5], [6]. Implementation of a maintenance strategy depends on the resources of the organisation such as personnel, spare parts and tools [7].

The common maintenance strategies are reactive, preventive and predictive maintenance [6], [8]–[10]. These maintenance strategies are implemented to keep equipment running, care for the environment and keep the quality of products at acceptable levels.

Reactive maintenance helps to keep response time low, equipment downtime to a minimum and maintenance personnel few. The strategy reduces maintenance costs, however, it fails to predict breakdowns and at times replacement is done instead of repairing or the other way round [11].

Breakdown maintenance technique is when unplanned maintenance is carried out in response to equipment failure [12]. The effectiveness of the technique is dependent on the functionality of the system to acceptable levels [12]. This technique results in high maintenance cost due to poor planning as a result of time constraint and incomplete repairs which focus on the symptoms of the failure [12]. As such it is not regarded as a good engineering practice.

With the Run-To-Failure (RTF) technique, the equipment is deliberately allowed to operate until it fails. Although RTF and BM are both Reactive Maintenance techniques, the difference is that there is a clear plan in place for RTF, stipulating the use of spare parts, personnel and methods, therefore, minimising the impact on production. Similar to BM, RTF is unpredictable, costly and requires a large number of spares that may be needed for breakdowns

Predictive maintenance was developed to reduce failure rates, repair rates, assess equipment conditions in real-time, detect problems of equipment before failure, reduce downtime and response time [13]. Monitoring methods include ultrasonic testing, lubricating analysis and vibration monitoring. The strategy is linked to sensor technology among other technological advancements [14]. The strategy helps improving reliability, availability, safety, efficiency and product/service quality [14], [15].

Predictive maintenance is based on two assumptions namely that deterioration rate is low enough to enable its detection before failure and that the system cannot be left to fail as this has huge consequences on costs, safety and environment [14]. According to Selcuk, (2017), a predictive maintenance strategy implementation plan should consist of data acquisition, data processing, and maintenance decision making.

Preventive maintenance as shown in Figure 1 has time-based or calendar-based and routine maintenance techniques [2], [15]. The strategy is carried out after the elapse of some time, hence it is carried out from a probabilistic model of component failure based on historical data [16]. The objectives of this type of strategy are to ensure safety, reliability and availability of components, labour costs and inventory costs [17]–[19].

Activities in preventive maintenance are grouped into six groups namely lubricating, cleaning, adjusting, tightening, supplying consumable materials and simple repairs [18]. However, its implementation comes with problems such as repetitiveness, errors during maintenance and lack of clear reasons for carrying out some preventive maintenance actions [20].

In this study, the application of these different maintenance strategies was undertaken. To be able to implement these strategies, a maintenance framework is needed, as such, framework concepts were introduced at the end of the maintenance strategies review in rail. The rest of the paper is arranged as follows. Section 2 covers the application of maintenance strategies in the rail environment. Section 3 covers the methodology, section 4 covers the literature review and section 5 covers the results of the systematic literature review. Section 6 has the framework development whilst section 7 provides the conclusion of the paper.

2 MAINTENANCE IN THE RAIL ENVIRONMENT

All of the maintenance strategies that have been described above have been implemented in the rail environment. Different rail organisations implement different maintenance strategies at different times.

This research views Total Productive Maintenance (TPM), Risk Based Maintenance (RBM), Reliability Centred Maintenance (RCM), e-maintenance etc as maintenance methodologies. This is because they are used in selecting and or implementing the strategies identified in Figure 1. For example in total productive maintenance, on the third pillar which is planned maintenance, a decision still needs to be taken on which maintenance strategy should be implemented [21], [22]. The components of RCM consists of all the maintenance strategies. The strategy to be implemented is selected based on the RCM steps [23], [24]. In RBM, on the fourth module, one still has to decide which maintenance strategy to implement. Hence these are in this research classified as maintenance methodologies.

2.1 Review of reactive maintenance

In using Figure 1, the analysis of reactive maintenance will encompass both corrective maintenance and run-to-failure.

Reactive maintenance is normally the last maintenance strategy in the railway sector to be utilised. In the rail environment, when trains fail, then maintenance is scheduled. Run-to-failure maintenance is implemented when applying preventive maintenance is difficult or expensive and failure consequences are insignificant. As a result, components are allowed to run up to failure [14], [25].

In reactive maintenance, train components can either be replaced or repaired. Components are fixed to working condition and maintenance to good as new should be scheduled. Adjustments and lubrication of components should also be done. The system should be controlled (that is in corrective maintenance technique) to prevent further problems [26].

In reducing train downtime, resources such as spare parts, tools and maintenance personnel should be on standby [27]. These in the rail environment could be parts that are always prone to failure and tools used in repairing or replacement. If these are to be purchased, it has to be done early before any unforeseen failure and maintenance personnel such as electrical fitter should always be on standby.

2.2 Review of preventive maintenance

Preventive maintenance is implemented in the rail environment for the upkeep of critical components. However, due to its problems of repetitiveness and lack of clear rationale in carrying out maintenance, maintenance ends up being costly especially when replacement instead of repairing is done [20], [28].

Furthermore, preventive maintenance is implemented to reduce the probability of failure, improving system reliability and availability [18]. However, the rolling stock organisations have to also comply with legislation and rules as stated by safety authorities when it comes to frequencies and procedures of preventive maintenance. An example is the Railway Safety Regulator (RSR), the custodian of railway safety in South Africa, requires that passenger and safety inspections are done regularly on each train set.

In implementing the strategy Lin, Pulido and Asplund [29], re-profiled wheelsets after a specified distance was covered. Re-profiling was done at the set time, hence in implementing the strategy, scheduling needs to be done. Garg and Deshmukh [30], describe scheduling as the bringing together of required resources. Poor maintenance schedules lead to high maintenance costs [31]. In rail environment the main aim of scheduling preventive maintenance is to meet all the requirements of all rolling stock system, sub-system and components timeously since tasks which are done too early or too late are associated with some unwanted costs [32]. In avoiding unavailability of rolling stock during high demand, countries such as the Netherlands schedule their train maintenance at night, however, this poses safety risks to personnel [33]. Different algorithms have been used to come up with optimal maintenance schedules [33]-[38].

Based on implementing preventive maintenance, the focus must be on resources available through establishing those that are needed, the level of skill of personnel required, management commitment and influence of other departments [39]. It is easy to implement preventive maintenance as only service time needs to be recorded [40].

However, it needs to be noted that frequent preventive maintenance actions can lead to depletion of resources and at times the maintenance tasks will be unnecessary [41]. Therefore, the number of times maintenance activities are carried out and how they are implemented has an impact on the preventive maintenance resources. The resources spent on each activity must be recorded so that future maintenance plans can be developed from records [17].

The maintenance strategy requires personnel with high technical skills, who can work in teams, share information, track and record maintenance activities, receive continuous training on personal management, control document and use computer systems [4], [28], [39], [42].

In implementing preventive maintenance, management should be able to plan and control a preventive maintenance strategy through the creation of effective communication among departments [39], [43].

2.3 Review of predictive maintenance

The objective of predictive maintenance is to reduce unnecessary maintenance tasks and reduce risks that come with preventive maintenance [16]. It is implemented to improve reliability, safety and availability of rolling stock [29], [44]–[47]. Predictive maintenance strategy can be used to predict wear, fatigue and failures [29].

Several software tools for data analysis, data extraction and for predicting the condition of wheelsets wear have been proposed for improving reliability and availability of rolling stock [45]–[47] [47]. Predictive maintenance is gaining acceptance due to increase in knowledge, technical skills, abilities to monitor, store and analyse the condition of equipment, the existence of different types of sensors and vast application of Wireless Network Systems (WNS) [14], [40]. These systems help in data evaluation and determining necessary resources [14].

For any organisation that seeks to implement predictive maintenance, it has to commit to purchasing condition monitoring equipment and its installation. These include sensors and wireless Network Systems (WNS), computer management systems, equipment hardware, and software among others [14]. Failure to do so leads the organisation to rely on human senses that are bringing in subjectivity.

Maintenance personnel should be trained in data collection and interpretation. These can be on visual inspection, vibration, online visuals and predictive maintenance techniques among other things [13]

Predictive maintenance provides better maintenance schedules as it is based on the condition of the equipment [40], [48]. Use of specialised components makes predictive maintenance difficult to implement. The predictive maintenance system should be built with a human aspect in mind, technical, and organisational aspects as these form the core factors in implementing the predictive maintenance strategy. Moreover, it requires maximum integration of sensors, feature extraction, classification and predictive algorithms [49]

Inspections are critical where there is no online monitoring. The quality and rate of inspections determine the action to be undertaken and when it will be taken [17]. However, according to Alaswad and Xiang [16], for years, predictive maintenance has assumed perfect inspections which are not the case in practice. Quality of inspections depends on inspecting personnel, their level of skills, availability of inspection tools and the time given to carry out inspections [17]. Three inspection schedules were highlighted by Alaswad and Xiang [16], namely, continuous monitoring, periodic and non-periodic.

To implement any of the maintenance strategies, organisations need to develop a framework that guides them in maintenance implementation. A framework is a bridge between the strategic plan and operational plan to improve the efficiency of maintenance performance [6].

Researchers have proposed several frameworks. Most of these frameworks are in the manufacturing industry. The frameworks differ in the aspects they cover. As such presents loopholes. Maintenance frameworks should be aligned to business objectives, production objectives and maintenance objectives [50]–[53]. Production objectives include strategic planning, tactical planning and operational planning. However, the frameworks proposed by these researchers do not explain about maintenance strategy process, maintenance tasks, maintenance implementation and maintenance strategy performance measurement. At the same time, other proposed frameworks focus on aligning maintenance framework with the corporate plan, implementation plans, performance measurement and feedback loop [4], [28]. The framework suggests establishing the interrelationship between maintenance strategy framework and maintenance strategy elements such as work control, personnel records, logistics support and maintenance tasks is important. However, the framework does not consider the link with business objectives, production objectives and has no feedback loop.

A maintenance framework is related to maintenance performance [54]. The suggested framework, however, lacked an explanation of the maintenance tasks that need to be performed.

From the literature review on maintenance strategy frameworks, there seems to be limited availability of a structured maintenance strategy formulation and implementation. It has also been observed that there are limited frameworks for the implementation of an effective maintenance strategy for the rail environment. Most of the currently available frameworks do not cover the full maintenance process. Hence this study developed a maintenance strategy implementation framework that can be used in the rail environment. The framework is holistic in nature as it covers business objectives, maintenance objective and the whole maintenance process.

3 METHODOLOGY

The research followed a systematic literature review. A systematic literature review is a scientific research approach that can be used to appraise, summarise and communicate findings and implications of a large number of research publications on a particular subject. It is an evidence-based process intended to evaluate all published and unpublished literature on the topic. On maintenance, several researchers also adopted a systematic literature review for their studies [55], [56]. A systematic literature review is used to gather and study a vast number of research studies and publications relating to a specific subject to answer predefined questions, by incorporating the practical evidence from all the relevant studies. The study was conducted in five phases as shown in Figure 2.

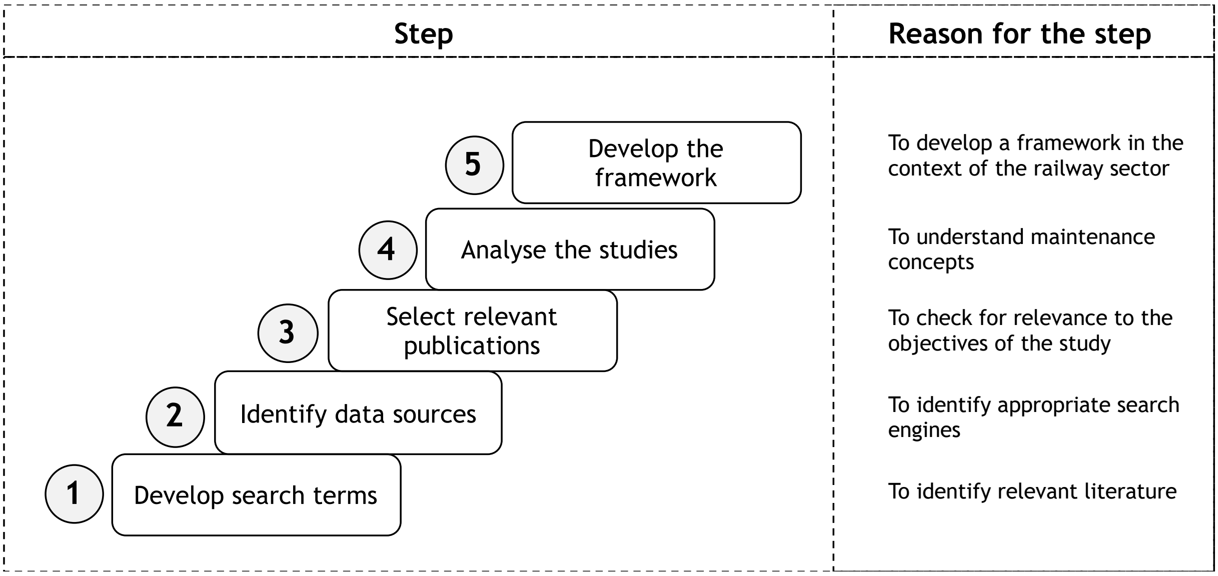

Figure 2 Flowchart of research methodology

4 LITERATURE REVIEW

This section of the literature review covers data sources and collection as well as selection criteria. On data sources and collection, search terms that were used are highlighted and the search engines. Under selection criteria, the explanation will be given as to how the author arrived at the articles that were reviewed and explanation as to those which were discarded will be given.

4.1 Data sources and collection

In identifying studies on maintenance strategies being implemented the following search term was used;

- Maintenance implementation on rolling stock

The search fields used were article title, abstract, and keywords. The search engines used were Scopus, Web of Science and Emerald. The initial search yield is displayed in Table 1.

Table 1 Initial search results

Search terms	Search field	Scopus	Web of science	Emerald
Maintenance implementation on rolling stock	Article title, abstract and keywords	68	17	500

4.2 Selection criteria

A total of 585 publications came as a result of the initial search. An extensive review was done to establish whether each publication was fit for the systematic literature review. The first screening criterion was to check whether or not the publication was related to the topic of maintenance implementation on rolling stock. The second vetting process was to check whether or not the publication was relevant to the scope of the study. A total of 473 publications were found to be unrelated to the topic of study. Of the 112 publications that were related to the topic, only 27 papers were relevant to the current study.

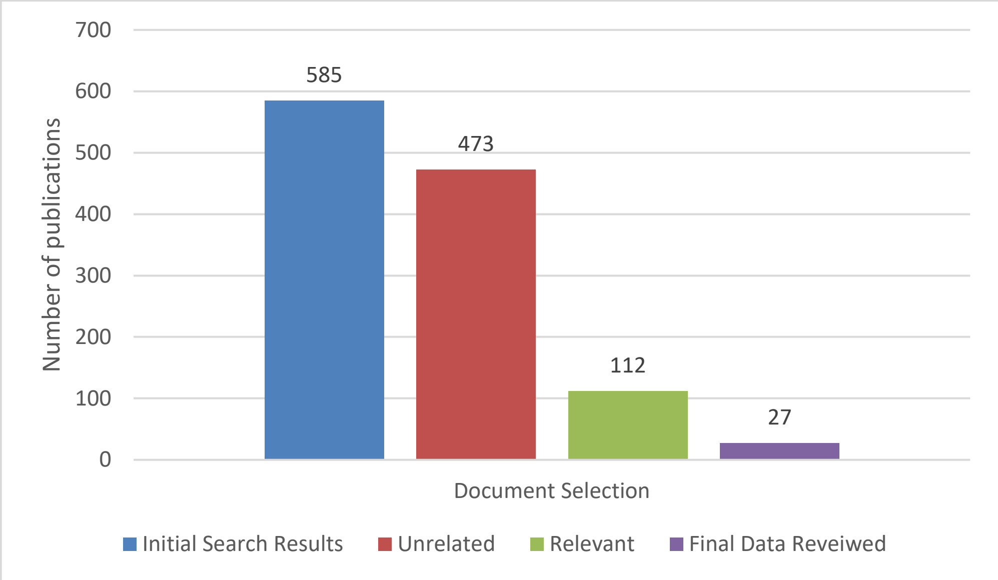

Figure 3 Document Selection

5 RESULTS OF THE SYSTEMATIC LITERATURE REVIEW

The following section is divided into two sub-sections: descriptive statistics and conceptual aspects

5.1 Descriptive statistics

On analysing the literature, documents that were related to maintenance strategies were in the form of journals, conference papers, industry research reports and book chapters. On review, the author focused on maintenance strategies implementation by selecting material with rich maintenance implementation empirical data. A total of 27 publications were relevant to the current study of maintenance strategy implementation. These were published from 1997 to 2019. Of these publications, 55 per cent were journal articles, 26 per cent were conference papers, 15 per cent were book chapters and 4 per cent were review papers as shown in Figure 4. From these papers, the next step was to read the whole paper to understand the study objective, the research approach used and the key concepts used in each paper.

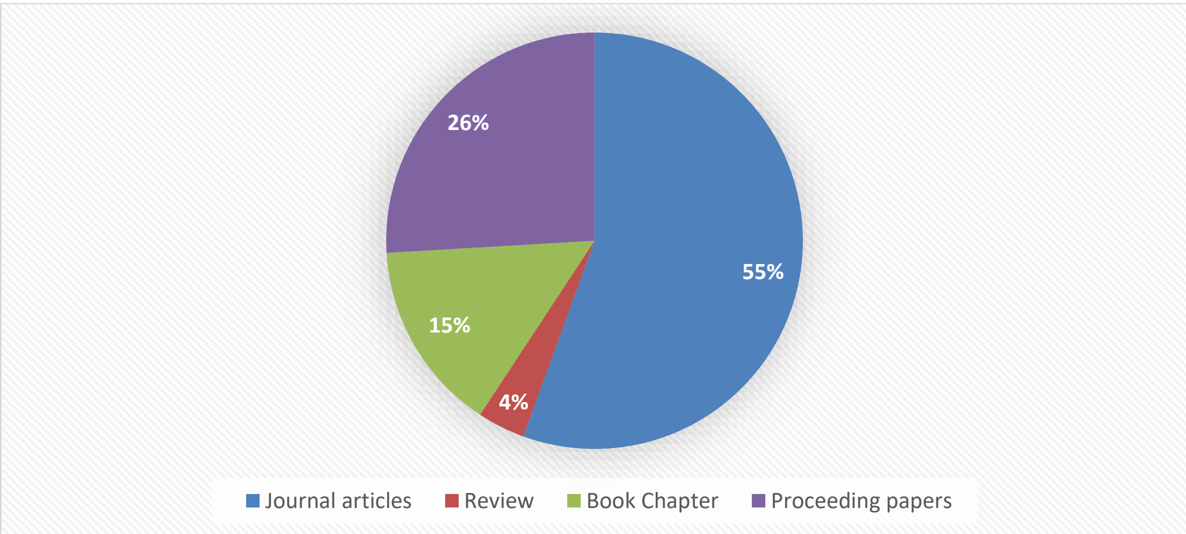

Figure 4 Paper Types

5.2 Conceptual aspects

The literature review was conducted to identify maintenance objectives, different maintenance tasks and maintenance strategy elements, criteria in deciding which maintenance tasks to perform and when they should be done. These were then termed maintenance concepts by the researcher. A total of 61 maintenance concepts were identified. These are summarised in **Error! Reference source not found.**.

5.2.1 Categorisation of concepts

The identified concepts were then grouped into 8 categories as shown in Table 2.

Table 2 Concept categories

Objectives Availability, Reliability, Reduction of unexpected failures, Reduction of downtime, Customer safety, Quality service, Protection of environment	**Personnel** Level of technical skill needed, Number of maintenance personnel needed, Continuous technical and interpersonal training of maintenance personnel, Communication Management commitment
Data acquisition and analysis Reporting, Failure effect, Benchmarking, Failure rate, Failure mode, Stock tracking, Equipment technical condition, Monitoring, Legislation and rules, Historical data collection and processing, Age of equipment, Operating time, Work order, Flow of information, CMMS	**Materials requirements** Spare parts management, Inventory cost, Labour cost, Tools
Planning Grouping of components, Level of maintenance needed, Procurement, Time allocation, Allocation of resources, Frequency of maintenance, Allocation of maintenance tasks, Coordination, Formation of maintenance teams, Determining maintenance actions, Contracting	**Execution** Measuring, Testing, Servicing, Overhauling, Inspecting, Replacing, Repairing, Cleaning, Tightening, Lubricating, Adjustment, Coordination, Recording
Maintenance program Maintenance procedure Benchmarking	**Scheduling** Scheduling

6 FRAMEWORK DEVELOPMENT

To establish a comprehensive maintenance strategy framework, the identified concepts and subsequently their categories were synchronised together. The framework development provides steps undertaken to come up with a maintenance strategy implementation framework for the rail environment. Moreover, the framework will give a clear outline of how a maintenance strategy can be implemented by an organisation.

6.1 Towards a maintenance strategy framework

As shown in Section 5.2.1, concepts were grouped into different categories. Figure 5 shows how these different categories interact with each other. The interaction gives a full picture of the maintenance process in the rail environment.

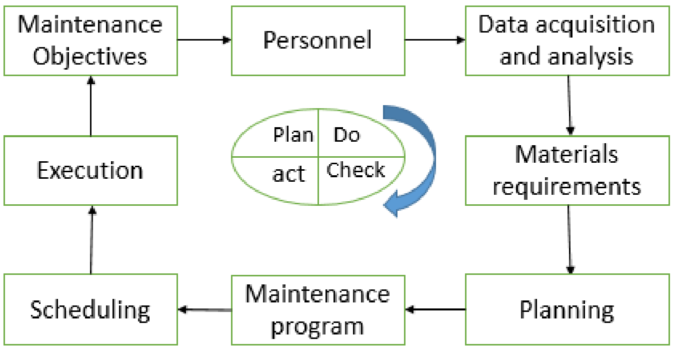

Figure 5 Interaction of categories

The maintenance process will start with the organisation spelling out their maintenance objectives[57]–[60]. This helps the organisation to focus on what is important to the organisation and is in line with the business objective. In the rail environment, reliability, availability, care for the environment should be of concern. These maintenance objectives help to identify the kind of personnel needed in the maintenance department hence as depicted by Figure 5, it is followed by personnel.

Personnel identified should be having technical skills to enable the organisation to meet the maintenance objectives. Based on the need to strive for excellence all the time, personnel must be continuously trained.

When the personnel to perform different duties has been identified, the equipment of the organisation is assessed through inspection, historical data or any other method to determine the necessary tasks that need to performed. The full determination of what needs to be done helps in identifying the kind of material needed and its quantity.

Material requirements are determined by the condition of the equipment. Tools and spare parts needed to restore the equipment to operation. Material quantity is easy to establish as on data acquisition and analysis, inventory levels would have been identified, therefore the difference from what is needed would need to be purchased.

Personnel, data acquisition and analysis and materials requirements can be grouped into resource requirements. Hence, as such, when resource requirements have been established, planning for maintenance needs to take place. At this stage, maintenance teams are formed based on the personnel available, tasks to be performed and the objectives of carrying out those tasks [58], [59].

Maintenance program specifies the level of maintenance that needs to be undertaken and when it should be done. This phase also specifies the maintenance procedure. This helps to establish a standardised way of doing things. Standardisation improves maintenance task control and helps in improving the quality of maintenance [58], [61].

When the maintenance program has been established, scheduling has to be done. Scheduling aims to bring together everything that is needed, such as resources (spare parts, tools, personnel, equipment) to the right place[61].

Upon bringing all things to the right places, the execution of maintenance tasks has to be undertaken {Formatting Citation}. These include cleaning, lubricating, repairing, replacement depending on the level of maintenance established through the maintenance program.

The maintenance process is evolutionary, it follows the PDCA principle (Plan-Do-Check-Act). It is the process of continuous improvement [58], [59], [62]. The PDCA aligns with the ISO55000 Asset Management Standard [57].

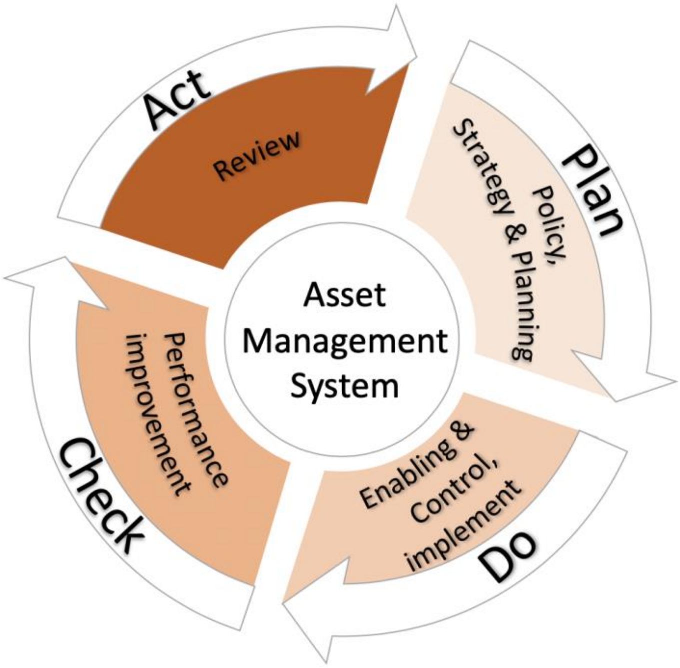

Figure 6 Plan-Do-Check-Act cycle[57]

6.2 Development of maintenance strategy framework

The developed framework synchronised all the concepts identified in Section 5.2.

The framework starts with the business objectives which are translated into maintenance objectives. It helps to bridge the gap between business strategy and maintenance strategy. This leads to an effective formulation of a maintenance strategy [50], [51], [53].

The maintenance objectives lead to operation and maintenance requirements. This stage consists of tactical and operational planning [52]. Maintenance strategy elements such as materials requirements, personnel and data acquisition and analysis are then included [4], [28], [63].

When the operation and maintenance requirements have been established, a specific maintenance program is formulated. It consists of planning and a maintenance program. Maintenance tasks that need to be performed are established. Scheduling of tasks and maintenance resources is also done [50], [52], [54].

It is followed by maintenance execution. On maintenance execution, the identified maintenance tasks in coming up with a specific maintenance program will be performed [4], [28], [54], [63]. Analysis of the repaired equipment has to be done. The results of the analysis are fed back to the program as an input. Hence the need for a feedback loop [4], [28], [52], [58], [63].

Maintenance strategy should be optimised to improve the quality of maintenance. As such specific maintenance program, maintenance execution should be under continuous improvement [4], [28], [52], [63].

The organisation, to evaluate its progress. It should have a maintenance performance measurement method. This could be done through benchmarking. This helps in continuous improvement [4], [28], [54], [63]

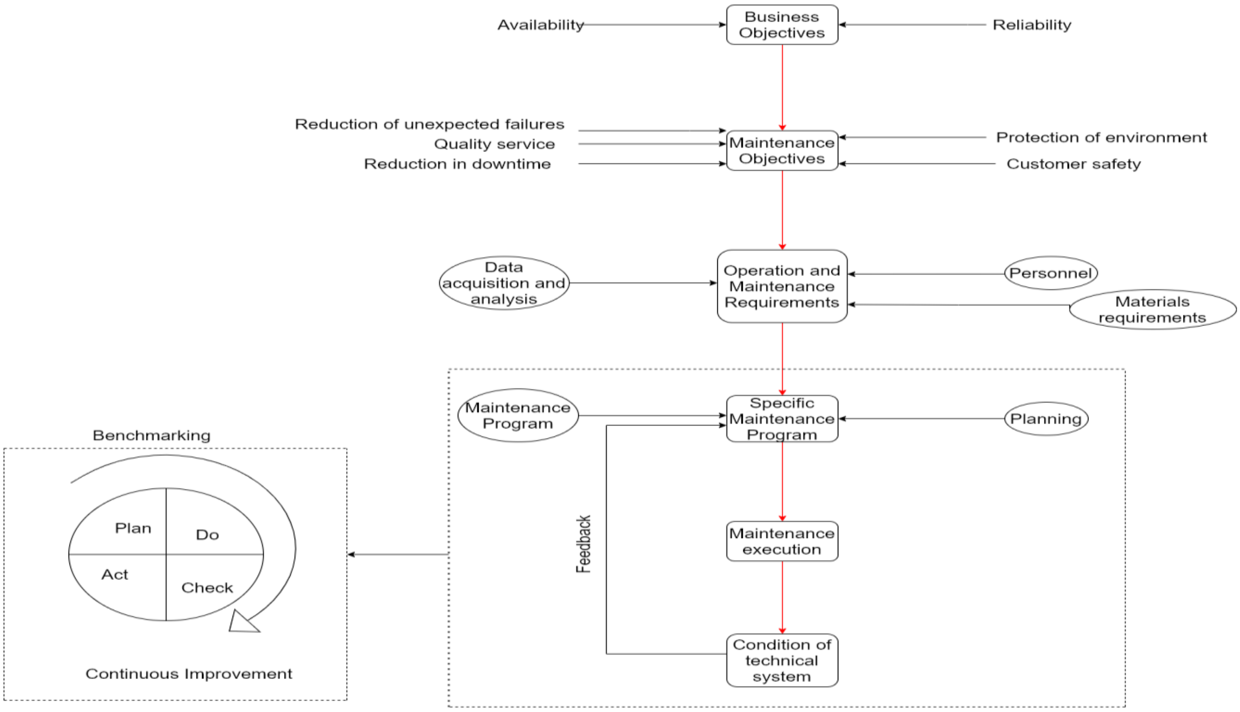

Figure 7 Developed Maintenance Strategy Framework

7 CONCLUSION

Based on an extensive review of the maintenance literature from different environments and world-wide railway sector, an approach (framework) for a maintenance strategy has been developed. It has been developed to make maintenance in the rail environment a more proactive approach. In conducting the literature review maintenance tasks/ activities, objectives, criteria for selecting maintenance actions and when they should be performed were identified for the formulation of a maintenance strategy framework.

The framework regards business objectives, regulations, health, safety and environment demands and interaction between different maintenance tasks. The maintenance strategy framework possible phases of activities, such as; objectives, personnel, scheduling, data acquisition and analysis, materials requirements, maintenance program and maintenance plan, and execution of maintenance tasks and continuous improvement of a maintenance process are given.

The framework establishes a clear link between maintenance objectives and business objectives. From the developed framework, it can be seen that business objectives influence the kind of maintenance objectives to be put in place. Maintenance objectives are there to enable the organisation in this instance to meet their business objectives.

The next step of the research is to validate the framework. This will be done through conducting interviews with subject matter experts in the field such as academics and rail maintenance practitioners.

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Appendix A Concepts Identified

Concepts	References
Repair	[1], [8], [41], [64]-[71], [10], [11], [13], [16], [26], [28], [33], [39]
Replace	[1], [8], [65], [67], [68], [71], [10], [11], [14], [16], [26], [28], [39], [41]
Inspect	[1], [8], [68], [71]-[73], [10], [14], [16], [17], [37], [41], [49], [64]
Coordination	[1], [38], [39], [74]-[76]
Availability	[14], [17], [76]-[85], [18], [24], [28], [44], [48], [66], [68], [70]
Quality of service	[14], [18], [78], [83], [84], [86]
Customer safety	[17], [44], [67], [70], [78], [80]-[82], [87], [88]
Reliability	[14], [17], [67], [69]-[71], [80]-[84], [87], [18], [88], [89], [24], [44]-[48], [66]
Safety of maintenance personnel	[28], [31], [39]
Frequency of maintenance	[20], [33], [41], [48], [71], [90]
Determine maintenance actions	[20], [28], [67], [84], [86], [91]
Spare parts management	[10], [25], [28], [67], [82], [88], [92], [93]
Number of maintenance personnel needed	[17], [25], [28], [39], [82], [88]
Level of technical skill needed	[13], [17], [94]-[96], [25], [27], [28], [39], [40], [65], [82], [89]
Tools	[17], [25], [27], [28], [80], [82], [88], [96]

Allocation of resources	[17], [25], [97], [98], [28], [31], [41], [71], [83], [85], [88], [89]
Maintenance procedure	[8], [13], [20], [85], [91], [93]
Time allocation	[8], [14], [17], [18], [25], [33], [39], [71], [82], [99]
Competency	[17], [27], [65], [69], [75], [80], [89], [95]
Flow of information	[27], [80]
Management commitment	[25], [27], [28], [39], [76], [85], [89], [95], [98]
Communication	[27], [43], [74]
Procurement of needed resources	[13], [14], [25], [48], [92], [93]
Work order	[19], [39], [92]
Computer maintenance management	[71], [92]
Formation of teams	[25], [28], [42], [92]
Continuous technical and interpersonal training of maintenance personnel	[13], [14], [89], [92], [100], [25], [28], [39], [68], [70], [74], [75], [82]
Reduction of downtime	[10], [13], [85], [90], [97], [101], [102], [19], [20], [24], [28], [48], [68], [69], [82]
Adjustments	[18], [26], [38], [67], [68], [70], [97]
Lubrication	[15], [17], [18], [26], [29], [67]
Operating time	[15], [37], [39], [49], [103]
Age of equipment	[15], [19], [41], [85]
Reduction of unexpected failures	[18], [25], [68], [85], [104]

Labour costs	[18], [40], [74]
Inventory cost	[18], [74], [94]
Historical data collection and processing	[16], [39], [41], [49], [70], [81], [94]
Tightening	[18], [67]
Cleaning	[18], [67]
Legislation and rules	[20], [85]
Use of scheduling software	[10], [31], [33]-[35], [41]
Allocation of maintenance tasks	[13], [18], [31], [91]
Monitoring	[10], [15], [105]-[107], [16], [24], [41], [44], [67], [69], [70], [94]
Equipment technical condition	[10], [39], [49], [65], [85], [88], [108], [109]
Level of maintenance	[14], [37]
Stock tracking	[25], [39], [110]
Recording	[16], [17], [26], [28], [109]
Document control	[39]
Failure mode	[20], [39], [41], [66], [82], [109]
Grouping components	[39], [94], [108]
Failure rate	[13], [39], [104], [108], [109], [67], [70], [71], [80], [82], [90], [91], [102]
Protection of environment	[14], [68], [70], [89], [111]

Benchmarking	[74]
Failure effect	[20], [67], [70]
Overhauling	[68], [69]
Servicing	[68]
Testing	[68], [70]
Measuring	[68], [70], [96]
Contracting	[58], [88]
Reporting	[58], [89]
Scheduling	[20], [29], [102], [112], [31], [33], [35]-[37], [40], [48], [88]

DEVELOPMENT AND DEPLOYMENT OF STANDARD CORE PROCESSES WITHIN THE GLOBAL QUALITY MANAGEMENT SYSTEM

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ABSTRACT

The implementation of harmonized processes across an organization is essential for operational consistency. The company where this project took place, is a key partner of the world's largest industrial groups such as Airbus, Alstom, Peugeot, Renault, Rolls Royce, Safran, and Thales. It holds two divisions dealing with Energy and Infrastructure (E&I), and Product Solutions (PS). The E&I division provides support to businesses involved in complex projects with strong regulatory constraints, while the PS combines the group's outsourced research and development expertise. Subsequently, the group then kicked-off a project aimed at developing a global Quality Management System. The objective is to have common processes across all countries to facilitate regional cooperation and transnational management. The objectives include:

- development and deployment of 12 standard core processes in four business domains
- rationalization of external audit bodies
- a single accreditation system

The activities include gap analysis of the processes and benchmark studies for best practices. The final phase of the project was to deploy these processes as part of the global QMS in the country processes.

Keywords: standard core processes, process standardization, quality management system

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1 INTRODUCTION:

Quality Management Systems (QMS) provide the tools to evaluate how the company systematically operates and offer a basis for continuous process improvement [1]. The American Society for Quality [2], defines it as a formalized system that documents processes, procedures, and responsibilities for achieving quality policies and objectives. Among other benefits, QMS assists in coordination and direction of activities to meet client, regulatory and continuous improvement requirements.

The issue of process complexity in companies is asserted by Rondini et al. [3], where they affirm that the complexity of organizing the service delivery process increases with different geographical locations and further characterized by different maturity levels. The authors focused on developing an approach for service delivery process standardization as a means to make the activities uniform and similar in different units [3].

The company being presented in the case study has common customer requirements, common international standards and a global organization in many countries and hence the need for a standardized global quality management system. Currently there are different processes which are implemented in each country. Furthermore, there are different certification bodies for different quality standards in each country. For example, the Indian division of the company used American Systems Registrar (ASR), while the British division used British Standards. However, the objective is to have common processes across all countries and strategic business units to facilitate the regional cooperation and simplify transnational management. The main aim was to provide a single quality management system that cuts across all business units and countries with the clear objective of providing common processes.

In order to develop and deploy standard core processes, it was important to divide the project into two categories namely:

- Domain related activities
- Supporting/enabling projects related

The main benefit of implementing a global QMS in the company include:

- Creation of synergy, transparency, independency and common understanding across the organization thereby improving efficiency.
- Standardization of quality practices to support business processes globally, where applicable, resulting in smooth services, method transfers and a consistent approach.
- Facilitation of communication between the Product Solutions division's operating entities.
- Ensure awareness of current regulations globally and proactively implement appropriate systems to ensure compliance.
- Employ a quality system which is owned by a global division rather than individual sites or a functional area.
- One common reporting or controlling mechanism (Key Performance Indicators for engineering projects).

The execution of tasks for this project was managed using the RASCI (Responsible, Accountable, Support, Consulted, and Informed) matrix model. To ensure optimal outcomes and success the RACI/RASCI prioritisation matrix technique is widely employed by project managers to assign responsibilities of individuals related to a task in the organization and in a project [4]. Cabanillas et al. [5], state that organizations need to manage the responsibility of the employees with respect to all the activities that are carried out daily. In their research, they found the RASCI matrix to be transformed with other matrices to be very useful to organizations and allows them to focus on responsibility management. RACI/RASCI prioritization technique organizes the projects in such a manner that the actors in the project know exactly what is happening and expected outcomes of the person and who must do what [6].

Research on project management shows that theoretically and practically, it is more effectual to separate and prioritize tasks in a project for the optimal deployment of human capacity [7]. Rojas and Figueroa [8], concur with the fact that amongst the wide array of decisions to be made by project managers, project selection (PS) and project prioritization (PP) are crucial for the success of the project through the effective management and allocation of resources to projects that are in alignment with the organization's strategic objectives.

2 METHODOLOGY FOR DEVELOPMENT AND DEPLOYMENT OF CORE PROCESSES

The activities involved in the implementation of the Global Quality Management System (G-QMS) are centred the four business domains of the company, namely management, business development, resources and operations. Many enabling projects are not necessarily included in the scope of business domains but are integral and act as catalysts to the success of the global QMS project. These projects include transnational single audit body project, framework agreement database project and others. The methodology thus is divided into two sections:

- methodology for business domain-related activities (standardized)
- methodology for supporting activities (differs for each process)

For this paper, the focus will be on the methodology for business domain-related activities. These business domains are defined as:

- ***Management-*** *responsible for the management of the Product Solutions division and related companies*
- ***Business Development-*** *responsible for the development of accounts, product & service portfolio and markets*
- ***Resources-*** *responsible for the management of all the skills, human and equipment resources.*
- ***Operations-*** *managing the business from bid to project closure.*

2.1 Methodology for business domain-related activities (standardized)

The methodology is divided into two phases for business domain-related activities. The two stages are creation or development and deployment phases.

2.1.1 Creation / Development Phase

The core process development is a first systematic step to manage and organize the implementation of the domain-related activities

Stage 1: Team and Solution Development

Appoint Process Owner & Fix Objectives	• Leader : Person from senior management named by executives who will lead the Core Process • Appoint a Quality Team Representative (different from the process owner). • Vision: Owner defines purpose of the core process based on business need and project objectives– clarify the goals.
Agree on contributing parties	• **Expert Knowledge:** Who needs to contribute – should consist of participants if possible from different countries to capture best practice and improve transnational buy-in. • Kick-off meeting / workshop – process owner explains vision, objectives and their expectations from the group. Agree on vision.
Develop Solution	• Stakeholder analysis - who is impacted and how. • SWOT analysis – understand your environment. • Existing process review – what already exists? / benchmark. • Produce draft of solution, review with working group.
Review & Update	• Define Reviewing group - get input from a broad population of future users as well as people who will have to deploy and ensure application. Get buy-in through their contribution. • Analyse feedback and take into account good ideas.

After the review and update, the next stage of core process development kicks in and is described below.

Stage 2: Plan communication & Pilot Deployment

Validate Solution:Quality Team & Executive	• Present & review solution with Global QMS Quality Managers Team. • Present & seek validation with executive members.
Communication & Deployment Plan	• Do gap analysis in each country – understand the effort needed to accompany the change. • Is a pilot phase needed to test & check the solution? • What communication and/or training means are best - posters, PowerPoint, training sessions.
Deploy	• Carry out pilot phase if decided to do so. • Adjust with lessons learned from pilot. • Deploy globally – detail planning, organize training. • Communicate, Communicate, Communicate.
Review & Update	• At least annually, Process Owner to review the process / procedure with Quality Managers and Principal Users. • Check application, continued relevance, update with lessons learned.

2.1.2 Core Process deployment Phase

Stage 1: GAP Analysis for - Quality Management Domain

This stage is implemented in the Quality Management Domain and lays the foundation for implementation in the operations domain

Gap Analysis

- What existing QMS documents / Tools / Templates are going to be replaced or modified?
- List of documents (process, procedures, tools, forms...) impacted by the introduction of the new document.
- Categorise the impact type (replace, modify) and summarise the changes in case of modification.

Plan

- Plan each change – list actions & owners.
- Is change simple (no external consultation required) or is a working group required to decide best solution?
- Plan the deployment and communication – refer to SWOT and stakeholder analysis. Decide communication strategy – flash info, message on internet, training needed.

Do

- Carry out the changes to documents - attention not yet published.

Deploy

- Publish the new or updated documents and communicate according to chosen strategy.

Measure

- Measure the changes that emanate from the deployment and compliance to the process.

Stage 2: Gap Analysis II – Operations

Gap Analysis

- How do the new documents impact day to day operations?
- What are the requirements of the document, how do they compare with current practices. What is the gap between them? What needs to happen for operations to be conforming?
- What is the ‘maturity ‘of the different entities and how to close these gaps easily?

Plan

- What population (process users) is impacted – Stakeholders.
- Are there different levels (hierarchy) of population - who are the ‘users’ that need detailed knowledge, which users only need to be aware?
- Is change simple (minor change to current practices, small heterogenic population...) or complex?
- Plan the deployment and communication – is a pilot phase required to test the solution?
- Decide communication strategy – flash info, internet message, training material, training direct or by cascade.

Deploy

- Carry out Training and communicate according to chosen strategy.

Measure

- Measure the changes that emanate from the deployment and compliance to the process.

3 RESULTS

3.1 Domain-related project: Benchmark Study: Strategic Account Management

a) Objective

The aim of this task was to develop a baseline for development of an accounts management process by benchmarking the division's current customer account processes against the energy & infrastructure division which had already implemented standardized processes.

b) Project Tasks

- Study the current strategic account documents (Table 1).
- Formulate a synthesis of items in all strategic plans.
- Find common and unique items between all documents for the strategic accounts.
- Compare against the standard processes being implemented in the E&I division.
- Decide on the important integral items and optional items.
- Formulate a new strategic account management plan template for PS (using the methodology for development and deployment of core processes discussed in 2).

c) Input Documents

The first step was to develop the internal analysis of the items contained in the account's management plan templates. This would assist in formulating a synthesis of items in all strategic account plans and find common and unique items between all documents for the strategic accounts.

Table 1: Input documents used for the benchmark study

Business Units	Documents Reviewed
Aerospace	• Strategic Plans • Customer Review Documents • Sales Kick Off Plan • Account Reviews
Automotive & Transportation	• Strategic Plans • Customer Review Documents • Sales Kick Off Plan • Account Reviews

For the benchmarking process, the strategic account template from the Energy and infrastructure was used as the base because it had been already implemented in the strategic business units of this division and therefore referred to as 'Best in Industry'.

d) Outputs /Results

The aim of the analysis of accounts management process documents was to scrutinize the importance of each item in the different strategic plans for each country and business units. These main items have underlying items such as position of client within the industry, market study, financial situation, performance. The new strategic account plan template was then devised based on the analysis and benchmark. The proposed accounts management process contains the four main items in table 2.

Table 2: The four main items in the proposed accounts management process

Executive Summary	Customer Presentation	Company-Customer Relationship	Key stakeholders and action plan
Customer analysis	Customer description	Account importance	
	Financial situation & operational performance	Company competitors at the customer	
	Market analysis	Key projects	Internal stakeholders supporting the account
Self-analysis	Customer competitors	SWOT analysis	
		Long term blueprint	
	Key departments	Action plan for the coming year	
	Customer supplier selection process	Investments/partnerships	Communication plan
		Financial plan	

3.2 Domain-related project: Practical Implementation of the Development and Deployment methodology: Strategic Account Management (SAM) Core Process

a) Objective

This core process aims to provide a standard process for strategic account management to adapt the Product Solutions & Strategic Business units' strategies to each customer, and is applicable across all transnational division's key accounts.

b) Development

The development of the SAM core process follows the methodology discussed in 2.1.1. (Core Process development method).

c) Result: Core process

The core process was developed using the methodology discussed in 2.1.1. and has standard contents such as process owners, requirements, regulations. The second section of the process contains upstream process, the scope of application, purpose, and downstream process. It also includes the main inputs and outputs (internal and external), main risks and opportunities. The final core process developed using this process development methodology is the process flow diagram developed is in presented in Figure 2.

d) RASCI

RASCI is a method to identify the roles and responsibilities in the process. This process can be an operational process or related to a project process, but it must be defined beforehand. The RASCI method involves building a grid. First, we define all tasks of the process, listed vertically in the grid, then all entities (or people) involved, listed horizontally. This ensures that every task or step is defined properly and every stakeholder knows their role in the process.

Table 1: RASCI Method explanation

R = Responsible	Person or authority which is ultimately responsible for delivering the project and/or task successfully. R is placed under the authority of A.
A = Accountable	Person or authority which has ultimate accountability and approval authority which reviews and assures quality, to which "R" is accountable.
S = Supportive	Person or authority which supports the "real" work with resources, time or another material benefit. They are committed to its completion.
C = Consulted	Person or authority which provides valuable information and/or expertise necessary to complete the project. Their contribution is important for successful implementation.
I = Informed	Person or authority which provides input and needs to be notified of results but does not necessarily need to be consulted.

Step	(R)esponsible, (A)countable, (S)upport, (C)onsulted, (I)nformed			**Accounts Management**	
	Executive	**Accounts Leader**	**Operations**	**Process Diagram**	**Output**
0				Start	
1	A	R		**Develop Customer Profile**	long term blueprint Turnover per activity/ site, Executive Communication Plan
2	A	R		**Customer Relationship Analysis**	
3	A	R		**Identify and Address Customer needs**	
4	A	R		**Competition Analysis**	SWOT Analysis
5	A	R		**Establish Account Objectives and Strategies**	Strategic Account Plan
6	S	R	S	**Provide a Detailed Roadmap**	
7	A	R		**Establish an Operational Plan**	Contract Plan Action Plan Communication Plan Deployment plan to regions
8	A	R		**Measure satisfaction**	Satisfaction Levels

9				Yes **Are there any deviations from business objectives / Satisfaction levels?** No	
10	I	R		Take immediate corrective actions. Conduct Root Cause Analysis and take long term corrective actions	
11	I	R		Review status, effectiveness of actions	
12				End	

Figure 2: Proposed Process Flow for Strategic Accounts Management Process.

3.3 Supporting/enabling Projects: Certification Analysis for Rationalization of External Audit Bodies

a) Background

The company has different audit and certification bodies in each country and its operating sites. There is a need to rationalize these bodies to a common audit company/platform because they are providing services for the similar standards i.e. ISO 9001, EN 9100 and ISO 14001. Appointing one company to do the audits in all sites may result in negotiation power to reduce audit duration and consequently audit costs and better rates for the certifications.

b) Project Tasks

- Analysis of the certification bodies in all countries sites including the analysis of the certifications/standards (ISO 9001, EN 9100, others) and cost analysis for the certification bodies/ each certification per site
- Meeting with the service providers: advantages and disadvantages of each service provider; and offerings
- proposals for the certification body requirements (whether there is a need for a single certification body, specific bodies, or combination of both)
- Preparation of the request for quotation (RFQ) for one single certification body.
- find common certification bodies dealing with the specific elements being certified

c) Milestones

The milestones that needed to be achieved are:

i) Analysis of certification bodies per country
ii) Stakeholder meeting worldwide(Key certification bodies)
iii) Specifications redaction
iv) Consultation of certification bodies for potential package offering
v) Choice of new certification audit body
vi) Gradual transition by sites to the new certification body

d) Results: Analysis of Certifications

After the analysis of all certifications, the following table was developed to illustrate that there were various company sites being certified for the quality standards, using different audit bodies in each country, further entrenching the need to rationalise and move to a single certification body.

Table 3: Quality certifications in each continent

Continent	Standard	Locations per certification
Asia: India	ISO 9001:2008 and AS9100C	2
Rest of Europe	ISO 9001:2008	38
	EN 9100:2009	21
	ISO 9001:2008	7
	ISO 14001:2004	2
	ISO/IEC 27001:2013	6

Continent	Standard	Locations per certification
Europe: United Kingdom	EN9100:2009	1
	EN9100:2009 + ISO 9001: 2008	5
	ISO 9001: 2008	4
	ISO 14001:2004	1
	OHSAS 18001: 2007	1

4 CONCLUSION

The model for development and deployment of standard core processes in the consulting firm was critical for the consolidation and standardization of processes. Standardization of quality practices to support business processes globally where applicable resulting in smooth services, method transfers and a consistent approach. The development phase focuses on team and solution development, plan communication & pilot deployment. The outputs of this phase are stakeholder analysis, SWOT analysis, and existing process review and draft solution.

The core process deployment phase focuses on gap analysis for quality management and gap analysis for operations. It follows the gap analysis, plan, do, deploy and measure flow. The main outputs for this methodology are a complete review of existing quality management system tools, and measurement of the effectiveness of the application. The measures vary from process to process. The gap analysis for operations follows the measurement of process effectiveness in quality management. This is utilized to measure the impact the new QMS documents on day to day operations. The model was used for the successful creation and deployment of processes in the company's business domains.

- Business development: framework agreement procedures, bids and contracts.
- Operations: peripheral procurement.
- Resources: recruitment and transnational worker transfer.
- Management: transnational travel.

This methodology forms a good foundation for standardization of processes in a transnational company. The limitations of this model are that it's very company-specific and adaptation will differ from company to company due to process variations. The methodology for developing and deployment of supporting/ enabling projects has not been defined yet, and this provides possibility for future work. Standardized approach in supporting/ enabling projects is critical in ensuring that there is an archive that can be utilised by as a template for any future projects, thereby reducing time spent on methodology definition.

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APPLYING LEAN AND CONTINUOUS IMPROVEMENT TOOLS TO ACHIEVE PRODUCTIVITY AND SUSTAINABILITY IN SMALL TO MEDIUM SCALE MANUFACTURING ENTERPRISES: A CASE STUDY

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ABSTRACT

Small to medium enterprises face serious competition from both firms of a similar size and larger ones. Competitors may use responsiveness, innovation or pure economies of scale to deliver value to customers. Small enterprises often have limited resources so as a result they have to find cost effective ways to achieve competitiveness. In this research, a case study of how small scale manufacturing businesses are employing low cost lean strategies to improve operational performance and achieve competitiveness in a shrinking market space. The challenges and opportunities of similar enterprises are presented in this research.

Keywords: lean continuous improvement, productivity, SMEs

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1 INTRODUCTION

Small and medium scale enterprises are facing huge challenges; falling market share, financial resources, limited resources and access to innovation and technology. There is increasing competition from cheap imported products, increasing costs of raw material and limited cash reserves. The advent of COVID 19 pandemic and the resultant economic fallout, threatens survival of most SMEs. Today's business environment, local and global characterised by free trade has exposed companies, particularly in developing economies to unprecedented competitive pressure. In light of these developments, innovative companies are looking for methods and tools to reduce costs and improvement of efficiency [1]. It is therefore important to continuously evolve the business models to meet customer needs, management costs and constantly improve operations while always meeting demand [2]. "Lean thinking" is a business philosophy widely used in manufacturing [3], which by 1990, was integrated by all Japanese automakers giving them competitive advantage over US manufacturers among them; 25 percent less time and 46 percent fewer employees to develop a product [4]. Lean manufacturing or lean production was introduced in Jim Womack, Daniel Jones and Daniel Roos' book, "The machine that changed the world [1991]" Which is a philosophy that aims to identify and eliminate non-value adding activities in operations [2]. Lean manufacturing is the systematic elimination of waste. Previous research works indicates that large companies are more willing to implement lean concepts than SMEs with the exception of SMEs that are contracted to supply large corporations for example automotive manufacturers [1]. This paper reports on how lean and continuous improvement tools also be used to improve operations of medium scale enterprises.

2 LITERATURE REVIEW

A lean process uses less of everything in all operations: human effort, capital investment, facilities, inventories, and time, resulting in increased efficiency [4]. Lean manufacturing uses several methods and principles in order to minimise costs in product or service design, deployment, manufacturing, logistics, supply chain costs, and customer service costs. Key principles emphasized by [2] and [4] in lean implementation include:

- clearly defining "value" according to what the customer wants and is willing to pay for,
- Investigating, defining and eliminating anything consuming resources without adding value.
- deploying processes that deliver what the customer values in the shortest possible time
- making the process flow smoothly
- applying "Pull, not push principles" starting with the project goal and "pulling" toward it only work needed to accomplish the goal by planning backward
- Pursuing "perfection" by continuous improvement of operations.

In practice, lean manufacturing focuses on 3M's [3]. These Ms are Japanese terms: Muda (waste), Mura (inconsistency) and Muri (unreasonableness) [3].

Lean principles focus of eliminating waste across operations [4]. Waste is defined as anything that adds cost to the product without adding value to it [1][2]. According to lean production philosophy, waste can result from several conditions in the production environment [3]. Excess production and early production captures resources too early in the production process resulting in the retention of value added and capital tie up in the materials and semi-finished subassemblies until the product is used or sold. Delays while waiting for raw material, or due to poor production line balancing result in the poor use of capacity and increased delivery time of final products. Unnecessary handling, movement and transport, can result in lost materials, damaged stock or wrong stock and are non-value adding processes [4]. Poor process design results in the overuse of manufacturing resources like man and machines leading to

higher manufacturing costs [2][4]. Excessive inventory leads to the committing of capital to a large "safety stock" of material. Inefficient performance of a process results in the over utilization of manufacturing resources and a more costly product thus (g) making defective items resulting in labour and material waste [1]. Successful implementation of lean thinking requires creating a New Culture Paradigm and one of a Non-Blaming Culture. This style of management creates a culture where:

- Problems are recognised as opportunities
- It's okay to make legitimate mistakes
- Problems are exposed because of increased trust
- People are not problems - they are problem solvers
- Emphasis is placed on finding solutions instead of "who did it" [1][2][3]

2.1 The 5 S's of Lean

Achieving order and visibility is at the heart of lean philosophy [4]. A structured way of implementing Lean in manufacturing in order to achieve this goal, involves applying the 5S principles [2]. The 5 S's are Japanese words namely: Seiri (sort, necessary items), Seiton (set-in-order, efficient placement), Seison (sweep, cleanliness), Seiketsu (standardize, continuous improvement) and Shitsuke (sustain, discipline) [1][3]. The aim of the 5's is to create order, improve visibility, storage, location and retrieval of materials, tools and accessories and allow operators to spend time efficiently on making the product. Thus, 5 S's principles emphasize efficient facility design and workspace management as an enabler of waste reduction.

2.2 Controlling a lean production facility

In traditional factory control, "push" control was the strategy used to regulate parts in a production environment. In a push system, when an operation is complete at a machine, the product or part is pushed to the next machine. If one machine works slower than the other machines in the system then product accumulates in front of the machine until no more room exists and the machine begins to physically "block" the flow of parts from the feeding machine(s) [3].

Today, many flow systems use "Pull" control rather than "Push"[3]. In a "Pull" system, parts or product is held at a manufacturing station until approval is issued from a downstream machine. This type of control is referred to as a Kanban system. Kanban is Japanese word that refers to the "paper authorization or approval" to continue to move a part [1]. The difference between a pull and a push system from Kaizenaction [12] is shown in the schematic below in Figure 1.

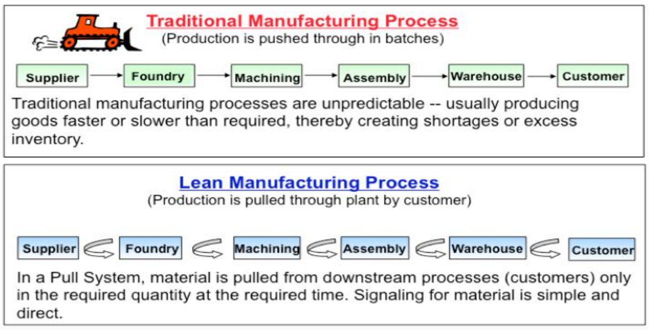

Figure 1. The difference between a pull and a push system

Traditional Kanban systems use physical cards or paper records as authorization to move a product. Today, paperless approval is more typically given to upstream machines in the form of "ANDON" lights or electronic messages [1].

2.1.1 Balancing and timing production

Pull-based production control systems tend to balance activities. These systems however only work on flow systems so it is important that part families are created so that the product in a manufacturing facility moves in a common direction. Kanban and JIT are also based on several other system requirements [1][2]. These are:

- Stability of preceding process
- Levelled production
- Takt time and production requirement
- Maintaining good quality
- Team member education and training

Takt is a German word for rhythm and refers to how often the part or product is required or the rate at which the product is required (typically by the customer). Takt time (time/piece), Tk , is computed as

$$Tk = \frac{\text{Available Operating time (sec/day)}}{\text{Daily Demand (pieces/day)}}$$

Cycle time is a measure of how much time it takes for a particular operation, which is also expressed in similar units (time/piece) [1].

2.1.2 Shojinka

Shojinka is a principle which entails continually optimising the number of workers in a work centre to meet the type and volume of demand imposed on the work centre. It requires workers trained in multiple disciplines; work centre layout, such as U- shaped or circular, that supports a variable number of workers performing the tasks in the layout and the capability to vary the manufacturing process as appropriate to fit the demand profile [1][2].

2.1.3 Single Minute Exchange of Dies (SMED)

SMED is a process that begins with detailing what happens to a machine between batches of parts [5]. Originally used in forming operations, its principle entailed changing a die on a forming or stamping machine in a minute or less by redesigning accessories, activities and steps. Broadly, it was extended to cover the ability to perform any setup activity in a minute or less of machine or process downtime in manufacturing [5]. Its elements are:

- Single-digit setup: performing a setup activity in a single-digit number of minutes, i.e. fewer than ten.
- One touch exchange of die (OTED): This is a principle involving literally changing a die with one physical motion such as pushing a button; broadly, an extremely simple procedure for performing a setup activity and screw fasteners are replaced with "quick-lock" mechanisms

Once a setup is documented, each setup element is analysed in order to determine if the element is an internal or external element [5]. An internal element is one that requires the equipment resource. An external element is one that can be done without the equipment or external to the equipment. That is, the machine resource is necessary in order to set the location of the tool with respect to the part. On the other hand, new tools could be loaded into tool holders or collected external to the operation of the machine. Loading the tools into tool holders would be an external element [5].

2.1.4 Five Steps of Lean Implementation

The process used to implement lean manufacturing is a straightforward one. However, it is critical that lean is implemented in a logical manner. The steps associated in implementing lean follow:

• Step 1: Specify Value

Define value from the perspective of the final customer, in terms of a specific product, at a specific price and at a specific time.

• Step 2: Map

Identify the value stream, the set of all specific actions required to bring a specific product through problem solving, information management, and physical transformation tasks. Create a map of the Current State and the Future State of the value stream.

• Step 3: Flow

Eliminate functional barriers and develop a product-focused organization that dramatically improves lead-time.

• Step 4: Pull

Let the customer pull products as needed, eliminating the need for a sales forecast.

Step 5: Perfection

There is no end to the process of reducing effort, time, space, cost, and mistakes. Return to the first step and begin the next lean transformation, offering a product that is ever more nearly what the customer [1].

2.1.6 Lean Process Techniques

Implementing lean involves various processes and management activities. Brock [4] identified the following: project team workshops, process mapping, target scheduling, good team management, target costing and computer modelling.

3 CASE STUDY

3.1 Background

For over 30 years, ABC Products (Pty) Ltd has gained experience in the designing and manufacturing of high-performance products using composite materials for Automotive and aerospace industries. After expansion into international markets, ABC developed carbon fibre products including interior products for aircrafts and main design parts for the high-end automotive industry. The company has a direct manufacturing workforce of over 300. In the production department, moulding capacity is more than 2500 mouldings per week. It is AS/EN 9100 and IS09001 Quality Management System accredited, and has established itself as a preferred partner in different industries by ensuring that quality checks are of the highest standard. However, current manufacturing processes are facing the following challenges:

- The impact of establishing correct takt times and cycle times for getting the right number of operators in each cell, for the purpose of line balancing resulted in failure to meet the daily target on production line. Failure to achieve current takt time was observed in the following workstations; kit cutting, moulding, curing, machining and assembly line.
- The impact of incorrectly defining mould requirements resulted in several line stoppages.
- There are also delays on the delivery of components from the suppliers.
- The impact of incorrectly defining machine loadings resulted in parts that to queued for too long.
- Incorrectly controlling, tracking or quantifying work in process (WIP) affecting lead times negatively.
- Delays in transporting the final product to customers.

3.2 Aim and objectives

The aim of the research was to identify areas experiencing bottlenecks on shop floor and suggest remedies to improve the efficiencies using lean manufacturing tools. The work sought to achieve the following objectives:

- To improve the utilization of workers through analysis of movements in order to eliminate transportation waste.
- To minimize production time using task design and time study.
- To improve the production method through process design.
- To minimise operator effort by identifying appropriate material handling equipment and proper work movement methods can minimize the effort of associates.
- To improve worker health and safety using elements of human factors engineering.

3.3 Methodology

According to Yin [6], a case study is useful for explaining present circumstances, e.g. "how" or "why" some social phenomena work. Case study research must not be restricted to only one case, but can instead consist of several cases. Multiple-case studies are often carried out to compare and contrast findings from each case. By doing so, both unique and common aspects can be identified and enable a theoretical reflection on the findings [7]. Polit and Hungler [8] refer to the population as an aggregate or totality of all the objects, subjects or members that conform to a set of specifications. The following participants with varied job functions were selected for an interview to determine their roles within the company and the manufacturing process:

Supervisor: Their function involves helping the team understand performance targets and goals, operator training in specific skills and scheduling work hours and shift patterns.
Production Line leader: A leader in charge of the entire production process for a particular area or set of products.
Operator: Operators carry out the work to be done as per standard operational procedure and work under and follow instruction from the supervisor.
Project engineer: Determines project specifications by studying product design, customer requirements, performance standards as well as completing technical studies and preparing cost estimates.

3.3.1 Time study conducted during investigation and calculation methods

In order to determine the standard time for a task, the task has to be broken down into elements. Kanawaty [9] defines an element as a distinct part of a specified job selected for the convenience of observation, measurement and analysis. Thereafter, each element of the task is timed using a stopwatch and it's duration termed the observed time (OT) is determined [10]. The rate of performance depending on the working condition referred to as the rating is allocated to 'pace' each operator task [10]. A rating (R) is multiplied by each element time and this is termed observed rating. Basic time is the time for carrying out an element of work at standard rating (100%). The researcher had to calculate the basic time for each element. The basic time or rated observed time is given in equation 1.

$$BT = OT \times R \tag{1}$$

100 % rating was selected as relevant standard rating to the current study [10]. At this rate, an average qualified worker can achieve set standard of quality with confidence and without supervision [9] [11]. Operators that would need supervision and performing under 100% were not selected to participate in the study. The frequency refers to 'how often' each element occurs in a work cycle. This is shown in Table 1 below. Kanawaty

[9] states that repetitive elements, by definition, occur at least once in every cycle of the operation; so, the entry to be made against a repetitive element will read 1/1, indicating that the element, for instance, occurs once in every cycle (1/1).

Kanawaty [9] defines relaxation allowances as an addition to the selected basic time to provide the worker with the opportunity to recover from the physiological and psychological effects of carrying out specified work under specified conditions and to allow attention to personal needs. Actual time of each element is the sum of basic time plus relaxation allowance (RA%) which is usually a percentage of basic time. The amount of allowance depends on the nature of the job. The rest allowance allocated to element 1,2 and 3 is chosen as 10%. Relaxation allowance is calculated as Selected basic time multiplied by relaxation percentage. Thus actual time (AT) is given as;

$$AT = BT + RA\% \quad (2)$$

Hence, the actual time for element 1,2,3 is calculated as follows:

3.3.2 Contingency allowance and standard time

Standard time (ST) is the time used for setting task times and takes contingency allowances into account. Kanawaty [9] defines contingency allowance (CA) as a small allowance of time which may be included in a standard time to meet legitimate and expected items of work or delays, the precise measurement of which is impractical because of their infrequent or irregular occurrence. The contingency allowance is given as 5%. Hence, the standard time is calculated as follows:

$$ST = AT + (AT\ x(ATx\ CA\%) \quad (3)$$

The observed time for the elements were as follows element 1 was 5 minutes. Element 2 was 42 minutes and Element 3 was 3 minutes. The calculation of a standard time is shown below in Table 1.

Table 1: Calculation of standard time

Element	1	2	3
frequency	1/1	1/1	1/1
Observed time	5	42	3
Rating (%)	100	100	100
Basic Time (R= 100)	5	42	3
Relaxation allowance % (RA)	10	10	10
Actual time (AT)	5.5	42	3.3
Total actual time (TAT) = 5.5+42+3.3			55
Contingency allowance (CA)			5%
Standard time (ST) = TAT + CA%			57.75

3.4 Results and findings

3.4.1 Questionnaire surveys

Information was collected by interviews from a sample of 39 employees. 38% represent employees who have been in the company for 2 to 5 years. 36% represent employees who have been in the company for 5 to 10 years. 26% represent employees who have been in the company for 10 to 20 years. The survey asked employees about their knowledge of productivity, factors affecting productivity and causing idle time and time utilisation issues and work load in their respective shifts.

3.4.1 Do you know how the company measures output/productivity?

When asked about whether the employees understand about measures of productivity, responses were as follows: 43% of the respondents understand how ABC measures productivity. 36 % of the respondents showed doubt about how ABC measures productivity. 21% of the respondents completely did not know how the company measures productivity. Responses regarding daily output clarityare shown below in Figure 2. There are not enough operators who are informed and know how the company measures productivity.

Is the daily output target clearly communicated	Participants responding
Yes	17
No	10
Unclear	20
Total	37

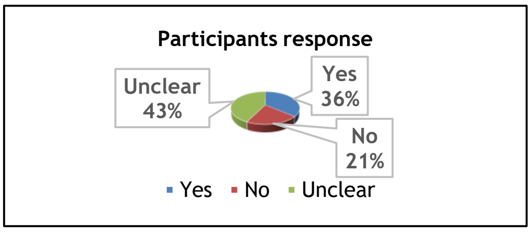

Figure 3. Responses regarding daily output clarity

3.4.2 What are the common issues encountered by production on a daily basis

The study was done to find the factors impacting operation time in work station, labour and plant utilisation. Of 39 operators interviewed, 77% of the respondents replied that their workstations are working continuously for 4-5 hours, while 2% is working for approximately 0 to 2 hours a day. The responses are shown below in Figure 4.

What are the common issues encountered in production daily	Participants response regarding issues they encounter
Waiting for decision from engineer	4
Waiting for material	5
Waiting for jigs	15
Fixing reworks	5
Waiting for moulds	10

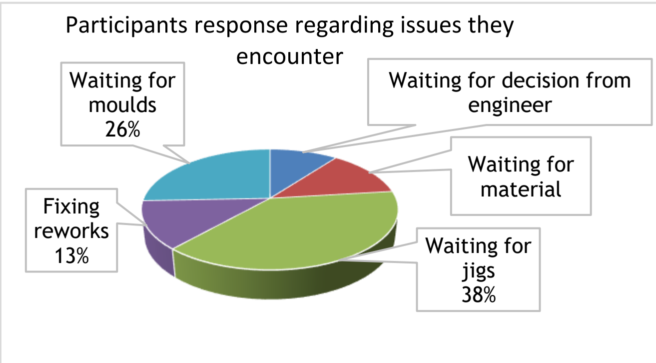

Figure 4. Responses regarding issues encountered in production daily

3.4.3 Working station loading during available time

The survey also investigated the utilisation of operators during a 7-hour shift during an average day. The responses were as follows: 32% of the respondents said that they wait for jigs in most of the time, 21% of the respondents said that they wait for moulds most of the time. The study reveals that there is a need for tool review requirements. Rate how much each workstation keeps an operator busy out of seven hours shown in Figure 5.

How much each workstation keeps the operator in an 8 hour shift	Participants response

0-2 hrs	1
2-3 hrs	3
3-4 hrs	7
4-5 hrs	36
Total	47

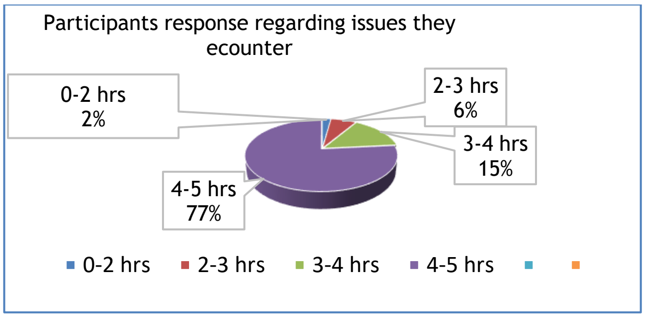

Figure 5. Working station loading during a 7 hour shift

3.5 Current layout of the moulding production process

The composite manufacturing process involves resin preparation, potting, moulding and assembly of components into subassemblies and final products. These processes constitute the main workstations.The line has 4 stations and 6 operators. A graphic of the manufacturing process is shown below in Figure 6.

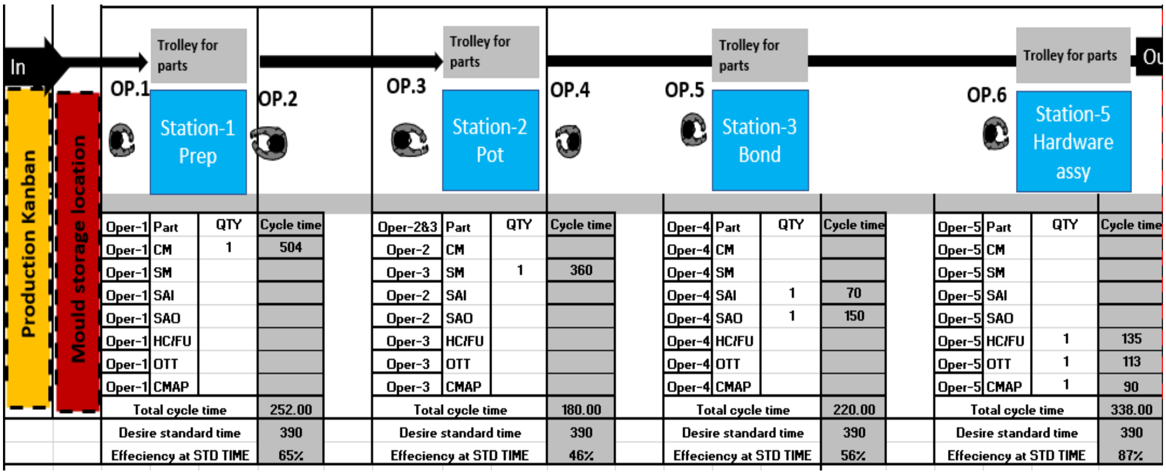

Figure 6. Current layout of moulding station

Station 1 is loaded at 65% at standard time; hence, the station is loaded 35% below the standard time. Station 2 is loaded at 46% at standard time; hence, the station is loaded 54% below the standard time. Station 3 is loaded at 56% at standard time; hence, the station is loaded 44% below the standard time. Station 4 is loaded at 87% at standard time; hence, the station is loaded 13% below the standard time.

3.5.1 Current layout of the Final assembly of the process

The line has 7 stations and 7 operators is shown in Figure 7 below. The line design does appear to conform to that of a lean line. The line set up indicates a poor workflow. Kanban storage is located too far from the stations and Final QC is located too far from the final workstation.

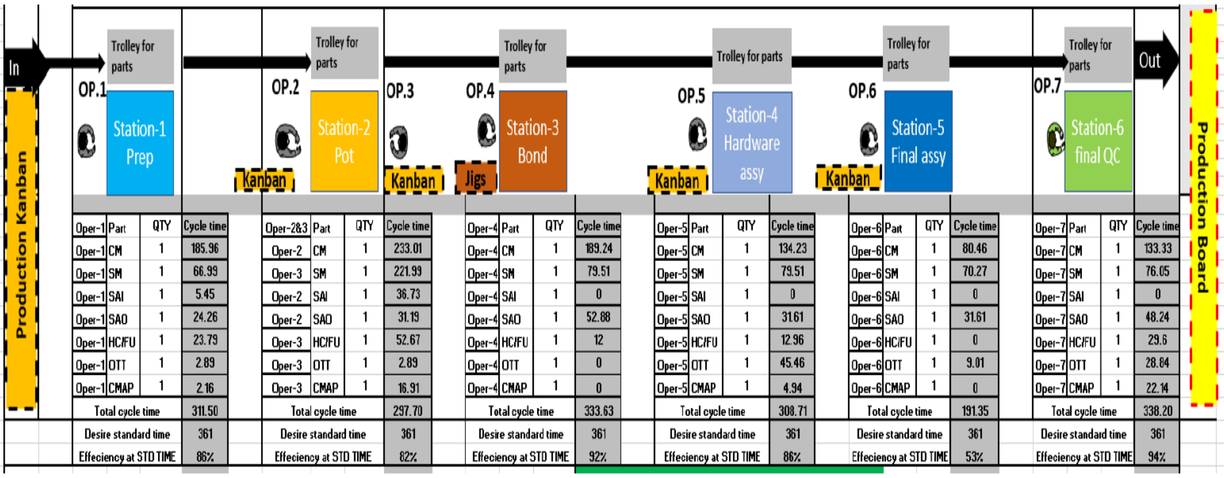

Figure 7. Current layout of assembly process

3.6 Current assembly work load per operator

In a 7-hour shift at 100% efficiency, the operators are supposed to work 420 minutes. However, at current plant efficiency of 85.6% , The current available time in a shift for assembly operation is

Plant availability = Total shift duration x efficiency = 420 x 85.6 = 361 minutes.

A study of the current assembly process showed the following operating loading Figure 8:

Operator	Available time per 7 hour shift (mins)	Operator Loading (mins)	% operator utilisation	Operator idle time	% idle time
1	361	285	78.9	76	21.1
2	361	193	53.4	168	56.6
3	361	450	124.6	-89	-24.6
4	361	255	70.6	106	39.4
5	361	294	81.4	67	28.6
6	361	110	30.4	251	69.6
7	361	158	43.7	203	56.3

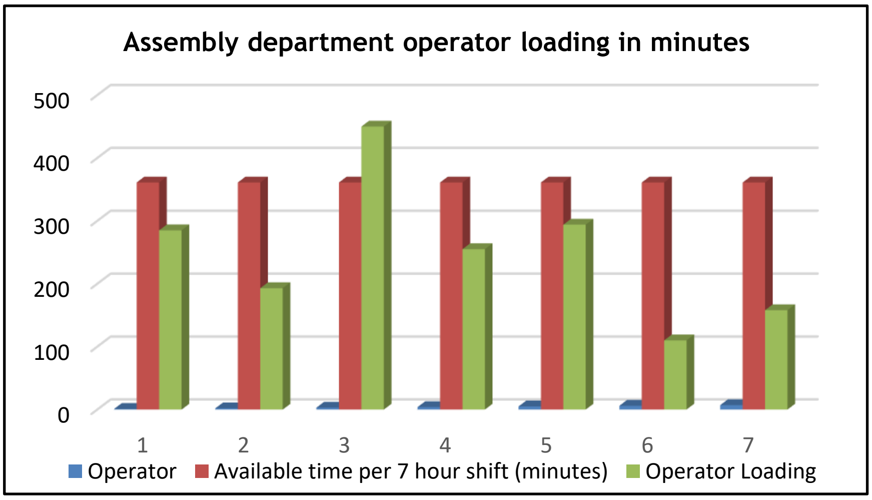

Figure 8. Current operator loading

For example: Figure 9 below illustrates the imbalance between the work stations and the idle time illustrates the waste in the form of waiting. Operators 4 to 7 have to wait for Operator 3 and Operators 1 and 2 build up stock for Operator 3

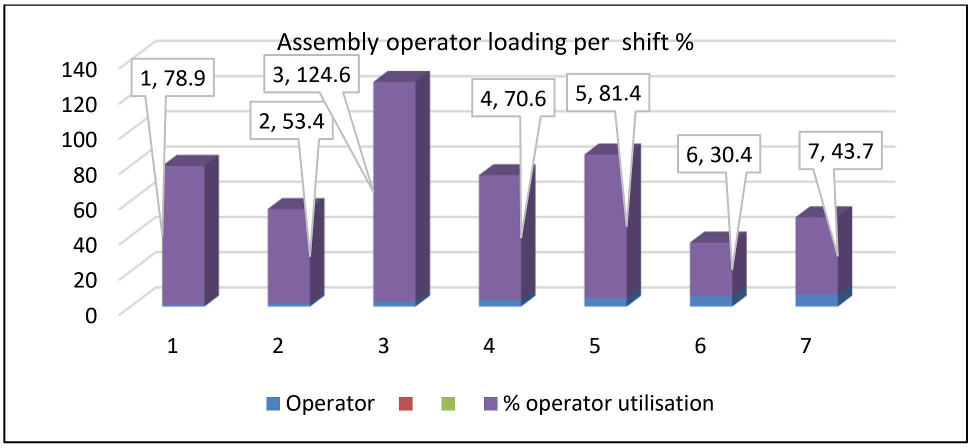

Figure 9. Current operator loading

4 DISCUSSION

There are several observation in the study of ABC Composites, which typical classify it as a traditional manufacturing facility and business. These are discussed as follows.

Poor or no communication of production targets and productivity benchmarks to the shop flow staff. This hampers autonomous planning of activities and the operators taking ownership of their daily activities and tasks. One of the principles of lean aims to first enable the processes run smoothly through exchanges of information and deployment of efficient processes [4]. Disruption in the processes lead to waste [1] in the form of idle machinery and operators and hampering the pursuit of perfection of the manufacturing and support activities [2]. In practice, lean manufacturing focuses on overcoming 3M's Muda (waste), Mura (inconsistency) and Muri (unreasonableness) [3]. Communication and documentation in a user friendly format can assist in generation storage and transmission of production information.

Operators on the shop floor are spending considerable time waiting for moulds to ebe allocated to jobs, instructions from engineers and accessories. From the viewpoint of of the 5's principles Seiri (sort, necessary items), Seiton (set-in-order, efficient placement) [3], the shop flow has challenges with storage and retrieval of equipment, tools and planning of production tasks. A rigours implementation of a 5's programme aimed to create order, improve visibility, storage, location and retrieval of materials, tools and accessories [3] would greatly allow operators to spend time efficiently on making the product. Initially it can be implemented in the framework of the current facility design and layout. However, if there is a need a comprehensive facility redesign project can be undertaken. Thus, 5 S's principles emphasize efficient facility design and workspace management as an enabler of waste reduction.

Operator and work station inconsistency is also a problem in achieving a lean process [4]. Operators need to be involved in the decision making process. Current production problems within their workstations must be exposed by discussing with operators and must be viewed as opportunities to learn by both operators, supervisors and engineers. A non blaming paradym should be adopted and emphasis put on problem solving and process improvement [1][2][3]. This can be achieved by developing standardised processes and procedures and procedures. Principles of Shinjika and SMED in machine set up, operations and die design to improve production efficiency.

Using the Shojinka principle continually optimising the number of workers in a work centre to meet the type and volume of demand imposed on the work centre can be achieved [2]. Workers can be trained in multiple disciplines. More flexible work centre layout, such as U- shaped or circular, that supports a variable number of workers performing the tasks in the layout and have the capability to vary the manufacturing process as appropriate to fit the demand profile can also be implemented [1][2]. Training workers in understanding the product and how its made can also assist develop them into product and process design and development teams for current and future products. This will also allow for redeployment of operators to other roles in times where there is low or no work on their workstations.

SMED is a process that begins with detailing what happens to a machine between batches of parts [5]. Broadly, it was extended to cover the ability to perform any setup activity in reduced times or less of machine or process downtime in manufacturing [5]. Working with die suppliers the engineers can repurpose existing dies to reduce set up time by simplifying and reducing set up procedures. Longer production runs by changing production lot sizing can also be implemented in product lines where there is possibility of making-to-stock if stock holding costing wont offset set up savings.

4.1 Balancing and timing production

Between assembly operation 2 and 3 there is a bottleneck and accumulation of work in progress on operator 3’s workstation. Thus, the assembly line is not balanced. In order to implement a Pull-based production control systems and to balance activities. These systems however only work on flow systems so it is important that part families be created so that the product in a manufacturing facility moves in a common direction. Kanban and JIT are also based on several other system requirements [1][2]. The following principles can be applied: ensuring stability of preceding process, levelled production, meeting Takt time and production requirement, maintaining good quality and team member education and training [2].

$$Tk = \frac{\text{Available Operating time (sec/day)}}{\text{Daily Demand (pieces/day)}}$$

The takt time must always be greater than one in order to meet demand with no backlogs. Cycle time is a measure of how much time it takes for a particular operation, which is also expressed in similar units (time/piece) [1]. The cycle time for all workstations must be balanced.

4.2 Work flow planning and redesign of layout to improve movement

The study of the processes at ABC and their products showed that there were several problems in the production line and work procedures.

- The impact of wrongly defining moulds requirements resulted in several line stoppages. During the investigation it was discovered that this sub-problem was valid and action was taken.
- The impact of wrongly defining machine loadings resulted in parts that queued for too long. During the investigation it was discovered that this sub-problem was valid and action was taken.
- The impact of wrongly defining the work in process (WIP) influences the lead times negatively. During the investigation it was discovered that this sub-problem was valid and action was taken.
- The impact of poor monitoring first in first out (FIFO) system resulted to several line stoppages, where the next process had to wait for a certain part

based on specific works order. During the investigation is was discovered that this sub-problem was valid and action was taken.

- What factors influence productivity? Poor standard time and insufficient tools were found to be the main contributing factors.
- What could be the reasons as to why time studies were not taken seriously by the firm? Senior team insisted that their time are correct and must be used.
- Production flow or work sequence is clear to the supervisors and operators. Only at moulding and kit cut
- The place lacked with 5s. Improvement of utilisation was also realised from implementation of 5's techniques to improve location of tools and accessories and flow of production instructions from engineers supervisors and operators to minimise work stoppages.
- Supervision at the moulding and kit cutting areas is improved, with leadership taking ownership and responsibility for the line (mention the relationship between good supervision and productivity here and also quantify what is meant by "Great" supervision)

4.3 Improvement of layout

Poor layout of the manufacturing process leading to poor product flow. The impact of incorrect takt times and cycle times for determining the right number of operators in each cell for the purpose of line balance resulted in failure to meet the daily target in production line. During the investigation, it was discovered that this sub-problem was valid and action was taken.

Current layout has 7 stations, the proposed layout recommends 6 work stations. Current layout has 7 operators and is shown on Figure 6. Figure 9, shows a proposed new layout. The current layout assigned two operators for the preparing station; the proposed layout recommends one operator for the preparing station because the station cycle time is below standard time and proposes two operators for the bonding station because the bonding cycle time is above standard time.

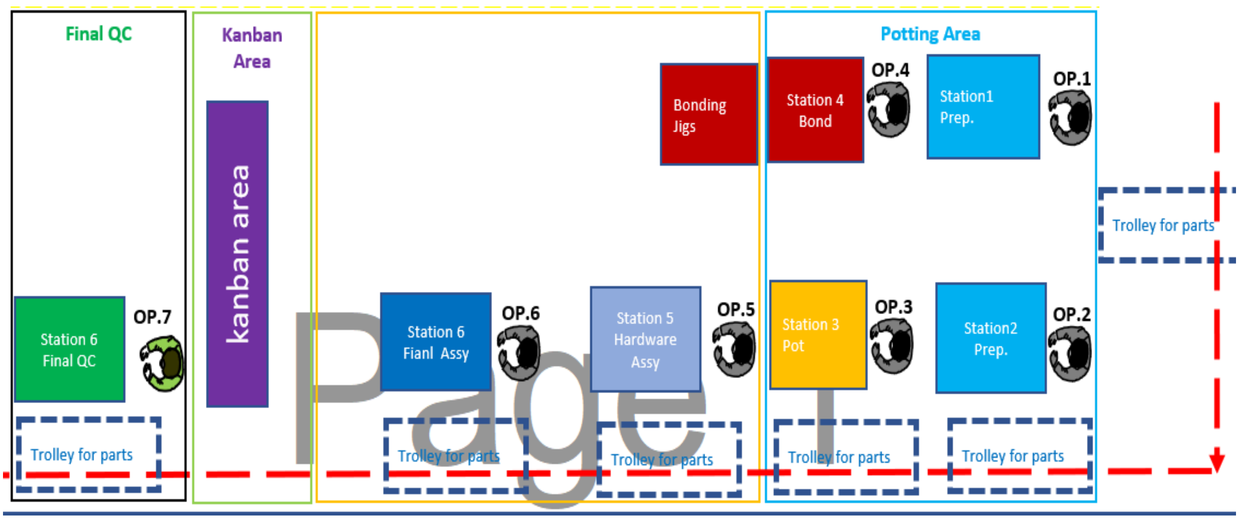

Figure 8. Proposed new layout

The new labour utilisation and efficiency for the operators is shown below in Figure 9.

Operator loading	Available time	New operator loading	% loading
1	361	311.94	86
2	361	300.93	82
3	361	293.56	92
4	361	334.52	86
5	361	308.72	53
6	361	191.34	94
7	361	338.19	93.7

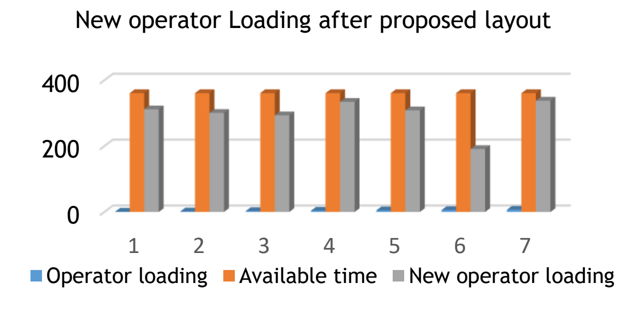

Figure 9. New labour utilisation and efficiency

Station 1 is loaded at 86% at standard time; hence, the station is loaded 14% below from the standard time. Station 2 is loaded at 82% at standard time; hence, the station is loaded 18% below from the standard time. Station 3 is loaded at 92% at standard time; hence, the station is loaded 8% below from the standard time. Station 4 is loaded at 86% at standard time; hence, the station is loaded 14% below from the standard time. Station 5 is loaded at 53% at standard time; hence, the station is loaded 47% below from the standard time. Station six is loaded at 94% at standard time, hence the station is loaded 6% below from the standard time.

Operator 1 is expected to work 361 minutes on a shift but loaded 311.94 minutes and idles 49.06 minutes on a shift. Operator two is expected to work 361 minutes on a shift but loaded 300.93minutes and idles 60.07 minutes on a shift. Operator three is expected to work 361 minutes on a shift but loaded 293.56 minutes and idles 67,44. Operator 4 is expected to work 361 minutes on a shift but loaded 334.52 minutes and idles 26.4 minutes on a shift. Operator five is expected to work 361 minutes on a shift but loaded 308.72 minutes and idles 52.28 minutes on a shift. Operator six is expected to work 361 minutes on a shift but loaded 191.34 minutes and idles 169.7 minutes on a shift. Operator seven is expected to work 361 minutes on a shift but loaded 338.19 minutes and idles 22.8 minutes on a shift.The new operator loading is shown in Figure 9.

5. RECOMMENDATIONS

Management should strive to raise the level of productivity and job performance by ensuring that their employees are adequately equipped with skills and that they provided with adequate resources;

- Management must consult the employees during the implementation of an efficiency and productivity reporting system. They must at all times get the buy-in from employees in order to ensure its effective functioning. The majority of employees possess untapped talent, innovation, creativity and the potential to perform to their best if given an opportunity.
- Realistic and achievable standard times must be set for all processes and these must be communicated to the employees. Furthermore these standards must be reviewed on a regular basis.
- Efficiencies must be measured on an hourly basis
- It is recommended that manufacturing organizations utilize efficiency reporting systems andadapt it to their specific needs
- It is more import to test run the line from the beginning of the project than late.
- It is important to verify plan manpower versus actual.
- It is recommended that senior management adopts change and give young stars opportunity to implement things under their guidance
- 5s is a fundamental tool of lean and needs to be implemented if the organistation wants to maintain order, organisation and ensure sustainable continuous improvement.These tools need to be introduced and embraced, starting from management and cascading the way down to the shop floor

6.0 CONCLUSION

The study aimed to identify an area within the case study company where lean concepts can be applied to improve processes, facility and operator utilisation. This involved establishing correct takt times and cycle times for getting the right number of operators in each cell, for the purpose of line balancing and to enable production to meet the daily target. The study aimed to improve production flow and propose optimal work sequences. The proposed new layout improved the flow, as it now facilitates a one-piece flow. The study introduced and effectively proposed areas where the company could implement relevant lean tools to improve transportation, visbility and order to simplify operator tasks with significant benefits such as increased productivity and balanced workload. More efficiency will lead to cost savings, competitivity in terms of lead times and product pricing.

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TOTAL PRODUCTIVE MAINTENANCE BASED ON EMPLOYEES' PERSPECTIVE: A CASE STUDY FOR ESKOM

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ABSTRACT

Total productive maintenance is supreme for organizations striving to remain competitive, sustainable, and improve productivity. Maintenance of infrastructures in any corporate establishment is subject to limitations in employees' perspectives. Contributing factors include financial constraints, education, resource constraints, technologies, training, and most importantly the cost of replacing infrastructure. The inabilities to deal with these and other limitations have resulted in significant constraints on the fossil power generating plants. This paper extensively investigates protocols relating to employees' perspectives suitable for effective implementations resulting in sustainable total productive maintenance. The Electricity Supply Commission (Eskom) located in the Republic of South Africa (RSA) is investigated to present a case. Eskom has embarked on different design constraints, role-out skills, and systems-based solutions towards ensuring sustainable total productive maintenance. This paper comparatively reviews the total productive maintenance implementations at Eskom and propose feasible sustainable strategies collected from best practice literature to improve current conventional applications.

Keywords: Electricity supply commission, Employee perspectives, Fossil power generating plants, Total maintenance management.

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1 INTRODUCTION

The current scope definition which resulted in a failure to adequately produce and supply electricity. The current state of project execution has turned to be a very tough process to perform due to the wrongly implemented Engineering and Maintenance philosophies. During the execution phase, the challenge further escalates beyond the projects end where products that is left abandoned and un-operational due to the absence of the link between these two philosophies. The definition of these philosophies. An engineering philosophy is application of scientific knowledge into the practical purpose through designs and experiments [Fig.1]. It calls for engineering research and design as the first process of developing a system. Maintenance Philosophy is high-level means or principle of how maintenance processes need to be carried out in an organisation [Fig.2]. This is translated in a principle framework that gathers the maintenance Policies and Technical systems. The objective is to focus on implementation of strategies, process and philosophies to improve the maintenance [Fig. 2] in power generation station through technical projects. According to Chemuturi [4], a literature establishes corporate sectors consider the implementation of total productive maintenance (TPM) as the obligation of quality sections or departments rather than the entirety of the business units. Electricity industries in South Africa are continually challenged with electricity restriction issues in form of power outages. This paper seeks to enhance the quality and reliability supply of electricity to consumers in South Africa.

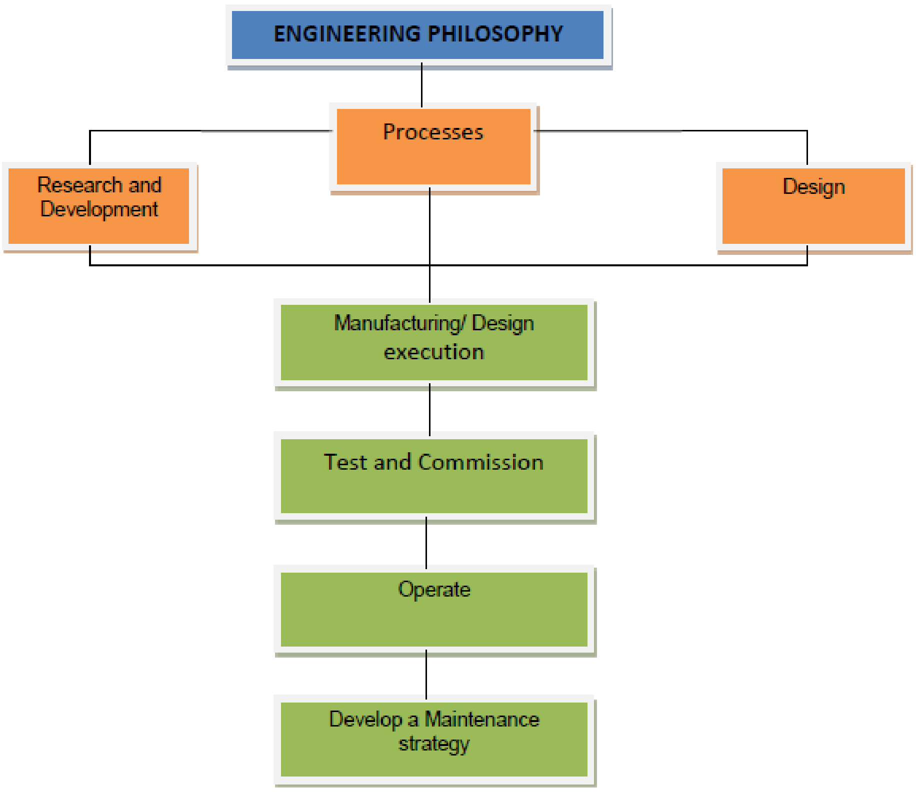

Figure 1: High-level Engineering Philosophy Hierarchy [5]

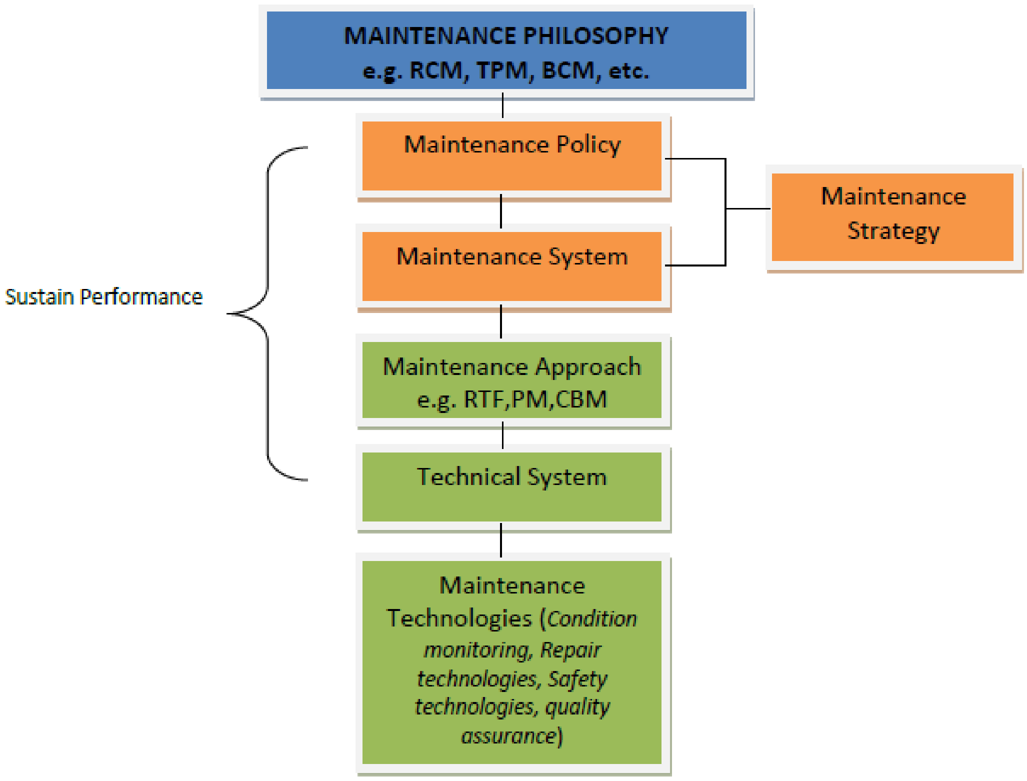

Figure 2: High-level Maintenance Philosophy Hierarchy [5]

2 LITERATURE

Phaala [1] argues that South Africa has experienced electricity restrictions in recent years, presenting a need for urgent best practice Quality Management Systems (QMS) measures. A white paper publication from statistics South Africa establishes the lack of an effective maintenance strategy implemented relative to the power generation and transmission system is a major cause of system downtime resulting in power restrictions. Electricity restrictions refer to shortages in the supply of electricity as compared to demand from consumers. Electricity restrictions describe the temporal shutting down of electricity generation and distribution system in selected discreet zones. This is a result of ineffective load generation maintenance at the power stations. Electricity practitioners in South Africa attribute population and economic growth as some causes of irregular maintenance. Staff Writer [6] public state that Ineffective planning and lack of vision relative to the South Africa energy requirements is attributed as a major reason for low generating capacity, resulting in power restrictions. The maintenance of equipment's history is also vital to ensure that proper decisions taken on equipment/purchasing/plant design is based on history of performance that particular plant area/equipment. The equipment standardisation is based on historical data also enhances plant performance. The spares inventory holding costs can also be minimised due to standardisation in the organisation. Continuous improvement process that strives to optimize production effectiveness by identifying and eliminating equipment and production efficiency losses throughout the production system lifecycle through active team-based participation of employees across all levels of the operational hierarchy. The operational excellence cannot be achieved without operational basics being in place. Therefore, it is also true with the implementation of total production maintenance and the pillars identified to support it [7].

Pandey [8] mention the pillars below:

I. Autonomous Maintenance (operator-based maintenance)
II. Preventative Maintenance (works management)
III. Focused Improvements (reliability basis optimization)
IV. Quality Management
V. Training and Skill Development
VI. Equipment Management
VII. Work Management pillar and its Implementation.
VIII. Health, Safety &Environment

At present, the old Eskom power plants are not achieving performance target, as they should be, and national control center finds it's difficult to balance the system and supply to the citizens and abroad. The only key performance indicator that is set by management has not been achieved. Therefore, there is a need for improving maintenance performance. The effort from Management, Artisans and Utility personnel working together will improve the plant performance. The objective is to identify the change management issues that were not handled properly for future full implementation of total preventative maintenance. Maintenance scheduling of generating units is an important task in a power plant and plays major role in operation and planning of the system. The economic operation of an electric utility system requires the highest degree of plant reliability, maintainability and availability in the face of increased demand in electricity consumption as is the case in South Africa.

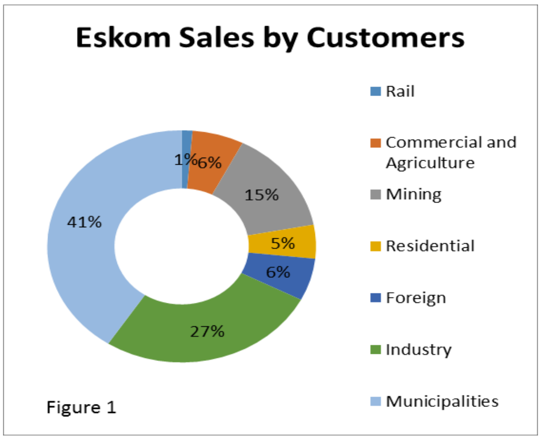

Figure 3: Eskom sales by customers [9]

For Eskom, providing reliable and affordable electricity is not only a commercial undertaking, it underpins the livelihood of South Africans [Fig.3]. The electricity distribution as compared with consumers' demands [2]. To achieve its mandate, conducting a timely and cost-effective maintenance policy is of paramount importance. As system equipment continues to age and gradually deteriorate the probability of service interruption due to component failure increases. To alleviate this expected outcome, maintenance of plant facilities needs to be carried out. Such maintenance involves planned preventive and unplanned actions carried out to retain a system at or restore it to an acceptable operating condition while preventing any deterioration process reaching system breakdown point. Reliability maintenance has been studied at a theoretical level intensively in the past and has kept growing as demand for theory that integrate modern environment and requirement is needed [Fig.4]. Wang and Pham [9] conducted an extensive review of many models for reliability, maintenance, replacement and inspection. The areas of interest that were reviewed are: imperfect maintenance, issue management, correlates failure and repair. However, as they also noted, modern systems have increased in size and complexity (in both hardware and software). As a result, classical statistical methods fail to adequately model large scale system reliability.

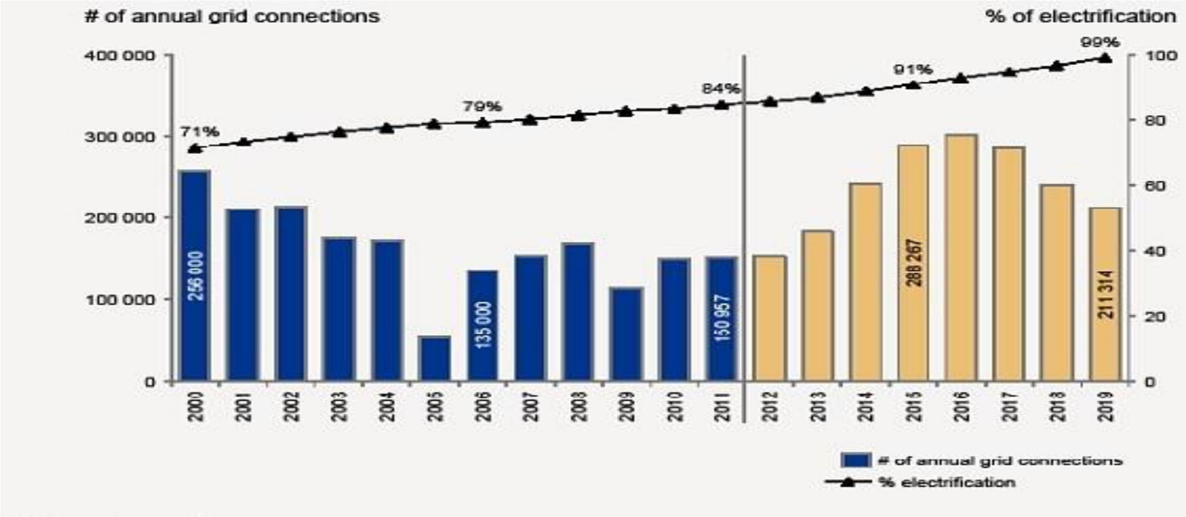

Figure 4: Past and future electrification in South Africa [16]

One of the well-established standard approaches in maintenance that has grown in importance to addressed issues such as technology and computational algorithms is Condition-based maintenance (CBM). Gebraeel, Lawley, Li, Ryan [13] states that a CBM approach is based on observing and collecting information concerning the condition and health of equipment to prevent unexpected failures and determine optimal maintenance schedules. The CBM approach has many advantages for maintenance management. The equipment catastrophic failures can be eliminated. The activities of Maintenance can be scheduled to eliminate or minimize overtime costs. Additionally, inventory can be minimized because equipment or parts will not have to be ordered ahead of time to support anticipated maintenance needs. There are several categories of research efforts done in the area of CBM that strive to increase the accuracy of time to failure prediction, including studies using Markov processes, neural networks, proportional hazard models, and degradation models. CBM utilizes condition monitoring (CM) information to schedule maintenance routines. According to Stephens [14] condition monitoring involves observing some health-related variables throughout a system's lifetime to determine its degree of degradation more accurately than information obtained a priori solely from statistical information. The real-time sensory signals, such as acoustic emissions, temperature, vibration, etc., are collected from a functioning component in order to assess the health of the component. Ghasemi, Yacout, Ouali [15] these sensory signals often exhibit characteristic patterns that are associated with the principal physical transitions that occur during degradation processes. These patterns, known as degradation signals, can be used to capture the current state of components and provide information on how that condition is likely to evolve in the future.

According to the Columbus Stainless article [10] the approach adopted in continuous supply of steel is that engineering and maintenance sections are responsible to protect and improve throughput, with throughput defined as the rate at which the system generates money through sales of prime products.

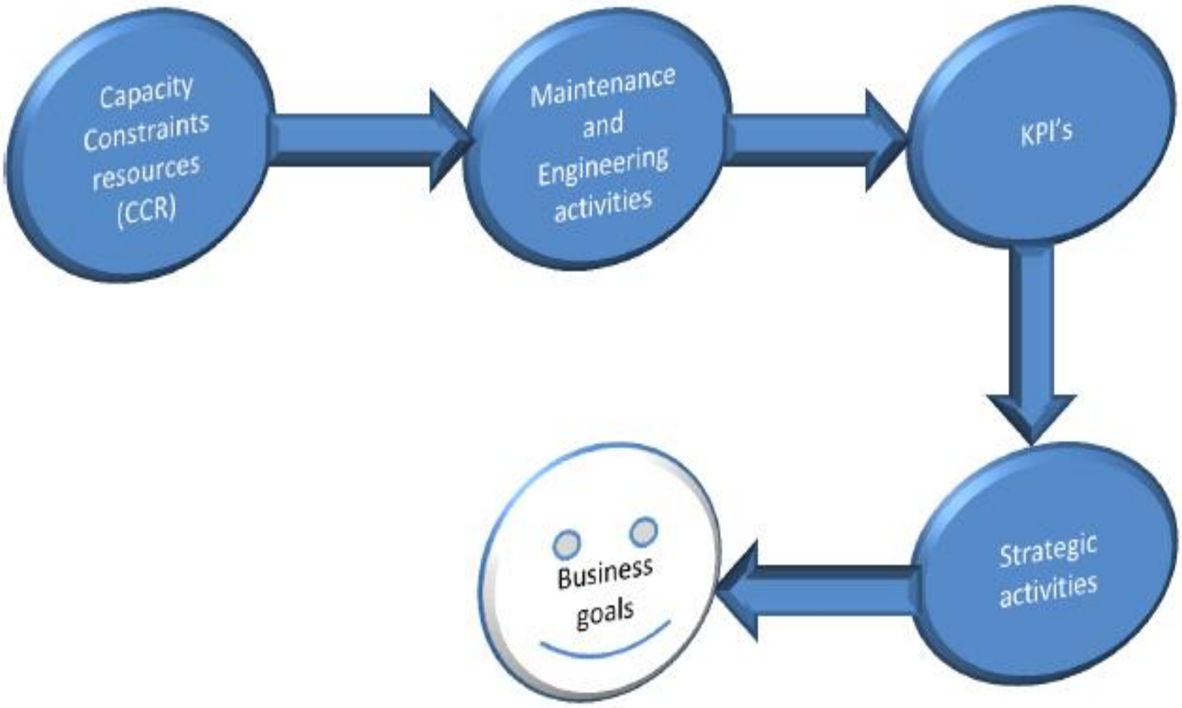

Figure 5: The Columbus stainless steel high-level implementation plan [10]

The [Fig.5] is a key to achieve capacity constraint resources (CCR) that requires a link between CCRs and maintenance activities. This link can only be achieved by implementing a new set of CCR-related key performance indicators indicating maintenance and engineering impact on each CCRs throughput. Designing and implementing these key performance indicators are however fairly complex and it is not a prerequisite for other critical maintenance and engineering actions to be implemented in the short term. These KPIs will govern all maintenance and engineering future strategic actions as it will ensure continuous and sustainable alignment to business goals and priorities at all times. The addition of quality management system can assist corporate activities to focus on reliably satisfying consumers' expectations in terms of electricity supply [3]. The biggest question is why it is critical for the link between these two philosophies to ensure easy project executions. The first objective is to identify the need and bring about expertise to resolve the problems associated with our organisational operations. This is done through a feasibility study where the study gets approved so that the detailed design with specifications gets undertaken. A thought process is then laid down on keeping the final product well sustained and operational. The design specifications concentrate more on product technical aspects with its operation. The project should be executed to address the gap and with an objective of benefits realisation beyond project completion. Part of performance monitoring and continuous improvement, the developed maintenance philosophy needs to be implemented through the product operational lifecycle model [Fig.6] to ensuring that the projects benefits are realised.

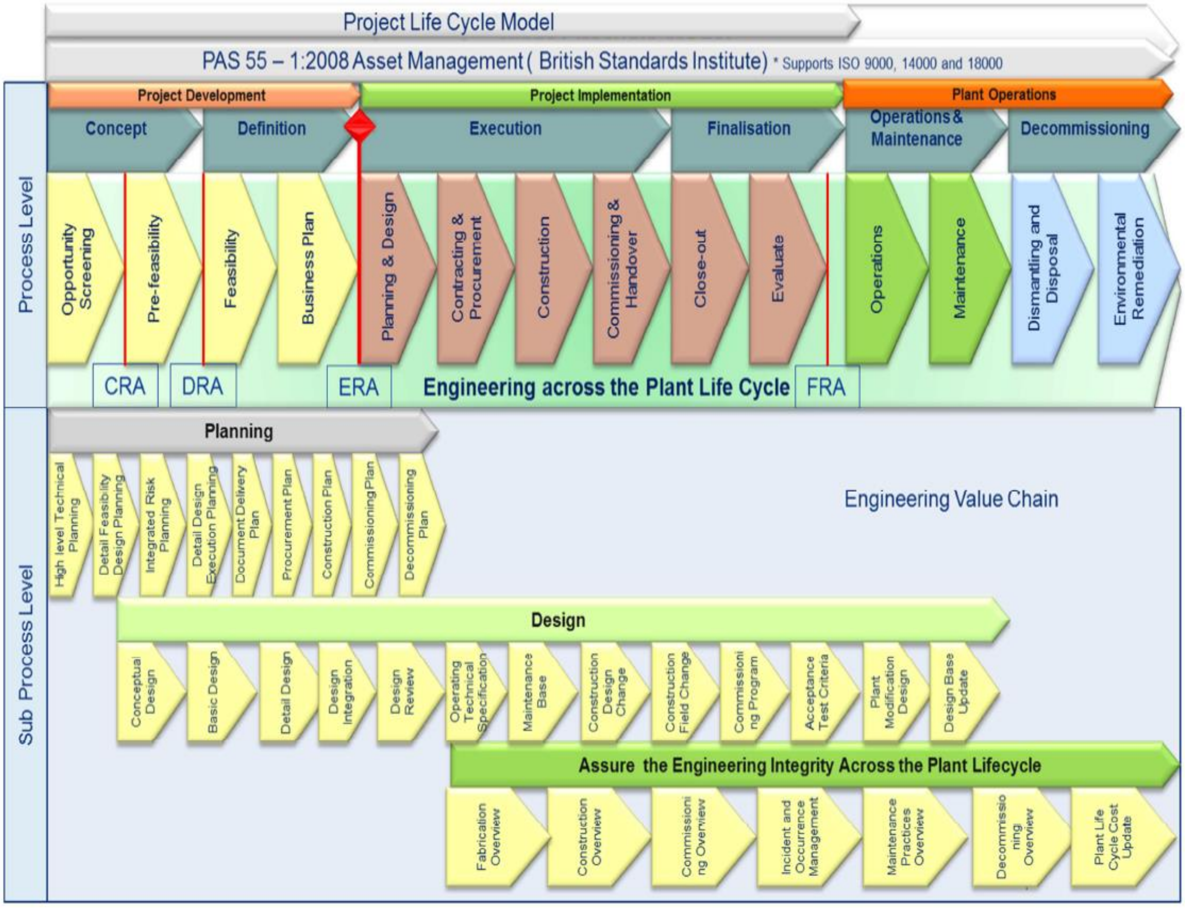

Figure 6: The link between the engineering and maintenance philosophy [11]

3 METHODOLOGY

The research method employed facilitates an effective structure for "Conducting", "Analysing", "Drawing conclusions" and "Presenting recommendations" in this research. A search of literature as a research approach explores documents defining best practice with regards to Total productive maintenance (TPM) benchmarks in electricity industries, in relation to a strategic defined business plan. This was considered as a point of reference and guide to initiate this research. Observations and interview as a research approach involve a detailed review of data showing some general patterns useful for general considerations with respect to maintainability of generating units and power plants. However, in order to apply in the future quantitatively the novel methods developed in the previous studies. The collection of data on times to failure and repair for the main parts of generating units. This data reflect 'real' times to failures not affected by external events such as "wet coal", for instance. The times to repair or maintenance is divided into two groups: the one that reflects the essential time for performing the required operations and the one due to delays, non-effective execution of tasks, etc. Decreasing the latter will create the possibility for improving availability/maintainability of generating units and power plants nationwide. The processes included quality policies, organization organogram, corporate objectives and training programs. Interviews as a research approach aimed at establishing the understanding of the respondents in relation to the questionnaire constructs. This was executed via emails and telephone communications. The quantitative survey questionnaire from the Maintenance department and from Engineering department was taken to measure the employees' perception of TPM and implementation of works management at Power Station. During the empirical study, the respondents were asked to indicate their level of agreement or disagreement with the TPM pillar of work management implemented. The questionnaires sought to collect data on the various questionnaire constructs. This presented a framework for identifying and addressing current limitations and recommending measures towards developing an effective integrated TPM. The reliability of the data collected is tested based on alpha principles, while triangulation approach is employed to test for the research's validity [12]. These are best practice reliability and validity testing approaches. The two sections where interviews and open questionnaires were conducted were engineering and maintenance employees. The Engineering section, which has system engineers, planners, technologist & supervisors and Maintenance section, which has artisans, utility men, technicians & coordinators. The ultimate milestone to achieve at the power station was to measure the positions and views of different sections concerning the implementation of total productive maintenance. The assignment subsequently was to identify the discrepancies in thinking that exist among the different sections in the plant areas and once identified, to define the statistical importance of these differences. It contributed to explaining the validity of the instrument used in the factor analysis. The data were also analysed using SPSS version 22.

4 RESULTS

The research results affirmed TPM as an essential tool in streamlining the business operations of a business unit because of the 85% response indicated that the is a general lack in maintenance in power stations [Fig 7]. The failures between environmental and mechanical realise that the main causes unit shut down failures are mainly of mechanical nature [Table 1, 2].

Table 1: Energy loses over years

Station Name	Date	Major Breakdowns	Megawatt loss	Frequency/month
Duvha Power Station	2015	Ingress air	100	1
	2016	Unit tripped	80	3
	2017	Compressor faul	100	4
	2018	Generator H2 leak	350	8
	2019	Tube leaks, Bunker failure	250	2

Table 2: Causes of Megawatt losses

1	TUBE LEAK 92ML REHEATER L.H.SIDE.	16	INTERIM REPAIRS.
2	OUTAGE ON AUX-COOLING NORTH.	17	Unplanned Slip
3	UNIT TRIPED	18	Trip during IR - Trip is part of a long term planned outage
4	EVAPORATOR WALL TEMP HIGH	19	Unplanned outage slip
5	EVAPORATOR SCREW WALL METAL TEMP HIGH.	20	Reverse Power Trip - Part of long term planned outage .
6	PLANNED MAINTENANCE	21	OVERSPEED TEST.
7	TO CHANGE FAULTY MODULE ON EHF SYSTEM.	22	Islanding test
8	ACTIVE COMP FAULT.	23	Trip on LP Turbine vibrations high
9	TUBE LEAK.	24	OFF FOR TUBE LEAK REPAIRS.
10	E MILL BUNKER STRUCTURE FAILURE.	25	TUBE LEAK 92M L,H,REAR RE-HEATER 2.
11	NEW REPLACEMENT AND SETTING OF PRESS BUTTON ON TURBINE.	26	TRIPPED.
12	TUBE LEAK	27	TUBE LEAK.
13	ACTIVE COMP FAULT	28	ACTIVE COMP FAULT.
14	TUBE LEAK,	29	TUBE LEAK - RH1 92M left rear
15	REPAIR GENERATOR H2 LEAK.	30	TUBE LEAK,REHEATER NR1.

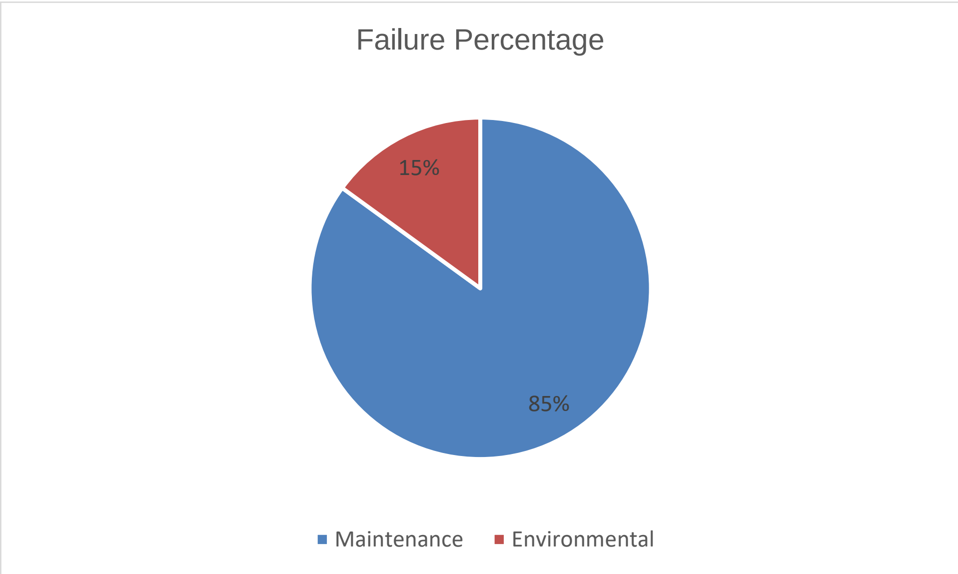

Figure 7: Failure percentage

This result is further illustrated in the histograms below. Furthermore, it appears that distribution to the Environmental Failures is not feasible. We will thus carry with finding a probability distribution only for the Mechanical Failures

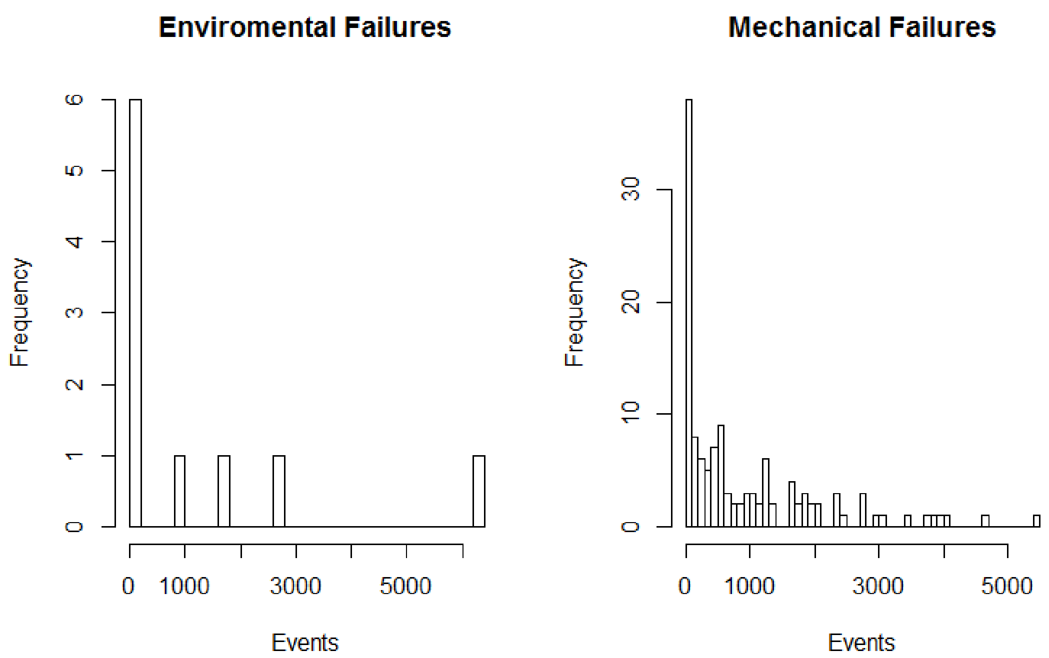

Figure 8: Environmental and Mechanical Failures

About 50 percentile interviewees had a concern on the integration and implement of philosophies with maintenance and engineering. A poor integration will add in poor project execution. A no link and lack in communication protocol will also add more stress to the customers as they demonstrate their dissatisfaction because of load shedding. The employees agrees that the skill shortage adds to more confusion as a side effect and as a result, it adds to poor implementation of the Engineering and Maintenance philosophy. Four fundamental solutions were introduced to mitigate the current or “as is” situation which is training, steering committee, performance monitoring and research. Having realised the skill shortage from our engineers, the training sections was assigned to address the competence gap. The high performance culture is always monitored by our Performance monitoring team to ensure or add on high availability of our plants. The newly established steering committee will ensure discipline and good practice to supersede customer satisfaction and reduce customers stress (load shedding). The above fundamental solutions avoid confusion and improve good implementation of the philosophies.

5 RECOMMENDATIONS

The focus of key performance indicators (KPI’s) is on the short-term successes linking respective sections both Engineering and Maintenance. The KPI’s of Engineering section objectives and accountabilities especially in terms of long-term Plant wellbeing is critical for long-term achievement and it is something that Eskom requires to give devotion to. The exceptional operational capability of Japanese companies e.g. Toyota is adequate evidence that TPM is important for operations success in the workplace. The successful implementation of TPM will improve cost savings at all ranks of operations are mitigated and manage efficiently. The TPM ought to be implemented without prolong it further, in discussion and participation with workforces, as the studies indicated. Employee’s engagement is important because TPM encompasses a culture change within any organisation. The approach is to implement in phases to safeguard that everyday operations are not affected. The organization should implement a complete quality management system that integrates and interlink all divisions. The Maintenance creativity of re-work strategies and measurement must be encourage to be implemented and be included in the quality management system. The nonattendance of quality management within the structures in power stations need to be addressed by management. One power station division within the structure should be responsible to safeguard that quality processes are adhered throughout. Sections within Power Station should be discouraged from working in isolations and closer relationship between sections will ensure operational success. The orientation in goals between section managers will facilitate employee relations between sections improving thus leading to effective implementation of Total Productive Maintenance. The senior manager of the power station should safeguard that intra-company politics within his staff of managers should not hinder or interfere with their main duties, of achieving operational milestones.

6 CONCLUSION

The critical and essential role that effective management and maintenance plays within power stations in ensuring availability of the plant generating and supply of electricity because of the high capital investment the power stations has made in procuring in building the assets. The problems and bottlenecks within operations processes were identified and the recommendation provided in the literature study, and are suggested out for management to implement for effective strategies and operations. The research survey in the form of interview and questionnaire was used to understand the severe impact of maintenance work management to efficient operations at Power Plant and also an understanding of possible implementation of TPM at Power Stations. The evaluation of the preparedness of the Power Station to launch TPM in order to enhance integration with other sections to lead to continued operations success at Eskom Power Stations was completed. The process and culture of continuous improvement was commenced during the study, and the determinations of management will be to instil a cultural change in power station to lead to long-term operational excellence. The empirical study results demonstration not only the problems in the implementation of work management but also present the room for improvements for further implementation of TPM at Power Stations.

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CATEGORISING SOUTH AFRICAN LEAN IMPLEMENTATION FRAMEWORKS: A SYSTEMATIC LITERATURE REVIEW

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ABSTRACT

Although Lean has become a global phenomenon, only about 10% of Lean implementations ventures are successful. Ergo, multiple researchers have designed and created specific Lean implementation frameworks, however there is a level of uncertainty regarding which frameworks exist for which application. Therefore, this research aimed to investigate studies on South African Lean implementation frameworks, by conducting a systematic review on applicable literature. It provides a fulsome synthesis and categorization of available Lean implementation frameworks. Furthermore, it was found that there are various types of frameworks, each with a specific target audience. However, it also highlighted the gaps in current research, such as a lack of culture specific frameworks in South Africa. This systematic literature review could support researchers and practitioners in understanding and selecting the Lean implementation framework that would best suit their needs.

Keywords: Lean, Implementation frameworks, South Africa, Systematic Literature Review

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1 INTRODUCTION

The Lean philosophy, developed in Japan during the 1930s [1], is a business management philosophy that is used to eradicate wastes and increase profits. Since then it has gained global recognition due to its organisational benefits (i.e. continuous improvements). Although Lean has become a global phenomenon, only about 10% of Lean implementations ventures are successful [2, 3].

Authors [4, 5, 6, 7, 8, 9, 10, 11, 12] have explained that Lean is a cultural change across an organisation, as it necessitates commitment from all levels within an organisation. They have also noted that Lean implementation differs in companies and/or industries, because the companies and industries are unique in structures and standards. Due to this, they explain that Lean requires some degree of customisation, as opposed to just utilising it as a simple toolbox.

Thus, there has always been a need for creating different implementation frameworks, that customise Lean implementations to certain aspects, such as different industries or knowledge areas. However, considering that there are several implementation frameworks available, a level of uncertainty exists regarding which frameworks should be used for which application.

Based on this background, this research paper intends to explore the available Lean implementation frameworks available in the South African context, in order to allow for the categorisation of them in terms of their application.

For purposes of this paper, a Lean implementation framework will be considered as a structured outline or figure, that is used to present actions and tasks that need to be implemented for Lean. Furthermore, it will contain some direction or incrementation of steps that must be followed at different stages or levels. Lean implementation models will not be included in the study since these models usually include optimisation models, which are more mathematical in nature and outside the scope of this study. Additionally, this study will not include Lean implementation roadmaps, as these are strategic tools for a specific project (which are not often reused). On the other hand, frameworks will be the focus, as these usually include practical steps for implementation on an organisational level.

2 RESEARCH METHOD

In order to achieve the aim, a systematic literature review (SLR) was conducted on applicable literature. It took the form of a scoping SLR, with a view to explore the scopes of various studies and the purpose of the designed frameworks within each study [13]. The SLR method utilised in this study was based on the proposed method by Albliwi et. al. [14].The sequence and grouping of the steps into research phases are illustrated in figure 1, while the detail of each step is as follows:

- **Step 1: Develop a research purpose and/or objective** – Clearly state the goal of the SLR
- **Step 2: Develop research protocol** – Create a research protocol that includes the purpose, inclusion criteria, exclusion criteria, databases, keywords and quality assessment criteria
- **Step 3: Establish relevance criteria** – State the reasoning for if a resource is relevant to this study
- **Step 4**: **Search and retrieve the literature** – Conduct searches on applicable scientific databases to find literature
- **Step 5**: **Selection of studies** – Use the inclusion and exclusion criteria to select studies
- **Step 6**: **Quality assessment for relevant studies** – Assess the quality of each paper

- **Step 7: Data extraction** – Extract relevant information from the papers
- **Step 8**: **Analysis and synthesis of findings** – Analyse and synthesise the data from the papers in order to find themes and patterns
- **Step 9**: **Report** – Report the review in detailed results
- **Step 10: Dissemination** – Publish the SLR

The outcomes of step 1- 6 are discussed in the sub-sections to follow, while the findings of the study (step 7 & 8) are documented in section 3. Steps 9 and 10 are addressed by publishing this research paper.

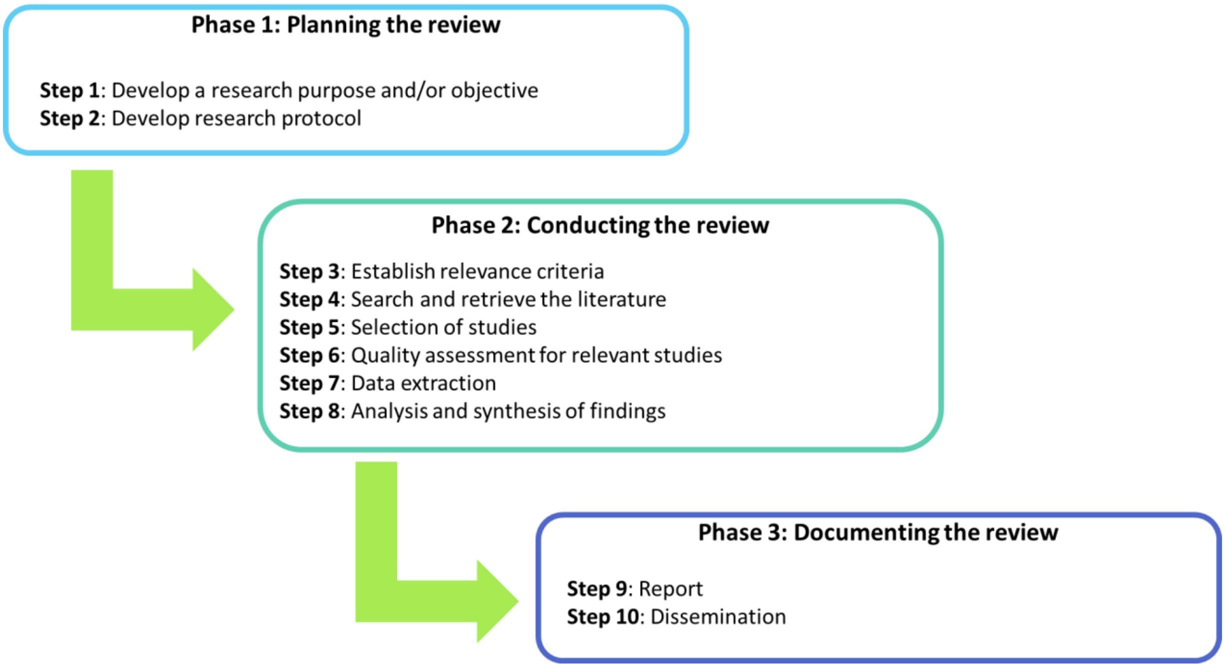

Figure 1 : Research method and phasess (Adapted from [14])

The SLR was conducted from February 2020 to June 2020 on the selected databases using the predetermined keywords.

2.1 Step 1: Develop a research purpose and/or objective

The purpose and objective of this research was to investigate the available South African Lean implementation frameworks, in order to allow for the categorisation of said frameworks, according to their purpose or intended application.

2.2 Step 2: Develop research protocol

The research protocol that was developed is captured in table 1. This included the purpose of conducting the study, as to keep the end goal in mind. It also encompassed the inclusion and exclusion criteria, in order to remove researcher bias and increase repeatability of the study. The databases that were selected for this study were based on their incorporation of Industrial engineering themed literature. Key words and quality assessment are included in the research protocol to provide guidance on what to search for and how to assess its quality. Furthermore, the research protocol was validated by a fellow researcher, by means of iterative discussions and deliberations.

Table 1: Research review protocol (Structure adapted from [13])

Purpose of the study	To investigate the available literature on South African Lean implementation frameworks and classification or categorisation them
Inclusion Criteria	• Literature that contains "Lean", "Framework" and "Implementation" in the title, abstract or keywords • Literature based in South Africa
Exclusion Criteria	• Literature referring to weight-loss/obesity • Non-English literature • Literature based in other countries (not SA) • Lean Six Sigma studies
Search Databases	• Science Direct • Scopus • IEEE Explore • Web of Science • EBSCOhost (Academic search premier, Business source premier, E-journals, MasterFILE premier) • Emerald Insight Journals • Google Scholar
Keywords	"Lean" AND "implementation framework" AND "South Africa"
Quality assessment criteria	• All duplicate literature must be removed • Recovered literature was checked for relevance • Evaluate based on their correct understanding and interpretation of Lean

2.3 Step 3: Establish relevance criteria

When establishing the relevance criteria, it was important to be specific, yet leave room for as many studies to be included as possible [13, 14]. Therefore, the following relevance criteria was developed by which studies were included:

- Literature that contained "Lean", "Framework" and "Implementation" in the title, keywords or abstract of the study
- Studies and frameworks that are based in or created for South Africa
- Creates and discusses a new framework for Lean implementation

2.4 Step 4: Search and retrieve the literature

The search and retrieving of the literature was initially done by using the databases stated in section 2.2. This yielded 1425 studies, of which 9 met the inclusion criteria. The huge yield was due to databases producing Lean articles that referred to other Lean frameworks (not included in their studies itself) and some frameworks that were not based in South Africa, but mentioned "South Africa" in their paper.

However, after the initial search, it was revealed that some duplicates existed in the 9 selected studies. Ergo, there was a need to conduct a secondary search on different databases.

The secondary search was conducted on the repository websites of universities in South Africa that have Industrial Engineering programs. These repositories include each university's PhD thesis, Masters dissertations, final year projects reports and other major reports. While it is unorthodox to use repositories for an SLR, it was select for the secondary searchers due to it richness in data. This yielded 11 229, of which only 7 additional studies were found that met the inclusion criteria. The large number of papers yielded during the secondary search (11 229) was attributed to the fact that the search function of many repository websites include all studies that contain the search terms (anywhere in the full text), and not just those that have the search terms in their titles or abstracts. The search and retrieval process that was followed, is documented in the "Identification" section of figure 2.

2.5 Step 5: Selection of studies

Once all studies were screened based on step 1's protocol, 16 studies were selected (9 from the initial search and 7 from the secondary search). Again, these studies were evaluated, in order to remove all duplicates, resulting in 8 studies being eligible for inclusion. The outcome of the selection process is captured in the "Screening" and "Eligibility" sections of figure 2, illustrating both the initial and secondary search results per database.

After selecting the studies, information of each study was captured, such as the names of authors, title of studies and year of publication (table 2).

2.6 Step 6: Quality assessment for relevant studies

After all duplicates were removed, the quality of the studies were assessed by reading the full texts. Papers were assessed based on their correct understanding and interpretation of Lean. It was found that all 8 papers were acceptable for inclusion.

Step 4 through to 6 of the selection process, as discussed in section 2.4 – 2.6, is captured in figure 2. It illustrates the different phases of the search at the left of the figure, as well as differentiates between the amount of studies found and selected from each database.

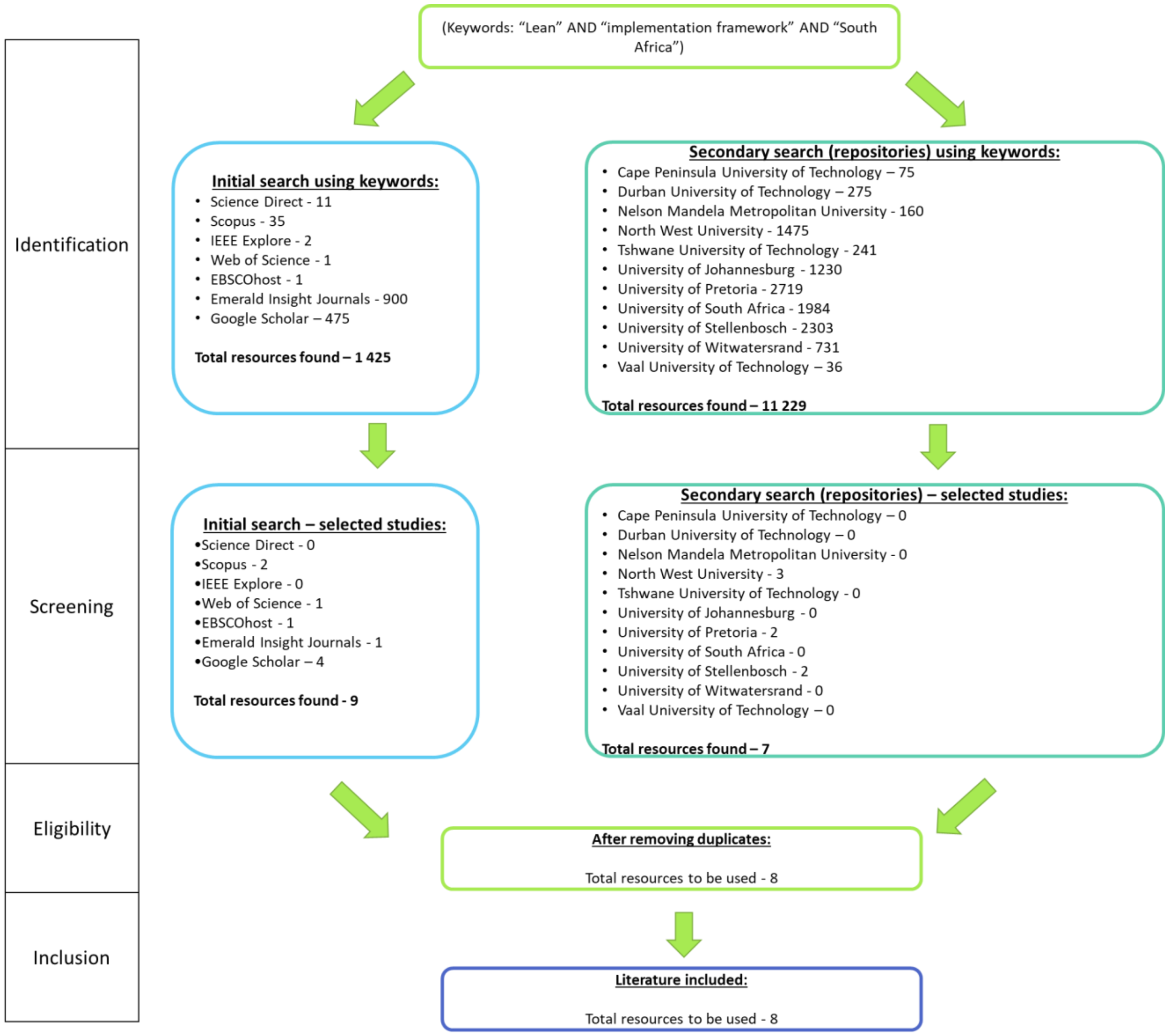

Figure 2: Selection process chart

3 FINDINGS

The findings (step 7 and 8) from following the aforementioned SLR methodology are discussed in the following sub-sections.

3.1 Step 7: Data extraction

Upon finalising the list of studies to be included and studying their full texts, a summary was developed explaining the Lean frameworks that were created in each study (Table 2). The summaries included (1) the knowledge areas that the implementation frameworks were created for, (2) a summary of elements (e.g. objects or tools), (3) the framework structure (e.g. cyclical or linear), (4) the research disciple the work was published in and (5) the type of study (Masters or Doctoral). Table 2 captures this information together with the author(s) details, year of publication and study title.

Table 2: Data extracted from applicable literature

#	Author(s)	Year	Research Title	Knowledge Area	Summary of elements	Framework structure	Discipline	Study type	Ref
1	I Maradzano, RA Dondofema & S Matope	2019	Application of lean principles in the South African construction industry	Construction	Lean implementation framework for construction. It contains phases, objective and tools for each step of the framework.	Cyclical	Industrial Engineering	Masters	[15]
2	R Coetzee	2019	Development of the Respect for People model for lean implementation in the South African context	Respect for people	Lean implementation framework that incorporates respect for people. It contains phases, value streams, organisational levels, respect for people themes and steps.	Cyclical	Industrial Engineering	PhD	[16]
3	K Sekoto	2019	A lean management framework for orthopedic operating theatres of a level three public hospital, North West Province	Scheduling in health care	Lean implementation framework for scheduling in an orthopedic theatre. It contains stages and objectives.	Cyclical	Business	MBA	[17]
4	E Zeelie	2019	A lean project management framework for additive manufacturing	Additive manufacturing project management	Lean implementation framework for project management in additive manufacturing. It contains knowledge areas and groups for the various stages of project planning.	Cyclical	Engineering management	Masters	[18]
5	JM de Villiers	2018	A Framework for Implementing Lean Practices and Tools to support ISO 55000 Compliance for Physical Asset Management	ISO 55000 compliance for asset management	Lean implementation framework to support ISO 55000 compliance. It contains Lean tools for ISO standards, in different	Cyclical	Engineering management	Masters	[19]

					aspects of asset management.				
6	TG Tendayi	2013	An Investigation into the Applicability of Lean Thinking in an Operational Maintenance Environment	Maintenance	Lean implementation framework for Lean thinking in maintenance. It contains maintenance criteria, Lean principles and tools.	Cyclical	Science and Engineering	Masters	[20]
7	S Phelta	2016	Building Lean and Agile supply chains for food fast moving consumer goods manufacturers and food retailers in South Africa	Supply chain	Lean implementation framework for integrating Lean and Agile into the supply chain. It contains levels and aspects of theory.	Cyclical	Business	MBA	[21]
8	A Christodoulou	2010	Factors of success for the effective implementation of lean manufacturing projects within the banking sector in South Africa	Banking industry	Lean implementation framework for projects within the banking industry. It contains levels and aspects of theory.	Cyclical	Business	MBA	[22]

3.2 Step 8: Analysis and synthesis of findings

The following sections analyse and discuss the various columns in table 2.

3.2.1 Distribution of studies

While the searches and inclusion of studies were not limited to specific years, the data shows that the earliest publication was in 2010 and the majority of the studies were published later in 2019. This could attest to Lean implementation in South Africa being a relatively new field of study, and it could suggest that the need for Lean implementation frameworks in the South African industry has increased significantly in the last decade. The number breakdown of the publication found per year group are illustrated in figure 3.

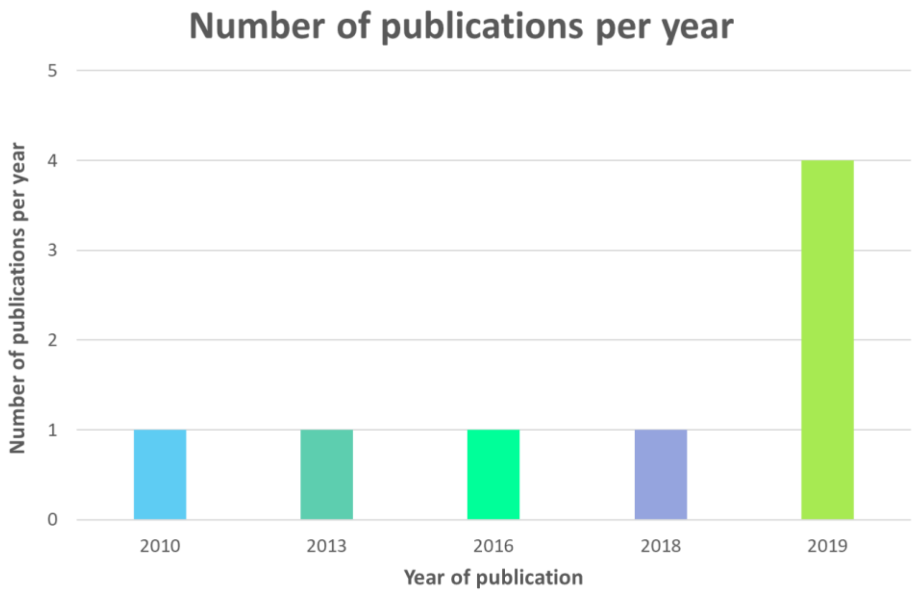

Figure 3: Bar graph of number of publications per year

3.2.2 Framework structure

From the analysis, it could be seen that all frameworks were cyclical in nature. This demonstrates the notion that Lean implementation is achieved through iterative cycles of improvement and adaption, as Lean is viewed as a cultural transformation rather than a simple set of (once-of) tools for improvement. Furthermore, this demonstrates that authors are staying true to the Lean philosophy when designing their frameworks.

3.2.3 Research discipline

This SLR was written as part of an Industrial Engineering study, as Lean is a popular branch in Industrial Engineering. However, it is well known that Lean is not purely an Industrial Engineering field of research, since it is recognised as a business philosophy as well. In a similar vein, the analysis of the selected literature, illustrated that 35.7% of the studies were in the business discipline, while only 25% was exclusively conducted in the industrial engineering discipline. Moreover, 25% of the studies were within the engineering management discipline and 12.5% of the studies was in the science and engineering discipline. The composition of publications per discipline are depicted in figure 4. This is an indication that Lean is mostly researched in the context of business, ergo highlighting the opportunity to explore it from the industrial engineering perspective in other ways.

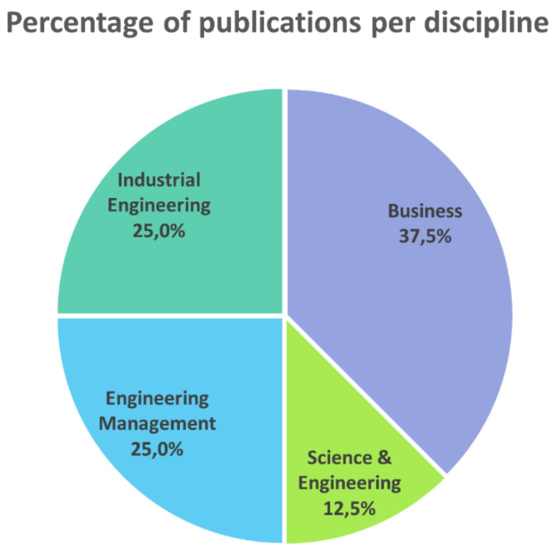

Figure 4: Pie Chart of percentage of publications per discipline

3.2.4 Study types

When analysing the studies, it was also found that the study type was heterogenous. Majority of the studies (50%) were masters studies in the engineering discipline, while 37.5% of the studies were in masters of business administration (MBA) and the remaining 12.5% were doctoral studies in engineering. This is indication that very few studies explore Lean implementation at a PhD level. This breakdown of publications per type of study is captured in figure 5.

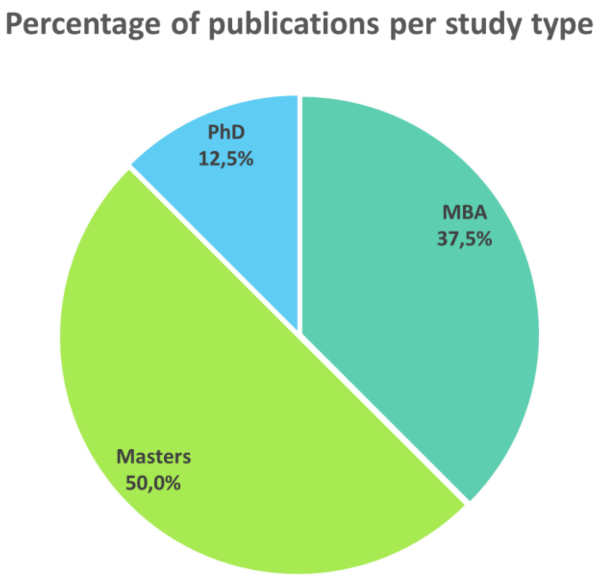

Figure 5: Pie chart of percentage of type of studies

3.2.5 Knowledge areas

When analysing the studies, the most prevalent fact was the diversity of Lean applications in different knowledge areas. Each Lean implementation framework was based in a different knowledge area (categories), with the knowledge areas being very vast. Knowledge areas of Lean applications included the following:

- Additive manufacturing project management
- Banking industry
- Construction industry
- ISO 55000 compliance in asset management
- Maintenance
- Respect for people
- Scheduling in Health care
- Supply chain

The aim of the study was to explore the available Lean implementation frameworks available in the South African context, in order to allow for the categorisation of them in terms of their application. The categorisation of the Lean implementation frameworks is captured in table 3. This diversity attests to the ability to apply Lean in a wide range of different type of industries and knowledge areas. However, each of these studies also validated the idea that Lean implementations need to be customised for different organisations and/or industries.

Table 3: Categorisation of Lean implementation frameworks

Knowledge area (Category)	Title of study
Additive manufacturing project management	A lean project management framework for additive manufacturing
Banking industry	Factors of success for the effective implementation of lean manufacturing projects within the banking sector in South Africa
Construction Industry	Application of lean principles in the South African construction industry
ISO 55000 compliance in asset management	A Framework for Implementing Lean Practices and Tools to support ISO 55000 Compliance for Physical Asset Management
Maintenance	An Investigation into the Applicability of Lean Thinking in an Operational Maintenance Environment
Respect for people	Development of the Respect for People model for lean implementation in the South African context
Scheduling in Health Care	A lean management framework for orthopaedic operating theatres of a level three public hospital, North West Province
Supply chain	Building Lean and Agile supply chains for food fast moving consumer goods manufacturers and food retailers in South Africa

4 CONCLUSIONS AND RECOMMENDATIONS

This paper aimed to explore the various Lean implementation frameworks in South Africa, in order to categorise them based on their application since it is important to understand what is available to be used in practice and industry. The compilation of these categories were presented in table 2 and 3 and found to be diverse in nature.

The aim was accomplished by conducting a scoping systematic literature review, via the methodology adapted from Albliwi et al. [14]. Studies were selected based on a review protocol. Additional to scientific databases, the SLR made use of university repositories for searches. Utilising university repositories was necessary in order to find more literature, as the primary search on the initial databases resulted in a few resources being found. Searching in these repositories proved to have some of its own challenges. When searching on repositories, one is not given the option to conduct the search in only the keywords, titles and abstracts sections. Rather, a Boolean search expression provides results where the search terms occur in any part of the full text of the publication. Nevertheless, this study highlighted what untapped resources university repositories are for SLRs, as many literature studies fail to utilise them.

The outcomes of this systematic literature review (table 2 and 3) could support researchers and practitioners in understanding and selecting the Lean implementation framework that would best suit their needs, based on the categorisation of knowledge areas.

While this study investigated Lean implementation frameworks in South Africa, it is recommended that future studies explore this on an international level, allowing for the categorisation of their research in the field. Furthermore, future research should also examine Lean implementation models and roadmaps (as opposed to only frameworks). By investigating models and roads researchers may be able to highlight their value and support other researchers and practitioners in understanding and selecting them accordingly. Moreover, this would aid in conceptualising the correlations and variations amongst frameworks, roadmap and models.

This study highlighted that Lean is diverse in its application to knowledge areas, as is displayed in the outcomes of the SLR. From the analysis it was observed that studies were done in various disciples, such as Industrial engineering, business, management engineering and science and engineering. However, studies are not limited to these disciplines, thus it is suggested that research explore Lean implementation frameworks in other subdisciplines of Lean (e.g. accounting and manufacturing).

Furthermore, the analysis found that Lean studies were done over various qualification levels, such as masters and doctoral level. Still, with only 12.5% of the studies being done at PhD level, it highlights the expertise of the field but also the lack of applied research on this level.

Publications found within this SLR demonstrated the diversity and range of Lean application in numerous knowledge areas within South Africa. However, Lean implementation frameworks are not limited to these knowledge areas, and future research should build on also developing frameworks in other knowledge areas, such as Lean and Green, Lean leadership, Lean accounting, Lean facilities planning or cultural adaptations of Lean.

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DIAGNOSTIC ASSESSMENT OF ELECTRICITY SERVICE DELIVERY AT A LOCAL MUNICIPALITY

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ABSTRACT

Basic services such as sanitation, waste removal, water, and electricity supplies are necessary for life, well-being, and human dignity. In South Africa, municipalities are the sphere of government constitutionally designated to provide these services. With months of rolling blackouts and volatile operating performance, electricity service delivery (ESD) deserves some attention as it is setting the country on a pathway to national emergency, weakening investors' confidence and stagnating South Africa's already problematic economic growth prospects. To understand the performance and impact of ESD therefore, a diagnostic performance assessment tool, satisfying domain-specific evaluation requirements, is needed. Aimed at guiding improvement in ESD, and using a local municipality as a demonstration case, this paper provides evidence from questionnaires and interviews as primary data and documentary evidence as secondary data to present critical failure factors of ESD. Furthermore, we use interviews with conceptual models to elicit and present functional requirements for a diagnostic assessment tool to assess ESD performance at the municipality.

Keywords: Service delivery, critical failure factors, performance management, design domains

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1 INTRODUCTION

Electricity supply is the backbone of almost all economic activities, powering critical systems and infrastructures required for the functioning of our modern economies and societies. It is a necessity for people's well-being, comforts of life and civilization, and if disrupted may lead to devastating economic and social consequences. It, therefore follows that the steady supply of quality electricity, at a cost affordable to an average South African is inevitable if we are to reach the National Development Plan (NDP) goal of sustainable electricity for all by the year 2030 [1] and create an environment conducive for investors and economic growth. Although the South African government has done a lot in terms of the percentage of households with access to electricity, recent reports by Statistics SA indicate that users are less happy about it [2]. The survey found that households' satisfaction with electricity supply declined between 2010 and 2018 from 67.5% to 65.7%, meaning electricity service delivery transcends mere access to the national grid. This study, therefore, considers other practical areas of electricity services beyond access. Missing in the Statistics SA survey however are any diagnostic (root cause) assessments of reasons for the decline in satisfaction, and probable solution pathways. This is problematic as historical patterns point toward perpetuation of the decline, given the advanced age of South Africa's electrical infrastructure and maintenance backlogs [3, 4]. We argue that any attempts at reversing the decline without appropriate measurement and baseline performance assessments would likely yield little or no result.

In South Africa, chapter 7 of the constitution [5] provides for three categories of the municipality – categories A (metropolitan), B (local), and C (district) municipalities. While the metropolitan municipalities are located in large, densely populated areas, with strong, complex, and diverse economies, the district/local municipalities are predominantly located in much poorer, sparsely populated rural areas. The latter enjoy less publicity when faced with service delivery challenges and sometimes takes a study such as this to unmask their challenges and profer solution pathways. Using a category B municipality as a demonstration case, and exploring functional requirements for a diagnostic assessment tool to assess electricity service performance, the primary objective of this study is to present critical failure factors (CFFs) of electricity service delivery to improve its performance at the municipality.

Section **Error! Reference source not found.** provides additional context on the local municipality that is chosen as our demonstration case. Section **Error! Reference source not found.** provides background on the electricity service delivery distribution that may affect citizens' experiences. We introduce some existing performance measures that are currently used across municipalities to compare their performance in section **Error! Reference source not found.** and conclude in section **Error! Reference source not found.** with a problem statement, i.e. the inability to identify critical failure factors within the municipal electricity service delivery and management context.

1.1 Municipality Context

When a community gets access to steady, sustainable, and affordable electricity supply, it becomes open to numerous economic opportunities whereby new businesses are formed, existing ones grow, micro-entrepreneurs flourish, and permanent jobs are created. On the other hand, power outages or erratic supplies negatively impact social and family life, disrupt production processes, damage appliances, and even cut revenue due to the municipality, as sales of electricity is a key revenue stream for the municipalities. In fact, the national treasury warns that municipalities will be financially constrained if they do not sustain the sale of electricity [6]. A good example is the Greater Kokstad municipality where 93% (93 cents of every R1) of its entire revenue was from electricity sales [7].

In a local municipality, a family requires energy for three main tasks: cooking, heating, and lighting, while small and micro enterprises require it for lighting and powering business equipment. Electricity is an ideal source of energy as it can be used to perform all these tasks. Our demonstration case municipality (DCM) is currently licensed under Electricity Regulation Act No 4 of 2006 [8] and provides non-discriminatory access to end-users within the municipality with the following power system resources (PSR) and assets:

a. 33/11kV 40MVA Sub-station
b. 30.7 MVA Installed Capacity
c. 12MVA Notified Maximum Demand
d. 72 Mini Sub-stations

A diagnostic assessment of how they have used these assets for electricity service delivery was conducted in this study while extracting critical failure factors for non/underperformance. Semi-structured questionnaires and interviews were used to collect primary data, with audited annual financial statements, fixed asset register, and electricity service delivery reports for secondary data to assist with verification and validation of the outcomes of the questionnaires. Research such as this is needed to communicate electricity service delivery performance to all stakeholders including policymakers in government, industry, citizens, and applied researchers.

1.2 Electricity Service Delivery Distribution

Although schedule 4B of the constitution [9] designates municipalities as the distributor of electricity, with Eskom – the national utility - as the generator, the South African Local Government Association (SALGA) points out that municipalities do not have service delivery agreements in place [10], making electricity accounting, service performance assessment and energy reconciliations to be very problematic. Another area of pain is in locations where distribution is shared between municipalities and Eskom, leading to great confusion as consumers have to use different tariffs in relatively close geo-locations. All these, in addition to inaccurate management of indigent 50kWh/month Free Basic Electricity (FBE), contribute to citizens' experience of electricity service delivery. Electricity service delivery, therefore, goes beyond electricity supply but encompasses other service areas of invoicing, response to service calls, speed and ease of creating new connections, etc. As the customer, citizens' general experience of ESD is a key metric of municipality performance as it gives feedback to municipal management and the department responsible for electricity services on how well they are doing. Their experience has been used to extract critical failure factors of ESD at the DCM. Figure 1 is a schematic of the electric system, denoting the municipality's boundary of distribution in green colour and end customers/citizens in black.

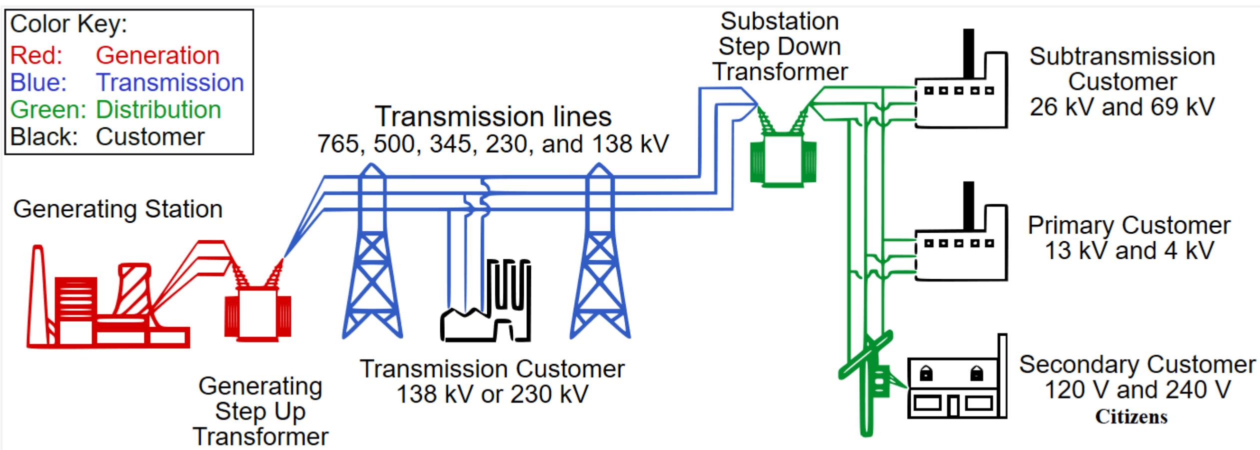

Figure 1: Basic Structure of the Electric System [11]

(Modified to show *legends* and *citizens*)

The questionnaire used for data gathering included some indicators to determine citizens' experience of electricity service delivery as outlined in section 2.3

1.3 Electricity Resources Performance

Apart from improving users' experience and service delivery, diagnostic assessment of electricity services has the potential to motivate power system resources (PSR) management to target and achieve higher service levels of quality, availability, and support. At the municipal level, PSR management scope covers electrical sub-stations, networks, meters, service connections, and sometimes public lighting [12, 13].

For PSR, some of the performance indicators [14] that are used include:

a. $System\ Losses\ (\%) = Electricity\ billed\ (GWh))/Electricity\ supplied\ to\ the\ grid\ (GWh)$
b. $Capacity\ factor\ (\%) = (Annual\ electricity\ \frac{generated (MWh)}{24hrs*365days})/Installed\ capacity\ (MW)$
c. $Load\ factor\ (\%) = Annual\ electricity\ supplied\ (MWh)/Peak\ annual\ demand\ (MW)$
d. $Operating\ ratio = Operating\ capacity\ (MW)/Installed\ capacity\ (MW)$

1.4 Problem Statement

Wilson and Howcroft [15], and Garg and Garg [16] define critical failure factors in respect of information systems (IS) as important areas where things must go wrong for an information system to fail. This, according to them is determined by people since they are the users. While defining failure as any IS project that is abandoned before completion, they identified three types; project (standards not met), systems (under par performance), and user (unusability) failures. In general, research works that give definition to CFFs and explore them in the municipal electricity service delivery context or perspective are rare to find, suggesting that there is a need to diagnose the critical areas that lead to system and service failures within municipality ESD. Related studies did not focus on the CFFs of the entire municipal ESD but only failures of component parts; electricity feeder failure factors [17], electricity distribution failure factors [18, 19], overhead lines failure factors [20], power transformer failures [21, 22], and transmission failures [23]. This study extracts CFFs of ESD both from the *consumer* perspective (section 1.2) and a *provider* perspective (section 1.3).

2 RESEARCH METHODOLOGY

Through qualitative research instruments and technical analysis of power systems resources, this study conducts a diagnostic assessment of ESD using a local municipality as the demonstration case. The assessment enables an unmasking of municipal ESD CFFs and the design of a model for sustained assessment and targeted improvements.

2.1 Research Questions

Within the given problem context, this study answers four key research questions:

- RQ1: What are the CFFs from a *provider* perspective for the DCM?
- RQ2: What are the CFFs from a *consumer* perspective for the DCM?
- RQ3: What is the health of PSR used for ESD at the DCM?
- RQ4: What functions are needed from an information system to identify CFFs for both perspectives and measure their improvement at the DCM?

2.2 Mixed Methods Methodology

A research design entails developing a framework that is used to seek answers to the stated research questions and objectives, that is, an implementation pathway or roadmap for the research [24]. Because of the nature of the phenomenon (CFFS of electricity service delivery) under study, this research adopts a mixed methods of qualitative and quantitative approaches.

Although the historical debate around qualitative and quantitative research paradigms subsists, recent thinking favours efforts aimed at using both effectively and efficiently [25]. According to Morse and Niehaus [26], and Terrell [27] mixed methods can be conceptualized as the outcome of the pragmatist paradigm, blending research methods from both qualitative and quantitative traditions. Given that a single method cannot be used to access all the information and insight required into the phenomenon under study, the mixed method provides a comprehensive approach to achieving a generalizable balanced research outcome.

As outlined in section 1.4, a review of existing literature shows a scarcity of studies that investigate the CFFs of municipal electricity service delivery holistically, rather, specific blocks of the entire value chain were studied. On the qualitative approach, Huy [28], as well as Randall and Mello [29], indicate that it enables analysis that generally leads to the development of a model/theory around the investigated phenomenon. We now elaborate on the population, sampling of interviewees, and data collection process.

a. **Research Population:**
   This study was conducted within the DCM. Having a total number of 24,179 households, the municipality ranks among the least connected to the national electricity grid in South Africa, with some 7,646 households (32%) without access to electricity. A different municipality, the Umhlabuyalingana local municipality, has the largest backlog in South Africa with some 81.5% unconnected households [2]. Of the entire DCM population, the study targeted adult members of households as research participants, with a municipal electricity account, who are permanently resident within the municipality. The study involved participants that would be willing to participate in the study. The intent is not to do hypothesis testing, but rather to obtain insight and understanding about the nature of existing CFFs and the means of identifying CFFs in the future. Yet, we still sampled participants from different strata to ensure measurement from different perspectives.
b. **Sampling Design:**
   The stratified random sampling technique was used to recruit participants for the study. This sampling method entails dividing target participants into various sub-groups/strata that share common attributes. According to Acharya et al. [30], the sampling method minimizes variability since the attributes of each stratum is well known. The target population was divided into two broad strata – municipal employees and residents (non-municipal) employees. The stratification was necessary to avoid bias as municipal employees may show sympathy or loyalty to the municipality which may affect their responses to the research questions, even though efforts were made to mitigate this risk by assuring them of confidentiality and anonymity. The notion of taking a stratified random sample to minimize the prospect of human bias is supported by Sharma [31], and Koyuncu and Kadilar [32] citing additional benefits as generalization and external validity. The two strata for this study are further sub-divided into two other (sub)-strata each: municipal employees (senior and management staff) and residents (residential and commercial users). The stratification is illustrated in Figure 2.

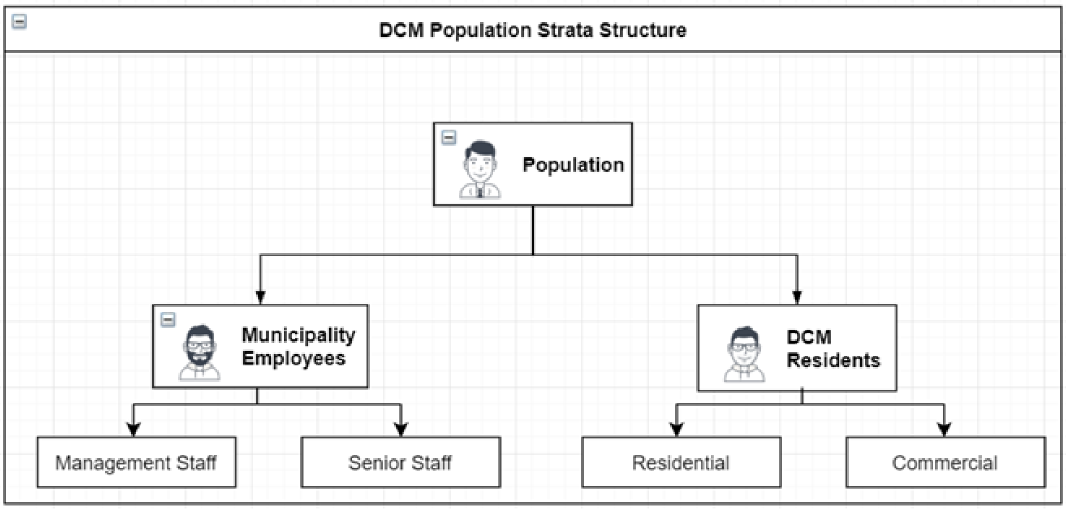

Figure 2: Stratification of Participants

The rationale for each stratum is outlined below:

i. Municipal management staff: This category of people has access to strategic information like budgets, national government plans, etc. on electricity service delivery which senior staff members may not have access to. Inputs assisted in answering RQ 1 and 4, as financial and municipal performance reporting fall within this portfolio of the group.

ii. Municipal senior staff: These are the people on the ground. They have hands-on experience with electricity service delivery which management staff members generally don't have access to as this type of work is not part of their job profile. Although the stratum is aimed at providing additional insight into RQ 1 and 4, an additional intent is to use its consolidated responses to guide verification and validation of management's responses.

iii. Residential customers: This is the majority by count (7,646 households). As the end-users, their input did not only provide answers to RQ 2 but also gave an independent assessment of municipal electricity service delivery performance.

iv. Commercial customers: This group is the highest paying stratum. Purposively targeted to provide insight on "value for money" and other service performance metrics, commercial customers' assessment of ESD is critical as many local municipalities depend on them for sustenance. Additional insight into RQ 2 was derived from this class.

Sample size was relatively small due to COVID-19 related restrictions whereby the municipal offices were closed, and both residential and commercial DCM residents were not easily accessible. Careful attention was therefore given to stratification, and techniques proposed by Francis *et al*. [33] on reaching *data saturation*. They proposed first, to conduct an initial analysis, and then to establish *stopping criterion* – a point at which no new ideas emerge. Table 1 outlines the saturated set of themes obtained from the participants.

c. Data Collection Process

Data was collected through questionnaires and semi-structured interviews, mostly over the phone (due to specific restrictions to movements due to COVID-19). Before interviews were conducted, each participant had to provide informed consent before commencing with the interview. Additional data was acquired from the municipality's enterprise resource planning program.

This (mixed methods) approach was necessary due to the nature of the phenomenon under examination, where quantitative data/analysis alone will not give the depth and insight required to judge service experience from users. Also, there are multiple stakeholders as indicated in section 2.2b (Figure 2), necessitating a concurrent triangulation approach for the purposes of confirmation, corroboration, and cross-validation. *Qualitative data* was collected via interviews (see a sample of questions provided in section 2.3) to extract the critical failure factors, while the results were validated against the outcome of a *quantitative data analysi*s extracted from the DCM's enterprise resource planning system and questionnaire (see a sample of questions provided in section 2.3).

2.3 Data Extraction and Analyses Methods

a. Data analyses were conducted by a transcript of voice recordings and statistical analysis of other quantitative data. Shown below are some of the data fields and records acquired during the investigation. Interview guide for the *semi-structured interviews* (*with the provider*) to answer RQ1 are:
   i. How available is electricity to the residents? What are the challenges to availability?
   ii. What is the quality level of electricity supplied to the residents? What are the challenges to the quality of supply?
   iii. How easily is a new household connected to the grid? What are the challenges to new connections?
   iv. How easily are faults resolved? What are the challenges to fault resolutions?
b. Some indicators, measured via a five-point Likert-scale, included in the *questionnaire* for the *consumer* to answer RQ2 are:
   i. Availability
   ii. Quality
   iii. Cost
   iv. Value for Money

   Inferences from other sections of the questionnaire are reported in section 3.2(b).
c. Data to answer RQ3 was derived from the conditional assessment of PSR outlined in section 1.3. Additional data on financial losses due to the health of PSR was obtained from audited financials, while the PSR asset register was retrieved from the municipality's enterprise resource planning software.
d. To answer RQ4, thematic codes generated from the outcome of RQ1 were clustered based on the theories on the main enterprise design domains as defined in [34].

Aggregating the analysis results within clusters, a conceptual model is proposed for diagnostic assessment and improvement of ESD at the municipality. We anticipate that collecting (and subsequently analyzing) these raw data would lead to a better understanding of the CFFs of electricity service delivery at the DCM.

3 RESULTS

In this section, we report on the results extracted during data-gathering, synthesizing per research question.

3.1 RQ1: What are the CFFs from a *provider* perspective for the DCM?

Data was collected via semi-structured interviews conducted over the telephone for four staff members (two senior and two management) of the municipality. These strata, referred to as the *provider* responded to the interview guide shown in section 2.3(a). Although a higher number of participants is desirable for this stratum, the size of the DCM and shortage of technical staff constrained the number of respondents to only four.

Transcripts of all the interviews were analyzed using ATLAS.ti, a qualitative data analysis program.

An initial transcription of the CFFs as provided by the respondents is outlined in Table 1, followed by thematic analysis. Table 1 indicates factors that contribute towards four performance areas. Guidelines from [35] were used in phrasing *performance areas*.

Table 1: Critical Failure Factors

Performance Areas	Factors (Management)	Factors (Senior Staff)
Availability of power	Unfunded budgets	Weak & aging infrastructure
	Aging infrastructure	Lack of spare parts
	Electricity theft	Financial constraints
	Inaccurate indigent accounting	Poor planning
	High level of employment	Technical people are not represented in management & council meetings
New Connections	High level of employment	Technical people are not represented in management & council meetings
	Too many poor households	The head of technical services for the municipality is not technical
Quality of maintenance	Aging infrastructure	Lack of spare parts
	Poor maintenance culture	Fire fighting maintenance approach
		No monitoring of infrastructure
Capability level of creating new connections	Lack of capital for expansion	Lack of service vehicles
	Too many poor households	Poor access roads to local communities
	Reduced support from the national government	Very long supply chain process for contracting
Capability level of faults resolution	Staff shortage	Shortage of spare parts
	Ineffective call center	Lack of qualified personnel
		Lack of training
		Unsafe working condition
		Lack of service vehicles
		Lack of record-keeping

Conducting a line-by-line coding of the transcribed data resulted in 21 open codes that were clustered and converged into themes and constructs. Through densification and comparative analysis of the codes and the contents they represent, the dominant factors that emerged from the interviews are:

- The municipality is financially constrained
- Infrastructures are old
- There is a shortage of spare parts
- There is a shortage of staff and skills
- Inadequate service equipment

3.2 RQ2: What are the CFFs from a *consumer* perspective for the DCM?

As noted in section 2.3(b), data was collected from the *consumer* using questionnaires that rated their experience of ESD. Although a near 100% response rate is desirable for a study such as this, only about 70% was achieved due to national lockdowns occasioned by the Covid-19. Fifteen (of twenty-two) respondents completed their questionnaires over the telephone and other remote conference call platforms such as Skype: Eleven residential and four business. Summary statistics and outcomes are presented below:

a. Consumers' satisfaction: Consumers' satisfaction with electricity *availability, quality, cost,* and *value for money* was tested. While consumers are fairly satisfied with availability and quality, on average they expressed frustration and unhappiness with *cost* and *value for money*. Figure 3 shows the statistics and graphical summary for all participants who rated the indicators from 1 (extremely unsatisfied) to 5 (extremely satisfied).

Variable	Total Count	Mean	SE Mean	StDev	Minimum	Maximum
Availability	15	3.067	0.153	0.594	2.000	4.000
Quality	15	2.933	0.182	0.704	2.000	4.000
Cost	15	1.1333	0.0909	0.3519	1.0000	2.0000
Value for Money	15	1.933	0.182	0.704	1.000	3.000

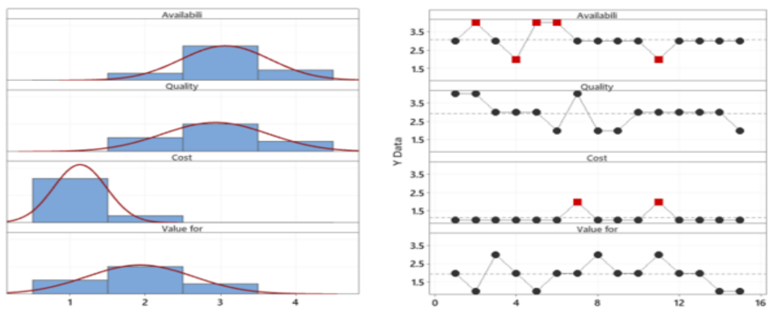

Figure 3: Statistical & Graphical Summary

Data points marked in red are *outliers* which on investigation were discovered to be mostly business/commercial consumers. This caused a *skew* in the cost statistics for ESD as the highest cost ratings came from only 13% (commercial) consumers that believe the cost of electricity is fairly justified. The satisfaction rating, which averaged to 2.3, is shown in Figure 4.

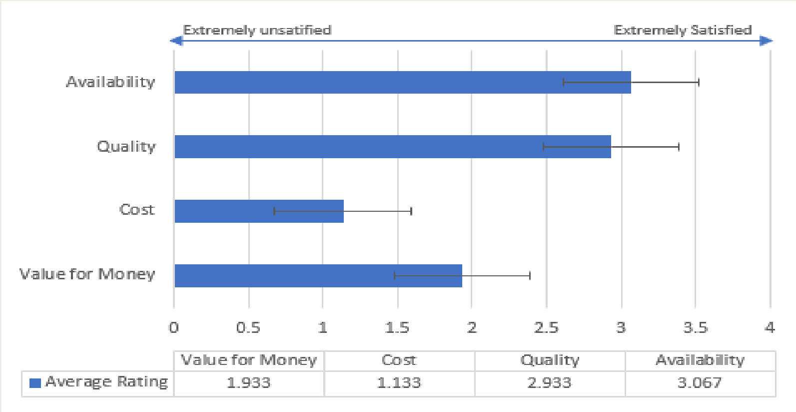

Figure 4: Consumers' Satisfaction Rating

b. **Critical failure factors**: *Consumers'* perspective of failure factors is different from *providers'*. ESD fails once their expectation is unmet - they are not privy to providers' requirements or challenges for providing ESD. 92% of interviewees concurred to experience power outages while 84% (of the 92%) agreed power was restored within 24 hours. On the quality of electricity, an overwhelmingly high percentage of 76% believe the quality of supply is satisfactory as they have never experienced damages to any of their appliances due to poor quality electricity supply.

   The questionnaire collected performance scores in 10 areas (indicators) from *consumers* and the CFFs derived from the performance scoring are listed below:

   i. Lack of notification ahead of power outages.
   ii. General outages (tagged load shedding).
   iii. Delay in service technicians responding to faults.
   iv. Service technicians are not equipped to resolve faults at the first visit.

3.3 RQ3: What is the health of PSR used for ESD at the DCM?

A preview of the health of PSR used for ESD at the DCM corroborated the outcomes of RQ1 and RQ2. Reviewing an independent conditional assessment of key PSR assets (transformers and power lines), the age analysis shown in Figure 5 was derived. Given the insight about lack of maintenance budget, it can be said that only about 8% of the PSR is well suited to support ESD in the municipality, with a whopping 80% nearing the end of their useful service lives.

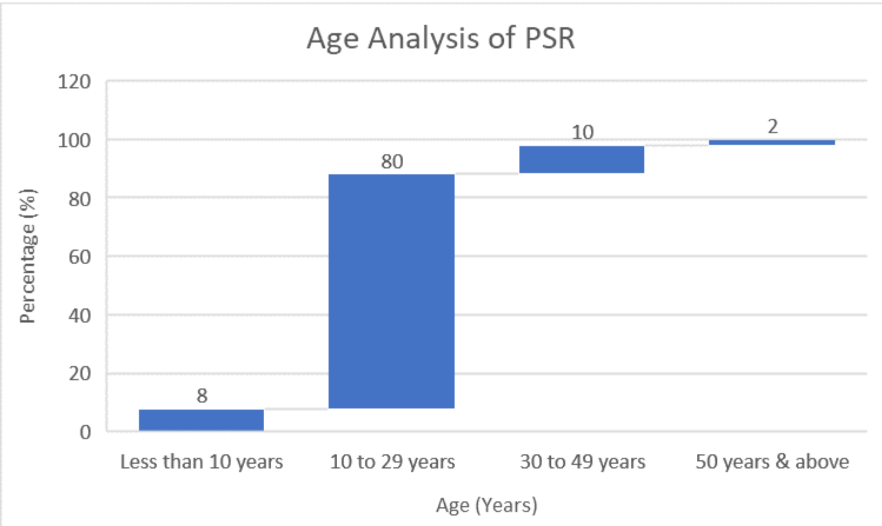

Figure 5: Age Analysis - DCM PSR

There is no universal consensus on the economic life of a power transformer as it depends on so many factors ranging from the environment, climatic condition, type, maintenance practice, load management (rated load kVA), etc. While the ANSI/ IEEE guide and standards for distribution and power transformers [36, 37] suggest 20 to 30 years under basic loading conditions and maintenance, Hillary *et al.*[38] indicated 25 to 40 years. Given the poor health (driven by age and deficient maintenance practice) of PSR at the municipality, huge losses have been recorded. Table 2 shows losses (technical and non-technical) for periods 2017-2018.

Table 2: Losses for period 2017 and 2018

	2017	2018
Units Purchased from Eskom (kWh)	47,719,811	48,119,089
Units Sold (kWh)	40,479,709	39,999,963
Units Lost in Distribution	7,240,102	8,119,153
Total Losses in Rands	**R 7,307,817***	**R 8,195,089***

*These amounts are significant to a local municipality

The final *condition index* was 41%, graded as "E+" and rated as "very poor". It can therefore be concluded that PSR in the municipality is not healthy enough to support the level of ESD required by the citizens.

3.4 RQ4: What functions are needed from an information system to identify CFFs for both perspectives and measure their improvement at the DCM?

Outcomes of RQs 1 to 3 were converged to guide functional requirements as a conceptual model for a diagnostic tool to assess and improve ESD at the municipality.

3.4.1 *Enterprise design domain clustering*

CFFs generated from RQ1 (rephrased/shortened) were clustered and shown in Table 3. Clustering CFFs in a logical, theoretically grounded manner helps to create a common understanding among stakeholders and eases the process of benchmarking. Enterprise design domains and levels have been defined and classified by several authors [39, 40] but with some levels of ambiguity, inconsistencies in demarcation, and difficulty in application. To eliminate these, De Vries [34] following the basic design process, proposed four key design domains (information and communication technology; organization; infrastructure; and human skills and know-how) and other facets.

Table 3: Design domain clustered CFFs

ICT Domain	Organization Domain
• Software/hardware: Infrastructure monitoring • Software/hardware: Electricity theft tracking • Software/hardware: Call centre services • Software/hardware: PSR record keeping • Software/hardware: Indigent accounting	• Infrastructure monitoring • Electricity theft tracking • Call centre operations • PSR monitoring • Accounting operations • Planning • Technical representation in top management • Supply chain process • Maintenance approach • Training operations • Staff retinue
Infrastructure Domain	**Human skills and know-how Domain**
• Maintenance planning tools • Infrastructure health • Access roads • Service vehicles • Working conditions	• Personnel qualifications
Other Enterprise Constructional Facets • Maintenance culture	

In accordance with Hoogervorst [41], appropriate design of design domains, and mature operation and management within design domains should address key *performance areas*. As indicated in Table 1, the CFFs highlight design-related factors (deficient design), as well as operating-and-management-related factors that need to operationalize certain *performance areas*. Interrelationships, support links, and multi-faceted interconnectedness across domains exist but are not shown in Table 3.

3.4.2 The conceptual model for diagnostic assessment of ESD

From an information system perspective, the model in Figure 6 is suggested to enable an on-going assessment of ESD to guide improvement. Input parameters for the model were derived from the first three outcomes of this study:

- Citizens' experience/perspective – derived from consumers via a survey – satisfaction rating (section 3.2 – 44%).
- Health of PSR – derived from the conditional assessment of PSR – condition index - (section 3.3 – 41%).
- ESD maturity – derived from the provider through iterative internal assessment (section 3.4). Table 3 provides some indication of factors that are currently problematic, classified according to key design domains.

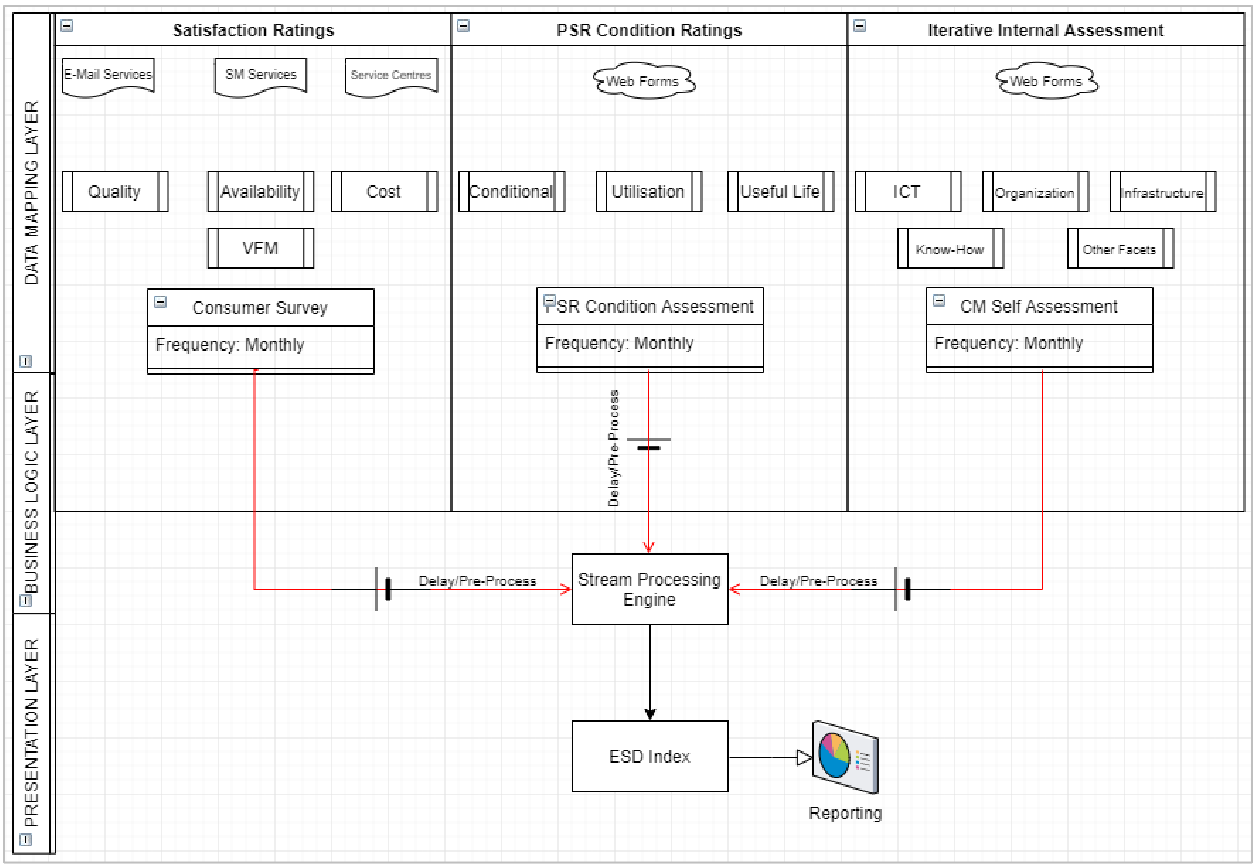

Figure 6: Conceptual Model for ESD Diagnostic

The three logical layers of the model are described below:

1. Data mapping layer: This is the layer where qualitative (consumer survey) and quantitative (PSR condition) data are collected for analysis of ESD on a regular basis. Data acquisition channels include e-mail, short messaging services, and survey terminals at service centers.
2. Business logic layer: Data transformation & analyses take place in the stream processing engine (SPE). The input/output controllers (delay/pre-process) ensure that all required input data have arrived before they are parsed into the SPE.
3. Presentation layer: This is the reporting platform whereby the Electricity Service Delivery (ESD) index for the month is broadcast.

Implementation of the diagnostic model (Figure 6) is of great importance as there cannot be any sustainable improvement without a measured state. In addition to guiding improvement, the model would support municipality budgeting, investments, planning, and PSR maintenance policies.

4 CONCLUSION

Life without electricity is unimaginable: It is a necessity for people's well-being, comforts of life, civilization, and all economic activities. Without electricity, economic growth is retarded, investor's confidence is suppressed and social activities are paralyzed. Although mandated by the constitution to provide basic services such as water, electricity, sanitation, and waste removal, municipalities, especially the local ones bleat under dwindling revenues, colossal debt, and unfunded budgets which threaten their ability to execute this constitutionally mandated role. These conditions inadvertently undermine public service delivery and the supposition of a developmental local government. Using a DCM and well known and a mixed methods research methodology, this study set to present critical failure factors of electricity service delivery at the DCM. Having gained insight into the CFFs, the study went further to model the required functions for a diagnostic measurement system to assess the health of ESD at the municipality, suggesting that clear and precise information is a bedrock for incremental continuous improvement. Qualitative and quantitative data-driven assessment of the DCM suggested a poor state of ESD and showed critical areas needing improvement.

Since this study only targeted a local municipality, we recommend that additional studies be conducted to apply the same model to benchmark other local municipalities and also to test larger, urban Metropolitan municipalities.

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DEVELOPMENT OF A HYBRID SUPPLY CHAIN RISK ASSESSMENT FRAMEWORK FOR RAIL OPERATIONS INDUSTRY

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ABSTRACT

Supply chain risk management (SCRM) plays a critical role in identifying, assessing, and managing the risks inherent to the system. The ability to assess and manage supply chain risk is an integral part of ensuring the sustainability of the supply chain (SC). In South Africa, a rail operator saw its operational output fall by 5% year on year and paying millions to customers for delays and lack of capacity in its loading yards. The aim of the papers to develop a hybrid supply chain risk assessment framework for the rail operations sector by reviewing supply chain risk assessment (SCRA) in different environments to formulating a framework that is robust and easy to use. The study explored the benefits and application of Pareto Analysis (PA), failure mode effect analysis (FMEA), fault tree analysis (FTA) to assess SCR's that are prevalent in the rail operations sector, and to develop an SCRA framework. The results in this paper show that exclusion of over carry loads when planning is a major cause of the operation missing major target due to under capacity.

Keywords: Rail operations Supply chain risk management

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1 INTRODUCTION:

Rapid changes in the supply chain (SC) environment and economic problems, such as market share loss, shrinking economic growth, and complicated relationship between members of the supply chain network and the uncertainty in demand, have made the SC more vulnerable to several risks. Various industrial trends, including outsourcing, supply base reduction, just-in-time (JIT), and shorter product life cycles have increased firm exposure to SCR [17]. SC can be loosely defined as an integrated network of companies that work together for the delivery of products, services, and information to the end-user at the right time and the right level of quality [43].

Over the years the SC environment has become more complicated, making it challenging to operate and sustain quality performance. Organizations have to deliver the right quantities, to the right places at the right time with the minimum costs and at the acceptable degree of quality to satisfy demanding customers [39]. To improve quality assurance in the supply chain network (SCN), companies have to develop SC partnerships with their strategic partners [30].

Supply chain risk management (SCRM) is a fundamental key area of interest in the development of a sustainable supply chain network. SCRM's fundamental role in the development of strategies for the identification, assessment, treatment, and monitoring of risks in supply chains to ensure the sustainability of the supply chain and its member organizations [17]. Risk in SCM can be viewed as the probability of an event or disruption that occurs and hinders the SCN from achieving the desired outcomes [21].

There is a significantly high level of risks for companies that are operating in a globalized environment. Upstream and downstream suppliers can be on different continents making risk management a complex but crucial task to achieve economic benefits and competitive advantage [43]. SCR's occurs due to external sources or internal sources. Supply and manufacturing risk has gained attention because of the high connectivity of the SC and the large nature of the global SC environment puts a strain on the ability of firms to achieve optimal performance [7].

Risk assessment gives organizations an insight into the risk inherent to the operating environment. From an industrial standpoint the process of "risk assessment" deals with the recognition, measurement, and/or analysis of the risks in a system [27]. Assessing and managing risk within an SC is critical in ensuring high-level performance and sustainability for the SC members [20].

1.1 Background

Railway traffic has increased over the last decade and will grow as the world is looking for cost-effective and environmentally friendly ways of moving goods and people. [47]. The majority of rail Original Equipment Manufacturers (OEM) operate in an environment where global SC is the way of moving goods and information. The globalization of the SCN presents benefits to be leveraged on and some risks that must be assessed and managed [25]. Supply chain architecture has changed dramatically and has brought various risks influencing organizations' capability to operate sustainably [7].

In South Africa, there is an elaborate recapitalization drive for both freight and passenger rail infrastructure. There has been an increase in spending since 2013, In 2013 R11 billion was spent which increased to R68 billion in 2017 to accelerate and modernize the rail transportation sector [35].

The rail sector transports a broad range of bulk freight commodities and containerized freight. It operates a rail network of 31 000 kilometers (KM) of the track which 20911 KM is route km over which commodities are moved locally and for exports to neighboring countries. The diverse rail network comprises 1 500 KM of heavy haul lines. The network also includes 3 928 KM of branch lines that serve as feeders to main lines. The network and rail service provides strategic links between ports, terminals, and production hubs and also provides connectivity to the railways of the Southern African Development Community (SADC) to support regional integration [50].

1.2 Research aim and methodology

This study aims to develop a hybrid supply chain risk assessment (SCRA) framework to assess and manage SCR within the rail operation sector. The adoption of well-established methodologies such as Pareto analysis, failure mode effect analysis (FMEA), fault tree analysis (FTA), and Plan-Do-Check-Act (PDCA) played an important role of making the framework effective in identifying, assessing, ranking, and managing SCR.

For this research study, a case study was carried out on a South African rail operator to investigate the SCR within its operating environment. The researcher used the following databases, google scholar, Emerald Insight, and Science direct to review SCR management papers to gain insight into the phenomenon, extensive SCRA literature in the rail industry was reviewed to explore and critique the methodologies that were applied while searching for a combination of techniques that can be combined to develop a hybrid supply chain risk assessment framework.

Secondary data was collected from public records such as reports, financial statements, and operational reports available in the public domain. The paper is structured as follows, Section 2 presents a literature review that gives an in-depth view of the learning areas that lead to the development of the risk assessment framework. Section 3 presents a detailed presentation of the proposed hybrid SCRA framework and elaborates on how the different tools within the framework can be applied and section 4 presents the discussion and conclusion.

2 RELATED LITERATURE REVIEW

2.1 Supply chain risk management

The process of SCRM must be a unified approach to prevent the occurrence of risks or minimize the impact of the occurred risks. Risk refers to the disruptions which caused malfunctions in the SC [29]. This process must comprise of risk identification, risk assessment, risk monitoring, and mitigation strategies [28]. The intension of the SCRM is to establish deliberate processes and procedures that give the organization ability to lessen vulnerability and ensuring business sustainability [17].

SCN's in all forms are increasingly facing volatility across a range of operating areas from sustainable operations, to raw material availability and foreign exchange rates. [41]. SCR can be classified but not limited to supply risk, demand risk, and operations risk [20]. These risks can be categorized as internal and external risks. Internal risks are those risks that are within the organization and are in the organization's control and external risk are those that are outside the organization and the control thereof. Internal and external risks can be broadly categorized as shown in Table 1 [39].

Table-1 Supply chain risk classification [39]

Internal risk	External risk
Process risk	Supply risk
Control risk	Environmental risk
Capacity risk	Demand risk

Risk assessment plays an important role in dealing with risk effectively [43]. Risk assessment is a significant process that allows smart decisions to reduce the overall impact that risks may have on an organization [28]. SCRA highlights potential pitfalls within the supply chain network that need to be managed or eliminated where possible, [29].

There is glaring evidence that SCR is becoming complex as the SCN is expanding and becoming global [41], thus, there is a need for companies to place a priority on the development SCRA approaches that are suitable for their organization's KPA's with clear success measurements. Risk assessment provides the foundation for a successful SCRM process and is key in the process of managing, reducing, and eliminating risks [14].

2.2 Risk assessment

The process of risk assessment in SCRM must be a holistic approach to prevent the occurrence of risks or minimizes their impact on the SCN. This process involves risk identification, risk assessment, risk monitoring, and mitigation strategies. Risk assessment is identified as the most significant facet of the risk management process [27].

ISO 31000:2009 considers risk assessment as the key process in risk management. Risk assessment is a three-step process, from risk identification to risk evaluation as shown in Figure 1 [13].

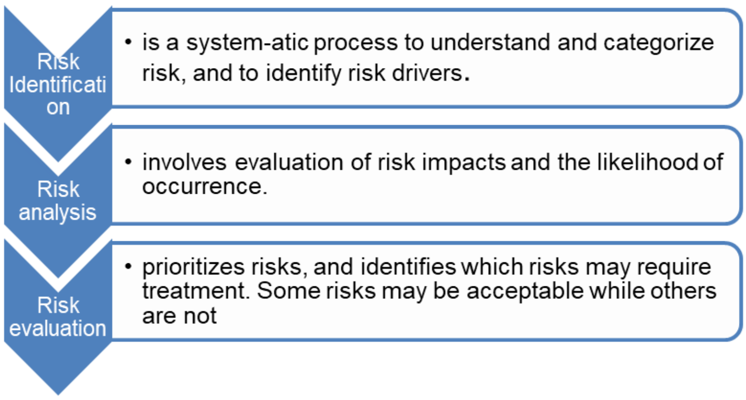


Figure-1: Risk assessment [13]

Risk identification involves gaining insights into any threat, uncertainty, vulnerability, and unexpected event that can become a source or trigger for risk to materialize [15]. The primary goal of the Risk Identification process is to identify the threats and opportunities which may affect the projects' objectives and consequently deliverables [6]. The process of risk assessment deals with the recognition, measurement, and analysis of the risks in a system [29].

SCRA must provide management with an understanding of where the greatest risks exist to prioritize resources for risk mitigation accordingly [22]. Risk assessments involve clarifying the nature of the risk, understanding conditions that may lead to the event, knowing how frequently such events have happened or can be expected to happen, and the potential impact of such events. Armed with this information management can take guided decisions [16].

Risk assessments have traditionally been based on the identification of hazards in the workplace and ensure that the risks are identified in such a manner that is relevant to the industry that is in question [40]. Risk assessment is not merely a tool to calculate the probability and expected consequences of a hazard, it is also the phase in which the appropriate actions to minimize the probability of risk occurrence is determined and the cost of resource allocation to manage the impact of the harm, in the event of its occurrence, is established [14].

A holistic risk assessment is vital for organizations in modern SC's as risk events often influence each other and rarely act independently. These leads to complexity in the SCN's that necessitate the development of systems that can assess the risk effectively [14]. Risk prioritizing highlight the significant few risks that need attention and key resource can be deployed efficiently to deal with the risks that matter the most [17].

An effective SCRA approach should precisely depict the propagation of different SCRs and analyze their impact on the overall performance of the system [10]. Key risk drivers must be measured and their impact understood ensuring that appropriate measures are deployed [23]. A comprehensive SCR assessment should link SCR sources with SC performance, which could generate effective proactive risk management strategies [9].

The framework developed in this paper must have the capabilities to prioritize the usage of resources in the SCRM process. As recent studies have shown, there are various risk assessment tools and methodologies available to help an organization assess risk. However, the prevention of accidents is based on risk analysis, which involves the identification of the hazards and the consequences and the likelihood of occurrence of each hazard [19].

2.3 Risk assessment methods in supply chain risk management in rail operations

The railways are an important part of the economies of the developed world. Developed countries' economic and social development depends on the optimal functioning railways, both freight and passenger rail. To showcase the importance of railways in first world countries passenger rail is developed into two sections, being urban rail (Gautrain) and passenger rail (Metrorail) [45].

The railway industry is concerned with availability, reliability, and safety with their environment, and risk management in railways focuses on the prevention of any system failures that will result in economic loss for the rail operators. When there is access to accurate and reliable data, probabilistic modeling like Monte Carlo (MC) was employed as a key method in the process of risk assessment [45].

MC is one of the suitable methods used for quantitative risk assessment since it can deal with the greatest possible number of risk factors [24]. MC is a quantitative technique used in many different types of decision analysis models including risk assessment in railways [18]. It generates results that depend on variables or factors defined as probability distributions. The method selects input values based on the probability of the event happening, to simulate the model, where the variables have a definite range of values. MC technique is employed to solve many problems, irrespective of complexity, dimension, or non-linearity value for any time or event [26].

The fuzzy reasoning approach (FRA) is vital to ensure the accuracy of the output where there is a shortage of data [45]. The fuzzy approach allows the use of expert opinion instead of statistical data for the analysis and reduces the uncertainties about the data [8]. The fuzzy theory has the capability of handling uncertainty and approximations in decision making. It has been stated that the advances in the methodology of the fuzzy theory established fuzzy logic to handle the problem of ambiguity in the evaluation of major-related risks for SCM [27].

It was concluded that the integration of MC with Fuzzy Reasoning has been proven to be effective for several applications in various industries especially pertinent to the railway industry. The approach would enable risk practitioners and decision-makers to get a better understanding of risks, the impacts of risk mitigation decisions, and thus enabling efficient asset management. The combination of MC Simulation and FRA enables the study of both the likelihood and consequences of a failure event that is uncertain in the natural and linguistic form [45].

2.3.1 Risk assessment in Chinese and Indian rail operations

In China, a hybrid risk assessment model was developed by applying a fuzzy Petri net (FPN) and fault tree analysis FTA. FTA-FPN applied in railway risk assessment, analyses risk factors of the fault tree, maps the fault tree of risk accident into a fuzzy Petri net, and builds up a railway safety risk assessment model [53].

In India a proposed risk assessment model using Analytic Hierarchy Process (AHP) was developed, However in the development process it was identified that the conventional AHP has a weakness of not being able to reflect the human thinking style. To overcome this deficiency a fuzzy extension of AHP was developed, fuzzy AHP [21]. Certain applications required a combination of two methods to ensure that a robust risk assessment model is developed, that is the basis of the framework to be developed, where two or more methods are working together to assess the risk to ensure that any weakness is covered by diverse features of the combined methods.

2.3.2 Supply chain risk assessment using FMEA in rail operations.

The popular method used in railway risk assessment is failure mode and effect analysis (FMEA), which focuses on potential failure to assess and prevent risk early on in the process. [21]. In the United Kingdom (UK), a rail operator was losing £50 (US$62) per minute of delay in service due to system failures that amounted to over 500 minutes delays for the period being studied. The railway industry in the UK is more advanced with a network of 17,732 KM and 1.65 billion passenger-kilometers annually [3].

Studies have shown that reliability and availability are key success factors for rolling stock maintenance and rail operation [12]. A failure of any of the rolling stock components causes a complete failure of the system, passenger inconvenience, and economic losses for train operating companies [3]. FMEA is an excellent tool for evaluating the potential failure and risks throughout the design, process, and service stages [5]. The results of the FMEA risk evaluation showed that out of the nine failure modes, the door system functionality alone contribute up to 75% of the delays [3].

The use of FMEA to evaluate the effects of different risk and highlight the risks that will harm the system is an advantage that the framework to be developed in this paper can leverage.

2.3.3 Development of a risk assessment framework in European rail operation

The Slovakian railway has undergone rapid changes such as structural reform to meet the common condition railway system in the European Union (EU). To meet EU's requirements a hybrid risk assessment framework combining Fault tree analysis (FTA) and Event Tree Analysis (ETA) model was developed. The risk assessment framework consisted of four subsystems that feed into each other to deal with risk within the system [33].

FTA is an analytical logic technique used in system reliability. It's a method that is used for analyzing the failure logic of a system and calculating its overall reliability [1].

The challenge with FTA is that it only focuses on one top event at a time, which means an entire tree needs to be generated for each top event [27]. To remedy this limitation FTA was applied with the Event tree Analysis (ETA) model. ETA is a technique to describe the consequences of an initiating event and to measure the likelihood of possible outcomes of the event [2] and it is a logical evaluative process that involves tracing forward in time or through a causal chain [38].

By applied two methods to perform a risk assessment in rail operation give an advantage that any missed opportunity by one method can be covered by the other method. Hybrid SCRA methods are key in the holistic assessment of risks in the systems. Rail operations require complex decisions that subsequently also require the simultaneous assessment of a large number of inter-related variables to arrive at a decision, developing a hybrid assessment method will provide a vital decision support system for operators [34].

3 CASE STUDY OF A SOUTH AFRICAN RAIL OPERATOR

The paper looks at a South African freight rail operator that operates a freight rail for exports of commodities. The rail operator's freight division has more than 28 000 employees and generates revenue of over R4.6 billion. The rail operator exports over 200 metric tons of commodities every year. The company experienced a loss of volume for the financial year ending March 2019 as shown in Figure 2.

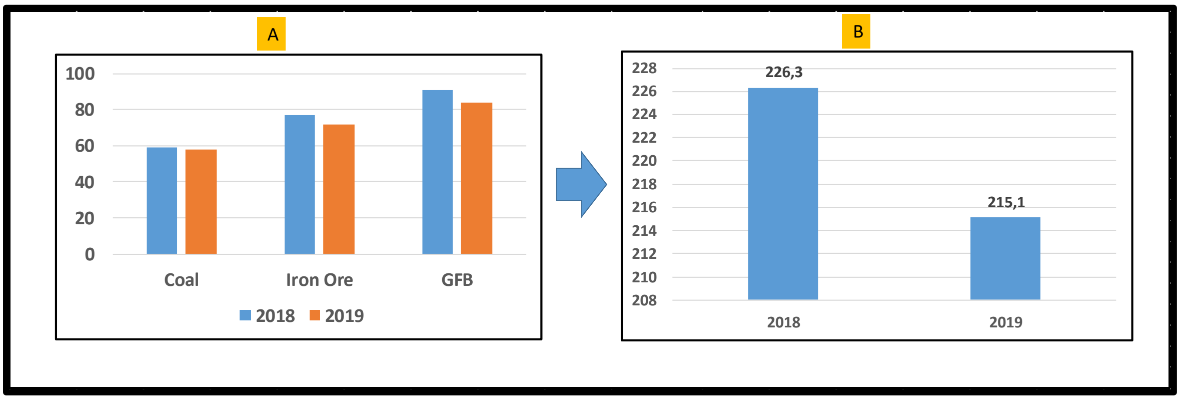


Figure-2: A-Commodity output and B-Total combined volumes

The company has budgeted R3.5 billion to upgrade infrastructure in all freight lines and modernize some of its locomotive fleet, ongoing maintenance of rolling stock and railway infrastructure is required to maintain assets at an acceptable railway service standard to achieve the required levels of reliability, safety, and availability [51].

As the basis for this paper, in its integrated report, under "Risk, Ethics and Governance", out of the 5 risks to the business that were identified, making freight rai competitive is one of the key success drivers [50].

To ensure that freight rail is improved and risk is averted, a risk assessment framework is required, the frame-work will have an integral part by performing the following activities:

- Risk measurement quantifies the likelihood of risks and its corresponding impacts;
- Risk prioritization ranks the most critical SCR; and
- Risk evaluation analyses of which risks will be selected for the RM phase [26].

At the iron ore line, the process of loading the commodity at the yards is as shown in Figure 3.

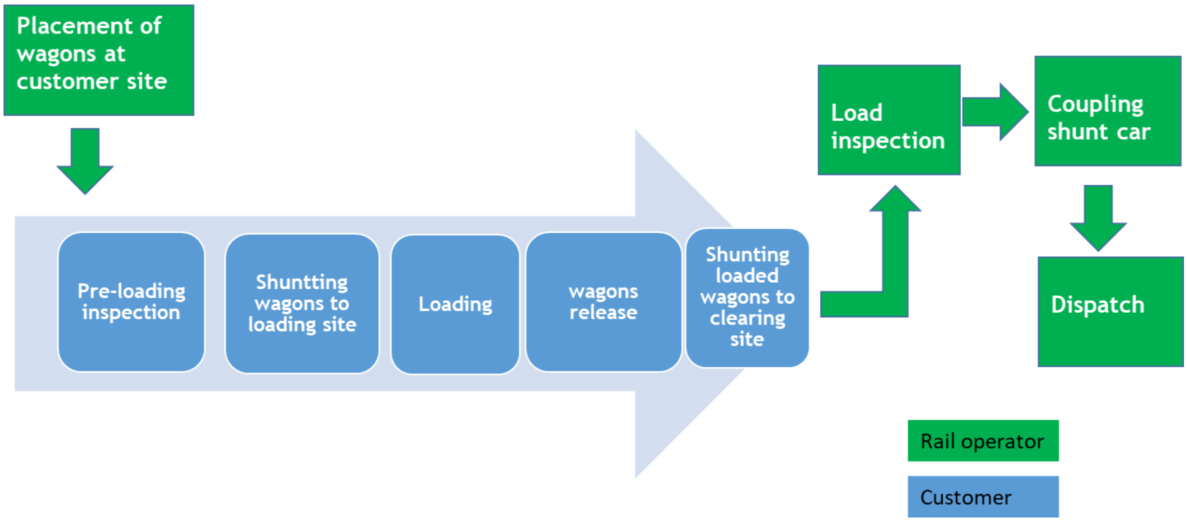


Figure -3: Commodity loading process flow

3.1 The proposed hybrid supply chain risk assessment framework

Risk assessment is a technical and scientific process through which the risks of a given system are identified and quantified [24]. Figure 4 shows the proposed hybrid SCRA framework.

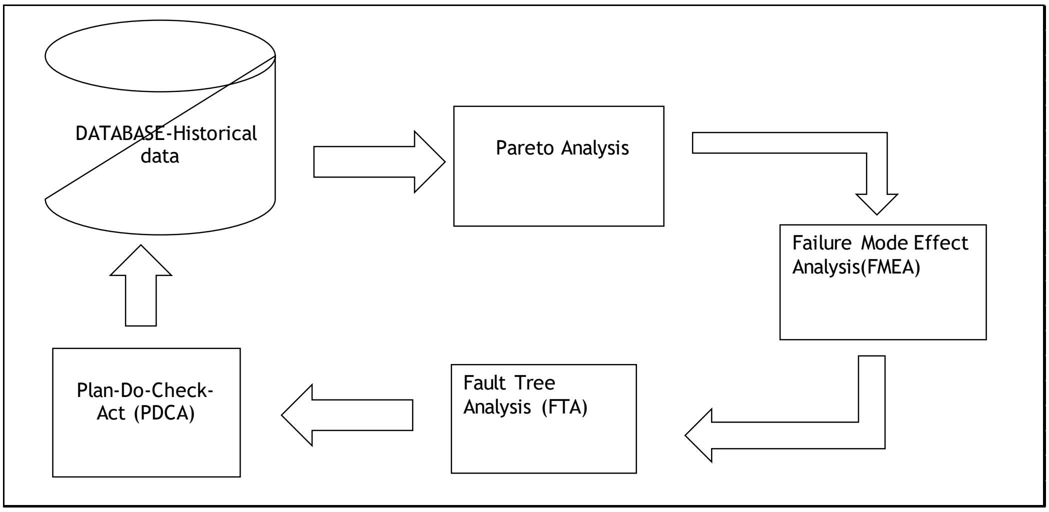


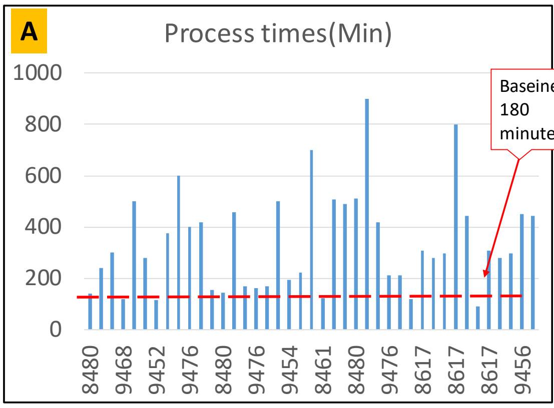
Figure-4: Proposed supply chain risk assessment framework

3.2 Application of the Hybrid supply chain risk assessment framework in the rail industry

Pareto analysis is an effective data-based technique that helps separate the primary uses of problems from the minor ones providing the practitioners with direction to focus attention on the relevant few. Pareto analysis has been employed as a problem-solving tool in many sectors including rail, economics, financial markets, engineering, aerospace, and many more [52].

Based on the data provided, the base principle that the Pareto analysis propose is that around 80% of the overall impact of errors in any industrial scenario is due to a small number of faults, called the vital few/critical faults, and 20% of the impact due to other faults that might be significant in other ways [44]. Pareto chart shown in Figure 5C is a graphical tool that helps to systematically break a big problem down into its parts and identify critical faults that are important and input into the FMEA [48].

From the database, the challenge in the process is the poor performance of the yard to adhere to the standard operating time of the process shown. The baseline is 180 minutes but the historical data shows that the process is totally out of specification as shown in Figure 5.



B Category	#Reason for delays	Percent	Cumulative Percent
Misalignment of service design and the ITP system	15	37%	37%
Skew and overloads	9	22%	59%
Under capacity of slots allocation	9	22%	80%
Locomotive failures	6	15%	95%
Poor next week business planning (72 hours countdown)	2	5%	100%

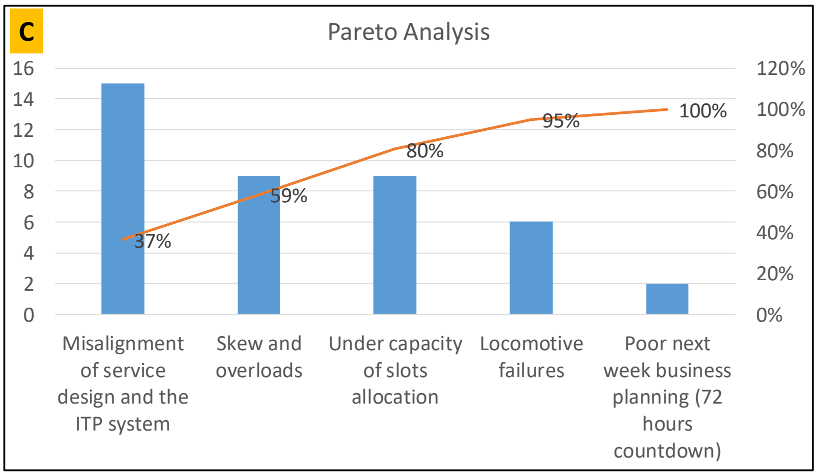


Figure-5: Pareto analysis

The 80% cause from the Pareto diagram presents a good input into the FMEA. The key to risk prioritization in FMEA is the calculation of the risk priority number (RPN), to determine the cause that poses more risk to the entire system.

FMEA is a well-established method for safety and reliability analysis of systems, or product improvement of systems in aerospace, nuclear, electronic, and automotive industries [31]. FMEA aims to assess the risk involved in the occurrence of hazards and undertake measures to control or eliminate it, primarily about hazards relevant for the railway system as shown in Table 3 [49]. The output from this process will then be an input to the FTA based on the RPN priority.

FMEA RPN calculated as follows:

Table-2: FMEA RPN calculations [3], [5].

Failure Mode Effect Analysis			
RPN(Risk Priority Number)=(Product of)	Severity	Probability of Occurrence	Probability of Detection
Rate	1-10	1-10	1-10
Meaning	10- Most serve	10- Highest Probability	10- Lowest probability

Table 3 shows the inputs of the Pareto analysis in the FMEA process and the ranking according to the RPN index.

TableError! Use the Home tab to apply 0 to the text that you want to appear here.**-3: FMEA**

Process Function	Potential Failure Mode	Potential Effect(s) of Failure	Sev	Potential Cause(s)/ Mechanism(s) of Failure	Occur	Current Process Controls	Detect	Total RPN	#Rank
			Rate 1-10 10 = Most servere		Rate 1-10 10 = Highest Probabiity		Rate 1-10 10 = Lowest Probability		
Misalignment of service design and the ITP system	Systems and actual process not aligned	Shortage of train/Long waiting time for train to be available	5	Planning not done properly/Plannin g process not followed	4	N/A	4	80	2
Skew and overloads	Unbalnced wagons	Derailment	9	Poor loading standards	2	Load Inspection before dispatch	6	108	3
Under capacity of slots allocation	No train available to collect loads	Paying fines to the customer/Hr lost	8	Poor long term planning and process control	7	N/A	3	168	1

The output of Table 3 is used as the input into fault tree analysis (FTA). FTA is a graphical representation of all the basic events that can cause an undesired event in a process or system. A fault tree describes the logical relation between basic events that can lead the system to a faulty state [4]. The output from this process will then be an input to the PDCA to develop improvement strategies to reduce the repetition of the same faults.

FTA has been applied in a different industry to perform different tasks, from medicine, police accident investigation, railway crossing safety, and reliability engineering. The method presents a vital tool that goes deep into the faults to understand the causes of the main fault. In the proposed framework the ranked output from the FMEA feeds into the FTA, where risk propagation is performed and visualized as shown in Figure 6.

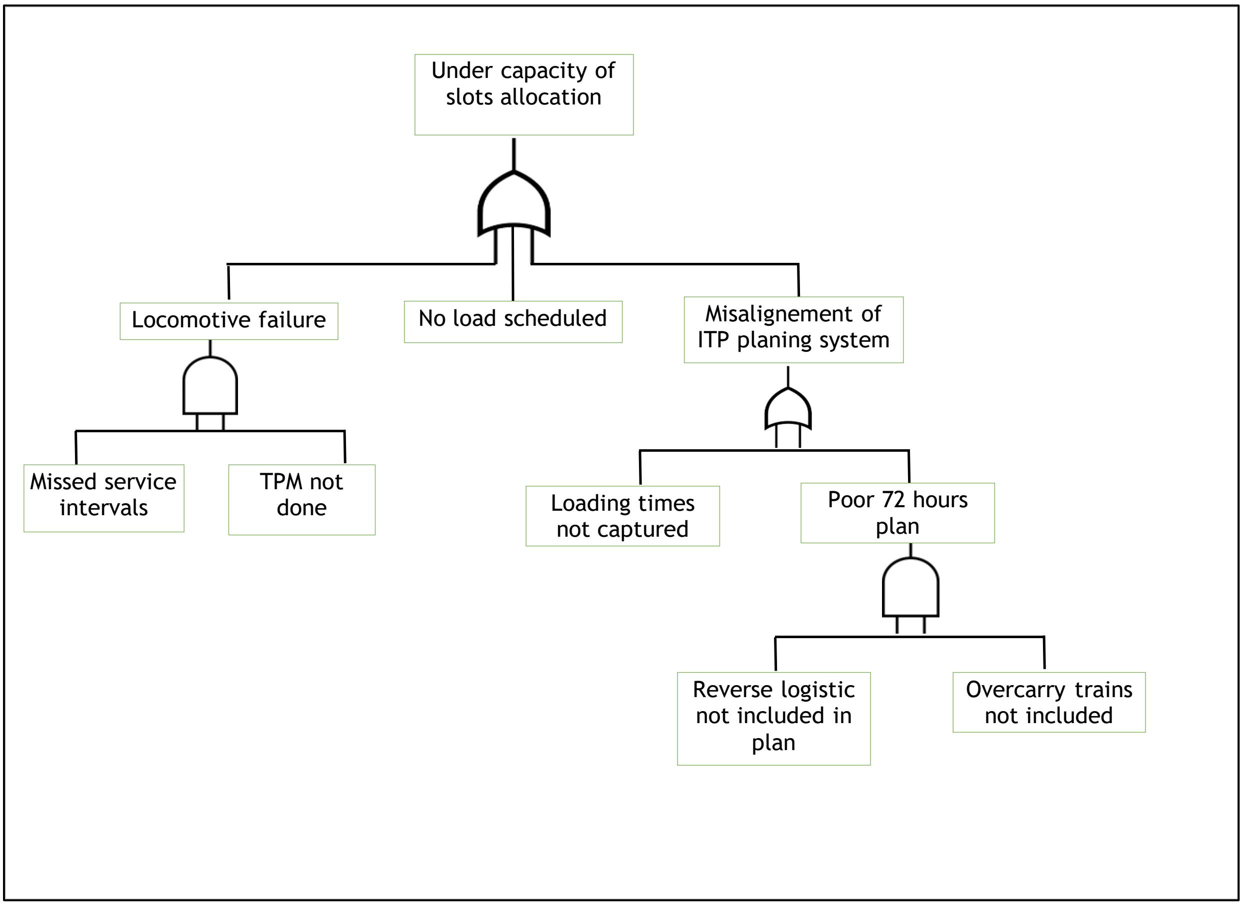


Figure-6: Fault Tree Analysis

As shown in Figure 6, the FTA results will be input to the PDCA, the FTA provide a guide for the PDCA as it looks at the cause of the faults that are already broken down. PDCA can now be developed and test solutions. Plan-Do-Check-Act-(PDCA) involves identifying a goal or purpose or a problem in the proposed framework, the problem is already identified and its propagation path is clarified by FTA, PDCA can start by formulating a theory, defining success metrics, and putting a plan into action. [37].

PDCA approach is used worldwide due to its simplicity and can be used by people on different levels in the company. However, some techniques are more complex which require a large investment in training and development [46]. The PDCA cycle is a fundamental concept of continuous improvement processes and provides opportunities for shop-floor improvement drive. The cyclic nature of PDCA is critical as it provides a feedback loop that always checks if the solution is working and keep improving the solution [37].

4 DISCUSSION AND CONCLUSION

4.1 Discussion

The developed hybrid SCRA framework is a tool that provides a clear systematic approach of assessing the risk that is within an SC system. By applying established tools such as Pareto, FMEA, and FTA to form the foundation of the framework provide practitioners with a structured effective tool to assess and manage supply chain risks. By incorporating PDCA in the framework it ignites the initiative to continuously improve and explore the possibility of eliminating the risks within the supply chain.

From the data available, Pareto analysis identified the significant causes of delays and the FMEA ranked them by the adverse effect they have on the system, which is the key factor that makes the formwork effective is the double ranking of the risk firstly by the Pareto and then by FMEA to determine the one with the most serves effect on the system. It was found that loading slots under capacity came as the one with the more negative effect on the system because the company has to pay money to the customer for delays, FTA played an important role to break down the problem to see that the exclusion of the over carrying loads in the planning is causing planning misalignment of loading slots and leads to delays.

4.2 Conclusion

The development of a hybrid supply chain risk assessment framework is critical to the success of rail operations in the assessment of risks within their operating environment. With the increase in the risk that SCN's are exposed to, understating risks that are within one's environment is key in the development of a sustainable supply chain. The assessment of the SCRA framework will play an important role in guiding efforts of managing risks.

Throughout the literature, as shown, the different methodologies have been implemented alone and deficiencies were identified and propose solutions presented includes a hybrid of two or more methodologies so that each method covers the deficiencies of the other, AHP was applied together with fuzzy logic to covers lack of data that affect AHP, a hybrid FTA-FPN was developed in China.

The developed hybrid supply chain risk assessment framework can be applied extensively in railway operations and manufacturing. The changing supply chain environment continues to persist and requires clear SCRM strategies to ensure success. The proposed framework is one of the tools that can be applied to enhance the management of the supply chain.

By applying a hybrid of methods is the framework presents a robust methodology to assess risk. The SCRA framework presents advantages that can be leveraged on to successfully manage risk within a SCN, the key being the two steps of Pareto analysis and FMEA that rank the risk twice to ensure that not only the significant problems are solved by the problem that has the most adverse effect of the SCN is resolved.

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USE GREEN INITIATIVES FOR MANAGEMENT OF LOGISTICS INDUSTRY

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ABSTRACT

In this case study, the warehouse was facing an impending energy crisis. Saving energy, finding and using alternative sources of energy were equally important. The potential benefits of using green initiatives may enhance the strategic process for managing movement and storing products. The purpose of this study was to discuss different approaches to save energy and delay the energy crisis as much as possible. Green and Energy Value Stream Mapping (EVSM) was an efficient approach to show areas where energy was wasted. These approaches reduced energy consumption by 25 c/kWh, which meant each manufactured product can save R4 /kWh. This study proposed Green and EVSM (GEVSM) factors to drive the future of the logistic warehouse.

Keywords: Energy efficiency, Energy Value Stream Mapping (EVSM), Green initiatives, Logistics, Warehouse handling equipment

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1 INTRODUCTION

The recovery of the world economy is moving at a slower pace than expected. The rise in energy consumption is expected to continue [12]. However, energy consumption is not the only input that determines the level of production. Although, the world may be shifting towards saving energy. Energy saving is significant to the logistics industries. Environmentally conscious industries need to save energy. The logistic industries are faced with challenges to find the best practices in managing warehouses to incorporate practices of green solutions. Using green initiatives are important for the logistic industries to save on energy bills. Therefore, these solutions were designed to contribute to improving the environment in the long-term.

Green manufacturing warehouse buildings are no longer just for business, but it is also a catalyst for innovation, finding new opportunities, and creating wealth. In this way, the logistics industry can achieve its environmental sustainability goals. Green initiatives are designed to help companies do the right thing. They seek to equip the world, to understand the upcoming opportunities and challenges, to manage changes in their environment [4].

Using renewable energy such as solar power in hot climates can reduce peak loads and avoid additional costs. With traditional buildings, material handling equipment includes conveyors, pallets, forklifts, packaging, and cranes. They have higher energy consumption, and therefore result in higher operations costs. The material handling of traditional equipment in the distribution facility accounts for more than 50% of the operating cost [2]. Many warehouses do not realise that the benefits of energy-saving solutions far exceed the operating costs of traditional equipment.

Efficient material handling design challenges warehouses to simulate the use of equipment handling through energy monitors. This is significant for saving energy costs when moving from electrical energy consumption to solar energy power. Even though solar has been criticized for being expensive, the fact has proved that solar energy is not only beneficial for the environment but also better for improving energy efficiency. The first step is to maximize energy efficiency to achieve environmental sustainability. Using these green initiatives as solutions are not only to save money but also to build brand recognition among companies. Investing in energy efficiency returns those investments in the future.

Investing in the energy-efficient movement of materials, to ensure the right amount of material, in the correct sequence, and the right condition is available, is the goal for environmentally conscious companies. The world's best product will be worthless if it cannot reach its destination. According to Glock et al. [11], material handling refers to the physical movement of materials from the point of origin to their destination, which involves lifting, picking, and moving and placing products. The effectiveness of material handling is not only about the movement of goods but also the investment of time and money to improve their material handling equipment to protect the environment. It incorporates a range of manual transportation processes that support logistics.

Greening manufacturing warehouse and traditional equipment can help to manage changes. This method helps to upgrade and replace the old industry's trucks, positioning equipment, load conveyors, stents, and support structure as an effective energy cost and fuel-saving strategy. The more materials transported, the higher the energy consumption, particularly material handling over an indefinite distance [26]. This has led to finding ways to improve energy efficiency to reduce energy consumption, including improving existing warehouse handling equipment that consumes more energy and replacing them with energy-efficient equipment.

1.1 Green energy value stream mapping

The Green and Energy Value Stream Mapping (EVSM) approach aims to reduce the non-value-added energy consumption of transportation materials. The energy used to transport materials using material handling equipment is non-value-added. These two strategies (EVSM and Green) can be integrated to reduce energy consumption [31].

EVSM is a tool developed to identify and understand the transportation of materials with an addition of the energy component to the cost. Muller et al. [21] extended the Value Stream Mapping (VSM) concept by incorporating energy consumption factors and focuses on transportation. Whereas Dewan et al. [6] described the method to maintain the original character and its inner logic. Also, Verma et al. [29] developed this method before Muller et al. [21] extended it to estimate the value of value-adding energy and non-value-added energy consumption. This method has proven to be the best tool for this purpose. As a critical tool during the assessment process, it can reveal substantial opportunities to reduce costs and improve environmental performance.

In these current tough economic times, managers of companies that support these green initiatives are becoming more eco-innovative and proactive. These companies are sensitive to the environment that creates a vision of care. Adopting these green initiatives requires several changes in the facility. Therefore, the right attitude from the management towards these green initiatives may vary, depending on how they deal with their internal characteristics.

In the past ten years, companies paid very little attention to reducing energy consumption and believed that the sustainability of the environment is a no-win proposition. There was a belief that protecting the environment will harm the companies. This created the impression that being green is a waste of money. Today, both the environment and companies can win, since new common wisdom has emerged around the globe to reconcile economic and environmental concerns. This paper aims to optimise the warehouse, mainly focusing on reducing transportation energy consumption to improve the energy efficiency of warehouse handling equipment.

2 OBJECTIVES

For this study to achieve its aims, the following should be addressed:

- Explore the importance of using green initiative practices in a warehouse.
- Identify which warehouse handling equipment has higher energy consumption.
- Reduction of energy consumption in the warehouse.

3 LITERATURE REVIEW

Improving energy efficiency, environmental performance and cost-effectiveness are some of the key challenges affecting the future competitiveness of many warehouses [14]. Previous studies have highlighted some of the company’s green initiatives. The green initiatives taken include; reducing carbon emissions in the delivery of goods and developing eco-friendlier products; saving energy; and having an environmentally conscious attitude. Low energy warehouse buildings join the energy-efficient features through an integrated warehouse design process. The main challenges of the warehouse are; energy efficiency, energy efficiency gap, energy efficiency technologies, handling equipment, and green future.

3.1 Uses of energy efficiency

Energy efficiency is regarded as doing the same work with less energy input to manage the growth of energy consumption [5]. Many manufacturing warehouses consume energy to carry out their activities. Toleikyte et al. [27], argues that companies can achieve energy saving, simply by realising all cost-effective energy-saving measures. Manufacturing warehouse managers that are effective can help to save energy by up to 30% [25] by investing capital on the green resources. Material handling equipment and transportation consume the most energy in the manufacturing warehouse. Practices of energy saving and energy efficiency equipment can reduce this consumption. Gilingham et al. [10] found that energy efficiency improvements are the most beneficial for transport. Efficient energy could save costs that would outweigh the cost of high-efficiency resources [8]. Adopting best practice techniques can help reduce the cost of distribution warehouses. Therefore, improving the energy efficiency of distribution warehouses is one of the cheapest ways to save energy.

High-efficiency resources optimise the power consumption in a manufacturing warehouse, without compromising the quality of material or goods. Materials are important for reducing power output and improving the energy efficiency of the equipment. Protecting the climate does not justify expensive investment if that is the only argument made for energy-efficient technologies. However, because increases in energy efficiency lead to more profitability, energy cost savings are gaining more attention. Müller et al. [22] claimed that energy efficiency is the most effective way to discuss climate change concerns while supporting economic growth.

Logistic industries present the best opportunity to save energy [18]. Collado et al. [3] define energy efficiency as a ratio between output and energy input. Therefore, energy efficiency seeks to reduce the energy input for the same output. These concepts support energy efficiency to save energy and promote environmental sustainability.

3.2 The gap in energy efficiency

Efficiency is a cost-effective way to minimize the resources input per output unit to ensure energy saving. As stated by Nolden et al. [23], energy efficiency can improve the performance of energy equipment. Energy efficiency has been considered as using electricity in the most cost-effective way which is especially important for high energy consumption resources. Despite the efforts made, achieving energy savings so far have been slow. Today, companies across the world are facing the challenges of increase environmental consciousness. Although the effects of energy switching conservation, changing habits, and climate. Many studies have shown that there is an urgent need to improve energy efficiency across companies. The cost-effective energy as the measures are not always implemented, and this creates the efficiency gap [20].

Based on the engineering economic analysis, efficiency refers to the gap as the levels of investment in energy efficiency that appear to be cost-effective [9]. However, this gap for energy is expected because theoretical energy consumption only incorporates handling equipment. These gaps remain between current knowledge and the implementation of energy efficiency measures by the movement of handling equipment. Furthermore, the performance gap is caused not only by energy-saving but also by the design of handling equipment. Thus, the potential for greater energy efficiency, particularly in logistic transport is concerned with savings and better performance. Zhang et al. [31] defined the optimal level of investments, technologies taken up by industry. Thus, this asserted gap exists between energy efficiency and investments. Therefore, bridging the performance gap of energy efficiency is needed to support an energy transition towards cleaner energy sources.

3.3 Energy efficiency technologies

The adoption of technologies that reduce energy consumption by reducing energy intensity is achieved by investing in technologies or material handling equipment that optimize energy efficiency to save energy. However, more efficient use of energy at all the phases of the logistic chain could reduce the negative impacts of energy consumption. The use of energy efficiency technologies has evolved significantly in the last decade. Although, many approaches to energy efficiency involve significant capital for its use. New energy-saving technologies usually have a longer payback period than traditional equipment. Furthermore, the way these technologies are used can have a significant impact on their effectiveness. Moreover, there is that with the adoption of distribution warehouses, the company has underinvested in energy-saving technologies. But it would invest in proven energy technologies to reduce energy consumption.

Uusitalo et al. [28] discuss technologies that usually assist to optimise energy savings across the logistics industry. Energy-saving can be achieved by not installing new technologies but rather change how energy has been used within a facility. Accordingly, upgrading technologies of efficiency alone cannot accomplish optimal savings, but when integrated with green warehouse and green material handling equipment it can lead to significant savings [21]. Therefore, more energy-saving technologies can widen the gap, while the refinement and technologies can narrow the gap.

The implementation of solar power provides opportunities for the environment to use energy in a manner that is sustainable [16], and it also provides opportunities for industries to integrate energy efficiency practices with the existing systems. Energy use could be cut using technologies known to be cost-effective. The new energy efficiency technologies last much longer and therefore need to be replaced less often. Therefore, improving the performance of the energy-saving equipment is of great significance.

3.4 Warehouse handling equipment

Counterbalance warehouse handling equipment provided by solar power energy is a good approach for the environment and is often used nowadays. Richards [24] assert that the warehouse handling equipment regularly required changes and when possible should avoid unnecessary movement. Equipment should be provided with an energy monitor and sleep mode. However, the use of energy-efficient handling equipment for lifting and handling materials can be significant to improve distribution warehouse productivity. Using the right warehouse equipment leads to increased efficiency. Although many companies continue to use traditional equipment. Therefore, choosing the right equipment that can save cost and time is crucial.

3.5 Future green warehouse and handling equipment directions

Recently, there are many green practices in warehouse implementation. It is due to these green initiatives focused on present circumstances rather than future proposals that further green initiatives prospects. Logistic industries can protect the future and outlook forthcoming for sustainable development [17].

3.5.1 Green generation

The warehouses can be completely independent and produce energy in the future using renewable energy sources. This is the perfect approach to cut emissions and energy consumption as solar power is a clean source of energy [19]. Companies that sustainably produce their energy exceed environmentally friendly methods, but this is not yet a cost-efficient approach. Choosing to produce affordable energy is a daunting task for sustainable managers.

Previous literature has shown that improving energy efficiency improvements cannot only bring expected energy effects, such as energy savings and energy cost savings but also add effects to non-energy benefits.

4 RESEARCH METHODOLOGY

This section outlines and defines the research methodologies and methods used in this study with the explanation of what the approaches were to use green initiatives practices in the company's distribution warehouse. This had addressed the objectives of this paper. Also, the researcher added how this information was presented and analysed, with the reasons for justifying these methods selected for this paper. Various steps were taken to address the challenges faced by the company along with the support of the topic paper.

This paper has used a qualitative method as well as a phenomenon approach to show how EVSM techniques could be used in the distribution warehouse. It is an important part of the study to understand the methodological procedures applied in the company. That's where the case study came in to explore the phenomenon in context rather than in isolation. The phenomenon approach occurred in a bounded context to employ a qualitative inquiry approach to be exploratory. The theory approach has been tested because it was not done before in the company.

The selected methodology of this paper was an intrinsic case study. This case study method was used due to its capacity for the challenges of the company. This paper approach links to the case study design involving energy efficiency in the literature. The strategy used by this paper is typical of emerging, new researchers as it lacks rigour when is compared with other research methods. This is the major reason for being extra careful to articulate research design and implementation. On the other hand, it is widely used because it offers insight that might not be achieved with other approaches. This case study approach uses the EVSM technique to collect energy value data records. This was recorded on an information sheet. This could not be possible with another alternative approach. Harrisson et al. [13] define a case study as a bounded context to describe a phenomenon. Yin [30] notes case study research cannot directly manipulate. Therefore, the context of the case is the most important factor in designing case study research.

The EVSM technique has been used in many studies. Not much has been done in the distribution warehouse. This paper has been used to analyse the outcomes of future scenarios to improve transportation processes. However, the technique aimed to improve energy efficiency and sustainability in the distribution warehouse. Although, the paper qualitative intrinsic case study approach uses the energy values to improve the companies challenges.

4.1 Single case approach

A single case approach was chosen to be the most appropriate method for improving energy efficiency. This approach has placed the researcher in the context of interest aligned to a single case approach. The case study was taken to collect the energy value given by the company in the case organization. It was not conducted to represent all other companies using the EVSM technique.

Company A is one of the leading flooring manufacturers. They offer a diverse portfolio of PVE-based products, such as floor and wall coverings. Company A aimed to reduce their daily energy consumption of material handling equipment by 30%. The researcher started to demonstrate to the company the efforts to use green solutions to grow their revenue in the existing distribution warehouse by the end of 2020.

The researcher in this paper played a role as an active participant to show the demonstration of using the EVSM technique to the company. The study was demonstrated under supervision through structured observation. This source was instrumental in gathering energy values to find solutions. Even though the recorded data value was collected through the available value of the transportation process. The energy value data was recorded to the EVSM technique for analysing. Company A was selected for this paper because of its reputation as a high energy consumption company. It was agreed, the identity of the company would not be revealed. Thus it is known as company A.

The handling equipment for transporting the pieces from manufacturing to the distributions warehouse where the final product is to be stored was investigated. In Figure 1, energy components are added to understand the impact of energy on every product. Company A had a cost 25 c/kWh for transport energy consumption and a total energy consumption cost of R20 /kWh for each production unit shown in Figure 1 below.

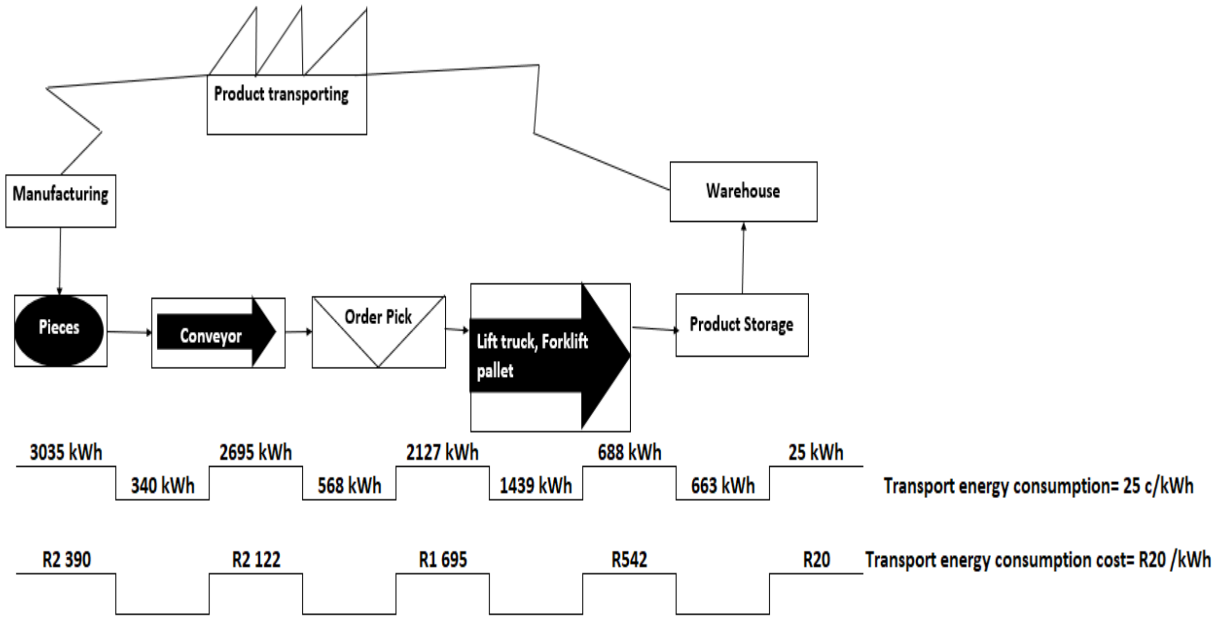

Figure 1: Current state EVSM for warehouse [29]

5 RESULT AND DISCUSSION

This section states the findings of the study. Which presents results and discusses with the reference to the aim of this study to use these energy value data effectively. This result of using EVSM and Green solution overcomes the company A energy-saving challenge.

EVSM has been developed by adding energy components in addition to the cost in VSM. The VSM technique identifies the level of energy that was used in each step to decide the new opportunities for energy efficiency.

EVSM technique is used to analyse the outcomes for future scenarios in an improvement option. This method is to study energy, and cost consumption of the transportation processes to get a baseline. The technique aims to analyse the energy consumption of each transportation process. It measured the energy and electricity for each sequence of the operation.

The future energy value stream map is shown in Figure 2 it is the planned energy efficiency improvement to meet the goal.

It was discovered that the installation of solar panel arrays on the rooftop had decreased both energy and cost demand consumption with 0.8% cost, and 3.5% energy. Through the use of EVSM, the energy demand has decreased from 25 c/kWh to 0 c/kWh after minor changes. Solar energy reduces electricity demand by R4/kWh. This translates to its reduction from R20 to R16 per manufactured product. The concept of this EVSM analysis was used to elaborate energy transport processes and analyse the input and output energies in manufacturing.

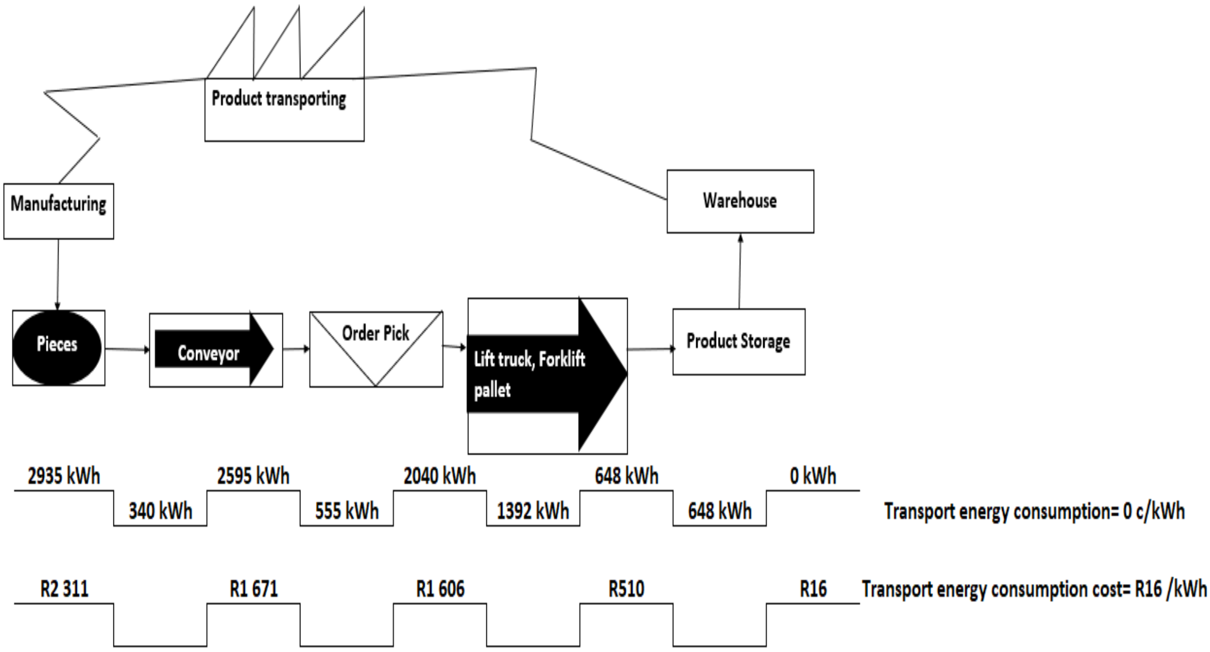

Figure 2: Future state EVSM for warehouse process [29]

Most industries have a rigorous energy efficiency goal. The future EVSM has drawn for an improvement. A lot of energy is wasted on transporting the products.

5.1 The root cause of green wastes

The cause-and-effect technique is used to uncover the energy used in the transport of products. To find where the causes of the problems in energy consumption lie. This analysis used brainstorming of visual representation to enable problem-solving to lower the warehouse energy bill, involving only the energy used in transportation. Figure 3 shows the factors affecting warehouse green wastes.

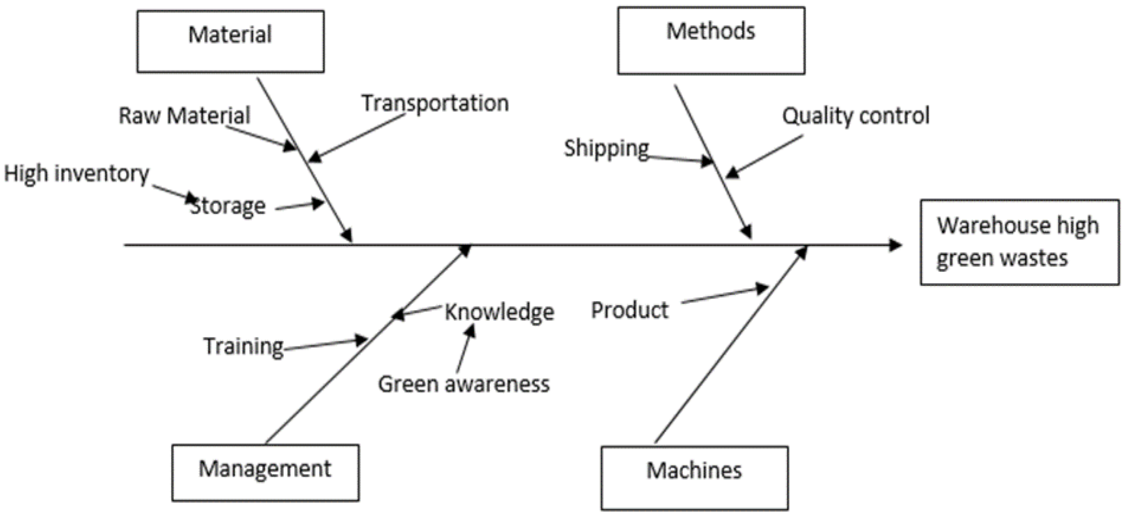

Figure 3: The root cause of green waste in the warehouse

The green wastes effect on the warehouse was determined by using extended VSM such as EVSM during unique processes [21]. However, converting the losses from material to transportation and energy consumption to one unit of measurement such as carbon footprint helps in understanding carbon emissions. This could help in prioritising the strategies to reduce the large carbon emissions by focusing on the processes that produce large amounts of carbon emissions. The cause-and-effect diagram categories have been discussed below.

Machines: After pieces of materials have been manufactured from different machines. The product is then moved and placed ready to be picked by warehouse handling equipment.

Materials: The raw material in the machine is then transported by conveyors. The product is moved by handling equipment required to be stored or placed in a warehouse.

Methods: The products that are in good quality are shipped-out of the warehouse for logistic purposes.

Management: Lack of training and knowledge was found to result in higher energy consumption in the warehouse. Green awareness is the best solution for logistic industries to reduce energy demand consumption.

The techniques of integrating Green and EVSM have been successfully piloted in an industry. Under a green warehouse, a continuous strategy improvement, using the PDCA cycle in Figure 4, was developed during green approaches with the traditional VSM has improved the company's green performance. It is an iterative, four-phased approach for continually improving energy consumption processes. This tool can help to solve problems more efficiently. PDCA is significant because it stimulates continuous energy efficiency improvement through transportation processes in the warehouse.

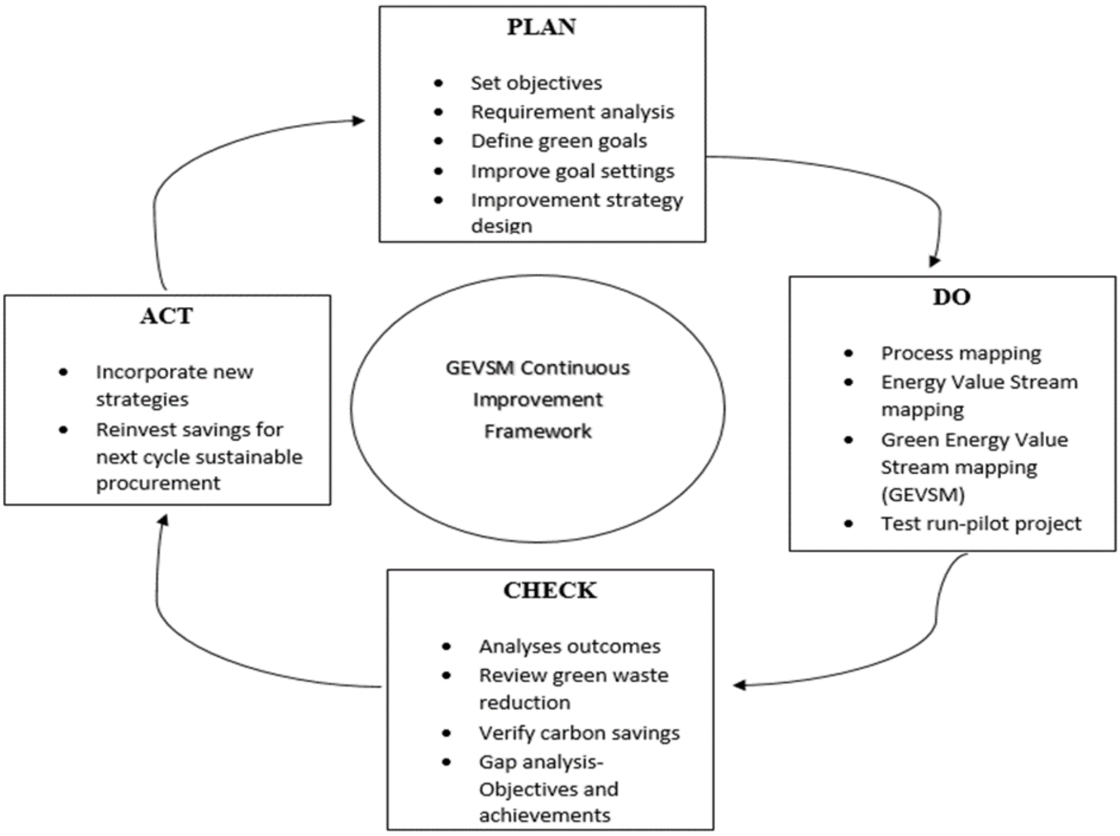

Figure 4: Future GEVSM of product transport process

6 RECOMMENDATION

The recommendations of this paper were directed to the case study company to solve energy consumption using the EVSM technique to save future energy. The above results clearly show the kind of cost and energy saving which can be made, by small changes, in the process flow. Thus, designing cost and energy-efficient EVSM becomes very important in today's scenarios. With the help of this new or extended VSM and green warehouse, the system can be improved.

This study seeks to use green solutions practices in the warehouse as the best approach to answer these research objectives to solve these challenges. EVSM is a very common technique identifying the present state and future state of transportation energy used. Green warehouse

In the warmer climate, warehouses could look to the sun as a solution for power. Incorporating a rooftop solar power array, which could generate a significant part of the warehouse energy. With over 1000 arrays of solar panels installed on the rooftop. Solar energy could generate 560 000 kilowatts energy, equivalent to 100 South African companies yearly [7].

6.1 Power play

Companies with power peak usage need to change the use of equipment such as lift trucks and forklifts during off-peak hours. This spread energy usage throughout the day. So, energy spread is used over each work shift.

6.2 Conveyor

The conveyors could be equipped with intelligent energy management. The equipment benefits from energy control applied to an incremental energy power reduction process. Which switches between the stop and four levels of different standby modes. This prevents machines from consuming more solar power energy.

Upgraded conveyor drives roller to a low-voltage motor with multiple speed settings. The conveyor with a slower speed reduces energy usage. Replace assemblies of a traditional pulley motor with an energy-efficient drum motor that reduces energy usage.

6.3 Pallets

The pallets that are from wood by-products are around 60% lighter than the hardwood [1]. Thus, energy, transportation, and handling equipment cost can be reduced. Warehouse pallets from wood by-products prevent millions of scraped woods from ending in a landfill.

6.4 Green footprint tracking

The adoption of these green initiatives establishes a performance baseline to track results. Spread the power usage out and reduce the peak use of conveyors. This strategy is to reduce the power usage spikes and lower energy within the cost range.

Introducing a sleep-mode for handling equipment lowers energy consumption. Running conveyors at full speed is unnecessary, and it wastes energy. At increased speed, more maintenance is required. Conveyors program time out when no loading occurs. This involves the recharging of lift trucks batteries in the warehouse.

This study recommends the path of reducing energy consumption to improve energy efficiency. Universally it is known that it is critical to reducing energy consumption for instance; slowing speed settings on conveyor components, adding sleep-mode to equipment, and shutting the conveyor if there is no load. Industrial trucks and conveyors are one of the biggest energy users in warehouses. Internationally there is an awareness of the importance to reduce energy consumption using technology that requires the energy that is less to operate the same function. According to the International Energy Agency, suggested transportation could reduce the needs of the world's energy by one third in 2050 and help control CO2 emissions produced in warehouses [15]. Another important solution is to remove subsidies from each government-led energy that promotes high energy consumption and the use of energy-efficiently [14].

7 CONCLUSION

This paper proves that EVSM techniques can be used to improve the energy-saving created for this company. It has been shown to the company that this technique and green initiative can reduce energy consumption for warehouse handling equipment. The results showed cost savings with minor changes in the warehouse handling equipment. Therefore, in this case study, EVSM has become a very important technique. With the help of the new GEVSM, Green, and EVSM, energy consumptions had been reduced. This extends the literature on energy efficiency and environmental sustainability. EVSM, an effective technique is important to reduce transportations non-value-added energy consumption. It has increased knowledge of the company and the structured observation of the case. These approaches used for this paper based on company A were very effective for the energy saving of warehouse handling equipment. This study provided a simple picture of this technique; it is not only for diagnostic purposes but also for energy-saving measures and budgeting also. Any warehouse can use this technique to further research improvements.

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SYSTEM DYNAMICS MODELLING OF GREEN SUPPLY CHAIN

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ABSTRACT

There is an emerging concern about pharmaceutical waste management and it has become necessary to green the supply chain by correctly disposing of expired drugs and reducing levels of preventable pharmaceutical waste. There are issues of returns and recalls that pharmaceutical companies face and a proper system should be in place for such instances.Sustainability is required in pharmaceutical sector therefore organizations in South Africa should start applying green principles by moving from reactive monitoring of general environment to proactive practices such as reverse logistics particulary post consumption of drugs in order to raise ecological efficiency. This study uses the system dynamics approach to illustrate and investigate the effects of reverse logistics on return of unused drugs for correct disposal and the effects of illegal dumping on environment. At the same time, to understand the dynamic interactions between elements of the drug disposal system through development of casual loop diagrams.

Keywords: Reverse Logistics, Green Supply Chain, System dynamics.

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1 INTRODUCTION AND BACKGROUND

Environmental awareness has increased due to the emergence of the fourth industrial revolution and this has pushed organizations to adapt to the shifting environment in areas such as supply chain [1]. Green supply chain management (GSCM) has many facets and can be viewed as green procurement or an encompassment of more fields such as manufacturing processes, consumers and external suppliers [2]. GSCM includes incorporating the green element into the product life cycle, designing, manufacturing, distribution and reusing the product. "Going green" is an integration of environmentally friendly activities into an organisation with the purpose of improving sustainability [1]. The notion of GSCM emerged in 1980s and it consist of incorporating green principles such as recycling, reverse logistics, remanufacturing as well as other innovations within the organisation's supply chain in the monitoring of environmental management programmes [3]. To mitigate challenges facing the environment such as pollution and energy consumption, effective greening of supply chain is vital. However, this is dependent on the balancing of market performance with environmental issues [4]. GSCM ranges all the way through the value chain from the product design phase to the end of life of the product and lastly to the recycling and product disposal [5].

Despite having disposal protocols in place here in South Africa, studies have shown that there are pharmaceutical drugs present in the environment and surface water [6]. There need to put in place a drug disposal system for monitoring the disposal of drug waste from households. Reverse logistics and green supply chain activities can help reduce wrong disposal of these drugs by providing drug take backs programs in the community, creating awareness within the community that all ununsed drugs can be taken back to the pharmacies where they can be collected and be disposed of in a correct manner [7] .

This paper seeks to incorporate one of the Green principles (reverse logistics) into the pharmaceutical supply chain in South Africa with special interest in the disposal of pharmaceutical drug waste. The aim of the paper is to;

1. Investigate the effects of reverse logistics on return of unused drugs for correct disposal.
2. Investigate how reverse logistics eliviate the problem of illegal dumping.

System dynamics modelling is used to illustrate the relationship between the environment and the disposal of medicines outside the regulations of the Department of Health and how reverse logistics can help reduce these dire effects on the environment.

2 LITERATURE REVIEW

Awareness of issues related to post consumer or End-of-Life pharmaceutical disposal management in South Africa is on the increase and has brought about more challenging and related issues in the management stream [6]. Different policies have been put in place, but still some of these challenging issues remain and pose hindrance to drug disposal management.

2.1 Effects of pharmaceutical drug waste on the environment

Worldwide, water resources are under persistent threat of being contaminated by a wide range of manufactured chemicals which can cause severe effects on human and animal health [6]. Waste Water Treatment works have an obligation to provide clean water to the population however, they face great obstacles to improve sanitation services throughout the country [6]. Removal of pathogens and pollutants from surface water aids the efficient operation of waste water treatment works (WWTWs). The goal of any WWTW is to ensure that water quality is at its maximum so as to ensure good health to the people that depend on those resources therefore all WWTWs should follow high operating standards. In the past, the effects of pharmaceutical traces in water were not perceived as threat to human and marine life. Recent studies have shown that pharmaceutical & personal care products (PPCPs) contributed more to water toxicity than traditional pollutants [7]. Researchers now believe that PPCPs in the environment can pose significant consequences on the effectiveness of ecosystems. This risk coupled with the increase in pharmaceutical misuse, could have dire consequences if no action is taken to mitigate this immediately [8].

Adherance to drug disposal is experienced at medical instutitutions but not much is done at household level. Approximately, 52% of population in Jonhannesburg throw medication away in the trash and 34% flush it or throw it into the sink as a means of drug disposal [8]. This process of illegal/wrong disposal of unwanted drugs results in these products finding their way into waste treatment plants. Some of the treatment methods do not completely remove these contaminats from the water and this poses a danger to human and the environment. Research has shown that most of the people are not aware of take back programs which facilitates the return of any unwanted drugs for proper disposal [7]. Therefore there is a need to strengthen regulation to prevent illegal dumping of drugs.

2.1.1 Studies on Pharmaceutical waste products on South Africa's environment

According to Archer [6], information concerning the presence of pharamaceutcal toxins in the environment is still limited however, the few studies that have been done confirmed the presence of pharmaceuticals with their corresponding percentage contribution. From these studies, it was revealed that contaminants are still being detected after undergoing the treatment process. These trends that reveal the presence of contaminants after wastewater treatment are also recorded worldwide for PPCPs [8], [9]. Such contaminants will end up back in the environment, or in drinking water and will affect both people and wildlife if they are not completely removed as shown in the reports by Archer [6]. This emphasizes the need to conduct comprehensive monitoring studies in South African surface water systems to report on the fate levels of pharmaceuticals and their effect on humans. However, this is a reactive measure but a more proactive measure is required which is to green the supply chain and include activities like recycling, remanufacturing, green procurement, reverse logistics etc [2].

2.1.2 Legislation in South Africa for disposal of pharmaceutical waste

According to Hoffmann [9] under The South African Pharmacy Council, pharmacists have the responsibility to ensure there is a system in place to manage the uncollected, spoilt, damaged and incorrect medicines. The minimum standards regarding destruction and disposal of medicines and scheduled substances according to the South African Pharmacy Council is as follows;

- Destruction of medicines and scheduled substances takes place in accordance with Medicines and Related Substances Act (Act 101 of 1965) and other applicable legislation.
- Under Act 101 of 1965, all medicines should be destroyed in a manner that does not allow retrieval, recovery and must not end up in municipal sewage systems or landfills [11].

2.2 Pharmaceutical supply chain

Pharmaceutical industry consists of processes, organizations and operations which are involved in the development, design and manufacture of useful pharmaceutical drugs [10]. Pharmaceutical Supply Chain (PSC) is one in which there is drug research, development, production, transportation and consumption [11]. Pharmaceutical operations produces high levels of hazardous waste which have substantial impact on environment [12]. Policy makers have started to emphasise the implementation of green operations due to the escalation of environmental awareness all over the world [11]. Disposal of unused/expired medication can be hazardous to the environment and with the increasing attention of pharmaceutical waste management, it is important to green the supply chain [13]. This is done by the correct disposal of unused medication and by decreasing the level of preventable pharmaceutical waste [13].

2.3 Green Supply Chain Management Intiatives

Incorporation of environmentally friendly practices into the organisation is what is meant by the term "going green" [4]. Greening the supply chain can be defined as the ability of a supply chain to balance marketing performance with issues pertaining to the environment [4]. Green Supply Chain Management is evolving towards more proactive practices such as remanufacturing, reverse logistics, reclamation and recycling [2].

2.3.1 Reverse Logistics

Logistics providers or other third parties can play a important role in the collection of pharmaceutical waste (expired/ unused medications) from community pharmacies and the transportation to designated places for disposal [11]. The design of a reverse logistics network can be challenging especially in the pharmaceutical industry due to high levels of unpredictability of the supply chain [14]. Businesses also undertake various initiatives in this field for reasons such as reducing the costs of reverse logistics activities, respectability, legal obligations and environmental responsibility [15].

2.4 Simulation Method

Frequently used dynamic modelling systems are System Dynamics (SD) [16], Agent-Based Simulation (ABS) [17] and Discrete Event simulation (DES) [18]. The selection criteria of modelling method depends mostly on the purpose of the model than the system being modelled although others argue that it is depend on preference of the modeller [19].

According to Lane [20], SD models are holistic and emphasis is on dynamic complexity between elements. DES models are more analytical and emphasis is on detail complexity [20]. In order to choose the right method, the objectives of the simulation should be defined because the problem should determine the method used. This paper will model pharmaceutical drug disposal system and effects of reverse logistics on illegal dumping. The purpose of the model requires SD approach as it can be used qualitatively and has strong links with problem structuring approach of causal diagrams. SD is used at a more strategic level to gain insights on interrelations between parts in a complex system and to support policy analysis and decision making [19]. In this study SD seems to be a good method for simulation prefred over ABS and DES.

2.4.1 Time horizon determination

Forrester [21] argues that time horizon for a model should be related to the problem under study and the potential decisions that are being deliberated on. He went further to say if the model is for prediction purposes, then a longer period may be required so that the transient behaviour can be observed. For purposes of this study, a simulation period of 50 years was chosen.

2.4.2 Description of important parameters in SD model

From literature the following variables were discovered to be of major effect on the disposal of expired medications. Aquino et al [7] identified the variables below as parameters that interrelate in a pharmaceutical diposal system.

Table 1: Description of important paramets used in the System Dynamic (SD) model

Sources	Variable	Description
[7]	Regulation	Legislative standard for proper drug disposal system management
[7]	Motivation to manage waste	The reason dispose of unused/expired appropriately, illustrate with the graph function
[7]	Illegal dumping/disposal	Wrong disposal of expired/unused drugs that end up in the sewer system and environment
[22]	Environment Contamination/stress	Strain on environment caused by illegally dumping pharmaceutical products into the environment
[7], [23]	Return of drugs (RL)	System of returning unused/expired drugs back to pharmacies or any medical institution for proper disposal
[7]	Collected Returns	Accumulated returns of expired/unused drugs that have been returned and stored awaiting proper disposal by the municipalities
[7]	Illegally dumped waste	Accumulation of illegally dumped pharmaceutical products in the environment

3 METHODOLOGY

A structured methodology is followed

The solution of the problem follows the procedure as outlined and Figure 1 expands on the methodology this research will undertake:

(a) Development of a causal diagram

(b) Development of the corresponding stock and flow diagram

(c) Development of a model

(d) Simulation of the model

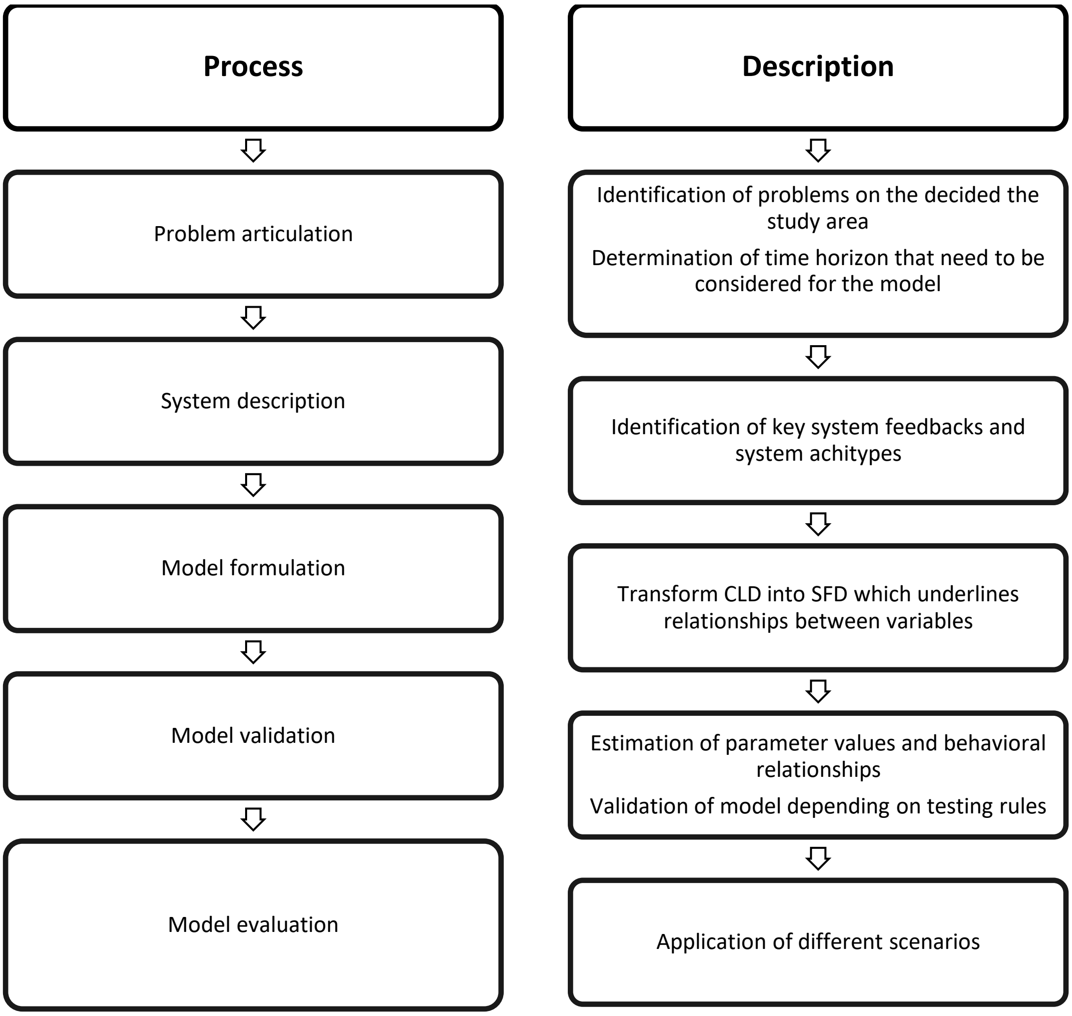


Figure 1: Methodology Process Flow

Using System dynamics approach, while analysing the structure of a system and developing the system, leads people to think critically about the problems they face. The most important one is that with a system dynamics approach, a person can establish a mental link between the structure of the system and the behaviour achieved as a result of the system. The system can be defined as a series of interconnected components that are consistently organized to achieve something [24]. System dynamics is an approach that aims to understand complex systems and develop policies that allow them to be changed in the desired direction. It deals with feedback and delayed responses that affect system behaviour. System thinking is an approach that takes into account all aspects from a wide perspective and focuses on the relationships between different parts of the problem.

3.1 System dynamic model development

Causal loop diagrams are an effective tool to show the feedback structure of the system. Loop diagrams consist of variables linked by arrows that show causal effects. Arrows show the relationship between the variables. The arrows on the arrows indicate the direction of the relationship between the variables. System Analysis discovers structures within the organisation in systems and it develops perceptions into the organization of causalities. System analysis identifies a problem and rearrange it in order to understand the various components and feedback relationships [25]. Group modelling is part of systems analysis where the problem is identified and casual loop diagrams are developed to refelect that problem [25].

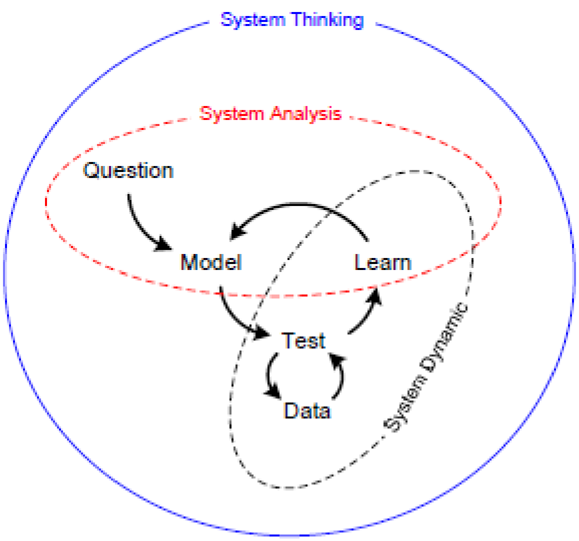


Figure 2: System Analyis [25]

3.1.1 Articulation of problem

Systems Analysis starts by defining problem statement which in this case is the process of disposal of domestic pharmaceutical waste excluding disposal at medical institutions and organisations and the effects on environment. Awareness of issues related to post consumer or End-of-Life pharmaceutical disposal management in South Africa is on the increase and has brought about more challenging and related issues in the management stream [6] . Different policies have been put in place, but still some of these challenging issues remain and pose hindrance to drug disposal management.

3.1.2 Casual loop diagrams (CLD)

In relation to System Dynamics, in order to disclose and reveal the relationships of various systems, causal loop diagrams (CLD) were applied. CLDs can be utilized to understand how a certain behavior or pattern has been manifesting, with this knowledge strategies can be developed to mitigate this behavior [25]. CLDs describes the system in casualties (i.e., cause-and-effect) relationship [16].In this study, CLDs were applied to demonstrate the relationship through cause and effect loops and connecting variables in the pharmaceutical waste management system, the degree of interconnectivity, the dynamic impact on the environment and how Reverse Logistics plays into this relationship. The terminology used in CLD, positive (+) or negative (–) sign at arrow heads are indicative of positive or negative causal influence connecting any two variables. The positive (+) sign symbolizes a causal relationship in which the variables change in the same direction, whereas the minus (-) sign symbolizes a relationship in which a change in one variable is in the opposite of the other variable. For example, a positive (+) sign linking illegal dumping and environment contamination with Emerging Contaminants (EC) and Endocrine Disrupting Contaminants (EDC) illustrates that an increase in illegal dumping would cause an increase in Environment contaminants and the reverse is true. Furthermore, the negative (-) sign linking Reverse Logistics and illegal dumping illustrates that a decrease in decrease in Reverse logistics would cause an increase in illegal dumping and the reverse is true. The CLD developed in this study is a conceptual model that identified various aspects of post-consumer pharmaceutical waste management particularly from households system and their dynamic interactions, the feedback loops were developed by the dynamics of the CLD model presented in Figure 3.

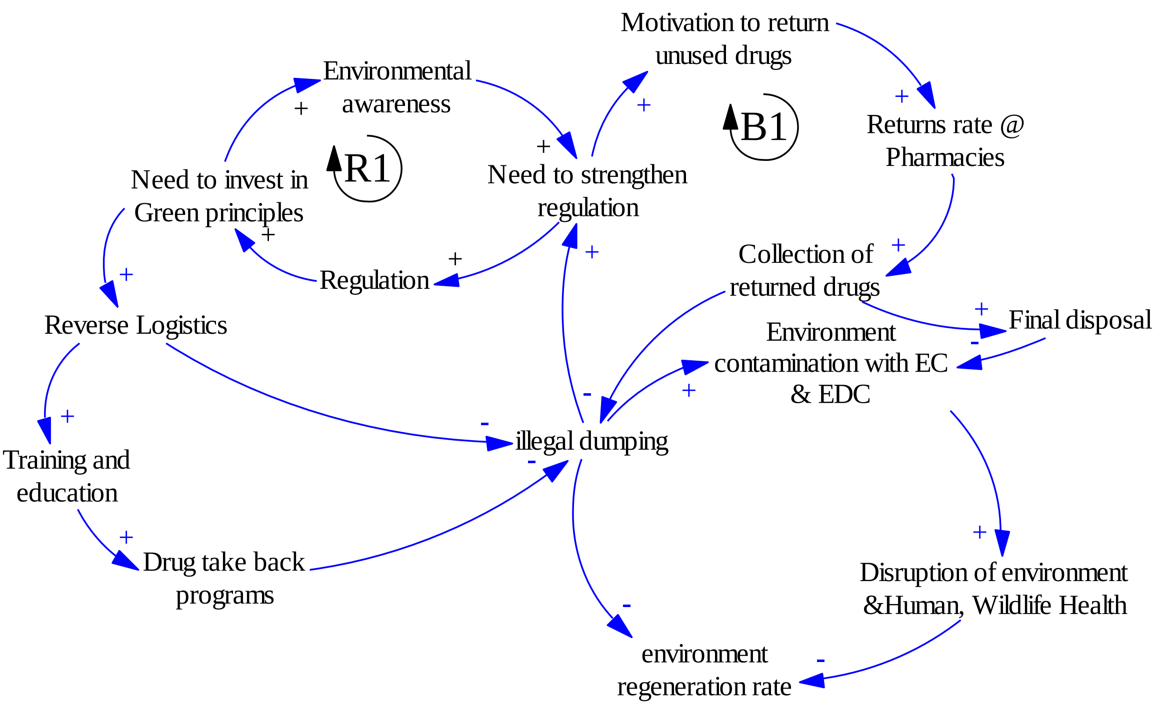


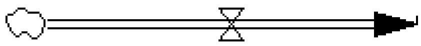
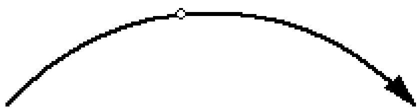
Figure 3: CLD for drug disposal management system

In a system structure, feedback loop is that which causes output from one variable to eventually have an effect as an input to that same variable [25]. They can have a positive influence and this is called reinforcing effect. An example of a reinforcing feedback is R1 from figure 3. Negative feedback loops have a balancing effect on the behaviour of the system and B1 is an example of a balancing feedback loop [25]. From the CLD , R1 and B1 are the only feedback loops discovered.

3.1.3 Stock and Flow Diagram (SFD)

Management of pharmaceutical waste in this case expired/unused medicines and drugs is affected by various interdependent activities. These activities were derived from literature and are complex and dynamic in nature. This knowledge is based on the principles of pharmaceutical waste and post consumer management. Dynamic evaluation of the model and simulation of post consumer disposal of expired/unused pharmaceutical drugs was performed by Vensim ple. Vensim ple software is a system dynamics tool that offers valuable ways to communicate with a visual or mental image in terms of system thinking how intricate ideas and systems work together. Table 2 shows the main tools used in Vensim ple modelling environment for the development of a model and the corresponding descriptions. These tools are stocks,flows and connectors. The resultant stock and flow diagram to the CLD illustrated in Figure 3 is shown in Figure 4.The variables described in Figure 3 must be conveyed into mathematical system equations inorder to simulate the model. The stock and flow diagram contains the essential details that enable the model to be simulated. Inorder to fully comprehend the model, all assumptions and initial values are given in Table 2.

Table 2: Structural components in a Stock and Flow diagram(SFD) [26]

Structural components	**Symbol**	**Function**
Stock		Denoted by a rectangular shape, which is the main source of where the flow comes out and also it will accumulate all the in-flows.
Flow		Information flow will either be inflow which is a positive flow or a drain (negative flow) into the stock. The boundary of the model is being indicated by the cloud symbol at the end of the flow.
Connector		It is an arrow shows the casualities (causes and effects) of the model

In order to transform the CLD into a Stock and Flow diagram, stocks and flows need to be identified from the CLD. Regulation, Amount of waste generated, Collected returns, Environmental Quality and Illegally disposed waste were identified as stocks. Flows act as connectors of stocks and they can either increase any stock that they flow into or decrease stocks they flow out of. Using this information, the CLD is then transformed into SFD model.

3.2 Definition of Elements and Assumptions

3.2.1 Model variable estimations

It is critical to first explain the underlying assumptions to gain insights on the modelling process before continuing to the validation and testing of the model. Regulation means the stated guidelines by the government for post consumer pharmaceutical medication management. In this case it encompasses proper mesures to dispose all unwanted drugs, measures to mitigate illegal dumping.In this study, an assumption was made that illegal dumping will gradually improve as local authorities enforce regulation measure on the pharmacies.Regulation was set with minimum value 0 an maximum 6, where the latter is the best case scenario and 0 the worst.

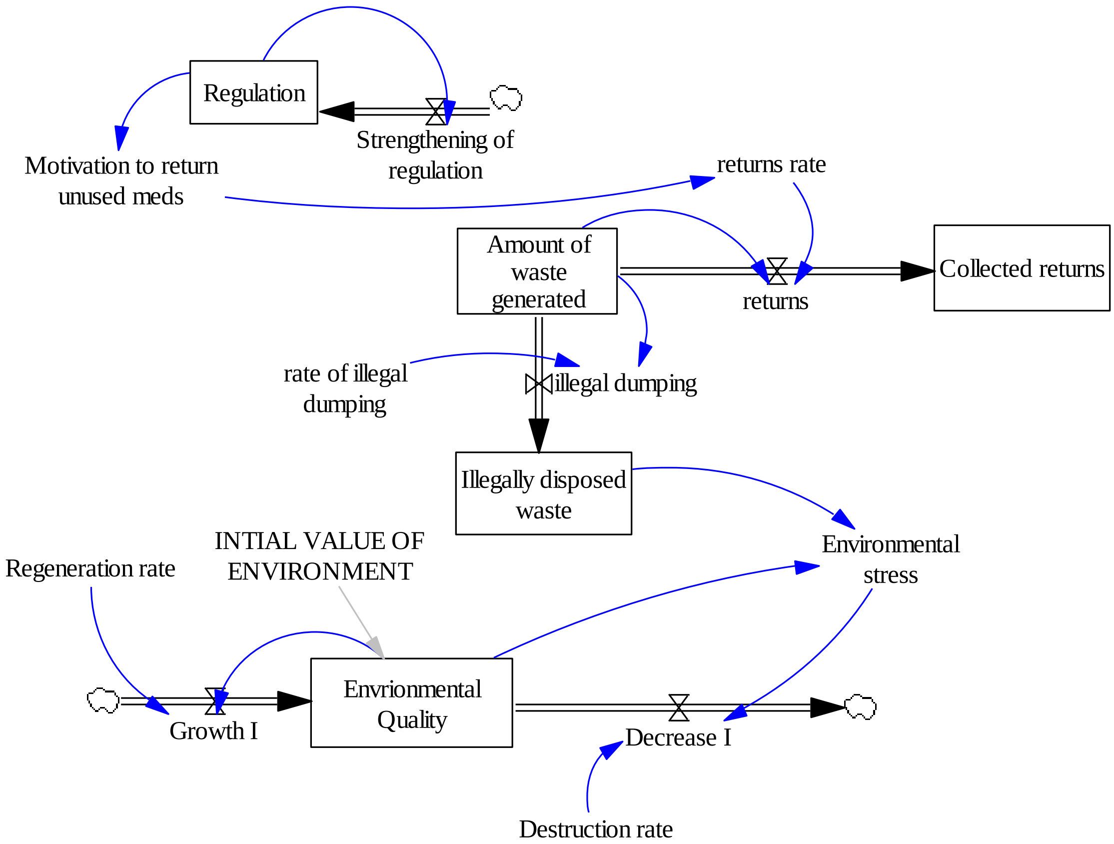


Figure 4: Stock and Flow diagram for pharmaceutical disposal and its effect on environment.

3.3 Discussions Simulation Results

3.3.1 Validation of the model

Table 2 described all assumptions and variables used in the model. However, it is important to verify if all the assumptions made are correct and reasonable with respect to the objectives of the study. Therefore, testing and validating the model was an important step in order to gain confidence in the reliability of the model's output. The validation process was performed using techniques by Sterman [27] and Ford [28]. Three tests were performed namely model verification, boundary and structure tests and dimensional consistency tests.

(a) Model verification is a process of cross checking if the model has all important assumptions that represent the objectives of the study. In order to do this, variables in the CLD were checked if they are consistent with the SD model. This test revealed that the objectives of the study.

(b) In order to test and confirm logic and the important structure of the model, a test called boundary and structural validation was performed. To achieve this, the CLD and SDs model were compared with pharmaceutical disposal systems from literature [8], [7]. This process revealed that the feedback loops and causal chains demonstrated in both the CLD and the SDs model were based upon accredited knowledge in pharmaceutical waste management.

(c) Unit check or Dimensional consistent tests require that all measurement units in the model obeyed physical laws.

Subsequently simulation of the model then followed after confirming all variablles and relationships. This study used a simulation period of 50 years and the process of altering parameters was assumed to be modified gradually with time.

3.3.2 Analysis of the simulation

The drug disposal system in South Africa was simulated using the SDs model and the simulation was performed to analyse different scenarios of policy measure such as regulation and the effects of return rate on the total amount of waste illegally disposed.

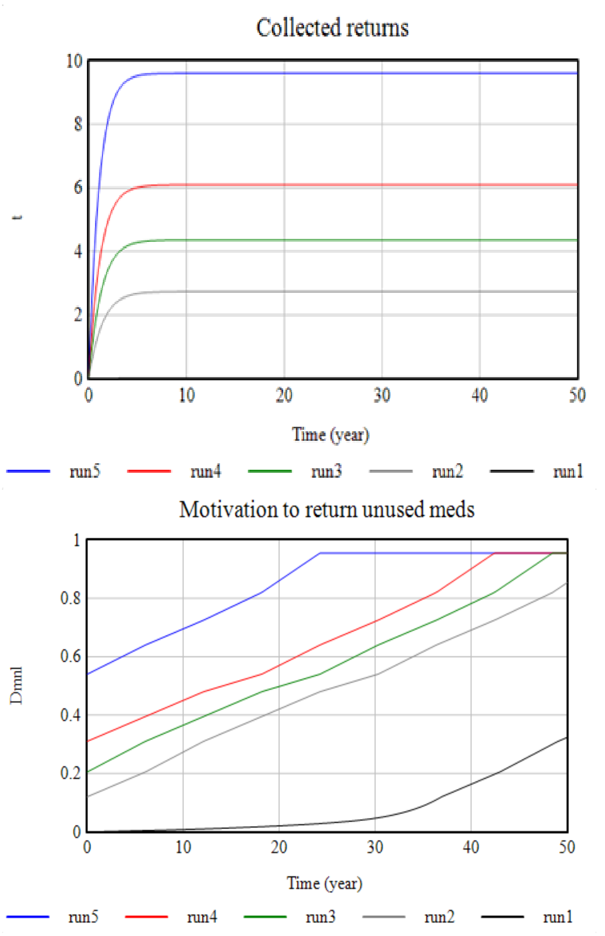


Figure 5 : Effects of Regulation on Motivation to return unused medication and amount of collected returns

Scenario 1:Changing Regulations

This scenario is focused with whether improvements in the regulation would have an effect on the amount of returned medications/drugs and motivation to return unused medications. Alternative values of regulation (regulation strengthening) ranged from 0 to 6 were assigned and simulated. The results are shown in Figure 5, both returns and motivation to return waste decrease with the decrease in Regulation and vice versa. Thus, regulation strengthening is significant and the influence of regulation on returning unused medication plays a vital role in the drug disposal management system. This reveals that the stronger the regulation is, the more waste/ unused/expired medications are returned, which is in accordance with the present practice of drug disposal management.

Scenario 2:Changing dumping rate

The graph below showed how three simulation runs were conducted by decreasing the rate of illegal dumping. It is evident that a decrease in illegal dumping rate leads to a decrease in amount of illegally dumped.

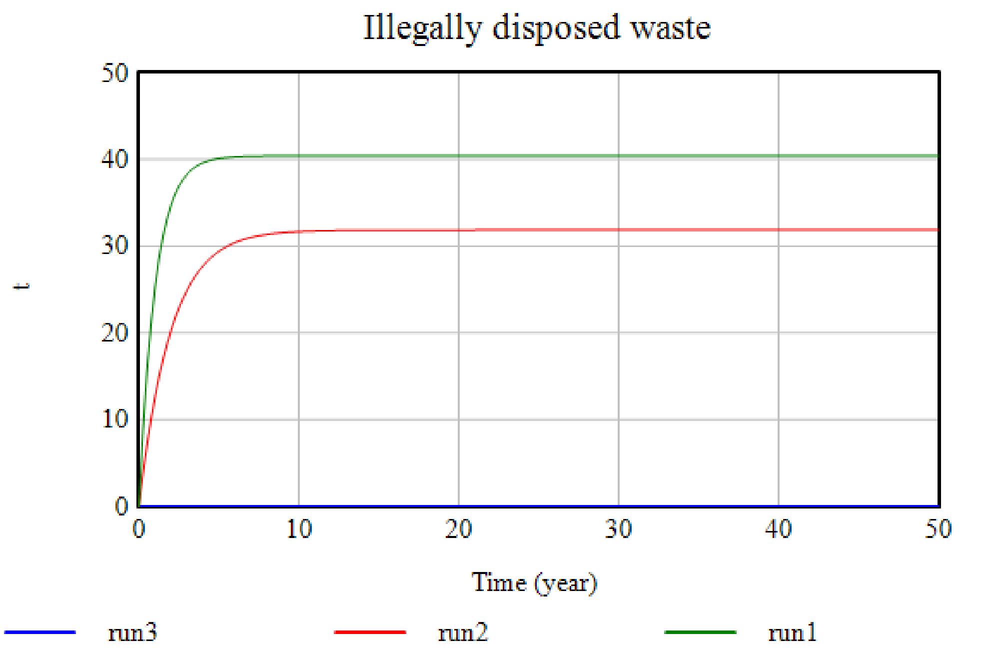


Figure 6:Effects of decreasing rate of illegal dumping on disposed waste.

4 CONCLUSION

This is study is still in its intial stages and the results presented are preliminary. There is need to further develop the model, quantify how the impact of illegal dumping is on the environment and how other policies can help eliviate this strain on the environment. In order to understand the behavior of a system and the relationships between variables, causal loop and stock-flow diagrams were developed. Increasingly, illegally dumped pharmaceutical drugs is becoming an important environmental issue. A causal loop diagram was developed to establish the casual relationships of variables within the problem and afterwards a stock and flow diagram was developed to illustrate the dynamic relationships among system quantities. The SD model was run for a period of fifty years and it was noted that the amount of waste collected increases as regulation is increased through regulation strengthening.The results also showed that decreasing the rate of dumping (through returning drugs to pharmacies) decreases the amount of illegally dumped waste. Both returns and motivation to return waste decrease with the decrease in Regulation and vice versa . Thus, regulation strengthening is significant and the influence of regulation on returning unused medication plays a vital role in the drug disposal management system. This reveals that the stronger the regulation is, the more waste/unused/expired medications are returned.

Recommendations from these deducations is that there should be an increase in Regulation strengthening so as to increase the amount of collected returns. The developed model is a useful predictive tool for decision making in drug disposal management system.This SD model can contribute significantly towards sustainable management of drug disposal in South Africa as it gives insights into policy measures from inferences deduced from the model. It can be used by policy makers and decision makers for experimental simulation and test different management strategies and policies of drug disposal management.

This study was only limited to the process of disposal of drug waste from households and drugs from hospitals were excluded. Further research could be directed towards reforming a more inclusive model and scenarios that illustrate detailed environmental impact that illegally dumped waste has. The disposal scenarios will differ from households to large organisations like hospitals hence it is important to include this in the model. This will give a detailed picture of the impact on the drug disposal system. Boundaries of the SD model can be expanded to include other policy measures and other variables within the pharmaceutical drug disposal system. Since there a few studies on the quantitative impact of pharmaceutical drugs in water bodies and environment, there is need to improve the model's accuracy and capability through updating more data from case studies.

5 APPENDIX

5.1.1 Equations and intial values used in the SD model

Amount of waste generated= INTEG (-illegal dumping-returns, 50) **(1)**

Collected returns= INTEG (returns, 0) **(2)**

Decrease I= Environmental stress*Destruction rate **(3)**

Destruction rate= 1 **(4)**

Environmental stress= Illegally disposed waste*Envrionmental Quality **(5)**

Envrionmental Quality=INTEG(Growth I-Decrease I,INTIAL VALUE OF ENVIRONMENT) **(6)**

FINAL TIME = 50 Units: year The final time for the simulation. **(7)**

Growth I= Envrionmental Quality*Regeneration rate **(8)**

illegal dumping= Amount of waste generated*rate of illegal dumping **(9)**

Illegally disposed waste= INTEG (illegal dumping, 0) **(10)**

INITIAL TIME = 0 Units: year The initial time for the simulation. **(11)**

INTIAL VALUE OF ENVIRONMENT=1 **(12)**

Motivation to return unused meds = WITH LOOKUP (Regulation, ([(0,0)-(10,1)],(0,0),(1,0.12),(2,0.205),(3,0.31),(4,0.395),(5,0.48),(6,0.54),(7,0.64),(8,0.725),(9,0.82),(10,0.955))) **(13)**

rate of illegal dumping=0.7 **(14)**

Regeneration rate=1 **(15)**

Regulation= INTEG (Strengthening of regulation,1) [0,6] **(16)**

returns=Amount of waste generated*returns rate **(17)**

returns rate=0.3*Motivation to return unused meds **(18)**

SAVEPER = TIME STEP Units: year [0,?] The frequency with which output is stored. **(19)**

Strengthening of regulation = WITH LOOKUP (Regulation,([(0,0)-(1,0.2)],(0,0.005),(0.1,0.01),(0.2,0.015),(0.3,0.025),(0.4,0.045),(0.5,0.065),(0.6,0.085),(0.7,0.105),(0.792049,0.127193),(0.9,0.145),(1,0.165))) **(20)**

TIME STEP = 0.25 Units: year [0,?] The time step for the simulation. **(21)**

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ADDITIVE MANUFACTURING: A COMPONENT OF SUSTAINABLE TECHNOLOGY DEVELOPMENT FOR GREEN ECONOMY

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ABSTRACT

Additive Manufacturing (AM) is one of the pillars of the fourth industrial revolution that is becoming embraced globally. AM comprises of producing objects layer by layer from a three-dimensional computer-aided system. It also is a disruptive technology that offers sustainability through improved productivity and resource-efficient processes. These are key elements of a green economy and competitive manufacturing. A green economy refers to industrial processes with low carbon emission, minimum waste of resources and social practices that do not degrade the environment. In the context of this paper, the green economy is defined as production technologies that are aimed at reducing environmental risks while promoting resource efficiency. This paper provides a review of AM as a viable industrial technology for a green economy. It explores possible AM strategies for metal production to point out that AM technologies can be more sustainable than traditional metal casting technologies.

Keywords: Additive manufacturing, Green Economy, Sustainable technology

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1 INTRODUCTION

Additive manufacturing (AM) has proven to be a viable technology to solve real-world problems through its ability to provide customized parts with complex geometries at shorter lead times. Due to these advantages, AM has been applied in many industries among which are the aerospace, automotive and medical industries [1]. The continued expansion of AM technology is driven by the need to manufacture lightweight parts with intricate shapes without the need for tooling as compared to conventional subtractive manufacturing. AM is the production of parts from a computer-generated model normally layer by layer [2]. It is a disruptive technology that offers sustainability through improved productivity and resource-efficient processes. According to Gibson, Rosen and Stucker [2], a disruptive manufacturing technology such as AM presents a smart way of producing objects with advanced product quality features that are nearly impossible to manufacture using conventional manufacturing methodologies. The significance of AM as a disruptive technology lies in the applied methodology and its capabilities in transforming raw materials into functional parts required by the industry. The sustainability and benefits of AM depends on the understanding of the technology usually known as process knowledge. According to Sithole et al [3], process knowledge is defined as the determination of process variables, their collection method, formulation and analysis approach to determine the varying process variables that are related with product characterization for specific objects/parts. Process knowledge is important for improving technology, product quality and also ensures sustainability. Process knowledge is one of the elements that can be used for improving manufacturing technologies and thus influences sustainability [4]. Sustainability is a phenomenon that is described in many ways and possesses different meanings for different industries. However, sustainability is generally defined as the ability to meet current needs without compromising the capability of the future generation to meet their needs. Meanwhile, sustainable technology refers to technologies that minimizes negative social and environmental impacts. It is governed by factors such as efficient resource and energy consumption, waste reduction and cost effective processes. Thus, sustainable technologies are able to improve organizational productivity and comparativeness.

This paper provides an overview of AM in terms of sustainable technology development. It aims to explain why AM is a good choice for sustainable manufacturing when compared to traditional manufacturing. This work seeks to highlight why the industry needs to embrace this change. This paper also covers the sustainability of AM, resource efficiency, environmental impact and finally, explains the quality improvement in AM.

2 SUSTAINABLE TECHNOLOGY DEVELOPMENT FOR GREEN ECONOMY

AM has advanced from a prototype and tooling technology to also enable direct manufacturing in different sectors such as automotive, aerospace, architectural, construction, medical, jewellery, furniture, etc. Furthermore, the application of AM continues to grow [5]. The development of AM as a disruptive technology is embedded in the proficiency of the process to produce parts of complex geometries without the need for tooling and to make parts that are difficult to manufacture using conventional manufacturing technologies [2]. As a result, AM technology shortens lead times, production costs, energy consumption and improves material efficiency [6]. AM technologies as categorized by ASTM F2792 standard are Powder bed fusion, Direct energy deposition, Material extrusion, Vat photopolymerization, Binder jetting, Material jetting and Sheet lamination [7]. AM technologies mostly used for direct metal part manufacturing are Powder bed fusion and Direct energy deposition. Figure1 illustrates the technologies applied in metal manufacturing.

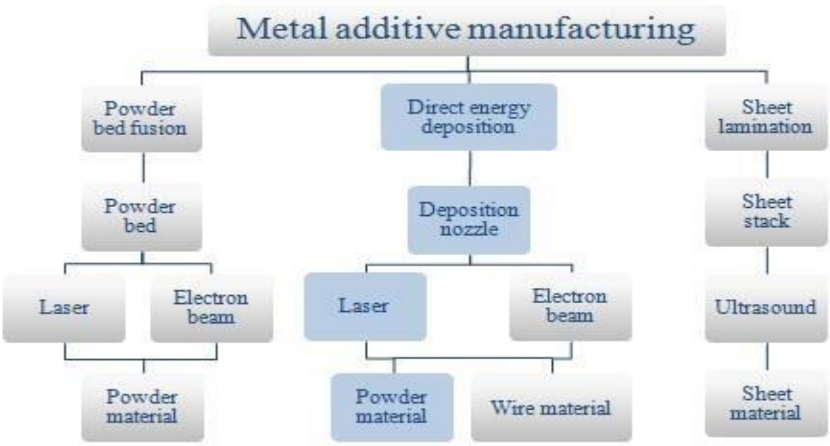

Figure 1: Schematic overview of Metal AM technology [8]

The principle in AM is that parts can be fabricated straight from a computer-generated model without the need for tooling [9]. Manufacturing improvements like production of complex objects in conventional manufacturing technologies require additional operations which then increases manufacturing costs [10]. In subtractive machining processes, increasing production of parts with intricate geometries increases process steps, tool paths and sometimes requires expensive customized tooling. According to Abdulhameed et al. [11], the current market competition in manufacturing requires the production of cost-effective complex shapes, at short lead times, with good quality and processes that require less-skilled workers [10]. AM can meet the current market needs without increasing production costs.

Sustainability in the production environment is influenced and driven by a cleaner, efficient resource utilization and improved manufacturing processes. Sustainable development is fundamentally engulfed in the green economy [12]. Green economy generally refers to industrial processes with low carbon emission, minimum waste of resources and social practices that do not degrade the environment. Peng et al. [6], discussed the sustainability of AM by focusing on energy demand and environmental impact. Figure 2 illustrates the dimensions of sustainability in relation to AM as discussed by Peng and colleagues. This figure summarises the sustainability of AM as a technology development for the green economy. It addresses the three fundamental aspects of sustainability which are economy, environment and society. AM has demonstrated great potential to be one of the leading sustainable manufacturing technologies when compared to conventional manufacturing.

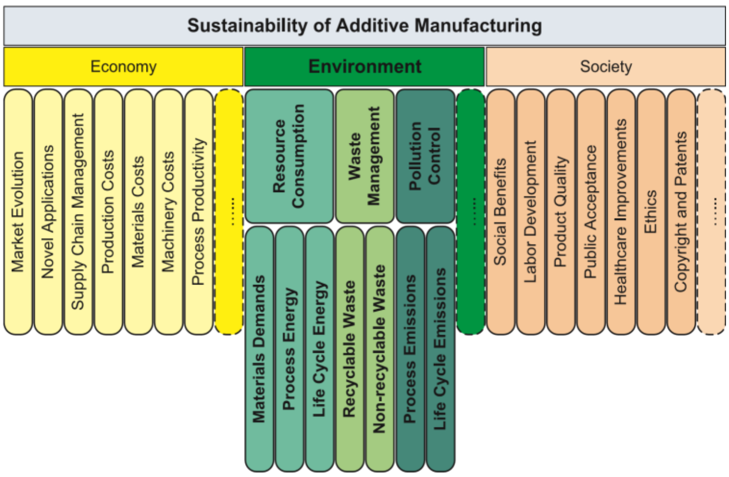

Figure 2: Sustainability of AM [6]

According to Resen and Kishawy [4], technology advancement can enhance the environmental impact and thus improve sustainability. Few studies have listed and studied the sustainability potential of AM. In AM, energy and material consumption are the main resources used in the technology [13]. Resource efficiency in AM depends somewhat on the size of the part being fabricated, the material used and the required properties of the part. Energy consumption for isolated processes can be low. However, when the total feedstock is taken into consideration, energy consumption can be high. At this stage, it is important to note that the determinants of a sustainable technology or green economy differ based on the nature of the manufacturing process and products being fabricated. However, the factors that determines a sustainable technology remains the same. The next sections describe the resource efficiency and environmental impact of AM to further outline the sustainability of the technology.

3 RESOURCE EFFICIENCY AND ENVIRONMENTAL IMPACT OF AM TECHNOLOGIES

AM is considered a green economy technology development due to its nature of production, state-of-the-art capability and potential in fostering sustainability [14]. The nature of production in this manufacturing technology is “additive” rather than “subtractive” as in conventional manufacturing [15]. In this process material is selectively deposited layer upon layer to form an apart/object [9], depending on the technology being used, a substantial energy source is passed after every layer of material deposition for fusion [2]. This process ensures that only the material required to make the part is used and the material not used can be recycled back to the system [15]. Figure 3 shows the nature of production in both subtractive and additive processes. As observed in this diagram, in a subtractive process denoted by the letter “A” a billet of material is shaped into the desired object by removing the material using a technology like CNC machining. While in Additive manufacturing, denoted by letter “B”, material is selectively added to form the desired object. Although CNC machining can produce three dimensional (3D) objects, the process becomes increasingly difficult with increasing geometric complexity and can result in a significant amount of waste material.

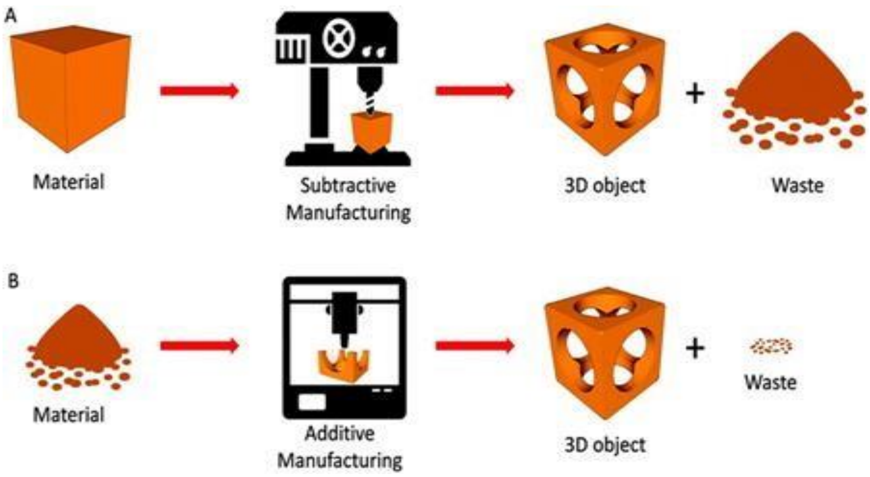

Figure 3: A. Subtractive vs B. Additive manufacturing [16]

Thus, the nature of production in AM promotes resource efficiency with increasing geometric complexity and in particular producing minimal waste. Comparing the nature of production in AM to subtractive manufacturing points out that AM is more sustainable with regards to environmental impact. However, AM has some drawbacks in its nature of production such as increased manufacturing times, high capital investment and low volume production [17]. According to Inovar Communications Ltd [5], AM is not yet suitable for mass production but rather for mass customization. Mass customization is defined as the production of not identical but comparable parts with features personalized by the customer [10]. Literature also shows that AM is a manufacturing technique that influences the production of customized products for a specific need in an industry or sector. The nature of production in AM fosters sustainability when compared to other manufacturing technologies. AM technology has the potential to be more sustainable in terms of environmental and social effects. The next section covers the state of the art capability of AM to point out its advantages that leads to sustainability

3.1 State - of - Art capability of AM

AM enables production of complex lightweight parts through the use of techniques like topology optimization, which in turn reduces the material and energy required to make such parts. According to Ma et al [15], AM has the potential to save energy and carbon emissions through production of lightweight parts for the aerospace and other heavy-duty industries, thus making AM an environmentally friendly process. Additionally, AM processes can be optimized to further reduce material utilization while producing lightweight and complex parts with hollow features [16]. Resource efficiency can be high in AM including the energy used to transform the input material into the output form. A study by Baumers et al [13], looked at energy consumption in AM and it was concluded that energy efficiency increases with improved productivity. Productivity in AM is influenced by process optimisation and process knowledge for improving designs and the technology performance. AM also shortens the supply chain by eliminating the tool-making process which is inevitable in traditional manufacturing for making complex shapes. AM also has the potential and capability to improve cost performance by reducing the number of supply chains and spare parts [18].

The nature of production in AM with regards to the number of process steps involved can also be compared with other traditional processes for metal manufacturing such as sand casting. Figure 4 shows the typical sand casting manufacturing process steps. A typical sand casting process possesses many interlinked and complex stages (Processes) [3]. In contrast, AM for metal production possesses a much shorter production chain when compared to a typical sand casting process which can result in lower manufacturing cost.

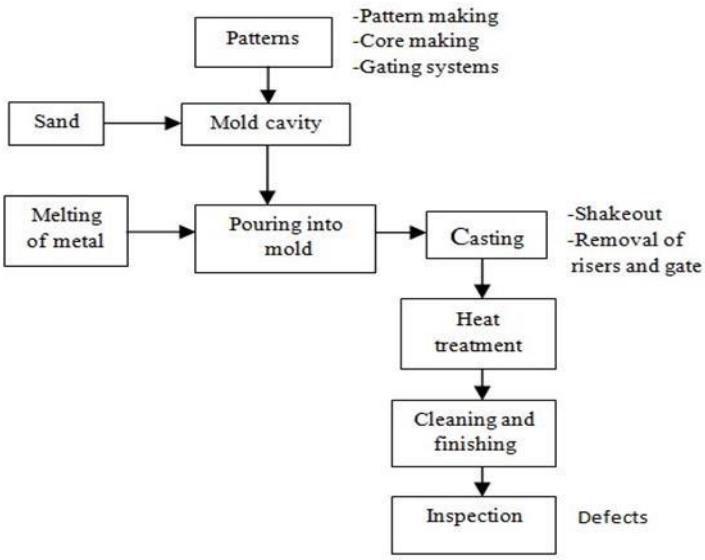

Figure 4: Sand casting process [19]

AM is also more sustainable when compared to the typical sand casting process because of shorter supply chains which minimizes resource consumptions. Reduction in the use of material saves energy and so minimizes carbon emissions. Direct metal manufacturing through AM reduces the number of process steps including removing the pattern making, sand mixing, metal melting and mould making stages. The reduction of these steps enhances resource efficiency, improves manufacturing cost and minimizes material wastage. In conventional manufacturing techniques such as sand casting, sustainability is in the material recyclability, which is mainly the sand [3]. However, the potential of AM in fostering sustainability is great when compared to other manufacturing technologies. The next section expands further on the sustainability of AM.

3.2 Potential of AM in fostering sustainability

The nature of production in AM fosters its sustainability by printing (mostly) only the material required for the part, which in turn reduces waste production. However, some additional material may be required to assist in the build process. Waste reduction in AM can be achieved through process optimization and part orientation on the build plate to reduce the number of support structures, which are removed and scrapped as soon as the building process ends.

According to Peng et al, AM can improve on waste production by up to 90% compared with subtractive manufacturing [6]. Albeit, AM produces less waste when compared to subtractive manufacturing, it is not a complete exception to waste production. Waste in AM is in the form of support structures, extensively used in metal manufacturing for example, as well as scrap produced during failed builds and materials that cannot be reused [6]. However, there is opportunity in the form of optimisation of complex parts and techniques for reduction of supports in AM to promote savings in waste and carbon emissions.

The sustainability of AM also lies in the shipment and inventory of parts. If parts are printed onsite, then no transport is required and therefore the overall carbon footprint can be reduced. In terms of inventory, AM reduces costs by ensuring we only print (spare) parts on demand. In particular, this minimises manufacturing and storage costs with less waste of material. The next section discusses quality management in AM, which is another aspect that fosters sustainability in manufacturing.

4 QUALITY MANAGEMENT IN ADDITIVE MANUFACTURING

Quality management in a production environment is meant to ensure that products are fabricated with maximum quality at minimum cost and ensure that they meet or exceed customers' requirements. Quality improvement is also essential for sustainability in manufacturing. Due to the capability and market demand of AM, quality plays a crucial role in this technology development. Quality control of AM parts must ensure that fabricated parts are fit for use in any form [17]. Although AM is a competitive manufacturing technology, it still possesses limitations in terms of surface quality, dimensional accuracy and lack of data repeatability in the process [18]. However, there are standards such as ISO and ASTM that govern AM technology to foster quality and also to ensure that AM parts are fits for use [20]. Apart from ensuring that fabricated parts are fit for use, these standards also ensure the sustainability of AM processes. Quality is a built-in feature of the process in AM technology. Understanding the process, the parameters and their correlation is important for ensuring quality of builds and reduction of failed builds. Process optimization is by far the most important feature for controlling and improving quality in AM. This reduces waste of material, minimises build failures and ensures maximum quality.

5 CONCLUSION

AM is a disruptive technology that has great potential for sustainability when compared to traditional manufacturing technologies. This technology can reduce material required in a supply chain and utilise less energy while minimising waste due to improved productivity. Despite of the well-known benefits of AM, this paper has outlined the efficiency of this technology in fostering sustainability. It has focused on the sustainability of AM, outlining the importance of AM in improving resource efficiency and environmental impact as green technology development.

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AN INVESTIGATION INTO THE ADEQUACY OF INFRASTRUCTURE IN ENGINEERING AND RELATED DESIGN (ERD) AT TECHNICAL AND VOCATIONAL EDUCATION AND TRAINING (TVET) COLLEGES IN GAUTENG PROVINCE, SOUTH AFRICA

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ABSTRACT

The purpose of this study was to investigate the adequacy of infrastructure in Engineering and Related Design at Technical and Vocational Education and Training (TVET) colleges in Gauteng Province, South Africa. The study was a cross-sectional survey that was conducted on National Certificate level 3 TVET college students that were pursuing their studies in Engineering and Related Design (ERD). The data collection tool was a self-administered, structured questionnaire. The respondents to the questionnaire were conveniently selected. The research findings revealed that in the TVET colleges that were sampled, there was a shortage of the workshop equipment and machines, audio-visual equipment, accommodation and transport. On the other hand, it was discovered that the majority of students were happy with classrooms, furniture, and library facilities. There is a need for the colleges to have adequate infrastructure in order to create a conducive teaching and learning environment.

Keywords: TVET colleges, infrastructure, vocational students.

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1 INTRODUCTION:

Technical and Vocational Education and Training (TVET) colleges in South Africa have the mandate to train future electricians, builders, carpenters, machinists, fitters and turners, welders, boiler makers and motor mechanics. The majority of students who are enrolled in vocational programmes are post-grade 9 school leavers. College records reveal that this group comprises students who performed poorly in secondary schools or did not gain entry into the universities. Students with grade 9, 10, or 11 passes qualify to pursue their studies at National Certificate Vocational (NCV) level. Students who enter the TVET colleges after completing grade 12 are allowed entry into the diploma programmes provided they obtained low pass grades at matric level.

The ERD subjects that are taught at TVET colleges expose students to the practical tasks on a day-to-day basis in order to help them learn how to operate the different machines in the workshop. TVET colleges draw upon various methods and techniques in order to make the workshop environment safe and clean.

1.1 Problem statement

The shortage of machinery and the lack of workshop management skills are factors that hinder practical training in most TVET colleges. These factors affect the throughput rate of TVET colleges. Over the years, the Government of South Africa has been funding tuition fees and other college costs to all deserving students, through the National Student Financial Aid Scheme (NSFAS). As government invests significantly in the TVET projects, it should be as concerned as the general South African citizen about the numbers, knowledge depth and skills of TVET college graduands.

There are many factors that affect the teaching and learning at TVET colleges. Some of the factors are the skills and the knowledge depth of the lecturers, governance of the college institutions, provision of practical training by the industry, and infrastructure that supports teaching and learning. Public TVET colleges seem to be struggling to sustain quality education due to inadequate financial support from the central government.

1.2 Purpose of study

The purpose of this study is to investigate the adequacy of infrastructure in the Engineering and Related Design (ERD) division at public Technical and Vocational Education and Training (TVET) Colleges in Gauteng Province, South Africa

2 LITERATURE REVIEW

2.1 Infrastructure in TVET Colleges

This study would like to put forward the conviction that having good infrastructure in an educational institution has a positive impact towards the attainment of quality education, good results and improved pass rates. Some of the important resources include adequate classrooms, furniture, machinery and technology. A learning institution that has a conducive learning environment should; provide comfort to the students, teachers and administrators; have proper lighting, water, electricity and internet services; have a provision for libraries, and laboratories, have facilities for entertainment, cultural activities, and development of talent, and have provision for sanitary services (CAF.com, 2016). Workshops during the Corona Virus pandemic and post corona period should revolutionise and ensure they adhere to all safety regulations meant to protect students and everyone in the workshop. Social distancing should be observed even when operating machinery in workshops. A different outlook of workshops is a reality.

Workshops in TVET colleges provide simulated environments for practical work that the students would do when they are in the workplace. The absence of these workshops in TVET colleges render teaching and learning ineffective (Buthelezi, 2016). Learners come to TVET colleges expecting to do modules that have a bias toward practicals; however, they then find themselves doing more theory than the practicals (Badenhorst & Radile, 2018). The learners apparently get frustrated and disorientated. According to Alexander & Masaobi (2017), the majority of TVET colleges do not have adequate equipment and proper machinery to facilitate successful teaching of engineering programmes. The shortages make it difficult for the TVET colleges to train and educate students who will make meaningful contributions to the industry (Alexander & Masaobi, 2017).

Buthelezi points out that the shortages in TVET colleges were not restricted to workshops only. The TVET colleges are also grappling with shortages of furniture, textbooks, libraries, computers, printers, photocopies and equipment that is necessary for vocational education (Buthelezi, 2018). These shortages were cited as contributing factors to the high failure rate in TVET colleges, (Buthelezi, 2018).

The majority of learners who enrol in TVET colleges are visual and kinaesthetic learners who need to combine viewing and listening in order to comprehend the learning content (Tilestone, 2010). The shortages of machinery and equipment discussed above, therefore creates a learning environment that is difficult to both learners and lecturers (Alexander & Masaobi, 2017). The shortages makes it difficult for the TVET lecturers to impart meaningful knowledge to the engineering students (Alexander & Masoabi, 2017). Another observation is that the infrastructure is getting old and obsolete (Buthelezi, 2018). The prevailing situation is blamed on insufficient budget allocation made to the TVET colleges (Buthelezi, 2018).

Papier (2006) also noticed that besides the shortages of resources in workshops, there are cases where lack of critical management skills in TVET colleges is an obstruction to meaningful and productive teaching and learning.

2.2 Impact of infrastructure on teaching and learning

There is strong evidence that quality infrastructure improves learners' academic performance and reduces dropout rates (Khakhau, 2019). Well-planned infrastructure, clean, quiet, safe, comfortable and healthy environment are important components of successful teaching and learning (Fisher, 2006). Quality infrastructure has an impact of reducing the student attrition rate in TVET colleges; it also positively influence the attitude, attendance and interest in learning (CAF.com, 2016). It is likely that there will be an improvement of attendance and classroom participation when there is adequate infrastructure in TVET colleges. Moreover, Armsterdam (2010) and Zulu (2020) report that there will be reduced incidences of aggression if there is adequate infrastructure at TVET institutions.

According to Dube & January (2012), lack of access to water and sanitation had the risk of leading to learners developing illnesses and missing school in Zimbabwean rural schools. This risk does not only affect Zimbabwean rural schools, it is a risk that affects schools from all quarters. A response to this challenge requires that there be adequate water and refuse reticulation system. This requirement has become even more critical and a non-negotiable factor in 2020 following the outbreak of the Corona pandemic. Rivera (2016) caps it by saying that it is essential for authorities to observe the significant role of infrastructure interacting with other essential educational inputs, so that comprehensive proposals are undertaken in order to improve the quality of education.

3 METHODOLOGY

The study was a cross-sectional survey that was conducted on National Certificate level 3 TVET college students that were pursuing their studies in vocational subjects in Engineering and Related Design (ERD). It was conducted in seven public TVET colleges in Gauteng. The colleges had a combined population of 458 students that were at National Certificate Level 3 of their studies. Of the 458 students, only 139 participated in the survey. The participants were conveniently selected in each college. The idea was to use the research findings as a basis for future studies.

The data collection tool was a self-administered. The study was quantitative and it was conducted with the objective of investigating how adequate infrastructure assisted the National Certificate ERD students at public TVET colleges in Gauteng.

The questionnaire was entirely composed of closed-ended questions. The questions were presented logically in order to ease the respondents through the questions. The questions required participants to simply rate the infrastructure in TVET colleges. Questionnaires were personally hand distributed to all the conveniently sampled level 3 ERD students across the seven TVET colleges, on different days.

The descriptive component of the study characterised the TVET colleges' 1) classroom environment, 2) furniture, 3) cleanliness of the learning environment, 4) the equipment and machinery in the workshops, 5) audio visual equipment, 6) lighting, 7) library facilities, 8) student accommodation, and 9) provision of transport.

3.1 Ethical considerations

Prior to conducting the survey, ethical clearance was sought from the University of Johannesburg Faculty of Engineering and the Built Environment ethics committee. Written permission was granted. The researchers also sought permission to conduct the study from eight public TVET colleges within Gauteng province. Seven out of eight public TVET colleges granted permission to conduct the study.

The researchers respected each participant's autonomy. The participants were informed of the purpose and benefits of the research. Confidentiality and informed consent were adhered to. The participants consented to be part of the study only after they had been informed of the purpose of the study. The consent document was included as an attachment to the questionnaire. The participants completed the questionnaire in safe and secure classrooms with no threat or potential harm posed to them. The participants were allowed to withdraw from participating in the study at any stage.

4 FINDINGS

The study revealed that there were a number of factors that negatively affected students in TVET colleges. Findings reveal that there are shortages of; equipment and machinery, library facilities, audio visual equipment, accommodation and transport. Collectively, these shortages resulted in the production of graduates that were poorly trained and therefore, could not compete in their respective industrial sectors.

The results in Table 1 give a summary of the findings on TVET college infrastructure ratings from selected level 3 students within the public TVET colleges in Gauteng.

4.1 Classroom

There were 137 students who responded to the question on classroom space. There were 25 (18.3%) who rated the space provided in vocational classrooms as poor and very poor. The remaining 82.7% rated the space as average, good and excellent. Khakau (2019) argues that quality infrastructure improves a learner's academic performance and reduces dropout rates. In this regard, the TVET colleges seem to create and maintain a conducive learning environment that retains the majority of students.

4.2 Provision of Furniture

Out of the 137 respondents, 41 (29.9%) students rated the available furniture as poor. The remaining 70.1% rated the furniture as average, good, and excellent. The figure indicates that the colleges are on average doing fairly well on the furniture aspect. Going by Armsterdam's (2010) and Zulu's (2020) sentiments, this is one area where the colleges are working very hard to improve attendance and classroom participation.

4.3 Cleanliness of the classroom environment

Of the 137 students who responded to the question on the classroom environment 43 (31.4%) rated the colleges as either poor or very poor in terms of cleanliness. The remaining 68.6% rated the colleges as either average, good or excellent in terms of cleanliness. Going by Fisher (2006) findings, colleges are doing fairly well in creating an environment that promotes teaching and learning.

4.4 Adequacy of Equipment and Machinery

There were 136 students who responded to this question, and 83 (61%) rated the equipment and machinery as poor and very poor. Only 39% rated the machinery as average, good, and excellent. This is a cause for concern. A study that was conducted by Tilestone (2010) reports that the majority of the students who go to TVET colleges were visual and kinaesthetic learners. Hence, the shortage of equipment and machinery in workshops creates a difficult learning environment because visual and kinaesthetic learners grasp what they learn if they see the material and are actively involved in shaping the end product (Tilestone, 2010). These are hands-on calibre of students; theory on its own does not take them anywhere.

4.5 Availability of Visual Equipment in Vocational Classrooms

The number of students who responded to the question on the availability of visual equipment in vocational classrooms was 136. The number of students who rated the equipment as poor and very poor is 85 (62.5%). This rating is very close to the rating on equipment and machinery which was at 61%. The lack of equipment makes it very difficult for TVET college lecturers to impart knowledge to the ERD students (Alexander & Masoabi, 2017).

4.6 Average Temperature in the Classroom

Of the 136 students who answered this question, 55 (40.4%) rate the average temperature in the classrooms as poor and very poor. In this case, the majority of 59.6% rated the environment as either average, good or excellent. Considering the fact that there are many conflicting demands on budgetary allocations, the TVET colleges are doing a great job on this aspect. However, Fisher (2006) found out that a comfortable environment is an important components of successful teaching and learning.

4.7 The Quality of Lighting in Classrooms, library and other learning facilities

On the lighting issue 33 (24.3%) of 136 students rated it as poor and very poor. 75.7% rated the lighting as either average, good or excellent. In as far as this issue is concerned, the TVET colleges are doing a commendable job in providing a conducive environment for learning.

4.8 Provision of Relevant Textbooks

Out of 133 students who responded, only 45(33.8%) rated the quality of textbooks as either poor or very poor. The majority, 66.2%, were happy. Books are central to learning. Buthelezi (2018) reports that the shortages of textbooks is one factor that is contributing to failure rates in colleges. In this regard, it is important that the TVET colleges pay more attention to the concerns of the students.

4.9 Provision of Accommodation

On the question related to accommodation offered by the colleges, only 126 students responded. It is assumed the other 13 who did not respond did not stay in college accommodation. Of the 126 who responded, 97 (77%) rated the accommodation provided by the colleges as either poor or very poor. The response presents a poor picture with regards to accommodation. As articulated by Zulu (2020), quality infrastructure has the effect of improving student attitude and interest in learning. This is one area where the TVET colleges need to improve.

Table 1: Public TVET College Infrastructure Ratings in Gauteng

		Very Poor	Poor	Average	Good	Excellent	Total
Space provided in vocational classrooms is…	Count	6	19	52	48	12	137
	%	4,4%	13,9%	38,0%	35,0%	8,8%	100,0%
Furniture (chairs and tables) in vocational classrooms is…	Count	13	28	40	47	9	137
	%	9,5%	20,4%	29,2%	34,3%	6,6%	100,0%
Cleanliness of the vocational classrooms is…	Count	14	29	33	42	19	137
	%	10,2%	21,2%	24,1%	30,7%	13,9%	100,0%
Machinery and equipment in vocational workshops is…	Count	50	33	23	22	8	136
	%	36,8%	24,3%	16,9%	16,2%	5,9%	100,0%
The audio visual equipment in vocational classrooms is…	Count	49	36	36	11	4	136
	%	36,0%	26,5%	26,5%	8,1%	2,9%	100,0%
The temperature in vocational classrooms is…	Count	27	28	40	30	11	136
	%	19,9%	20,6%	29,4%	22,1%	8,1%	100,0%
The quality of light in vocational classrooms is…	Count	11	22	37	47	19	136
	%	8,1%	16,2%	27,2%	34,6%	14,0%	100,0%
Vocational textbooks found in the college library are…	Count	26	19	33	33	22	133
	%	19,5%	14,3%	24,8%	24,8%	16,5%	100,0%
Accommodation provided by the college to learners is…	Count	70	27	18	9	2	126
	%	55,6%	21,4%	14,3%	7,1%	1,6%	100,0%
	Count	89	20	12	3	3	127

Transport provided by the college to learners is… %	70,1%	15,7%	9,4%	2,4%	2,4%	100,0%

4.10 Provision of Transport

The number of students who responded was 127. The 12 who did not respond might not be benefiting from college transport. There were 109 (85.8%) students who rated the transport as either poor or very poor. This is an essential service where the colleges are not doing well. This is one component that Fisher (2006) mentions as an important component of successful teaching and learning. In this regard, it is important that the colleges pay attention to it.

5 CONCLUSIONS AND RECOMMENDATIONS

The study found out that there are areas where the TVET college infrastructure is below expectations and others where it is above expectations.

Infrastructure components that the students were not satisfied with are the workshop equipment and machinery, audio visual equipment, accommodation, and transport. The first two components are central to learning. Tilestone (2010) reports that the majority of students who go to TVET colleges are visual and kinaesthetic students who need to combine viewing and listening in order to understand the learning content. In this regard, the TVET colleges need to improve and provide more equipment and machinery in classrooms and workshops. According to Amrsterdam (2010); Zulu (2020), this will improve attitude, interest in learning, class attendance, and classroom participation.

The majority of students were happy with the quality and space in the classrooms, furniture, cleanliness of classrooms, ventilation, lighting, and books. These components provide comfort to students and are important components of successful teaching and learning to take place (Fisher, 2006).

An improvement in these areas has an impact on reducing student attrition and failure rate [CAF.com (2016); Buthelezi (2018)].

In the prevailing environment where there is a shortage of resources, TVET colleges must assume a cautious approach and aim to attain a 50% rating on all the components of the infrastructure. A green sustainable economy may be achieved by positively transforming the TVET college infrastructure and aligning it with the advancing technology. Through continuous improvement initiatives, the TVET colleges can then work their way up and produce graduands that are adequately trained to compete in their respective sectors of the industry.

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HEURISTIC TO SOLVE THE FIXED CHARGE SOLID LOCATION AND TRANSPORTATION PROBLEM WITH TRUCK-LOAD CONSTRAINT

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ABSTRACT

In this paper, a variant of the Fixed Charge Solid Transportation Problem (FCSTP) that integrates both facility location and truckload constraint is presented. This is termed Fixed Charge Solid Location and Transportation Problem with Truck Load Constraint (FCSLTP-TLC). FCSTP assumes shipment is done with an optimal number of conveyances in one lot. However, the reality that shipment may not be always done in one lot by a selected conveyance and also that facility location costs could be very strategic in determining other tactical, operational and sustainable costs are motivations for the FCSLTP-TLC. Using Benchmark data from the literature, solution to the FCSLTP-TLC was obtained using an adapted commercial solver solution (CPLEX) and an alternative solution due to possible intractability of the CPLEX solution. The solution results were compared based on solution value and time. Performance tests conducted suggests that the alternative solution approach is competitive.

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Keywords: fixed charge, facility location, truckload constraint, heuristic, CPLEX

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1 INTRODUCTION

The classical transportation problem that minimizes allocation cost from source to destination has been extended to capture some reality encountered with distribution problems. Some extensions made were done to capture the reality of fixed charges, economies of scale, demand uncertainties, multi-index transportation and facility location in the distribution problems. The resulting distribution problems have been described as problem variants of the classical transportation problem. The requirement to jointly plan individual optimization problems together to prevent suboptimal solutions has generally been effective in reducing costs for the problem variants. These problem variants usually are involved with medium to long term decision making. Another reality that has impacted our present day is the introduction of some constraints to distribution due to forced regulations or policies. Government or logistic regulatory bodies could impose truckload constraints or what appears to be a maximum load to carry per routes during disasters, scarcity or shortages resulting from supply chain disruptions to ensure equity in product supply. Such limiting constraints might not be initially planned for but might be required for decision making for medium to long run.

Some transportation problem variants modelled are the Fixed Charge Transportation Problem (FCTP) discussed by Aguado [1], Yousefi et al. [2], Hajiaghaei-Keshteli et al. [3] and Step-Fixed Charge Transportation Problem (SFCTP) noted by Altassan et al. [4], Molla et al. [5], Yousefi et al. [6] and Oyewole and Adetunji [7]. Besides, a variant of the transportation problem known as the Solid Transportation Problem(STP) noted by Schell [8] has been extended by Halder et al. [9], Sanei et al. [10], Kundu et al. [11], and Das et al. [12]. Distribution problems under demand uncertainties such as in Zhang et al. [13], Liu et al. [14] are also some of the extended transportation problems reported in the literature. Most of the problem variants mentioned above jointly planned distribution problems for short to medium terms. Other problem variants that include long term decisions such as facility location were discussed by Oyewole and Adetunji [15], Das et al. [12]. Facility location costs are strategic and can further reduce costs and ensure sustainability for organizations if jointly planned with other operational and tactical decisions within organizations. Recently, Balaji et al. [16] introduced decision making under the truckload constraint. They noted the reality of making shipments in more than one lot and thus incurring multiple fixed charges. Since the truckload constraints are limiting constraints of some sort, organizations might have little or no control over it when imposed. Therefore it will be of great advantage for organizations to know how to jointly plan their distribution in such events.

Solutions to some of these problem variants such as SFCTP and variants of the STP indicated earlier have been noted by Sanei et al. [10] and Balaji et al. [16] to become intractable (NP-hard) with exact methods such as Branch and bound, Branch and cut as problem size increase. Therefore other solutions which might not guarantee optimal solutions but could provide good solutions within appreciable time limit might be necessary. These have been largely referred to as Heuristics such as in Samadi et al. [17] and Hornstra et al. [18].

In this paper, a distribution problem that jointly considers fixed charges, facility location, solid transportation and the load limiting constraint per route is presented. This has been termed the Fixed Charge Solid Transportation problem with Truckload constraint (FCSLTP-TLC). The objective of the FCSLTP-TLC is to minimize total transportation and location costs by determining the optimal allocations from open locations through open routes by a set of conveyances when a maximum load limit (truckload) is placed on each route. Attempts were made to solve this problem by using the CPLEX mixed-integer solver. Also, due to the possible intractability of the model for certain problem sizes an alternative solution method was developed. Some performance comparisons are conducted with both methods and also possible insights suggested based on the constraint of maximum load limit per route.

2 MODEL DESCRIPTION

The FCSLTP-TLC is formulated as a Mixed Integer Programming (MIP) problem, with m-sources, n- destinations, a- conveyances and the truckload constraint W. This extends the model of FCSLTP as presented by Sanei et al. [10] and Oyewole and Adetunji [19] by considering the truckload constraint discussed by Balaji et al. [16] as maximum load requirement per route. In the FCSLTP, fixed location costs, route fixed charges and variable route costs and problem capacities are jointly used in determining whether the locations will be opened or closed for shipment along the transportation route. The FCSLTP inherently assumes the cost of routing by conveyances does not affect optimization decisions and shipment is planned in one lot. In the Truck Load constraint (TLC) the shipment is planned to be in either one or more than one lot.

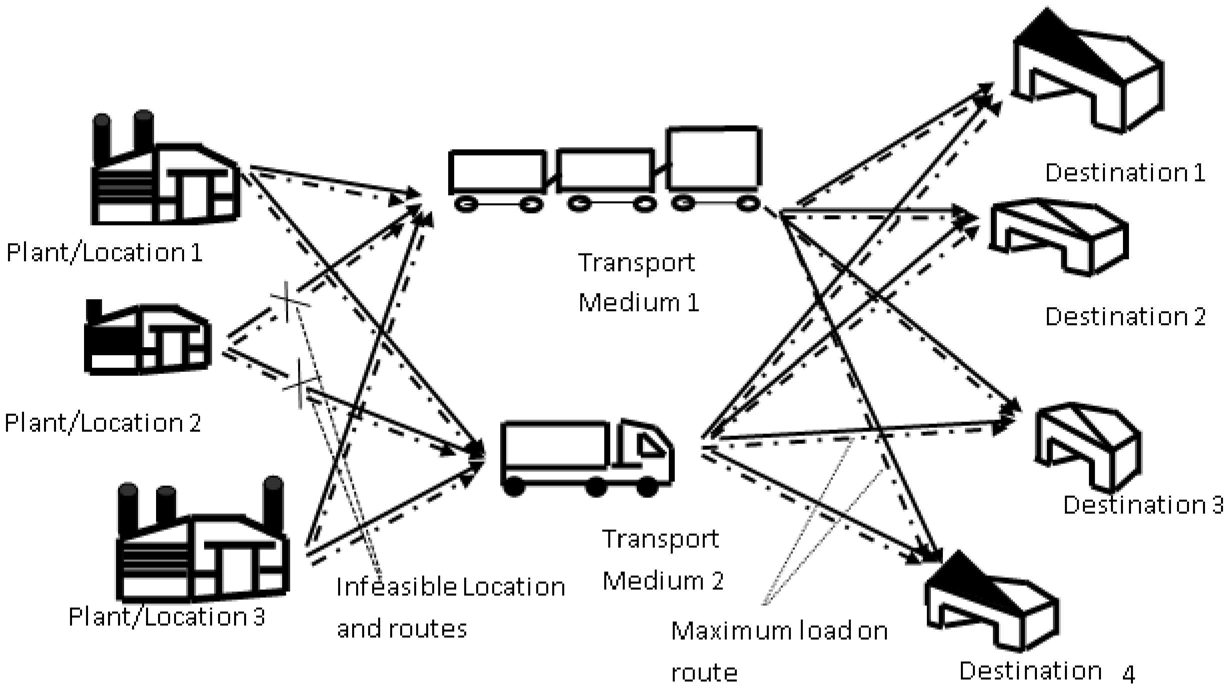

Figure 1: Schematic Representation of The FCSLTP-TLC

2.1 Model assumptions for the FCSLTP-TLC

The following basic assumptions are made in our model formulation:

1. Deterministic parameters (variable costs, fixed costs, and capacities)

2. Two echelon distribution problem.

3. Fixed location costs, route variable cost, one route fixed-charge cost and the maximum load per route which is described as similar to a truckload constraint in this paper.

4. One planning period and single item distribution problem.

2.2 Model Development

The parameters and variables used in the model formulation are given in section 2.2.1:

2.2.1 Parameters

i: Index for sources or possible locations (e.g. plants, warehouses, depots)
j: Index for destinations (customers, other warehouses etc.).
r: Index for conveyances (or Transportation mediums).
m: Number of sources.
n: Number of destinations.
a: Number of conveyances.
c_{ijr}: Variable cost of shipment on route (i,j)using conveyance r.
S_i: Capacity of source $i \ \forall \ i = 1 \dots m$.
D_j: Demand at destination $j \ \forall \ j = 1 \dots n$.
T_r: Capacity for the conveyance $\forall \ r = 1 \dots a$.
F_i: Fixed cost of opening the facility at location i.
H_{ijr}: Fixed cost incurred for shipping through route(i,j)using conveyance r
W_{ijr}: Maximum load requirement through route (i,j)using conveyance r

2.2.2 Decision Variables

x_{ijr}: Quantity of products transported from source (i) to destination (j) using conveyance (r).
y_i : Binary Location variable for setting source (i) as either opened or closed. Where $y_i = 1$, if source(i) is opened or $y_i = 0$, if source (i) is closed.
z_{ijr}: Integer variable for incurring one or multiple fixed charges on route (i,j,r)

2.2.3 Objective function (minimum cost function) for FCSLTP-TLC

This formulation is termed the original problem (OP)

Min(OP):

$$\sum_{i=1}^{m} F_i y_i + \sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{r=1}^{a} c_{ijr}x_{ijr} + \sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{r=1}^{a} H_{ijr}z_{ijr} \qquad (1)$$

Subject to

$$\sum_{j=1}^{n}\sum_{r=1}^{a} x_{ijr} \leq S_i y_i \qquad \forall \ i = 1 \dots m \qquad (2)$$

$$\sum_{i=1}^{m}\sum_{r=1}^{a} x_{ijr} = D_j \qquad \forall \ j = 1 \dots n \qquad (3)$$

$$\sum_{i=1}^{m}\sum_{j=1}^{n} x_{ijr} \leq T_r \qquad \forall \ r = 1 \dots a \qquad (4)$$

$$z_{ijr} = \begin{cases} Integral\ part\ of\ \left({x_{ijr}}/{W_{ijr}}\right) + 1 & if\ \ x_{ijr} > 0\ \ and\ remainder\ \left({x_{ijr}}/{W_{ijr}}\right) > 0 \\ Integral\ part\ of\ \left({x_{ijr}}/{W_{ijr}}\right) & if\ \ x_{ijr} > 0\ \ and\ remainder\ \left({x_{ijr}}/{W_{ijr}}\right) = 0 \\ (\ 0\ ) & if\ \ x_{ijr} = 0 \end{cases}$$

$$\forall \ i = 1 \dots m,\ \forall \ j = 1 \dots n,\ \ \forall \ r = 1 \dots a \qquad (5)$$

$$y_i = 0\ or\ 1 \qquad \forall \ i = 1 \dots m \qquad (6)$$

$$x_{ijr} \geq 0 \qquad \forall \ i = 1 \dots m,\ \forall \ j = 1 \dots n,\ \ \forall \ r = 1 \dots a \qquad (7)$$

Expression (1) is the minimum cost or objective function of the FCSLTP-TLC. The first term is the facility location cost. The second term is the route variable cost per conveyance type. The third term is the route fixed charge incurred per conveyance type due to truckload constraint.

Constraint (2) ensures that the supply capacity is not exceeded.

Constraint (3) is the demand to be met at each destination.

Constraint (4) ensures that conveyance capacity is not exceeded.

Constraint (5) is the maximum load per route requirement which has been termed as the truckload constraint.

Constraint (6) refers to the facility location requirement.

Constraint (7) refers to the non-negativity constraint for the continuous variables.

3 SOLUTION METHODS

In this section, the attempts made to solve the FCSLTP-TLC using a commercial solver such as the CPLEX optimization studio is presented. The solution obtained is termed solution approach A. An alternative solution method developed, is presented and termed solution approach B.

3.1 Solution approach A

The CPLEX commercial optimization studio primarily uses the branch and cut algorithm to solve Mixed Integer Problems (MIPs) and can generate exact solutions if the MIP is correctly coded in the optimization environment. However, due to the limitations encountered while coding the integer variable z_{ijr} related to the constraint (5), to be solved with CPLEX, the integer constraint was relaxed to a continuous variable $\overline{z_{ijr}}$. The continuous variable $\overline{z_{ijr}}$ obtained thereafter was subsequently converted to the integer equivalent z_{ijr} to ensure the feasibility of constraint (5). The $\overline{z_{ijr}}$ was used to generate a CPLEX Lower Bound (CLB) for the FCSLTP-TLC. The CLB was thereafter used to generate the corresponding upper bound z_{ijr}. The derived upper bound from CPLEX lower bound has been termed CPLEX Upper Bound (CUB).

3.2 Solution Approach B

This solution approach uses three techniques to solve FCSLTP-TLC. Firstly, a linearized expression is developed. An attempt is made to linearize the binary source variable y_i and the integer variable z_{ijr}. Secondly, a variable fixing method based on the linearized expression is used to select sources from other competing sources. Thirdly a linear transportation problem is formulated to be solved.

3.2.1 Linearization

From constraint (5) an approximate expression for z_{ijr} is obtained. This is given as $z_{ijr} = \frac{x_{ijr}}{w_{ijr}}$. The expression is substituted into the objective function (1) to give the expression below:

$$\sum_{i=1}^{m} F_i y_i + \sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{r=1}^{a} c_{ijr}x_{ijr} + \sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{r=1}^{a} H_{ijr}\frac{\boldsymbol{x_{ijr}}}{\boldsymbol{W_{ijr}}} \qquad \textbf{\textit{(8)}}$$

Using the upper limit of constraint (2) i.e.

$$\sum_{j=1}^{n}\sum_{r=1}^{a} x_{ijr} = S_i y_i \qquad \forall\ i = 1 \dots m$$

The expression $y_i = \frac{\sum_{j=1}^{n}\sum_{r=1}^{a} x_{ijr}}{S_i}$ is obtained and substituted into equation (8) to obtain

$$\sum_{i=1}^{m}(F_i \times \frac{\sum_{j=1}^{n}\sum_{r=1}^{a} x_{ijr}}{S_i}) + \sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{r=1}^{a}(c_{ijr} + \frac{H_{ijr}}{W_{ijr}})\, x_{ijr}$$

$$= \sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{r=1}^{a}(\frac{F_i}{S_i} + c_{ijr} + \frac{H_{ijr}}{W_{ijr}})\, x_{ijr}$$

$$= \sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{r=1}^{a}(C_{ijr})\, x_{ijr} \quad \forall\ i = 1 \dots m, \forall\ j = 1 \dots n,\ \forall\ r = 1 \dots a \qquad \textbf{(9)}$$

Where C_{ijr} => relaxed variable cost of shipment on route (i, j)using conveyance r

3.2.2 Variable fixing for y_i

Using equation (9), an expression is extracted and given below:

$$\sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{r=1}^{a}(C_{ijr}) \quad \forall\ i = 1 \dots m \qquad \textbf{(10)}$$

Equation (10) is used to calculate the corresponding value for each location i.

For illustration purpose, an m- source FCSLTP-TLC problem will have C_{1jr} , C_{2jr} , … , C_{mjr} values calculated for each source ($i = 1 \dots m$). The lowest values from (C_{1jr} , C_{2jr} ,….,C_{mjr}) are selected such that the total selected source capacity is greater than all demand requirements. k is used to denote the number of the selected source capacity, where $k \leq m$ *and indexed with* l.

3.2.3 Linear transportation problem

Using the k-selected sources in 3.2.2, the transportation problem below with some constraints similar to that of the FCSLTP-TLC to maintain feasibility is presented.

Minimize:

$$\sum_{l=1}^{k}\sum_{j=1}^{n}\sum_{r=1}^{a}(c_{ljr} + \frac{H_{ljr}}{W_{ljr}})\, x_{ljr}$$
(11)

Subject to:

$$\sum_{j=1}^{n}\sum_{r=1}^{a} x_{ljr} \leq S_l \qquad \forall\ l = 1 \dots k$$
(12)

$$\sum_{l=1}^{m}\sum_{r=1}^{a} x_{ljr} = D_j \qquad \forall\ j = 1 \dots n$$
(13)

$$\sum_{l=1}^{m}\sum_{j=1}^{n} x_{ljr} \leq T_r \qquad \forall\, r = 1 \dots a \qquad \textbf{(14)}$$

$$x_{ljr} \geq 0 \qquad \textbf{(15)}$$

Expression (11) is the objective function or relaxed minimum cost function to determine the final allocation of the original problem (OP).

Constraints (12) to (15) are similar to that presented in Constraints (2) to (7) except that the number of sources considered have been reduced to l such that $l \leq m$ (initial number of sources).

In expression (11) the term $\frac{F_l}{S_l}$ is omitted in the objective function due to the less significant role it might play in achieving the minimum cost solution. Besides, it had been used in the variable fixing technique of 3.2.2

Using the selected sources ($l = 1 \dots k \leq m$), and variables y_l, x_{ljr} and z_{ljr} subject to constraints (5), an upper bound feasible solution to the original problem (OP) is obtained. This solution is termed as the Heuristic Upper Bound (HUB).

4 DATA GENERATION AND EXPERIMENTATION

Solution approaches A and B, were coded on the ECLIPSE development platform using Java to observe the performance of both solution techniques. Solution approach A was solved using the IBM ILOG CPLEX 12.8 as the MIP default solver. Solution approach B required coding the linearization and variable fixing method and finally solving the resultant transportation problem with any linear programming software. The CPLEX linear solver was selected. A windows 8.1 operating system with 6GB Random Access Memory (RAM) was used for the computation experiments.

4.1 Data generation for the problem sizes

Uniformly distributed data used by Sanei et al. [10] and Oyewole, Adetunji [19] were utilized for the experimentation. A method for generating facility location cost presented by Gadegaard et al. [20] was used. This calculates the facility cost using the values of the source capacities and is given as $F_i = U(0{,}90) + \sqrt{S_i}\ U(100{,}110)$. For the purpose of using a uniform basis of comparison, W_{ljr} was chosen to be constant for all routes and its value randomly selected to be equal to 50% of maximum demand for each problem instance. A total of 50 problems were generated. These consist of 10 problem sizes and 5 problem instance per problem size. Table 1 below shows the problem sizes considered. In addition, the data distributions used in generating the problem parameters are given in Table 2.

Table 1: Problem Sizes And Number Of Instances Used For Experimentation

Problem Size No.	Problem Size $\boldsymbol{m \times n \times a}$
1	5×5×2
2	6×6×2
3	7×7×3
4	9×9×4
5	10×10×5
6	12×12×6
7	15×15×7
8	20×20×8
9	25×25×8

10	30×30×9

Table 2: Parameter Distribution Used For Experimentation

Parameter Distribution
S_i : U(200, 400)
D_j : U(50, 100)
T_r : U(800, 1800)
c_{ijr} : U(20, 150)
H_{ijr} : U(200, 600)
$F_i = U(0{,}90) + \sqrt{S_i}\, U(100{,}110)$
$W_{ijr} = \quad x\,\%\ of\ \ Max\ \ D_j$
$0 < x < 100$
$x = 50\%$ (selected for experimentation)

4.2 Experimentation

The experiments conducted were primarily to assess the effectiveness (minimum cost solution) and the efficiency (solution time) of the solution approaches. For the effectiveness of the solution, the average of the five (5) problem instances per problem size were computed and recorded as average CPLEX Lower Bound (CLB avg), average CPLEX Upper Bound (CUB avg) and average Heuristic Upper Bound (HUB avg). The same procedure was followed in computing the efficiency of both solution approaches. The average solution time computed in seconds(s) was termed CUB avg(t) and HUB avg(t). Another computation performed was the percentage (%) mean difference of the average values obtained for effectiveness. The first reason was because of the likelihood of solution approach A not providing optimal solutions due to how its upper bound was derived. Also, it might be of interest to know the Upper bound objective value gap compared to the corresponding lower bound value. Secondly, it might be of interest to know the gap between actual upper bounds computed for solution approaches A and B, for the effectiveness of the developed solution technique.

5 RESULTS AND DISCUSSION

Results obtained under experimentation for effectiveness are shown in Table 3 below. These results are also represented by Figure 1 to show the converging and diverging trends of the solution approaches as problem size increase. The derived CPLEX solution approach (CUB avg) suggests a superior minimum cost value compared to the HUB avg over the problem sizes considered. However, solution approach B (HUB avg) suggests some promising ability to obtain solutions in the neighbourhood of 5% of CUB avg.

Table 3: Average Minimum Cost Solution And Mean Difference

Problem Size	CLB avg	CUB avg	HUB avg	%mean difference (CUB avg/ CLB avg)	%mean difference (HUB avg /CUB avg)
5×5×2	18912.073	20022.818	21303.012	6%	6%
6×6×2	23024.020	24212.404	26101.522	5%	8%
7×7×3	22447.419	23817.331	26244.575	6%	10%
9×9×4	27328.205	31229.094	32618.134	14%	4%
10×10×5	29039.380	30784.090	34369.591	6%	12%
12×12×6	33629.028	35921.985	37873.417	7%	5%
15×15×7	39842.966	43045.431	45723.223	8%	6%
20×20×8	48887.835	53315.021	58324.727	9%	9%
25×25×8	63898.106	68746.426	72300.467	8%	5%
30×30×9	74165.592	80065.806	83602.501	8%	4%

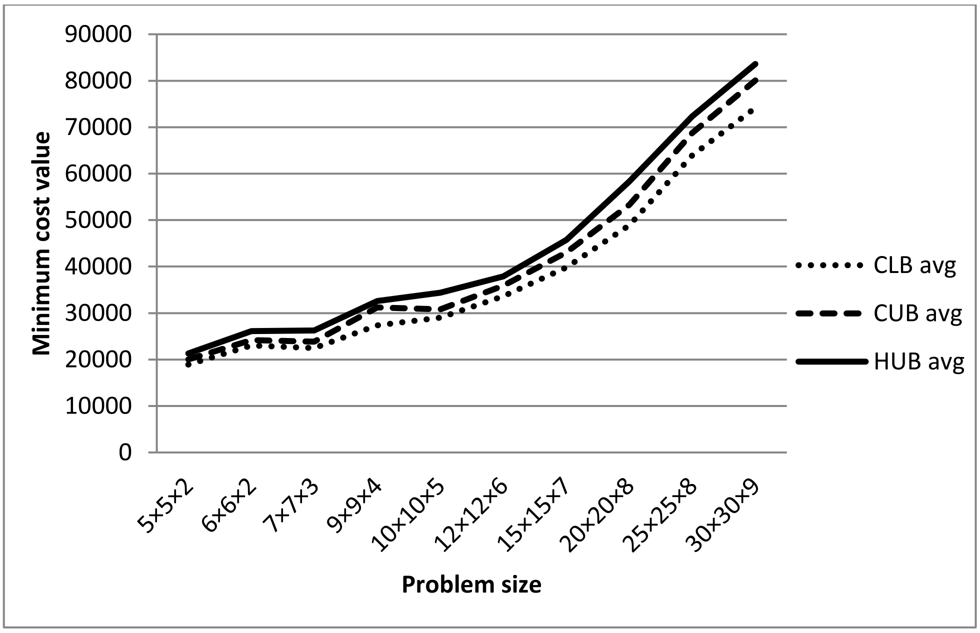

Figure 2: Minimum Cost Value of Solution Approaches

Results obtained under experimentation for efficiency (solution time in seconds) are directly illustrated in Figure 3 below. The plot suggests a tendency of the derived CPLEX upper bound solution to become slower to achieve compared to the developed heuristic. The differences in computation time between the two solution approaches become very significant as problem size increase. For startup businesses and operations managers who might be willing to trade off the best solutions for good solutions due to lack of resources to obtain or speed computation time, the heuristic might be beneficial. Moreover, the heuristic showed a tendency to obtain minimum costs within 5% gap of the derived CPLEX solution approach within an appreciable time. The 5 % level of significance has been used due to the popular alpha level applied for many empirical tests.

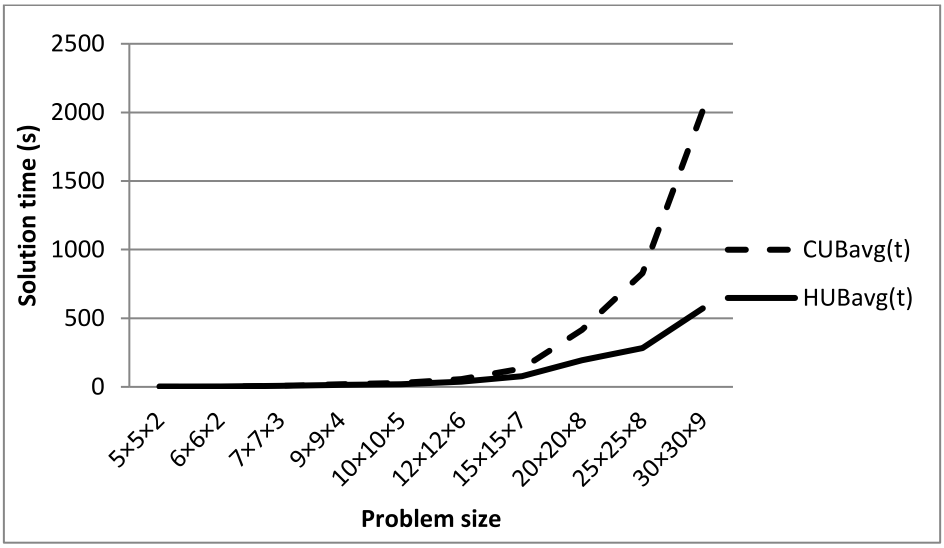

Figure 3: Solution Time of the Upper Bounds with Problem size

6 CONCLUSION AND FUTURE DIRECTION

A distribution problem that jointly optimizes fixed charges, facility location, solid transportation and the load limiting constraint per route was presented. This problem was termed the Fixed Charge Solid Transportation Problem with Truckload Constraint (FCSLTP-TLC).

The CPLEX mixed-integer solver was adapted to solve this problem. However, due to the possible intractability of FCSLTP-TLC for larger problem sizes, an alternative solution method was developed. Moreover, the resources for obtaining very good solutions might not be available or costly to achieve. As a result, other solutions could become competitive in such scenarios.

Performance comparison using effectiveness showed the ability of the derived CPLEX technique to obtain better minimum costs. However, these solutions could become slow to achieve with an increase in problem size. For certain problem sizes, the developed heuristic showed a tendency to obtain good solutions and was generally faster than the derive CPLEX solution. The truckload constraints with similarities to maximum load on route limit show a possible application in distribution scenarios under strict regulations or forced circumstances which organization might not often plan for.

It might be necessary to observe the sensitivity of each solution approach with different truckload constraint or maximum load per route limits. Besides, a comparison could be made between FCSLTP with and without truckload constraints to observe the possible gains with both models. Finally, other solution techniques such as the Lagrange relaxation heuristics, metaheuristics or other local search techniques can be developed for a better competitive solution to solve the FCSLP-TLC.

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ECO-INDUSTRIAL PARKS – APPLICATION OF A MATERIAL FLOW ANALYSIS TO IDENTIFY OPPORTUNITIES TO BUILD RESILIENCE IN AN INDUSTRIAL AREA

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ABSTRACT

Transforming an industrial area into an eco-industrial park is a strategic mechanism for strengthening business' resilience to long-term resource scarcity, through improved resource efficiency. Eco-industrial parks (EIPs) capitalise on proximity and co-location of businesses to enable the building of resource efficiency through industrial symbiosis (IS). IS identifies opportunities for collaboration between businesses through the provision and/or management of under-utilised/waste resources (i.e. materials, water, waste, heat/steam, etc.). The proximity and co-location of businesses are critical when fostering collaboration, as logistics (and the associated costs) is often one of the biggest barriers to IS. This paper describes a project that seeks to improve the environmental, social and economic performance of a specific industrial area in Cape Town utilising a Material Flow Analysis (MFA). The MFA highlights the resources flowing in and out of the area to identify potentially financially viable and mutually beneficial IS opportunities for businesses, thereby building resilience.

Keywords: Eco-Industrial Park, Resilience, Material Flow Analysis

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1 INTRODUCTION

Business sustainability has become increasingly challenging in recent years, with businesses having to maintain financial viability in a time of limited economic growth, as well as needing to survive chronic stresses (e.g. load shedding) and acute shocks (e.g. drought, disease outbreaks) [1]. The recent Covid-19 crisis has exposed a range of risks associated with South Africa's manufacturing systems [2], the vulnerability of our supply chains [3] and the difficulty of adapting and responding quickly to disruption [4]. Thus, building business resilience to shocks and stresses is quite crucial, especially with the looming risk of climate change effects (particularly resource scarcity).

According to Lelièvre [5],

> *"Business resilience has a productivity component and a flexibility component. High productivity helps a company protect its margins, ride out smaller changes and respond to larger ones. The flexibility of a value chain is determined by its ability to continue generating profit under different supply and demand conditions."*

Therefore, businesses need to take advantage and optimise the aspects that they have control over and build flexibility in areas where they have less control (to mitigate the impacts thereof).

An eco-industrial park is an area where companies cooperate with each other and with the local community through efficient sharing of resources (e.g. skills, materials, services, etc.) to obtain financial benefits, improve environmental quality and build resilience [6]. These collaborations enable optimisation of business processes and the adaptation to various resource constraints.

The City of Cape Town recognises the importance of eco-industrial parks in its Resilience Strategy [1]. The strategy highlights several pillars to enable and build resilience within the city. One of the key actions identified – under *Pillar 3: Capable, job-creating city* - was to;

> "*Develop eco-industrial parks using industrial symbiosis (IS) methodology.*"

According to Chertow [7], the resilience of individual businesses in industrial areas can be strengthened by converting existing (brownfield) industrial areas or developing new (greenfield) industrial areas into eco-industrial parks. The City of Cape Town, therefore, contracted GreenCape[†] to unlock some of the opportunities in an industrial area using IS, thereby facilitating the transition into an eco-industrial park and enhancing the resilience of the businesses in the area.

1.1 Montague Gardens as a potential eco-industrial park (EIP)

According to Bellantuono et al. [11],

> *"Eco-industrial parks promoted or supported by governmental initiatives, with high heterogeneity (a diverse range of companies and by-products[‡]),*

[†] A not-for-profit organisation established to support the development of the green economy in the Western Cape

[‡] Waste streams can be considered under-utilised by-products, however not all waste streams can be reused: as reuse opportunities may not currently exist, or the streams may be too contaminated, or too costly to process.

and characterized by the presence of collaborative networks among firms and with governmental agencies, anchor tenants, and shared support services, are more likely to adopt a wider range of sustainability practices."

Taking these features into consideration, the greater Montague Gardens industrial area was identified as the ideal location for consideration as a potential eco-industrial park. The area is managed by a central body, is optimally situated in terms of logistics and has many manufacturing companies with a high level of heterogeneity. These aspects of Montague Gardens are explained in detail below.

1.1.1 Presence of a City Improvement District (CID)

The current brownfield industrial areas in Cape Town consist of several smaller parks and individual businesses clustered together to form an 'industrial area'. These areas are generally managed by a non-profit organisation known as the 'City Improvement District (CID)', to whom property owners agree to pay a levy for supplementary services set to enhance the physical and social environment of the area. These organisations also engage with the local government council on behalf of the businesses in the area. In the case of the Montague Gardens greater area, the monitoring body is the Montague Gardens-Marconi Beam Improvement District (MMID). This body is managed by a board of directors comprising of local property owners and business people committed to the improvement and upliftment of the area.

1.1.2 Geographical context and infrastructure

Montague Gardens is centrally located and is close to several major highways: the N7, N1, M5, M8 and M14. The area is located to the north of Century City and to the south of Killarney Gardens and can be considered the gateway to the West Coast region. Montague Gardens is a 15-minute drive from both Cape Town International Airport and the Port of Cape Town. The majority of the industrial activity within the area has tended towards the small to medium scale (small factory units), with the larger facilities being utilised as distribution centres due to the proximity to logistics networks (road, rail and air).

2 AIM OF PAPER

This paper describes a study done for the City of Cape Town to explore the potential for transforming an existing industrial area to an eco-industrial park through IS. The study focused on understanding and unlocking opportunities for collaboration over the *physical exchange of materials* with the aim of stimulating a collaborative network amongst companies in the area and commencing the transformation to an eco-industrial park. It was therefore necessary to understand the current material flows for the area. For this purpose, a Material Flow Analysis (MFA) was selected as it focuses on identifying and quantifying the resource inputs (raw material) and outputs (products and by-products/waste streams), making it possible to identify critical nodes of intervention for improved resource efficiency. The MFA also provides insight into the respective material sources and sinks and the associated supply chain networks.

3 LITERATURE REVIEW

3.1 Collaboration as a mechanism for resilience

Collaboration at all levels is the key principle underpinning eco-industrial park success. According to Domenech [2];

"In an eco-industrial park, companies typically collaborate and benefit at three main levels: a) physical exchange of materials, energy, water and by-products, b) sharing of infrastructure, thereby leading to the creation of

> *shared economic opportunities as well as improved environmental performance and ecosystems, and c) learning from each other by exchanging knowledge and innovation."*

Other levels of collaboration could include the procurement of shared suppliers (e.g. safety equipment) and services (e.g. joint health and safety training, catering, recycling, etc.) as is demonstrated by the Fort Devons eco-industrial park in the United States [8]. Such a collaboration between companies is termed 'industrial symbiosis' (IS) [9]. The transformation of an industrial area into an eco-industrial park utilising IS enables the optimal utilization of resources and services in the entire area and not just the individual companies [2]. This ensures that the associated benefits are shared by all.

3.2 Proximity as a mechanism for resilience

The shortages and supply chain disruptions caused by Covid-19 have exposed the disadvantages of relying primarily on globalised production with complex supply chains, the division of innovation and manufacturing, and just-in-time production [2]. Globalised production has fragmented knowledge [4] along the supply chain, eroding the connections between research, design and manufacturing and the associated sharing of skills; as well as reducing the understanding of the resource implications of final product [2]. In an article on *Rethinking Globalized Supply Chains*, Harvard Professor Willy Shih [4] comments on how Toyota (the pioneers of Lean and just-in-time production) has always maintained a localised (within same region or at least same country) supplier base, demonstrating that localised supply chains facilitate increased flexibility, as companies can collaborate quickly and adapt to volatility.

Increased resilience will always have a cost implication. As Mirchandani [10] has succinctly stated;

> *"Manufacturers will need to navigate the imperative for greater resilience versus the attractiveness of lower costs. As ensuring resilience is likely to be a future expectation of investors."*

Taking advantage of collaborative networks such as manufacturing clusters or those enabled by eco-industrial parks (and the accompanying benefits of proximity) will not only assist with creating resilience, but can also reduce the manufacturing costs [9].

4 METHOD

4.1 Scope of the Material Flow Analysis (MFA)

In order to make the MFA tractable, a number of key decisions were made that defined the scope of the MFA.

- *Focus on flows and not stocks.*
  The MFA looked at materials that moved in and out of facilities within a year, i.e. a temporal system boundary was chosen and taken to be operating at a steady state, where the net movement of materials with time was assumed to be zero (mass inflows equal outflows). Stocks were not considered as they represent stagnant flows that can stay in an area for periods longer than a year.
- *No logistics.*
  The MFA did not consider any fleet movements or the associated emissions.
- *Existing recycled and reused material flows on site would not be counted.*
  The MFA did not capture the volumes for by-products that are used internally by companies; it only captured data on by-products that left the company sites.

4.2 Data gathering in Montague Gardens

Key to the success of the study was the gathering of a comprehensive data set which would ideally represent data from all companies in the greater Montague Gardens area. The data required includes the quantity of raw material inputs and by-product/waste stream outputs. Given the scale of the selected area (with an estimated 201 businesses), a more strategic approach to data gathering was needed. Therefore, the approach was to target companies that are likely to benefit from industrial symbiosis and to ensure that a representative sample of companies in terms of volume of material and type of industrial sector were selected for analysis.

The study focused on the 141 manufacturing companies in Montague Gardens. Since manufacturing companies tend to have larger opportunities for collaboration (e.g. through industrial symbiosis) as they have the capacity to generate and take in by-products from each other. These companies were then divided up into their various sectors[§] (Figure 1) to ensure a complete picture of the material resources was captured.

The 16 largest manufacturing companies (anchor tenants) in the Montague Gardens were also identified, based on the size and nature of the organisations. The engagements focused on targeting these firms first as they would control the largest (and presumably most consistent) material flows within the area.

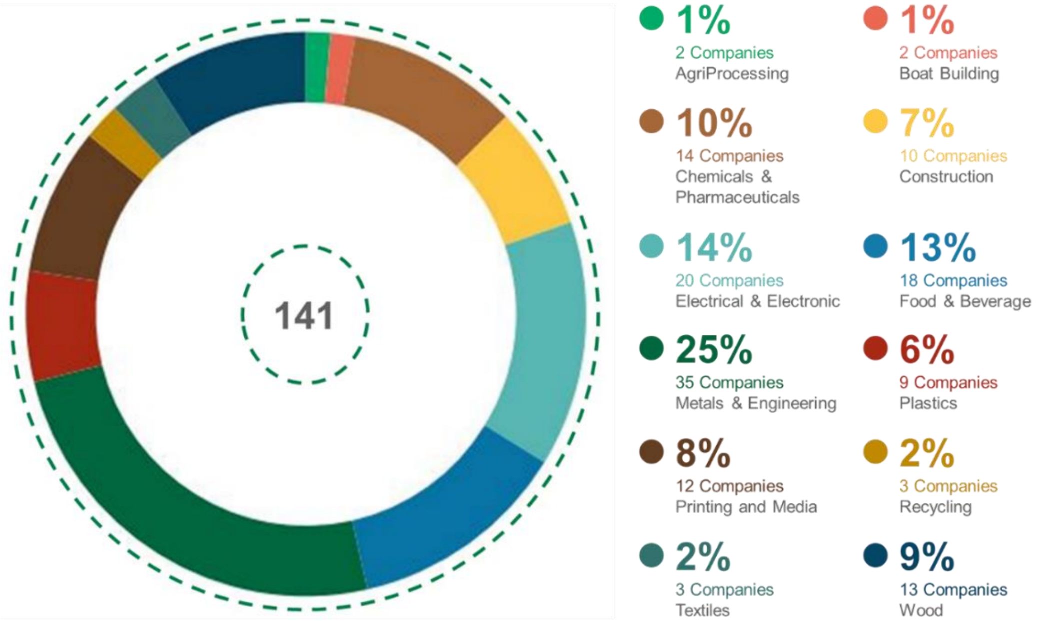

Figure 1: Breakdown of the 141 manufacturing companies in Montague Gardens by sector

[§] For deeper insight, the food and beverage manufacturing sector is distinguished from the rest of the agriprocessing sector. For this purpose, the food and beverage manufacturing sector is defined as the value-added agriprocessing portion focussed explicitly on manufacturing of food and beverages within the broader agricultural and agriprocessing value chains that would include processing of other primary agricultural produce.

RESULTS AND KEY INSIGHTS

4.3 Engagement

The manufacturing companies in the area differed quite substantially in size, from very small (e.g. metals and engineering) to quite large (e.g. chemicals and pharmaceuticals). 120 of the 141 manufacturing companies in the area were contacted:

- 25% opted not to participate in the study, largely because they were quite small and felt that the study did not apply to them or that they could not obtain value from the study.
- 18% were completely unreachable, and could potentially be closed.
- 21% agreed to a site visit; 90% of these companies provided data.
- 36% were in the progress, with discussions around identifying the correct contact person and planning for a potential site visit, however, data gathering via site visits were discontinued when the Covid-19 lockdown began.

Table 1 depicts the number of companies in each sector and the engagement response. The quantity of resources utilised by the respective sectors depends mainly on the size of the companies rather than the number of companies in the sector. Therefore, the prioritisation of the 16 anchor tenants in Montague Gardens ensured that the largest material flows were captured.

Table 1: Sector specific breakdown of engagements with the 141 manufacturing companies in Montague Gardens

Sector	Not contacted	Not Interested	Unreachable	Visited	In Progress
AgriProcessing		1		1	
Boat Building				1	1
Chemicals & Pharmaceuticals	3	3	1	5	2
Construction	2	2	1	2	3
Electrical and Electronic	1	9	6	4	
Food & Beverages	2	4	3	5	4
Metals & Engineering	11	6	6	2	10
Plastics	1		2	3	1
Printing & Media		5	4	3	2
Recycling	1			2	
Textiles			1		2
Wood		6	2	3	2

4.4 Material resources analysis

Of the companies in Montague Gardens that provided data, 70% provided material resource input and output data, spanning across 10 (out of 12) sectors. **Error! Reference source not found.** indicates the percentage of the overall material inputs and outputs contributed by the different sectors. It is clear from this that the chemicals and pharmaceuticals sector far outweighs any of the other sectors in both mass of inputs (96%) and mass of by-product (83%) outputs[**], as the sector constitutes 25% of the anchor

[**] Products were not considered in this case as the focus is on industrial symbiosis i.e. utilisation of under-utilised resources and collaboration for efficiencies, albeit that there could be further opportunities for sale of intermediary products within the areas but it was assumed that local collaboration would already exist if it were feasible.

tenants in the area. The high volume of material inputs and outputs from this sector makes the data from some of the smaller sectors appear insignificant (e.g. 0.0% for agriprocessing).

The next biggest input stream (by mass) is the printing and media sector. The stream consists mostly of paper, as one of South Africa's largest printing companies is based in Montague Gardens. The third and fourth largest input streams are into the food and beverage and the construction sector, specifically sugar for a sugar processor and cement components for a cement mixing plant.

The food and beverage sector and the printing and media sector are the second and third largest producers of by-products (after the chemicals and pharmaceuticals sector) respectively. 99% of the by-products generated by both of these sectors are diverted from landfill for reuse, according to the data provided by companies that participated in the study.

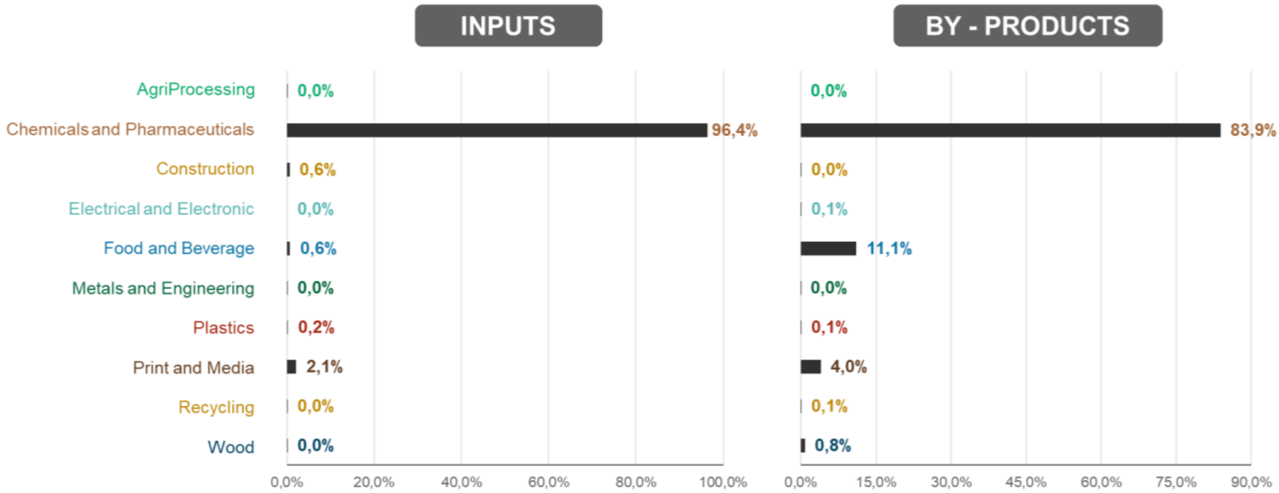

Figure 2: Material resource inputs and by-product outputs from the material flow analysis (MFA) (% of sector inputs/total material inputs and % of sector by-products/total by-products)

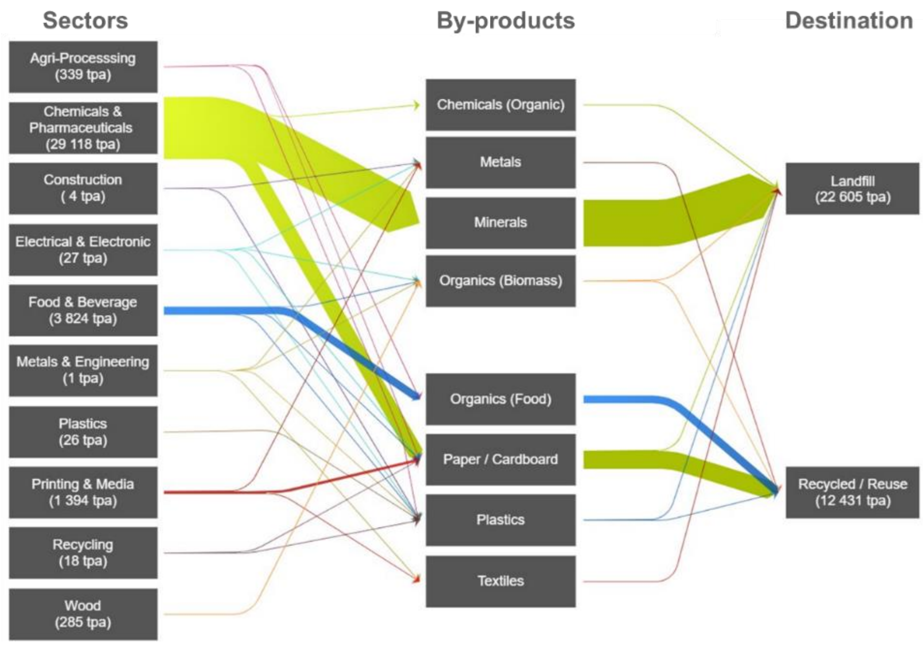

Figure 3: Sankey diagram depicting the by-product outputs in tonnes per annum (tpa) and their respective destinations for Montague Gardens

The MFA was done specifically to understand the range of material resources coming in and by-products/wastes going out in order to identify potential opportunities for collaboration if none already existed. Figure 3 illustrates the relative mass of by-products and the sectors responsible for producing the by-products (where by-product mass is demonstrated by the width of the connecting arrow) and their respective destinations. The large amount of by-products streams that are not landfilled and are currently diverted for reuse (35%), suggests that companies are attempting to find alternative uses for by-product streams and there may be a fair amount of collaboration between companies to divert these waste streams.

Information on the current reuse activities occurring in the greater Montague Gardens area is detailed below.

4.4.1 General recyclables management across all sectors

A variety of approaches are used to handle dry recyclable waste:

- Some companies separate their recyclables from the general waste and take it to the city drop-off in Killarney Gardens (4 km away).
- Companies sometimes choose to sort their paper/cardboard and sell it to the Montague Gardens paper aggregator.
- Some companies have a contractor that removes all their waste (including recyclables which can be mixed or separated from general waste), or only the recyclables.
- For those who choose not to divert the recyclables themselves, the high-value recyclables are often extracted by informal waste pickers. However, market volatility in recycling has quite a serious impact on what the waste pickers are willing to take.

Broken pallets are widely reused by all sectors in Montague Gardens by either sending them to Cape Town pallet refurbishers, dog kennel manufacturers, or giving them to the local Montague Gardens informal waste pickers.

Scrap metal is sold to one of the two scrap metal dealers in the Montague Gardens area.

4.4.2 Sector-specific recyclable management

Certain sectors may have sector specific by-products/waste streams. The mechanisms utilised to recycle these streams are detailed below.

In the **agriprocessing and food and beverage sectors**:

- A fruit and vegetable processor recycles its boxes by giving it to a nearby wholesale bakery and a juice manufacturer (within the Montague Gardens area). The fruit and vegetable processor also sends its vegetable offcuts and peels to a composter in Cape Town. The diverted boxes and the organics constitute 93% of the company's by-products/waste streams.
- A sugar manufacturer sells its sugar waste from floor sweepings to pig and bee farmers around Cape Town. The company also sells the polypropylene woven bags used for sugar packaging to plastic recyclers in Cape Town.
- A meat manufacturer freezes bones from its processing plant and sells them to a bone-meal manufacturer in the province.

In the **chemicals sector**:

- An adhesive manufacture diverts its solvents to a solvent recycling company in Cape Town.

- A paper manufacturer diverts its paper sludge to a brick manufacturing company in Atlantis.

In the **plastics sector**:

- A plastic crate manufacturer diverts the plastic dust from its manufacturing process to a roof tile manufacturer in Atlantis.
- A cornice manufacturer diverts its polystyrene offcuts to a recycler in Cape Town.

A **printing and media** company sends the majority of its paper waste to one of the large paper recyclers in Cape Town.

In the **wood sector**, two companies divert their wood sawdust waste, one to a composter (treated sawdust) and one to an animal farmer (untreated sawdust). The diversion to the composter is due to a GreenCape industrial symbiosis introduction in 2017 and continues to date; the collaboration has saved the company over R10 000 in disposal costs.

4.4.3 Additional collaboration recommendations enabled by this study

During the MFA study, several opportunities for industrial symbiosis were identified. These connections are detailed below.

The study highlighted the opportunity for:

- A dairy manufacturer in Montague Gardens to divert its liquid dairy waste to a livestock farming group within the Western Cape. The connection has assisted the manufacturer with diverting 15 tonnes per month of liquid waste from its plant. Thus, enabling the manufacturer to become legally compliant, as liquid waste has been banned from landfill as of 23rd August 2019.
- A diving equipment manufacturer to divert their used ink cartridges to an e-waste solution provider that assists with diverting ink cartridges from landfill.
- An electronic assembly company that generates waste polypropylene as a by-product from its process to divert the waste stream to a plastics recycler in Cape Town.

The study also highlighted the opportunity for the paper manufacturer that was diverting its paper sludge to a brick manufacturer in Atlantis, to negotiate to send its ash waste to the same company as well. If successful, the paper company would be able to divert almost all of its waste streams. The ash accounts for 99% of the landfilled portion of the chemical and pharmaceutical sectors’[††] by-products, and 97% of the total landfilled waste in Montague Gardens assessed in this study.

4.4.4 Breakdown of landfilled waste streams

Figure 3 demonstrates the mass and type of by-products/waste streams that are currently landfilled in Montague Gardens annually by those companies who provided data for the study. The bulk (97% - 21 840 tonnes per annum (tpa)) of the landfilled waste is due to the ash produced by the chemicals and pharmaceuticals sector. The

[††] The sectors are not grouped according to the Standard Industrial Classification (SIC) codes. For the purpose of this study, paper manufacturing was classified under the chemicals and pharmaceuticals sector.

second-largest landfilled waste streams are from the agriprocessing (1% - 277 tpa) and the wood sector (1% - 265 tpa) respectively, with the last 1% shared amongst the remaining seven sectors.

The viability of the solution for the ash will largely depend on the cost of transporting 21 840 tpa of ash. However, the Montague Gardens rail network can potentially be leveraged; as the ash solution provider is based in Atlantis, which forms part of the rail network.

Material flow data from the study revealed that the landfilled waste from the agriprocessing sector consists largely of plastic and paper towels from a meat processing company in Montague Gardens. The plastic is quite contaminated and is not easy to process, whilst the paper towels would need to be treated as hazardous and disposed of appropriately. There is potential to incinerate both streams at the incineration plant in Cape Town, however, the cost associated with the solution currently makes landfill more favourable.

The landfilled waste from the wood sector is addressed under 4.2.5 Opportunities for future collaborations/synergies.

4.4.5 Opportunities for future collaboration/synergies

4.4.5.1 Treated wood waste

From engagements with companies in the Montague Gardens area, wood waste was identified as a problematic waste stream as there are at least three board cutting stores and six furniture manufacturers in the area. The challenge with wood waste is ensuring the separation of treated and untreated wood, as the solutions vary in treatment types and cost for each of the streams. Most treated wood waste solutions (e.g. gasification), tend to be quite costly, and require large homogenous volumes; therefore, collaboration between companies is crucial to obtain economies of scale.

4.4.5.2 Rail network

The cement mixing depot is one of the only rail users in Montague Gardens. There has been speculation about the revival of the line. However, currently the concern is that if current company stops using the line, Transnet, the state-owned rail operator, will stop servicing the rail and it risks becoming obsolete.

According to the national Department of Environmental Affairs *Freight shift from road to rail report* [12];

> *"One of the most favourable measures identified to significantly reduce South Africa's greenhouse gas emissions… is the shift of freight from road to rail. It has the potential to save almost 3 000 ktCO2eq."*

This suggests that the Montague Gardens railway line is potentially a carbon reduction opportunity for the area, as the rail network is not only still functioning, but is also still being maintained for PPC. Utilising the existing railway network for the transportation of raw materials into the area and products and by-products (e.g. ash) out of the area could assist Montague Gardens with being seen as a carbon reduction zone, especially with the introduction of the carbon tax in 2019. In addition, Montague Gardens' centrality (proximity to airport, port and road network) could also be leveraged to optimise the transportation of finished goods in and out of the area via the rail network, creating a low carbon distribution hub.

4.4.5.3 Metalwork park

There are 35 metalwork companies in the Montague Gardens area, with operations ranging from cutting/bending/punching to boiler making and surface finishing. The companies indicated that there is a demand for additional metalwork capacity in the area, however, the equipment can be quite costly. The establishment of a metalworking park in Montague Gardens where companies in the various stages of the metalworking process could all share spaces, equipment and resources, would create collaborative links and reduce the inefficiencies of logistics that are common in small scale metalworking projects. The collaboration might also create the ability for smaller companies to attract more work or use their skills in a complementary manner to gain market access. There has been some discussion between the different metalworking companies in the area, but facilitation and other support may be required to unlock the opportunity.

4.5 Sources and sinks

4.5.1 Sources of material inputs

The majority of the material inputs for Montague Gardens companies are sourced from other parts of the country. With less than 15% sourced within the province (including the city) as shown in green in **Error! Reference source not found.**.

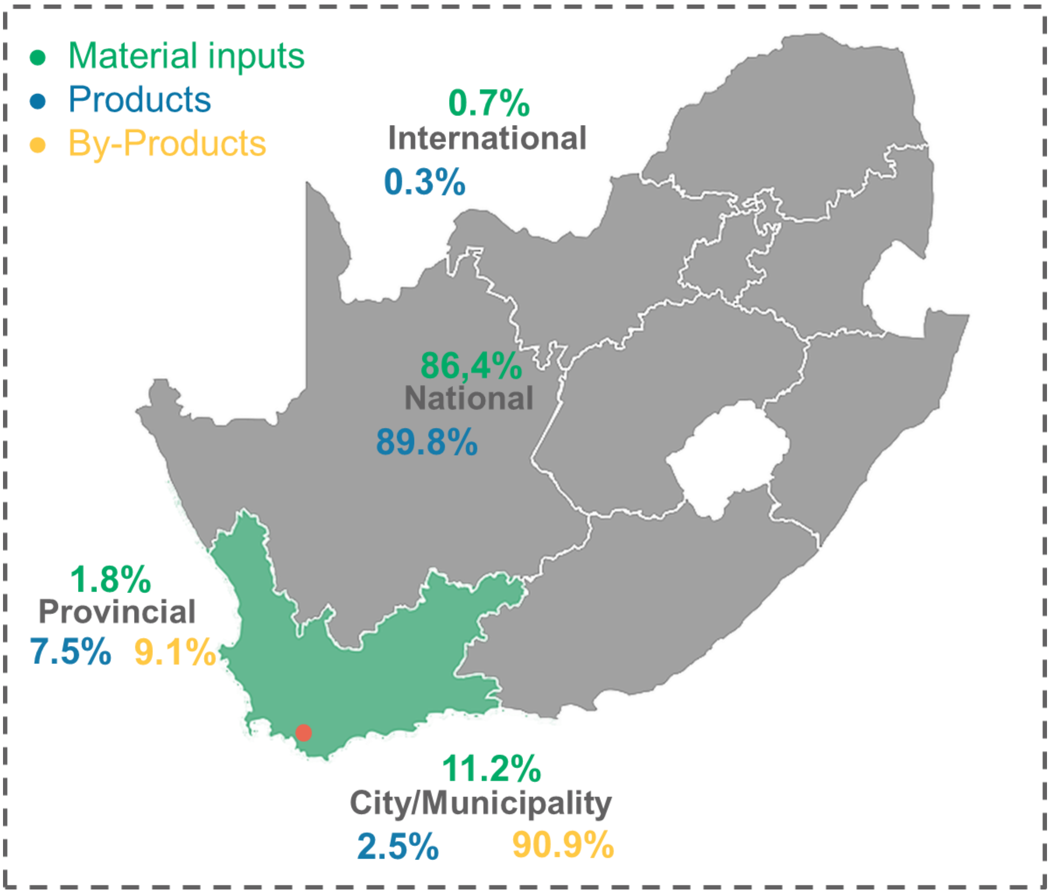

Figure 4: Sources and sinks of material inputs, products and by-products in Montague Gardens

Error! Reference source not found. Figure 4 demonstrates that only 0.7% of the total material inputs required by companies in Montague Gardens are sourced internationally. However, an analysis by sector (Figure 5) indicates that 60% of the material inputs required for the plastics sector and 27% of the material inputs required for the food and beverage sector are imported.

The imported material for the plastics sector is for one of the four plastic manufacturing companies (that participated in the study) in Montague Gardens. 90% of the plastic manufacturers' material inputs are imported, with no substitutes available in South Africa. Taking into consideration the recent supply chain disruptions due to the Covid-19 outbreak (and other potential shocks and stresses), the manufacturers' reliance on imports poses a serious risk to the continued resilience of the business.

Two of the five companies (that participated in the study) in the food and beverage sector rely on international imports. For one of the companies, the imported material constitutes 1% of their total material inputs, with limited substitutes available in South Africa. The second company is a sugar processor that imports the majority of its sugar supply, as the cost of sugar (and the associated taxes) within the country has increased. Since South Africa produces sugar, any disruptions in supply may have a smaller impact on the company's supply chain and resulting resilience.

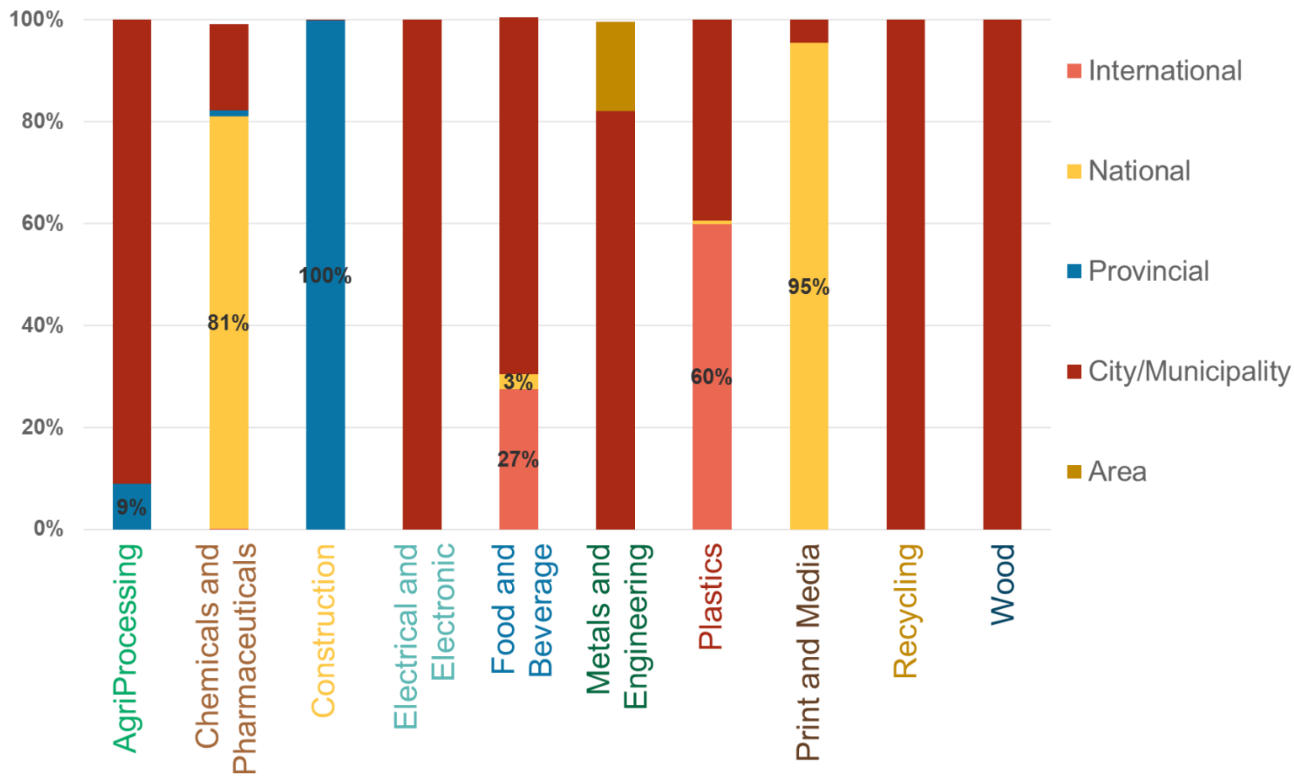

Figure 5: Graph depicting the sources and respective percentages of input material for each sector in Montague Gardens

4.5.2 "Sinks" for product outputs / market for products

Based on data received from companies (that participated in the study), 89% of products manufactured within Montague Gardens are transported out of the province. This not only demonstrates the value of the Montague Gardens' transport networks (airport, port and road network) but also supports the case for the opportunity associated with the railway network.

4.5.3 Sinks for by-products/waste outputs

All of the by-products/wastes from companies (that formed part of the study) in Montague Gardens are handled within the province. This can largely be attributed to the associated logistics costs of moving waste material. The majority of the by-products (both in number of collaborations and mass are handled within Cape Town, and not in Montague Gardens. Eight of the eleven largest (> 100 tonnes per annum) by-products in the area are being diverted from landfill for reuse outside of Montague Gardens. The solutions for these streams already exist in Cape Town, and the business case (including the logistics cost) for diversion has been validated. Therefore, there is no need to solve for these by-products within Montague Gardens.

The three remaining waste streams that are not being diverted (ash, paper and plastic waste, and treated wood) have been discussed in the sections above. Two of the waste streams already have potential solutions in Cape Town (i.e. ash to the brick manufacturer, contaminated plastic and paper towels to an incinerator). Therefore, the potential for the establishment of a local solution (within the Montague Gardens area) is mainly for the treated wood waste.

5 CONCLUSION

5.1 Material flow analysis (MFA) as a tool for resilience

The material flow analysis revealed many interesting insights in how an eco-industrial park can be leveraged to strengthen the resilience of an industrial area. The methodology was fundamental in identifying the eco-industrial park features that exist/ or that needed to be stimulated in the Montague Gardens area. It also enabled the collection of quantitative information that will potentially facilitate new opportunities for collaboration and investment; to further strengthen the resilience of the area.

5.2 Montague Gardens as an eco-industrial park (EIP)

As noted, research indicates that eco-industrial parks are more likely to adopt sustainability initiatives (thus promoting resilience) if they have high heterogeneity (a diverse range of companies and by-products), and are characterised by the presence of collaborative networks, anchor tenants and shared support services (including a management entity) [11]. The study, therefore, focused on analysing and unpacking these features within the greater Montague Gardens area. The strategic focus on anchor tenants enabled the study to identify sufficient opportunities for the area, with the data that was provided.

The Montague Gardens area has demonstrated potential towards transitioning into an eco-industrial park. The area is filled with a variety of small to medium size companies that are flexible in nature due to their type of operations (make-to-order).

The study revealed that material flows are largely externally focused with minimal flows occurring between companies in the area. The majority of the material inputs required within Montague Gardens are sourced nationally (across the country). Therefore, the risks associated with (international) supply chain disruptions, due to shocks and stresses, are fairly limited.

The existing by-product collaborations (largely with companies outside of Montague Gardens) demonstrates an openness and a need to reduce costs and explore additional revenue streams. The Montague Gardens-Marconi Beam Improvement District (MMID) and the Killarney Gardens drop-off demonstrates the value of shared services as a mechanism for reducing overall costs. However, a much higher level of collaboration will be required to properly transition the area into an EIP and realise the associated resilience benefits.

5.3 Key recommendations for the transition towards an eco-industrial park (EIP)

To enhance the Montague Gardens ability to transition to an eco-industrial park, the area would ideally need a management body (or expansion of the remit of the Montague Gardens-Marconi Beam Improvement District (MMID)) that could optimise the area by leveraging its network of companies to, among others:

- Facilitate targeted investment promotion (e.g. wood waste solution providers), business expansion and retention in the area
- Facilitate shared services (e.g. staff transport and logistics)
- Facilitate green services such as energy service companies, water service companies, and a central sorting waste area (with waste pickers) and waste management services.

Such coordination and optimisation through the management body would reduce the overall cost to individual companies and facilitate the formation of a resource-efficient, low carbon zone.

The key opportunities that can be pursued to increase the level of interconnection and collaboration in the area in line with a transition to an eco-industrial park and strengthen resilience are:

- Leverage the rail network to reduce the carbon footprint of logistics towards becoming a low carbon zone.
- Expanding collaboration beyond the exchange of physical resources [2] to include the procurement of goods or services (catering, training, supplier service agreements, equipment, etc.).
- Establishment of a central metalwork park (potentially incorporating circular principles in the form of a centralised rework hub – where products can be repaired or remanufactured for reuse would increase the resilience and competitiveness of the area).

The transformation of industrial areas into eco-industrial parks will increase the ability of businesses in the area to be able to respond shocks and stresses; as the optimised processes, collaborative networks (and associated cost benefits) [9], flexibility [5], and decreased reliance on external forces (due to strengthened supply chains) [2] all serve to enhance the overall resilience of the area.

The concept of eco-industrial parks demonstrates the value of looking beyond company boundaries, to optimisation opportunities that may exist within the surrounding area or within a company’s very own by-products/waste streams.

This study would not have been possible without the support and funding from the City of Cape Town’s Resilience department; thus, increasing the understanding of the establishment of eco-industrial parks within South Africa.

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INVESTIGATION AND ANALYSIS OF PERCEIVED CHALLENGES FACING SOUTH AFRICAN FOUNDRIES TOWARDS IMPROVING PRODUCTIVITY

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ABSTRACT

The foundry industry plays an important role in the economy because it produces semi-finished products with a variety of high-quality components for other industries. However, most foundries operate in a very competitive environment, therefore it is essential to improve productivity in order to increase the global competitiveness of the South African foundry industry. Foundry productivity is influenced by a diversity of challenges with several authors identifying these challenges. The aim of the study is to identify these challenges impacting foundry productivity through the use of the relative importance index. The study also sought to explain why South African foundries productivity is declining. The objectives were achieved through a research design which included a literature review, survey questions, structured interviews and case studies. Research results showed that the greatest challenge is human capital while the lowest-rated challenge is a lack of access to markets. The literature review confirmed that foundries suffer from various problems in their daily business. These include the rapidly rising cost of electricity, poorly financing, poor management, poor business confidence and poor infrastructure. This paper thus contributes to the understanding of productivity and challenges influencing the improvement of foundry productivity on foundries.

Keywords: economy, competitive, productivity, challenges.

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1 INTRODUCTION

Productivity has been subjected to numerous studies and has become a global concern [1]. It is an important component to economic growth and influences all aspects of our economic life [2]. Productivity is a key factor which brings success to any establishment. Many researchers from different fields: economic, accounting, engineering and managerial have contributed to the definition of productivity and the most popular definition was described by Stevenson [3] as an index that measures output (goods and services) relative to the input (labour, materials, energy and other resources) used to produce it.

Today, productivity has become the national concern of both the developing and the developed countries or economies [1]. The government of any country is continuously searching for economic growth which is dependent upon productivity growth, [4]. It is widely believed that the productivity level and its growth is a precondition of people's standard of living and a key determinant in defining and maintaining economies competitiveness in the globalised economy [5]. Standard of living means the degree of material well-being available to a person or a class or community, which is necessary for sustaining and enjoying life [6]. Productivity aims at the maximum utilisation of resources for yielding as many goods and services as possible, of the kinds most wanted by consumers at the lowest possible cost [2]. Higher productivity leads to a reduction in cost of production, reduces sales price of an item, expands markets and enable goods to compete effectively in the world [5].

Despite increased efficiency in some casting foundries, the overall productivity for the casting foundries in South Africa has declined. In 2007, the outputs were 660 440 tons compared to 375 240 tons in 2013 [7]. There have been discussions about improving performance and productivity in South African Casting Foundries (SACF). Low productivity and the increase in the cost of production have become severe challenges faced by SACF. The consequences of lower productivity have resulted in lower outputs which discourage foundries from investing in productivity improvement [8]. The need for productivity improvement in the foundry industry has been confirmed by Johnson [1]. The benefit of improved productivity is employment creation.

In a survey conducted by South African Institute of Foundry (SAIF), it was established that more than 80% of manufactured products contain castings [7]. In addition, the foundry industry plays an important role in economic development as it produces semi-finished products for other industries. However, since 2007 the number of foundries in South Africa have downsized to 170, [7], with some in-house foundries producing for their own consumption. According to the National Foundry Technology Network, NFTN report [9], 15 foundries have closed since 2010. The factors leading to these closures were identified in literature as the inability of South African foundries to compete with countries like India, China and Brazil [10]. In a highly competitive environment, foundries must focus on productivity to meet the requirements of customers. Productivity is critical for the long-term competitiveness and profitability of foundries.

Foundries in South Africa are challenged by low productivity, hence, it is difficult for foundries to compete at a global level. In general, foundries face various challenges in improving productivity. There have been several investigations into the challenges faced by foundries in improving productivity. These challenges include inadequate and unskilled workforce [11], frequent machine breakdowns [12], lack of familiarity with new casting techniques [13], high defect rate [11], lack of financial management skills [7] and rapidly rising energy costs [14].

This paper begins by investigating challenges in casting foundries in improving productivity. It will then go on to analyse to what extent these challenges affect productivity improvement. Consequently, in an attempt to increase efficiency and effectiveness in the foundry industry, the paper will also investigate tools that can be used.

1.1 Research objectives

The objective of this research is:

- To investigate and understand the perceptions surrounding the possible challenges that would impact South African foundries.
- To rank the perceived challenges faced by South African foundries.

1.2 Research questions

This study sought to address the following research question:

- What are the perceived challenges faced by South African foundries?

2 LITERATURE REVIEW

2.1 Foundry overview

A foundry is a factory where casting processes are carried out [15]. Metal casting is one of the most ancient techniques used for manufacturing metal parts. Metal casting is a manufacturing process with a relatively high level of energy consumption. It is the process of forming metallic objects by melting metal, pouring it into the shaped cavity of a mould and allowing it to solidify [16]. Figure 1 shows the steps in the casting process.

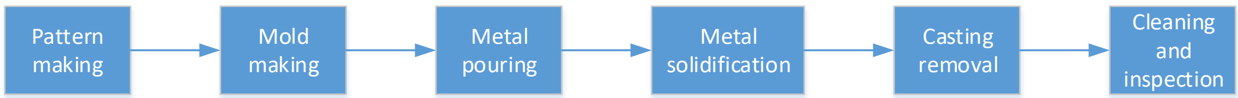

Figure 1: Casting process flow [16]

Foundries are classified generally according to the type of metal cast in the unit. Ramana Rao [16], classified foundries into two broad types: ferrous foundries and non-ferrous foundries. Ferrous foundries cast carbon, steels, alloy steels, iron and grey cast iron, whilst, non-ferrous foundries include aluminium and copper alloys.

Foundries are also grouped by the nature of their production. Ramana Rao [16], grouped the foundries as:

- “Jobbing foundries -Execute casting orders for small quantities.
- Mass production foundries – Produce castings for automobiles, valves in very large quantities for each pattern. The production line is automated.
- Captive foundries – Cater to the needs of the main industry to which the foundry belongs”.

The foundry industry in South Africa is mostly dominated by jobbing foundries. One of the main challenges faced by jobbing foundries is that they manufacture a diverse and complex range of products.

2.2 Challenges faced by the foundry industry

In today’s knowledge economy, foundries in the developing countries are facing various challenges. These challenges have been widely investigated [17]. These include poor financing, hence, most of the foundries use obsolete equipment causing low productivity, poor management, quality, efficiency and environmental pollution control measures being gradually introduced by the government which causes extra expenditure [18]. Quality tests should be implemented in order to comply with quality parameters. Tests on castings evaluate characteristics such as chemical composition, hardness, surface qualities, impact resistance and dimensional properties. Ensuring efficient processing and workflow are key aspects to improving production and productivity. Other challenges include the weight of the castings. The castings often weigh a great deal, requiring various material handling systems for safety and transportation. Finished products and raw materials require adequate storage space; this implies that foundry owners have to plan for long term growth.

The foundry industry has over the past decade failed to keep up with global advances in technological developments [19], hence, this has hampered the competitiveness of the SA foundry industry in the international marketplace. The CEO of SAIF suggests that to become more competitive the foundry industry must strive to be technologically advanced to cater to new demands, which will trigger growth for the industry.

SAIF [20] highlighted challenges faced by South African foundry industry as:

- “Rapidly rising energy costs and the need to improve energy efficiency.
- Import leakages which caused a reduction of orders.
- Poor material conversion efficiency.
- Lack of skills development and training.
- Limited access to capital.
- Recent technological developments which require special skills.
- Lack of access to markets.
- The foundry environment which is dark, dirty and dangerous”.

2.3 Productivity improvement techniques

There are several productivity improvement techniques that an organisation can use for productivity improvement. After World War II, the Japanese developed a number of productivity improvement techniques. These techniques can be applied effectively in any organisation. Table 1 presents some of the selected improvement techniques that can be used by foundries in improving productivity.

3 RESEARCH METHODOLOGY

The research methodology of this research included a relevant literature review and a detailed case study on four foundries, on which two were small-sized and two medium-sized foundries. Case studies can be used to explore, describe, explain and compare, Yin, [24]. The research design of this study followed a survey on four foundries. A questionnaire on challenges in improving productivity in foundries was developed. The challenges that have a high probability of influencing productivity improvement in South African foundries were selected based on the findings of various authors. Thirty-seven challenges considered for the study were categorised into six groups namely Process, Workforce, Equipment/Machine, Market, Raw materials and Workplace. Two questions were asked for each of the challenges selected. The first question required the respondent to indicate if a challenge had an impact on improving foundry productivity and secondly how often it occurred. The challenges in the questionnaire were rated according to a Likert scale ranging from 0-4 on both categories. The respondents included senior managers, production supervisors and shop floors of the four studied foundries.

After rating the challenges, the first stage was to calculate the Relative Importance Index (RII) for each challenge based on the two categories of questions. The Relative

Importance Index allows for comparison of different challenges and thereafter ranking the challenges. The relative index was computed as follows:

$$\text{RII} = \frac{\sum W}{A * N}$$

Where;

W = is the weight given to each challenge by the respondents and ranges from 0 to 4;

A = the highest weight which is 4;

N = the total number of respondents.

A Modified Relative Importance Index (MRII) adopted from El-Gohary & Aziz [25] was used in the second stage. Modified Relative Importance Index is the average of two RII values. The first RII value is based on the perceived impact of the challenges whereas the second RII value is based on the frequency of occurrence of the challenge. MRII was calculated as follows:

$$\text{MRII} = \frac{RII\ of\ the\ impact\ of\ the\ challenge + RII\ of\ the\ frequency\ of\ occurence}{2}$$

A challenge may have a high impact; however, it may not occur frequently. Conversely, a challenge may have a low impact but occur frequently. Hence, MRII was used as it considers both the perceived impact as well as the frequency of occurrence. A Microsoft Excel spreadsheet was utilized to capture and to analyze the data for each challenge.

Structured interviews were arranged with senior managers and production supervisors. Senior managers and production supervisors were asked on their opinions regarding the challenges they are facing in improving productivity.

4 FINDINGS AND ANALYSIS

As foundries strive to compete in the global economy, they should understand challenges that influence productivity improvement. Productivity improvement is crucial in foundries for their survival.

Out of 85 questionnaires distributed, only 53 were collected for analysis which represent 62% response rate. The respondents were 6 managers, 12 production supervisors and 35 shop floor workers. From the 4 point Likert scale, relative importance index and average relative index (MRII) which combines the impact and frequency of occurrence were calculated.

4.1 Process challenges affecting improving productivity in foundries

The main purpose of the study was to investigate and analyse challenges SA foundries are facing in improving productivity. Based on the MRII ranking, it can be seen from Table 2 that the three main challenges that were considered to have a high impact are high energy consumption, excessive rework and inappropriate work methods, respectively. The foundry industry is reported to be an energy-intensive industry as melting and solidifying metals requires a high amount of energy. This result agrees with the work of Rasmeni and Pan [26] who found that the foundry industry consumes high energy compared to other sectors. Furthermore, it has been reported to be the second largest user of energy in the world industrial sector [26]. Energy is considered as an input in the production process. Therefore production costs will increase as a result of high energy consumption. However, there are management practices that could be adopted to improve energy efficiency and the key barrier to energy efficiency in foundries is a lack of information about energy efficiency measures [27]. Excessive rework and inappropriate work methods contribute to additional costs to the foundry. In today's competitive environment, foundries need to focus on improving their work methods and add new quality checks to their workflow as well to reduce waste. Appropriate work methods can decrease production time. In addition, finding new and innovative work methods will ensure that production operates at full capacity during busy times thereby increasing productivity. The lowest rated challenge is poor material conversion efficiency.

Table 1: Productivity improvement techniques

Technique	Summary	Researcher/s
5s	"This tool is a systematic method for organising and standardising the workplace. The activities are (1) Sort out (2) Set in order (3) Shine/Cleanliness (4) Standardise (5) Sustain".	[21]
Kanban	"A manual system used for controlling the movement of parts and materials that responds to signals of the need for delivery of parts or materials. Hence, it controls the required parts at the required time".	[3]
Kaizen	"Kaizen is the Japanese name for continuous improvement of the system. It is the process of identifying and eliminating wastes as quickly as possible at the lowest possible cost".	[21]
Just-in-time	"A highly coordinated processing system in which goods move through the system, and services are performed, just as they are needed".	[3]
Value stream mapping	"It is employed to identify the areas that need to be improved and to decide the wastes to be eliminated. It provides a graphical flow of the process and supports the related value stream analysis tool. It also provides the scope for the project by defining the current and future states of the system".	[22]
Work Standardised	"Operations are organised in the safest, best known sequence using the most effective combination of resources. The job is broken down into elements".	[21]
Total Productive Maintenance (TPM)	"It is a maintenance program, which involves a newly defined concept for maintaining plants and equipment. The employees are given greater responsibility for quality, productivity and the general functioning of the system. The goal of the TPM is to increase production, increase employee morale and job satisfaction".	[23]
Total Quality Management (TQM)	"A philosophy that involves everyone in an organisation in a continual effort to improve quality and achieve customer satisfaction. It is a management system that is used to continuously improve all areas of a company's operations".	[3]

Table 2: Process challenges

Process	Relative Importance Index (RII)			
	Impact of challenge	Frequency of occurrence	Modified RII (MRII)	Ranking based on MRII
High energy consumption	0.823	0.827	0.825	1
Excessive rework	0.794	0.726	0.760	2
Inappropriate work methods	0.712	0.685	0.699	3
Non-productive activities	0.652	0.608	0.630	4
Poor information flow	0.568	0.524	0.546	5
Poor material conversion efficiency	0.516	0.487	0.502	6

4.2 Workforce challenges affecting improving productivity in foundries

Differentiation on the basis of knowledge and skills is very important in foundries as they strive to compete in the global economy. Major challenges of the workforce were found to be the level of education (0.863), inadequate experience (0.798) and lack of skills development and training provided (0.756). Low-level education and lack of skilled labour are concerning issues for the foundry industry. It has been reported that training provides an opportunity to develop and expand the knowledge and skill of the workforce, [12]. However, employers find these development opportunities costly. Furthermore, workers do not perform their duties whilst taking part in training sessions which affects the completion of production. However, despite all these hindrances training activities have a positive impact on workers performance. The report shows that new knowledge and skills obtained and existing knowledge and skills are enhanced. This will lead to an increase in process efficiency and an increase in capacity in adopting new technologies. In addition, it also increases job satisfaction and morale among workers.

4.3 Equipment/Machines challenges affecting improving productivity in foundries

There is a growing adoption of new and advanced technologies, hence, foundries should be implementing these technologies to remain competitive as well as to increase productivity. Lack of advanced technologies in foundries was ranked the highest with a value of 0.848 and followed by frequent machine breakdowns with an MRII of 0.773. According to Wacker et al, [29] nowadays the major daily problem that is encountered by manufacturing companies including foundries is machine breakdown. The most interesting finding is that equipment or machine of any type regardless of complexity and price is liable to breakdown. Frequent machine breakdown has a direct impact on productivity improvement. The frequency of occurrence does have a major effect. Therefore it can be concluded that the frequency of machine breakdown occurrence does affect productivity.

Table 3: Workforce challenges

Workforce	**Relative Importance Index (RII)**			
	Impact of challenge	Frequency of occurrence	Modified RII (MRII)	Ranking based on MRII
Level of education of workforce	0.889	0.863	0.876	1
Inadequate experience of workforce	0.805	0.791	0.798	2
Lack of skills development and training provided to workforce	0.741	0.783	0.762	3
Recent technologies developments which requires special skills	0.807	0.704	0.756	4
Poor management skills	0.748	0.712	0.730	5
Lack of communication	0.644	0.687	0.666	6
Low productivity of workforce	0.629	0.604	0.617	7
Absenteeism of workforce	0.562	0.554	0.558	8
Low motivation of workforce	0.533	0.509	0.521	9
Worker disputes	0.492	0.403	0.448	10

The perceptions shown above are more from the shop floor workers who constituted almost 66% of the respondents. This explains why the last three factors scored lowly.

Table 4: Equipment/Machine challenges

Equipment/machines	**Relative Importance Index (RII)**			
	Impact of challenge	Frequency of occurrence	Modified RII (MRII)	Ranking based on MRII
Lack of advanced technology	0.857	0.839	0.848	1
Frequent machine breakdowns	0.781	0.705	0.743	2
Low efficiency of equipment	0.699	0.683	0.691	3
Improper equipment	0.683	0.694	0.689	4
Shortage of equipment	0.696	0.679	0.688	5

4.4 Market challenges affecting productivity improvement in foundries

The relative importance index and ranking of market challenges are summarised in Table 5. Limited access to finance has been ranked first. This challenge is the main important because it promotes sustainability and growth in foundries. It has been revealed that the lack of capital and access to finance were two of the most serious challenges to foundries [11]. Foundries were not able to make improvements in technology needed to increase productivity because they lack access to finance

Table 5: Market challenges

Market	Relative Importance Index (RII)			
	Impact of challenge	Frequency of occurrence	Modified RII (MRII)	Ranking based on MRII
Limited access to finance	0.923	0.897	0.910	1
Import leakages which causes reduction of orders	0.837	0.809	0.823	2
Effect of globalisation	0.671	0.686	0.679	3
Economic risks	0.663	0.605	0.634	4
Lack of access to market	0.501	0.453	0.477	5

4.5 Raw materials challenges affecting productivity improvement in foundries

The starting point for any final product is reported to be raw materials, as a result, it is vital to use the best practices for managing raw materials. With an average relative importance of 0.723 shortages of raw materials was considered the main challenge in improving productivity in foundries. Although the frequency of occurrence does not have a major effect, the impact of material shortages leads to longer lead times. Lead time is very crucial for foundries because products need to be delivered to customers in time to gain a competitive advantage. Raw materials shortage degrades foundries ability to produce enough products to meet customers' requirements. It is reported that consequences of raw materials includes an interruption of production schedule, late delivery, increased production lead time and increased work in the process [19]. The results indicated that the frequency of occurrence of late deliveries of material did have an effect as the relative importance index value is higher (0.725) than the impact relative index of 0.710. The least rated challenge in improving productivity in foundries was the poor quality of material.

Table 6: Raw materials challenges

Raw materials	Relative Importance Index (RII)			
	Impact of challenge	Frequency of occurrence	Modified RII (MRII)	Ranking based on MRII
Shortage of raw materials	0.737	0.709	0.723	1
Late deliveries of material	0.710	0.725	0.718	2
Unreliable suppliers	0.703	0.638	0.671	3
Delay in manufacturing raw materials	0.672	0.591	0.632	4
Poor quality of material	0.608	0.622	0.615	5

4.6 Workplace challenges productivity improvement in foundries

The foundry industry has been reported to have poor housekeeping practices, dangerous and dark [27]. Hence, young generations are not enthusiastic to work in these harsh conditions. It was observed that the three main challenges that affect productivity improvement as perceived by respondents in SA foundries were: poor housekeeping practices, dangerous working environment and unavailability of resources. The challenge that was reported to have a high frequency of occurrence is a dangerous working environment. This is as a result of the foundry workers being exposed to various hazards such as emissions of heat rays that cause high temperatures, metal dusts, toxic fumes, noise and vibrations during the foundry operations.

Table 7: Workplace challenges

Workplace	Relative Importance Index (RII)			
	Impact of challenge	Frequency of occurrence	Modified RII (MRII)	Ranking based on MRII
Poor housekeeping practices	0.886	0.893	0.890	1
Dangerous working environment	0.809	0.927	0.868	2
Unavailability of resources	0.828	0.842	0.835	3
Dark working environment	0.801	0.829	0.815	4
Changes in government regulations and laws	0.653	0.660	0.657	5
Environmental and social factors	0.617	0.576	0.597	6

4.7 Interviews

Three senior managers with foundry experience averaging nine years and two production supervisors were interviewed. Production supervisors interact with the workers and processes every day.

The majority of interviewees confirmed that the foundry industry is facing various challenges in improving productivity. Three senior managers interviewed indicated that most foundry workers had no formal education. Hence, this high level of little or no education suggests the difficulties foundries are facing when it comes to adoption of new technologies in the foundry industry in order to improve productivity. One senior manager stated that, “Local foundry industry is facing strong technology challenges as the industry moves into the international market place caused by low investments in acquiring new machines”.

It became apparent during the interviews that training and availability of skilled workers is an issue that the foundry industry has to deal with. Most managers were concerned with the issue of lack of access to finance and they emphasised that government must intervene to implement financial policies that could assist to access to finance as most foundries are made up of small to medium-sized foundries. One production supervisor stated that “Finance has always been a problem for our plant and management has always raised issues of lack of finance every time we want new equipment”. Most senior managers indicated that improving financial accessibility could directly enhance productivity. Furthermore, they emphasised that, finance is the most important factor in determining the survival and growth of foundries in SA.

In addition, interviews revealed that poor confidence and poor infrastructure contributes to the challenges of influencing productivity improvement in foundries. One senior manager stated that “Infrastructure is one of the most important factors for growth with high-quality infrastructure services foundries will be able to remain competitive”. Production supervisors further commented that poor confidence of workers leads to poor performance which affects productivity in foundries.

5 LIMITATIONS

The current research was conducted in foundries operating in Gauteng only. Future studies could be done in other provinces of South Africa which might produce different results. In addition, only four foundries were studied and more workers responded making it difficult to generalise these results. The nature of the studied industry is such that there are more workers than managers. Interview participants were limited to those who were interested in the topic.

6 CONCLUSION

In this rapidly changing world, understanding challenges that influence the improvement of foundry productivity should be a priority for all foundries as productivity is regarded to be the main value-adding strategy in manufacturing. The survey investigated these challenges and the analysis of the data revealed that a lack of capital has the most profound impact on foundries. Most foundries are in the survival mode, hence, they are desperately in need of investment to improve their processes in order to improve productivity. Therefore, government involvement is urgently required. It has been concluded that SA foundries productivity is declining because of issues such as energy cost, labour, raw materials, environmental regulations and the use of imported products instead of locally manufactured which contributes to the foundry industry not producing at full capacity due to insufficient demand. In addition, the demand for advanced cast components and global competition has made improvements to casting technologies worldwide.

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ADDRESSING PART SHORTAGES WITHIN AN AVIATION COMPANY IN SOUTH AFRICA, BY UTILIZING THE DMADV METHOD IN CONJUNCTION WITH LEAN PHILOSOPHY

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ABSTRACT

The aviation industry in South Africa consists of multiple processes and integrated systems. However, they experience multiple manufacturing challenges such as production delays. Aircraft delays are mainly caused by part shortages in the system. The aim of this study is to address these part shortages experienced in an aviation company by using Lean philosophy. The DMADV(Define-measure-analyse-design-verify) methodology was utilised. A Process flow diagram, Pareto chart and 5S audit were used to determine the current state. A root cause analysis was conducted via a 5 why and a thematic map analysis. Solutions were designed based on Kernel Theories and verified using the Delphi-method. The solutions were demonstrated using statistical control charts. This case study emphasizes the importance of communication between the different organisational levels within a company. The impact and the importance of cultural differences in an integrated supply chain are investigated and lean philosophy is applied to ensure horizontal alignment between employees.

Keywords: Aviation industry, Lean philosophy, Part shortages

1. INTRODUCTION

Organisations in the aviation industry can avoid difficulties and pitfalls in their manufacturing systems by implementing a new production philosophy which eliminates the need to produce based on a forecast, rework or the acceptance of non-conformances [1]. The aviation company used as case study specialises in the design, development and manufacturing of sailplanes. A sailplane is a high-performance aircraft which can soar for hundreds of kilometres in the sky, by only consuming sun-energy.

This aviation company consists of multiple integrated manufacturing processes, systems and production stages to successfully deliver high-quality aircraft. Conversely, the problem is that the company is experiencing part shortages in these processes and production stages which ultimately results in production delays. However, the reason behind this is unknown.

A manufacturing process is a series of events that an aircraft has to endure in order to be delivered to the customer as an end-product. The kitting process is one of the most imperative processes in the manufacturing of an aircraft. Kitting is a process where multiple components are grouped before being distributed to the different production stages (Phases in the manufacturing processes i.e. integration, finishing, canopy). Before distribution, the kit is evaluated and inspected via kitting coordinators.

The kitting storage consists of various input and output processes. The input processes are defined as the metal storage, stage 2: control surfaces, small composite and sub-assembly, design organisation (DO) and computer numerical control (CNC). The output processes are defined as stage 3: Canopy, fuselage and trim, and stage 7: final assembly. The kitting storage also has support departments such as IT management, human resources, finance and infrastructure. Additional processes are also described as spare parts and approved maintenance organisation (AMO). Figure 1 illustrates the manufacturing stages, technical and additional support sections within the aviation company:

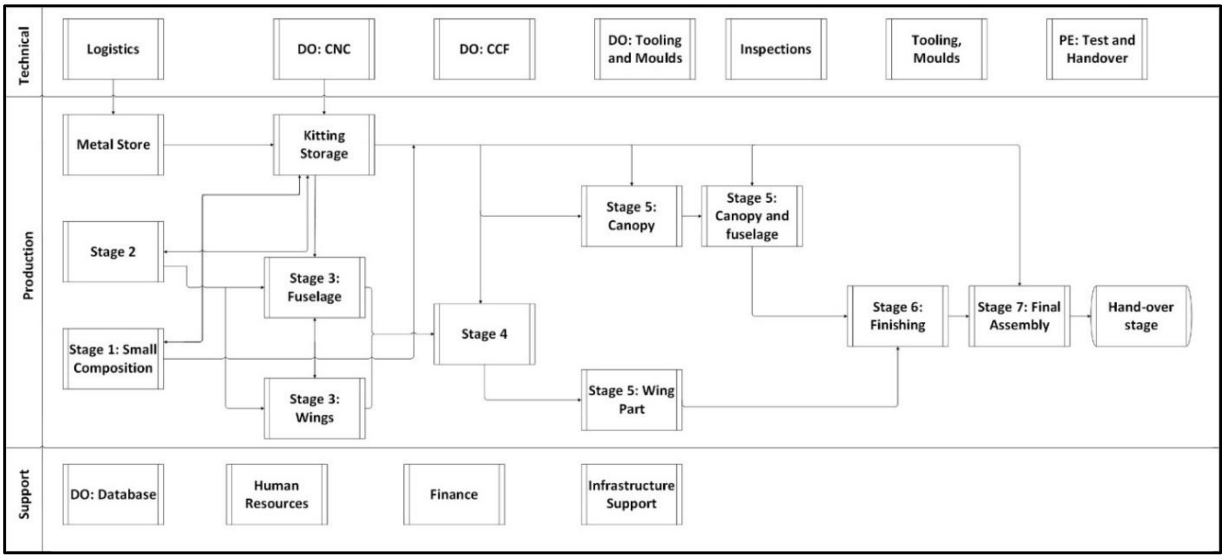

Figure 1: Internal manufacturing stages within the aviation company

The implementation of the lean philosophy in the aerospace industry has a significant effect on all processes and systems [2]. Furthermore, improving these processes and systems within the manufacturing should not include large-scale investments, but rather work simplification by eliminating wastes [3]. Various case studies (similar to this case study), are identified and explained throughout this research paper [3]. This could justify exploring the implementation of lean philosophy at the organisation.

2. RESEARCH AIM

The research study aimed to investigate and address the root causes of the part shortages experienced in the organisation. Section 3 explains the research method utilized throughout this case study to address this aim.

3. RESEARCH METHODOLOGY

This study made use of the DMADV method, as it is the best suited for improvements, adjustments, or the creation of new concepts. The DMADV methodology is applied if the existing processes need to be redesigned to reduce variability [4]. This aligns well with the goal of this study since lean is new to the organisation. This methodology integrated a variety of other methods at the various phases (Table 1).

Table 1: Overarching Research Methodology

Phases	Methodology	Outcome
Define	➢ Gemba Walks ➢ Literature Study	§4,1: Problem, Aim and Deliverables Literature Study → Adapted case studies
Measure	➢ Pareto Analysis ➢ Conducted 5S Audit	§4,2,1: Pareto Chart §4,2,2: 5S Audit Sheet → 5S → Sort, Straighten, Shine, Standardize, Sustain
Analyse	➢ 5-Why analysis ➢ Thematic Analysis	§ 4,3,1: 5 Why Table § 4,3,2: Thematic Map Root Cause 1, Root Cause 2, Root Cause 3, Root Cause 4
Design	➢ Kernel Theories	§ 4,4: Proposed Solutions
Verify	➢ Delphi Method	Survey Results and Control Charts § 4,5: Results: Verified Solutions

3.1 Define Phase

All processes, systems and production stages were identified during the define phase. The company follows an integrated supply chain where different parts and components (consisting of small different parts) are imported from various countries. The stages that manufacture in-house parts are integrated with all of the different production stages. Gemba walks were conducted to observe the current processes and problems. A comprehensive literature study and theoretical background were performed on topics to gain fundamental knowledge in order to investigate any similar case studies (see the Boeing case study [5] and Appendix A) for a better understanding. The outcome of the define phase is captured in section 4.1.

3.2 Measure Phase

The current state was investigated using a Pareto chart, with the outcome discussed in section 4.2. Radson and Boyd [6] stated that the Pareto chart is a very good decision-making tool which can be used for quality improvement efforts [6]. Moreover, a 5S analysis was conducted on the kitting storage, as it is a method used in organising the workplace, to eliminate wastes and to increase efficiency [7]. Ward and De Brito [8] stated that this lean tool can potentially improve flight safety by ensuring that the right equipment, tools and documentation are placed in the right area [8].

The results obtained from the 5S audit sheet are elucidated in section 4.2.

3.3 Analyse Phase

A 5 why and thematic analysis was conducted during this phase. Liker [9] [10] explained that the first step in any problem-solving process is to understand the actual situation [9] [10]. Gangidi [11] added on this, by stating that a problem can start as a human error, but the system can affect the overall human interactions within the organisation [11].

A 5 why analysis was conducted on 20 parts which were not delivered on time in the kitting storage (findings available in section 4.3.1). The thematic analysis is a structural method used to identify and organize trends and patterns. The patterns identified are very important, since they show relation to a specific root cause [12]. In this case study, a thematic analysis was conducted to particularized and confirm the links and various patterns of the 5 why analysis. (Outcomes available in section 4.3.2).

3.4 Design Phase

The design phase consists of a concept design where various solutions were proposed to address each root cause. The final design consists of solutions that would address the part shortages experienced within the organisation. These solutions were designed using kernel theories. Ohno [3] believed that improving the methods within the manufacturing should not include large scale investments, but rather include work simplification by eliminating wastes [3]. Kernal theories are from science and serve as a design requirement [13] to address each root cause. The 14 lean management principles were utilized as kernel theories throughout this case study.

Ohno [3] expressed that reducing manpower and inventory is part of waste elimination. He considered waiting as a waste since it is not contributing value to the process. Lean implementation has a significant effect on industries such as automobile and aerospace, therefore it is imperative to implement lean in an industry which can fully benefit from it [2]. Various barriers exist when implementing lean [14]. Researchers found that one of the biggest reasons why lean is not successfully implemented is because the worker focuses too much on the type of tools, rather than concentrating on personal issues within the organisation. Barriers that were identified were transformed into decision criteria for the solutions [14] because the opposite of a barrier is a potential success factor.

A solution was designed for each root cause. These solutions were evaluated based on the following criteria (derived from the opposite of lean barriers), using a 5-point Likert scale:

1. Cost to the company
2. Lack of Resources
3. Hierarchical Issues
4. Cultural issues
5. Poor communication
6. Resistance from employees
7. Resistance from management

3.5 The Verification Phase

For the verification phase, the Delphi method was used in conjunction with surveys. Skulmoski and Hartman et al [15] defined the Delphi method as a research instrument and is described as an iterative process where anonymous judgements are collected using analysis techniques and datasets [15]. The objective of this method is to explore various ideas in a very creative and reliable manner [15]. In this case study, a survey was designed which specifically focused on the problems and solutions [15]. A minimum requirement of a 75% average was taken to be a consensus amongst participants on the survey.

The consensus is reached if every person scores each statement above 3.7 (on a 5-point Likert scale) [16]. To adhere to the three-sigma limits, a sample between 20-25 participants were taken to conduct the survey [17]. The survey was conducted on floor workers, team leaders and management, to ensure that the sample accounted for various levels within the organisational hierarchy.

4. FINDING

4.1 The Define Phase

From Gemba walks, it was observed that all parts are first transported to the kitting storage where they are grouped before being distributed to the various stages. Additionally, the problem and aim were identified:

- **Research Problem**: The organisation was experiencing part shortages in all their production stages resulting in major production delays.
- **Research Aim**: To investigate and address the root causes of these part shortages.

From investigating the literature, researchers [5] found that the 787 Dreamliner (world's fastest aerospace contractor and US largest aircraft exporter) created by Boeing in 2003 experienced a similar problem as this organisation [5]. To reduce the development time from six to four years, Boeing used an unconventional supply chain which is new to the aviation industry. By investigating the foregoing, multiple risks and challenges were defined and linked to the current problem experienced by this organisation [5]

4.2 The Measure Phase

During the measure phase, several parts which were not delivered on time throughout all the production stages and processes were investigated and analysed using a Pareto Chart, as depicted in figure 2:

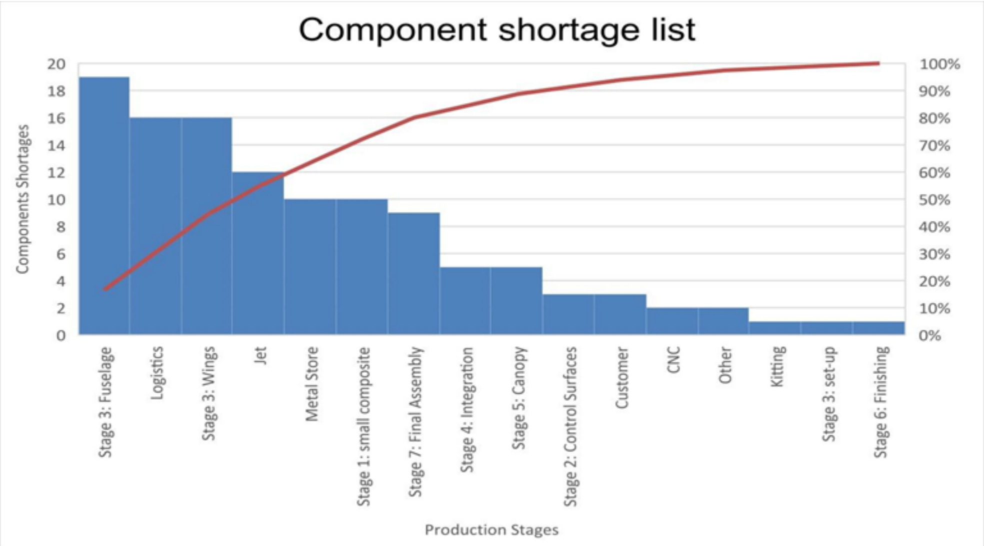

Figure 2: Pareto Chart - component shortage list

From figure 2, it was concluded that 20% of the production sections are causing 80% of the part shortages, namely the following sections:

1. Stage 3: Fuselage
2. Logistics
3. Stage 3: Wings
4. Jet
5. Metal Storage

6. Stage 1: Small Composite
7. Stage 7: Final Assembly

All these stages receive their kits from the kitting storage. However, they were experiencing major part shortages. Thus, the root of this problem originated from the kitting storage. It was of paramount importance that a further investigation was conducted in the kitting storage.

A 5S audit sheet was utilized to investigate the current state of the kitting storage, results illustrated in table 2. Multiple questions were asked to employees within this section.

Table 2: 5S Audit Sheet Results

Phase	Investigation/observations
Seiri (Sort)	1. Multiple equipment and tools were laying around in the kitting store 2. Some of the aircraft parts were placed on the racks, but other parts were placed at random places 3. Most of the parts placed in the storage were in use
Seiton (Set in order)	1. Not all the racks were labelled, this resulted in parts not being placed at the correct location 2. There were Kanban cards, but the Kanban system was not working accurately. It was observed that some of the minimum quantities were zero 3. There were safety equipment and supplies available for the workers
Seiso (Shining)	1. The entire kitting storage was dirty and was not kept clean. However, it was taken into consideration that it is a manufacturing storage 2. There were no cleaning assignments present in the storage 3. All parts and components were kept clean. The lighting was also sufficient
Seiketsu (Standardize)	1. There were signs and colour coding implemented. Some of the aircraft parts had unique labels. However, it is not used to its full potential 2. There was no 5S checklist visible in this storage
Shitsuke (Sustain)	1. Employees had no idea what a 5S was and no success stories were displayed

4.3 The Analyse Phase

4.3.1 The 5 Why Analysis

A 5-why analysis was performed through Gemba walks on the part shortages experienced in the kitting storage. The kitting storage receives parts from the metal storage, small composites, off the Shelf and Design Organisation.

Twenty parts which were not delivered on-time from these sections were investigated via a 5 why analysis, (captured in table 3). If the part shortages experienced in the kitting storage are addressed, the part shortages in the rest of the production stages will be addressed as well, since they all receive parts from the kitting storage.

Table 3: 5 Why Analysis conducted on 20 parts

Part No	Why 1	Why 2	Why 3	Why 4	Why5
Part 1	This part was not delivered on time	An invoice was never sent to the supplier to confirm payment. This resulted in the supplier not knowing if the part was payed for	Lack of communication	**Low employee skill level**	Poor management regulations
Part 2	This part was not delivered on time	Supplier did not receive the required parts on time by their suppliers	Ineffective process design. There are no spare parts	Insufficient Kanban system	**Low employee skill level**
Part 3	This part was not delivered on time	The machine which manufactured this particular part was broken and out of order	Tooling, wear breaking due to Pre-maintenance inspection requirement not performed.	Lack of employee supervision: There is no form of support or guidance for the employees working in the kitting storage	Poor management regulations
Part 4	This part was not delivered on time.	Poor planning. Pre-planned lead time was 12 weeks. Actual lead time was 14 weeks.	Lack of communication between the employees and supplier	**Low employee skill level**	Poor management.
Part 5	This part was not delivered on time	This particular part (metal part) was not put on the shortage list	Lack of awareness. Store manager in the kitting store was not aware that the part was in demand	Metal store did not communicate effectively with the kitting store	Metal components are kit in the kitting storage. **Thus, there are no kitting coordinator in the metal storage.** This causes lack of communication
Part 6	This part was not delivered on time	The sub-assembly(springs) for this part was not ordered by the kitting store manager	Lack of awareness. Store manager in the kitting store was not aware that the part was in demand.	Metal store did not communicate effectively with the kitting store.	Metal components are kit in the kitting storage. **Thus, there are no kitting coordinator in the metal storage.** This causes lack of communication
Part 7	This part was not delivered on time	Metal shop waited for the required welded parts (raw materials) to return from the supplier to the metal store.	Ineffective process design. There are no spare parts	Insufficient Kanban system	**Low employee skill level**
Part 8	This part was not delivered	The part number was not put on shortage list	Lack of awareness. Store manager in the kitting store was not aware that the part was in demand.	Metal store did not communicate effectively with the kitting store.	Metal components are kit in the kitting storage. **Thus, there are no kitting coordinator in the metal storage.** This causes lack of communication
Part 9	This part was delivered late	The part number was not put on shortage list	Lack of awareness. Store manager in the kitting store was not aware that the part was in demand.	Metal store did not communicate effectively with the kitting store.	Metal components are kit in the kitting storage. **Thus, there are no kitting coordinator in the metal storage.** This causes lack of communication
Part 10	This part was not delivered on time	Hydro cut parts were not delivered.	Hydro cut machine was broken and out of order for three weeks.	Tooling, wear breaking due to Pre-maintenance inspection requirement was not performed.	Lack of employee supervision: There is no form of support or guidance for the employees working in the kitting storage

Part No	Why 1	Why 2	Why 3	Why 4	Why5
Part 11	This part was not delivered on time	Hydro cut parts were not delivered.	Hydro cut machine was broken and out of order for three weeks.	Tooling, wear breaking due to Pre-maintenance inspection requirement was not performed.	Lack of employee supervision: There is no form of support or guidance for the employees working in the kitting storage
Part 12	This part was not delivered at the store room in time	The worker which is responsible for this part did not complete the task that was given to him. He did not follow his generic correctly	Lack of work discipline	Lack of employee supervision: There is no form of support or guidance for the employees working in the kitting storage	Poor management regulations.
Part 13	This part was not delivered at the kitting storage on time	The worker which is responsible for this part did not complete the task that was given to him. He did not follow his generic correctly	Lack of work discipline	Lack of employee supervision: There is no form of support or guidance for the employees working in the kitting storage	Poor management regulations
Part 14	This part was not delivered on time	Change in customer request. The composite stage had to change the design which was time consuming	Items/parts that have to be modified are not considered in the process design	Ineffective process design. No spare parts available. Thus, it is due to an insufficient Kanban system	**Low employee skill level**
Part 15	This part was not delivered on time	Change in customer request. The composite stage had to change the design which was time consuming	Items/parts that have to be modified are not considered in the process design	Ineffective process design. No spare parts available. Thus, it is due to an insufficient Kanban system	**Low employee skill level**
Part 16	This part was not delivered on time	The mould machine was broken	Tooling, wear breaking due to Pre-maintenance inspection requirement was not performed.	Pre-maintenance inspection requirement was not performed	Lack of employee supervision: There is no form of support or guidance for the employees working in the kitting storage
Part 17	This part was not delivered on time	The mould machine was broken	Tooling, wear breaking due to Pre-maintenance inspection requirement was not performed.	Lack of employee supervision: There is no form of support or guidance for the employees working in the kitting storage	Poor management regulations.
Part 18	This part was not delivered on time	This required part was not collected at the composite stage	Lack of communication between the composite department and the kitting store room.	**Lack of employee skill level**	Low employee skill level caused that human errors occurred when handing over the kit. Not all of the parts were in the kit when handed over to the stage leader
Part 19	This part was not delivered on time	The mould machine was broken	Tooling, wear breaking due to Pre-maintenance inspection requirement was not performed.	Lack of employee supervision: There is no form of support or guidance for the employees working in the kitting storage	Poor management regulations.
Part 20	This part was not delivered	Employees did not follow their generics.	Lack of discipline	Lack of employee supervision: There is no form of support or guidance for the employees working in the kitting storage	Poor management regulations

4.3.2 Thematic Analysis

A thematic analysis was conducted to particularized and confirm the links and various patterns from the 5 why analysis that was performed as demonstrated in section 4.3.1. The results of the thematic analysis are depicted using a thematic map in figure 3.

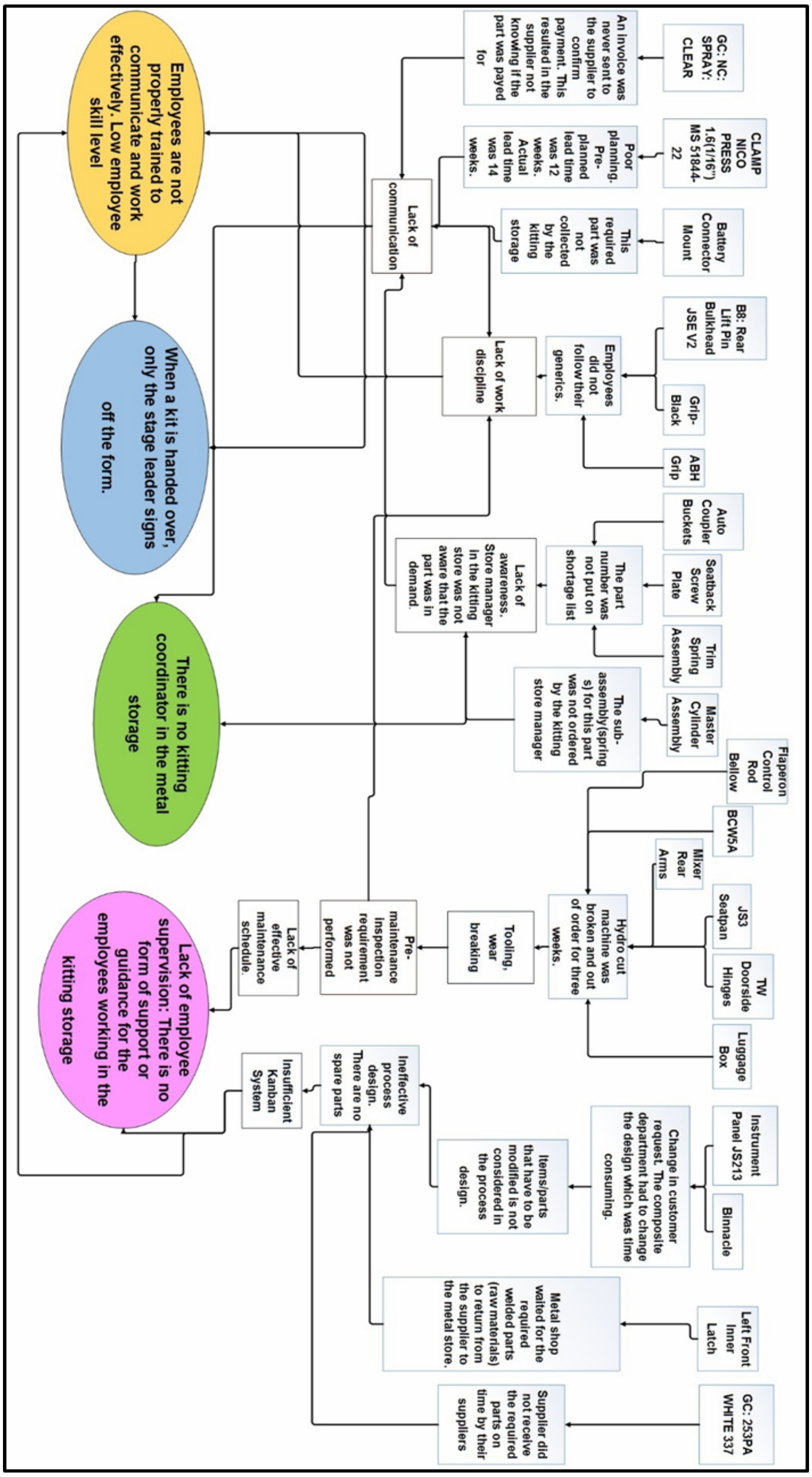

Figure 3: The Thematic Map

Four main root causes were discovered from the 5 why and thematic analysis. Each root cause and an explanation are depicted (detailed in table 4).

Table 4: The 4 Root causes identified

Root Cause identified	Description of the Root Cause
Low Employee Skill Level	1. Employees do not follow their generics, this resulted due to the lack of employee discipline 2. Lack of communication between all employees, this resulted in an invoice not being sent to the correct supplier at the correct time and date, employees being incapable to plan according to standard lead times and all storages not operating sufficiently
Lack of employee supervision: There is no form of support or guidance for the employees working in the kitting storage	1. No schedules were updated for stages and machines due to lack of supervision 2. Employees do not follow their generics 3. Lack of service and maintenance
When a kit handed over, only the stage leader signs off the form	1. Stage leaders are not at their stages most of the time 2. Human error: Stage leaders sign off form even though not all parts are in the kit (no quality inspections) 3. Transportation waste is caused because the stage leaders are forced to walk up and down between stages and the kitting storage
There is no kitting coordinator in the metal storage	1. The metal parts are stored in the metal storage, however, they are kit in the kitting storage. This causes a lack of communication between all stages, storages and the kitting storage. 2. Motion waste: the metal parts can be kit in the metal storage, but they are kit in the kitting storage. This causes unnecessary motion-and transportation waste in the organisation

4.4 The Design Phase

A comprehensive literature study and theoretical background were performed on the four root causes. The lean management principles were utilized as kernel theories to design solutions to address each root cause. The root cause, kernel theory, best-suited solutions, references and implementation details are demonstrated in table 5. (It is important to take note that Px denotes the number of the lean management principle used for each kernel theory)

Table 5: Solutions that were designed for each root cause

Root Cause	Kernel Theory	Solution	Implementation Details
Low Employee Skill Level	<u>*P9:*</u> Grow leaders who thoroughly understand the work, live the philosophy and teach it to others <u>*P10:*</u> Develop exceptional people and teams who follow the company's philosophy <u>*P11:*</u> Respect the extended network of partners and suppliers by challenging them and helping them improve	Conduct monthly employee training <u>*Reference:*</u> [18]	<u>*Requirement:*</u> All employees must be present to be trained effectively <u>*Implementation:*</u> Monthly training will be conducted. Each employee will be given a chance to give feedback on any problems, defects or improvement opportunities identified during the month <u>*Hypothesis-based Outcome:*</u> Employee skill level will be improved. Communication and other required skills will be improved, which will decrease overall human errors within the system

Root Cause	Kernel Theory	Solution	Implementation Details
Lack of employee supervision: There is no form of support or guidance for the employees working in the kitting storage	*P5:* Build a culture of stopping and fixing problems to get quality right the first time *P7:* Use visual control so that no problems are hidden *P9:* Grow leaders who thoroughly understand the work, live the philosophy and teach it to others	Implement visual management to help guide and support employees working in the kitting storage (Maintenance schedules and 5S forms) *Reference:* [8]	*Requirement:* Visual forms and posters must be designed to successfully implement visual management *Implementation:* Visual forms will be designed. These forms will be used as supervision when an employee is uncertain on how to conduct a certain activity. These forms will also indicate when machines need to be serviced. The 5S forms will also be used as a guideline on how to ensure that the workstation is always clean and neat *Hypothesis-based Outcome:* Employees will ensure that machines are maintained and serviced regularly. The workstation will always be kept clean
When a kit handed over, only the stage leader signs off the form	*P4:* Level out the workload (heijunka) - Work like the tortoise, not the hare *P7:* Use visual control so that no problems are hidden	Improve quality at source by ensuring that both the kitting coordinator and the stage leader signs off the kit form *Reference:* [9] [10]	*Requirement:* For this alternative to be successful, the kitting coordinator and the stage leader need to sign the form. *Implementation:* Upon kit collection, the kitting coordinator and the stage leader will sign the form. Having two employees signing the form will guarantee that all of the parts are in the kit. This will decrease human error. *Hypothesis-based Outcome:* Having both employees signing the form will ensure that no human errors are made. Both employees will ensure that all of the parts are in the kit. This will result in the elimination of transportation waste between the storages.
There is no kitting coordinator in the metal storage	*P4:* Level out the workload (heijunka) - Work like the tortoise, not the hare *P6:* Standardised tasks are the foundation for continuous improvement and empowerment *P7:* Use visual control so that no problems are hidden	Reduce manpower in the kitting storage by moving one of the kitting coordinators to the metal storage to ensure that the metal components are kit separately. *Reference:* [3]	*Requirement:* For this alternative to be successful, the kitting coordinator will have to be placed in the metal storage. The remaining kitting coordinator will stay in the kitting storage. *Implementation:* The kitting coordinator kitting the metal parts will be placed in the metal storage. The other kitting coordinator will remain in the kitting storage to kit all of the other kits. *Hypothesis-based Outcome:* The metal storage kits will be kitted and directly distributed to different stages. This will ensure that no unnecessary motion occurs between the storages.

4.5 The Verification Phase

A survey was developed and conducted to verify if the proposed solutions would address the various root causes, and in turn the part shortages. The Delphi method was used as a method as explained in section 3.4. The survey was designed to gain information regarding improvement opportunities and employee feedback on the various solutions. The Likert scale, also known as the five-point bipolar response, was used as the scale for the survey [19]. The root cause, solution and survey statements are demonstrated in table 6.

Table 6: Survey Design

Root Cause	Solution	Survey Statements
Low Employee Skill Level	Conduct monthly employee training	Monthly employee training will help address low employee skill level
		To conduct these employee training, the organisation can start by conducting one training session a month.
		To conduct these employee training, key improvement areas and skill types first need to be identified.
Lack of employee supervision: There is no form of support or guidance for the employees working in the kitting storage	Implement visual management to help guide and support employees working in the kitting storage (Maintenance schedules and 5S forms)	Visual Management will help guide and support employees working in the kitting storage (Maintenance schedules and 5S forms)
		To implement visual management, the organisation can start by designing 5S forms
		To implement visual management, the organisation can start by designing structured visual schedules for all employees and machines
When a kit handed over, only the stage leader signs off the form	Improve quality at source by ensuring that both the kitting coordinator and the stage leader signs off the kit form	By ensuring that both the kitting coordinator and the stage leader signs off the kitting form will reduce the chance for human errors occurring.
		To ensure that both employees sign off the form, management can start by designing a new checklist for the employees in the kitting storage
There is no kitting coordinator in the metal storage	Reduce manpower in the kitting storage by moving one of the kitting coordinators to the metal storage to ensure that the metal components are kit separately.	By moving one of the kitting coordinators to the metal storage will ensure that the metal components are kit separately. By moving one of the kitting coordinators to the metal storage will address the lack of communication between the kitting storage and the metal store

This survey was conducted using the Likert scale on all three organisational levels: Managerial level (15% surveyed), team leader and group leaders (15% surveyed) and team members (70% surveyed). To adhere to the three-sigma limits, as explained in section 3.5, 20 samples were taken [17]. This ensured more accurate results. Control charts were designed to demonstrate all results. Control charts for statements 1-9 were in control and had no outliners. However, control chart 10, demonstrating statement 10 had one outliner.

Upon investigation, it was revealed that the outlier was an employee (in management) that disagreed with statement 10, who was a 35-year old, with 9 years of working experience. From the analysis in section 4.3, it was concluded that the organisation had poor management regulations meaning that management has a different view of the real situation. Management also does not perform regular Gemba walks. Management is thus not aware of machines not being serviced, invoices not being sent at the correct date. According to Bicheno and Holweg [20], lean implementation normally fails due to senior management, they also declared that lean implementation requires a change in the entire organisational structure [20].

All ground floor workers agreed to statement 10 since they deal with the problem every day. In addition to this, it can be concluded that this point is out-of-control due to this manager having a different view of the real situation compared to the rest of the employees.

From this evaluation, this individual's score was removed with cause from the chart, and the average recalculated. Upon the recalculation, it is revealed that the average of statement 10 is now in control and consensus has been reached. Wright and Kelley [21] stated that the main purpose for analysing data is to summarize it so that it is clearly understood by the reader and it will help the analyst evaluate the data more accurately [21]. Table 7 depicts the average response for each survey statement, as well as illustrating that consensus has been reached across the board.

Table 7: Results from the survey conducted

No.	Survey Statement	Average	Percentage of Average	μ > 75%
1	Monthly employee training will help address low employee skill level.	4,25	85%	✓
2	In order to conduct these employee training, the organisation can start off by conducting one training session a month.	4,35	87%	✓
3	In order to conduct these employee training, key improvement areas and skill types first need to be identified.	4,55	91%	✓
4	Visual Management will help guide and support employees working in the kitting storage (Maintenance schedules and 5S forms)	4,40	88%	✓
5	In order to implement visual management, the organisation can start off by designing 5S forms	4,25	85%	✓
6	In order to implement visual management, the organisation can start off by designing structured visual schedules for all employees and machines	4,40	88%	✓
7	By ensuring that both the kitting coordinator and the stage leader signs off the kitting form will reduce the chance for human errors occurring.	4,25	85%	✓
8	To ensure that both employees sign off the form, management can start by designing a new checklist for the employees in the kitting storage	4,40	88%	✓
9	By moving one of the kitting coordinators to the metal storage will ensure that the metal components are kit separately.	4,55	91%	✓
10	By moving one of the kitting coordinators to the metal storage will address the lack of communication between the kitting storage and the metal store	4,55	91%	✓

From table 7, all statements scored an average above 75%, verifying employee agreement for all solutions proposed to address the organisation's problem. The consensus was reached and no additional rounds needed to be conducted for the Delphi method.

5. CONCLUSION

The aviation organisation (used as a case study) experienced part shortages in all of their production stages. After investigation, it was concluded that the root causes originated from the kitting storage. The kitting storage's current state was investigated via a Pareto chart. Thereafter, a root cause analysis was conducted on the kitting storage via a 5 why and thematic analysis. Four main root causes emerged from this root cause analysis. Four solutions were designed by utilizing kernel theories. During the verify-phase, a survey was designed using the Delphi-method.

The survey consisted of 10 statements. All 10 statements scored an average above 75%, hence verifying employee agreement that all proposed solutions will address the root causes. From this study, it was stated that it is very important to implement lean in an industry which can fully benefit from it [2]. Different risks were also identified when implementing lean. Boeing is an example; due to cultural differences, employees did not communicate with each other. This resulted in a production delay in the 787 Dreamliner. From the Boeing case study, it was also observed that management was not aware of the actual situation [5]. The organisation used as a case study experienced the same challenges as Boeing. Thus, emphasising the importance of communication, Gemba walks and the impact that cultural differences have on the production of the aircraft.

The importance of lean and the impact it will have on this industry can be observed in this case study. Lean theory emphasis that management must conduct regular Gemba walks to understand and grasp the real situation [9] [10]. The organisation used as a case study is following an integrated supply chain, which consists of different people from different backgrounds, languages and cultures. Conflict existed among employees when the 5 why analysis was performed. Employees started blaming each other for why the parts were not delivered on time. Thus, the impact of cultural differences in an organisation can also be witnessed by these activities. Furthermore, the challenges of conducting a 5 why analysis, in reality, were highlighted. From this case study, various lessons were learned. The lack of communication from management reflected the lack of communication between employees working on the ground floor. Therefore, it is always very important that management reflects high-quality work and help guide and support employees working on the ground floor, this will give workers a new impetus to improve their work ethics.

6. LIMITATIONS AND FUTURE RESEARCH

While this study showcases the issues of management not having a clear understanding of ground floor challenges, it is recommended that the organisation conduct regular investigations on the ground floor to evaluate the real situation and the employee working atmosphere. It may also be recommended that top management train employees according to lean philosophy and guide and support them at all times. Subsequently, performing quality checks in all stages will contribute towards process efficiency.

The organisation used as a case study is currently operating for over 10 years. Thus, employees are fixed on doing their work a certain way. In this study, lean is defined as a culture, rather than a mindset. However, implementing lean in such an environment where employees are resistance against change, is a limitation. Thus, performing regular training sessions will be recommended, in accordance with a change management project.

The current Kanban system is insufficient; it will be recommended that the organisation evaluates this system for further research. This project addresses the part shortages experienced by the organisation. However, this study and the methods used in addressing these part shortages can also be applied in other organisations in the aviation industry

In conclusion, it is imperative for an aviation organisation that consists of an integrated supply chain and multi-cultural environment to ensure consistent communication from top-management and regularly implemented training program.

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APPENDIX A

The following table is a demonstration of the literature study that was conducted when this research study was addressed:

Table 8: Literature study topics for this research study

1. Lean Management	2. The 5 Why Analysis	3. The Kanban system	4. The Pareto Analysis	5. Survey Design
6. Lean Maintenance	7. The expanded 5 why analysis	8. The Poka Yoka implementation	9. Control charts	10. The Delphi method
11. Lean Manufacturing	12. The 5S Analysis	13. Six Sigma method: DMADV method	14. Thematic Map Analysis	15. The Likert scale
16. Integrated supply chain: Adapted case study	17. Visual Management	18. Six Sigma method: DMAIC method	19. Kernel Theories	20. Lean implementation in the aviation industry

PACKAGE FREE FOOD RETAIL?

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ABSTRACT

Food retailing continues to be package intensive; this drives both food waste and packaging waste at different stages in the value chain. Packaging waste has grown exponentially, increasing the carbon footprint, and damaging the environment. Given South Africa's finite landfill capacity, it is simply not sustainable to continue with current disposal practices. This study aims to determine what are the drivers of food packaging in South Africa and the resultant environmental and cost implication thereof. An exhaustive review of literature was performed to identify these factors. The results show that it is crucial that packaging designers must consider redesign for end-of-life recyclability, retailers should include recyclable and recycled products in their packaging and consumers have to be encouraged to adopt reusable packaging options such as containers. The combined actions of the consumer, industry and policymakers will be essential to aid in the implementation of effective waste management strategies.

Keywords: Food Packing, food supply chain, drivers of food packaging, environmental impact of food packaging, food packaging legislation, sustainability in food packaging

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1 INTRODUCTION: PACKAGING FRESH FOODS

Packaging is one of the most important aspects of the food manufacturing process; it helps prevent deterioration (damage and decay) and maintains the quality of foods and beverages from environmental influences during storage, distribution, retail, and consumption. Packaging is also used for product differentiation, marketing, and communication [1].

Over the past years there has been an increase the volume of food packaging material at landfill sites due to increased consumption of food products as the population rises. South Africa's remaining landfill sites are filling up at an increased rate and there are no new recovery options have been established, to implement viable alternative waste disposal solutions [2]. Lack of innovative waste management solutions have led to the continual increase in the exploitation of raw materials rather reprocessing used materials [3].

Whilst packing increases costs in the supply chain, the need to reduce costs must be carefully weighed against the basic technical requirements for food safety, product integrity, efficient logistics service, and marketing needs. Companies that are involved in packaging design and development need to factor in changes in legislation, technological, marketing, logistics, and environmental requirements when making strategy-based decision. There is a constant challenge to provide more cost effective packing performance that satisfies the needs and wants of the user (consumer, retailer, distributor), whilst minimising the environmental impact of products and the services required. Increased pressure from a number of key players most notably, consumers and legislation has forced the food packaging industry to evaluate the amount of packaging waste utilized and disposed [4].

Peelman et al. [5] suggest three levels where sustainability of food packaging can be attained these include: at the raw materials level – through the use of renewable and recycled materials to reduce carbon emission; at the production level - through more energy-efficient processes; and at the waste management level - through reuse, recycling and biodegradation.

This research seeks to address the current alignment of the supply chain practices at various operational levels to evaluate the sustainability of food packaging in South Africa.

2 INSIGHTS FROM LITERATURE

2.1 Types and properties of packaging materials for food systems

There are variety of aspects that need to be considered in food packaging, these include the selection, labeling and design of packaging materials, as well as the storage, transportation, and distribution of food products. It is important to understand the interactions among these elements to deliver optimized packaging systems that aid both the manufacturer and customer in relation to cost, convenience, protection, marketing, and sales.

There are a wide range of materials that have been used for packaging, commercially and locally namely: paper, earthenware, wood, vegetable fibers, plant leaves, glass, metals and plastics. Whilst most food products are packed using a single packing materials, a combination of more than two packaging materials is often necessary to deliver the best packaging solution in transportation (commonly plastic foam and cardboard are used as are multi-material protection) [6].

Selection of packaging materials for food products is primarily determined by the properties and type of food being packaged [7]. It is fundamental to consider not only the food itself, but also the general properties of different packaging materials [4].

Additionally, cost, brand image, and environmental concerns must also be accounted for.

Figure 1 provides a breakdown of the most commonly consumed materials for commercial food packaging in South Africa in 2017. As of 2017, paper and paperboard hold the largest share of South Africa's packaging materials with a volume of 2067,1 metric tons in 2017, this represents 52% of the market. Paper has become the most commonly used packaging material for various food industries due to its low cost [8].

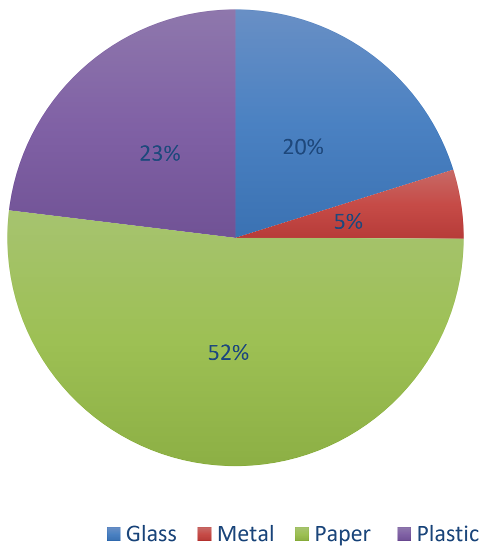

Figure 1: Packaging material consumption [8]

2.1.1 *Paper and paperboard*

A wide range of paper and paperboard is utilized in packaging, this range from lightweight infusible tissues for tea and coffee bags to heavy duty boards used in distribution. Paper and paperboard account for half of the total packaging market and can be found wherever products are produced, distributed, marketed, and used. Paper and paperboard are classified in two main categories - folding carton and corrugated packaging. The use of paper and paperboard has been on the rise as we move into the digital age. Packaging industries may be one of the sectors set to benefit in the digital age if changes are made to take better advantage of newer technologies.

Paper and paperboard packaging are found in primary packing at the point of sale and in secondary packaging for storage and distribution. Paper and paperboard packaging can withstand a wide temperature range, from low temperatures of frozen foods to high temperatures of heating in microwave and conventional radiant heat ovens. They are desirable not only due to low cost and processing ease during manufacture but also due to the ease of collection, reuse, and recycle after use. Paper and paperboard packaging provide the rigidity and flexibility needed for various types of packing items including folding cartons, corrugated boxes, and lightweight and biodegradable bags. Paper is the common choice of selection to help communicate product information, storage guidelines and nutritional value to consumers. Paper is often combined with materials such as oil, wax, polymers, and metals through the process of coating or lamination to improve the gas barrier properties and strengthen it. Multilayer packaging materials are currently used for products such as beverage cartons of milk and fruit juices. The multilayer films help extend the shelf life of these products to six or more months [6].

2.1.2 *Plastics*

Plastics are defined as, 'organic macromolecular compounds obtained by polymerisation, polycondensation, polyaddition or any similar process from molecules with a lower molecular weight or by chemical alteration of natural macromolecular compounds' [4].

They are used extensively in food packaging and processing due to their availability, chemical resistance, and impact strength. A large portion of plastics used in food packaging are thermoplastic, due to their ability to be repeatedly softened and melted when heated. These characteristics have major implications when it comes to the use and performance of plastics, in moulding, film manufacture and heat saleability. Plastics are ideal for food packing as they are inert making them resistant to many types of compounds, they do not react with inorganic chemicals, including acids, alkalis and organic solvents. Additionally, most plastics do not support microbial growth due to their high molecular weight structure [9].

In 2017, 867.8 tonnes [8] of plastic were consumed by packaging in South Africa, making it the second most used packaging material with the lowest cost factor. Plastic containers and flexible packaging such as drums, intermediate bulk containers (IBCs), crates, tote bins, fresh produce trays and plastic sacks are often used to store and distribute food in bulk. They are desirable for the packaging of food as they offer a wide range of appearance and performance properties [6].

2.1.3 *Glass for food packaging*

Glass containers are used to package a wide range of foods from granules to dry powders examples include instant coffee, dry mixes, spices, processed baby foods, dairy products, jams, marmalades, spreads, syrups, processed fruit, mustard, and condiments. Glass bottles are also desired in the packaging of liquids specifically carbonated drinks as they are strong enough to resist expansion forces exerted during the high pressure sealing process [6]. Glass bottles are used for bottling liquids such as mineral water, cooking oil, soft beverages and alcoholic beverages including beers, wines, spirits, and liqueurs. According to Consol SA [10], the alcoholic beverages industry accounts for approximately 85% of sales in the glass packaging industry.

Glass has its advantages and disadvantages as a food packaging material. A disadvantage is that it is susceptible to breakage on physical impact and high pressure, despite this flaw it used in food packaging as it provides good barrier properties against gases and chemicals and can withstand high temperatures. Furthermore, it is durable and provides good insulation to keep foods fresh during storage. It is relatively easy to reuse and recycle the bulk of glass used for food and beverage packaging. Based on statistics provided by BMi Research [8], 758.8 tons of glass were consumed for packaging in 2017, 43.6% of this was recovered for recycling. It is important to recycle glass to make new glass since it is typically less expensive, as opposed to making glass using raw materials.

2.1.4 *Metal for food packaging*

Metal is used for food packing as it provides good protection against physical damage during transportation, distribution, handling, and storage of food products. Metal-based packaging materials provide excellent barrier properties against water, oxygen, and gases due to their impermeability making them an ideal material to use in food packaging applications. Metal is packaged in different forms such as containers, tubes, cans, caps, and closures. There are major health and product safety concerns relating to metal packaging which can contain lead, bisphenol A, mercury, cadmium all of which are carcinogenic and toxic if consumed. A key disadvantage of metal is that it is not inert to food products; therefore, it needs to be coated with protective layers to inhibit the interaction of food-metal [11]. Compared to other packaging materials, metal has the highest recyclability due to its magnetic properties, which aid in its separation. The annual consumption of metal in South Africa in 2017 [8] was 183.3 tonnes, which indicates a 5.8% decrease in the volume of metal packaging produced in 2016. This is seemingly small compared to the other packaging materials; however, it is predicted that the metal packing industry will grow due to its excellent recovery rate.

2.2 Life Cycle Assessment of food packaging

There is pressure on the packaging sector to examine its environmental footprint - to reduce, reuse and recycle used packaging materials to reduce the overall carbon footprint throughout the product life cycle. The life cycle assessment method is an approach that can be utilised to determine the relative impact and contribution that specific packaging materials will have on the environment at each stage of its journey through the supply chain. A life cycle generally consists of five stages: (1) extraction and manufacturing of the raw materials, (2) production, (3) transportation and distribution, (4) usage, and (5) disposal as illustrated in Figure 2 [6] [4].

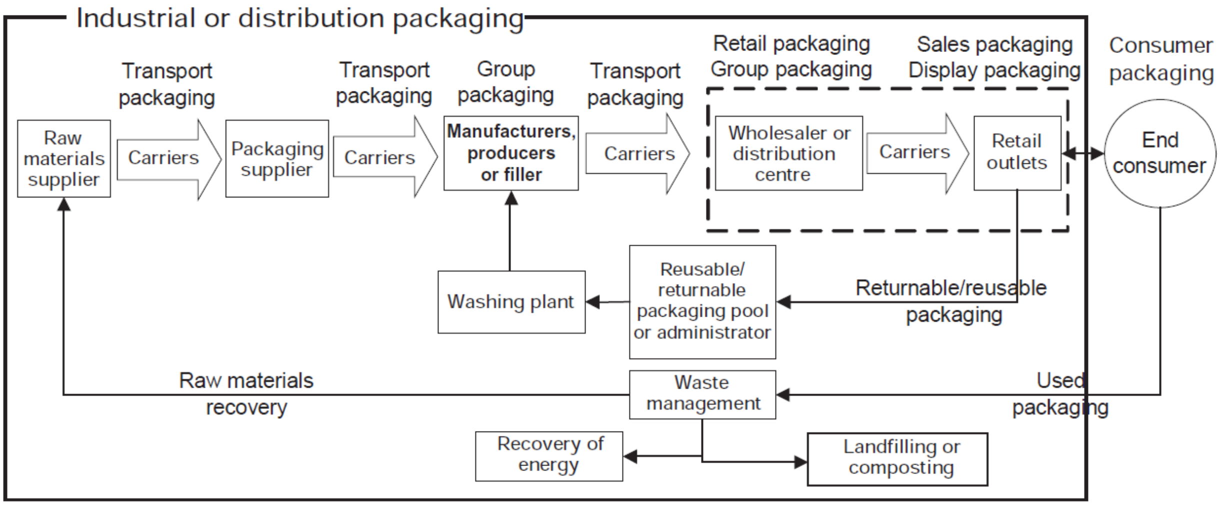

Figure 2: Packaging Life Cycle [4]

Life Cycle Analysis has become an important decision-supporting tool in packaging design, as it helps assess multiple impact categories from the raw material supplier to the final disposal at landfill. Packaging designers should perform a life cycle analysis to confirm whether design changes in packaging materials do in fact contribute to improved environmental impact [12].

Most of packaging LCAs performed have been of a comparative nature. Humbert et al. [13] performed a study to investigate the primary energy and greenhouse gas emission impacts of two packaging alternatives (glass jars and plastic pots) for baby food packaging containers. The study revealed that, glass jars exerts 14–27% more primary energy and 28–31% more global warming potential impact than the plastic pots. The result was attributed to material production, packaging weight and on-site preservation parameters of the two packaging options. Keoleian et al. [14] performed a study to compared glass, linear low-density polyethylene (LLDPE) pouches, high-density polyethylene (HDPE), paperboard carton and polycarbonate packaging systems that were used to deliver milk. The study revealed that polycarbonate bottles, refillable HDPE and flexible pouches have the lowest life cycle environmental impacts amongst the packaging options. It is important to merge design and packaging material innovations to help reduce the total impact of packaging materials in the packaging life cycle.

3 PURPOSE

This paper explores the interrelations of vital supply chain functions in the food industry where packaging considerations must be taken into account these include logistics, distribution, marketing, and retail. The research identifies key factors that influence the integration of sustainability in food packaging development processes and the dependencies and interrelations within the food packaging supply chain.

To understand this, several sources have been analysed these include academic sources, governmental and non-governmental reports, as well as verified news publications. The sources selected address challenges faced by the food packing industry to transform due to regulatory and social pressure over the rise in carbon footprint resulting from the amount of packaging and packaging waste.

4 METHOD

A qualitative research approach was employed, as it is tailored to analyse the specific areas of interest through the use of a thematic analysis. The research is exploratory in nature, it seeks to understand, "how" the food packaging industry operates and "why" it operates in the manner in which it does. The paper describes the main findings of the qualitative research, addressing the need for sustainability considerations in the food packaging industry in South Africa. An exhaustive review of past studies on food and beverage packaging, was performed to analyse the: (1) Drivers of food packing in South Africa; (2) Cost and environmental implications of packaging in the supply chain; (3) Food packaging Legislation in South Africa ; and (4) factors that lead to sustainable packaging development.

Table 1 list the inclusion and exclusion criteria that were identified and applied in the analysis of combined data from the different sources. These included:

Table 1: Inclusion & Exclusion Criteria Applied in selection

Inclusion Criteria	Exclusion Criteria
From 2010 -2020	Incorporate packaging and sustainability in areas outside the food industry
Written in English	Refer to the involvement of packaging outside of food governance and packaging legislation
Abstract must container contain one of the key search terms: "food Packing", "food supply chain", "drivers of food packaging", "environmental impact of food packaging", "food packaging legislation", "sustainability in food packaging"	Exclude studies that are not published for the South African Context
Reports that refer to the packaging at a program or governance level	Descriptive or opinion pieces were excluded

Figure 3 illustrates the decision steps taken at each stage of the exhaustive review to examine food-packaging waste along the entire food supply chain in South Africa.

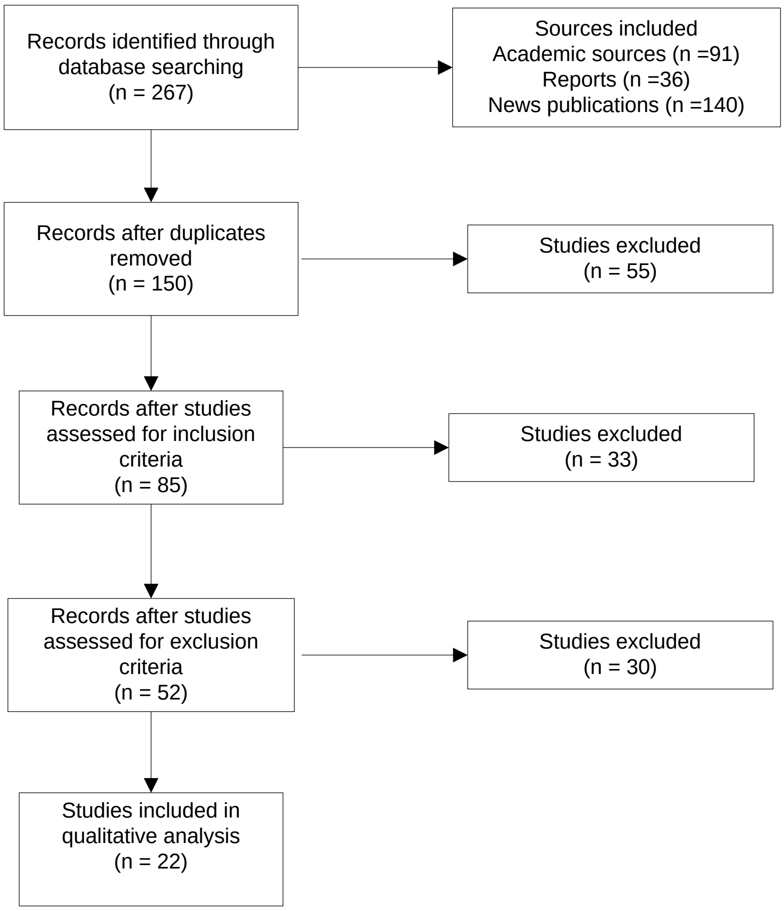

Figure 4: Decision steps at each stage of a systematic review

Table 2, presented in the Appendix, provides a detailed breakdown of the sources that were included in the qualitative analysis of the study including the author name, title, source type and year of publication.

5 RESULTS AND DISCUSSION OF FINDINGS

5.1 DRIVERS INFLUENCING PACKAGING

5.1.1 *Product Protection*

Protection is considered as the most important function of packaging; it protects products from damage and ensures that the product is treated hygienically. This plays an important role during transportation as damage during transit of food products is well documented [15]. Replacement of orders cause delays and adds further costs, resulting in the loss of profits and customers. Most food transportation carriers invest in Goods in Transit Insurance covers to help insurance against damage while in transit. Many banks and business insurance companies in South Africa offer Goods in Transit insurance as a service package offering. Under Section 65 of the Consumer Protection Act (CPA) the transporter is liable for any loss resulting from failure to reasonably handle and safeguard cargo, while in their possession. CPA clearly defines how the transporter should handle cargo and the consequences in the event they fail to do so [16].

To help determine the type and quantity of protection required during storage and transportation the relevant characteristics of the food products (shelf life and temperature requirements) and the associated hazards of the distribution environment need to be considered. Food products are especially vulnerable to chemical and biological changes, raising food safety and quality concerns. There are various transportation hazards associated with the food distribution environment these include: insect infestation, cross contamination, improper holding and loading practices and exposure to extreme temperature and moisture conditions [6]. Packaging components such as modified atmosphere packaging films have been designed to allow breathability and improved insulation to help improve the shelf life and quality of food products that reach retailers. Advancements in packaging technology have, allowed for the creation of tailored solutions that protect fresh food products with specific atmospheric requirements [17].

5.1.2 *Traceability*

Along with providing protection, packaging is used for traceability as food supply chains and logistical information become more comprehensive. The mandatory requirement for traceability was initiated into South Africa's legal framework for the food industry in 2018 [18], this was prompted by the world's largest listeriosis outbreak [19]. The outbreak highlighted the need for an effective traceability system, this has been affirmed by a similar scale recall of canned pilchards in 2020 [20].

With the integration of emerging electronics, packaging systems have advanced to provide more visibility in the flow information and products. Electronic data interchange (EDI) and control has made headway in providing effective and integrated management of the distribution and warehousing of food products. EDI systems eliminate errors and time spent on manual entry to provide accurate and timely information on the status of packaged food products, which helps improve service levels, and shortens lead times.

When food products are picked from the warehouse, information about the status change is captured. This information is necessary not only for distribution but also for the replenishment and adjustment of inventory levels [21]. Packaging must be designed to facilitate transitions between operations in logistical systems, where food products change location and ownership to satisfy functional needs [22]. In South Africa, most food retailers use bar codes that allow for the automatic scanning at a retail check-out counter to minimise the cost of price marking, check-out, inventory control and reordering [4].

5.1.3 *Attracts consumers*

Packaging helps grab the attention of consumers, it provides information on the ingredients of the product, the usage, and benefits of the product, it also serves the key function of differentiating the product from its competitors. Packaging is used by marketing to help influence buyer decision through, persuasive logos and promotions. When used correctly, packaging can be more effective than an advertising campaign for retailers. The information on packaging labels is commonly perceived by consumers as a promise of quality. Packaging supplies the consumer with critical information about the use of a product and, in some instances, it may indicate the packaging material with a symbol. Facts that are provided by packaging include: volume, weight, nutritional value of ingredients, manufacturer's details, cooking and opening instructions. As consumers become more health conscious they require more detailed information about products with, product manufacturers in recent years adding more nutritional and informational labels to their products [4] [23].

Sustainability attributes in food packaging drive consumer choice Consumers view biodegradable and recycled products in packaging as an attractive quality. Approximately, 30% of South African consumers claim to have switched their regular brand for one with more sustainable packaging [24].

5.1.4 *Demand for Specific types of Packing*

In the past, food retailers did not have much control over the packaging types and material they received, manufacturers (who planned packaging to fit their cost and requirement structures) dictated this. This is increasing changing in recent years, with large retailers stipulating their packaging requirements to best suit their brand image and values. Woolworths has redesigned most of its food packaging to reduce the amount of packaging needed, it has also incorporated the use of recycled and recyclable material to minimize the amount of packaging waste that ends up at landfill sites. For example, in 2016 [25] Woolworths replaced plastic milk bottles with one containing 30% plant based material, that was made from sugar cane, this reduced the dependence on oil-based alternatives.

In addition to dictating packing types retailers work together with logistical providers to evaluate the durability of different packaging types and structures to redesign packages with better maximize cube utilization in transit. They even have control over the label design of individual food products that are printed to include their own brand name. Large retailers generally specify that fast-moving products need to be packaged on display-ready small pallets that create minimum waste. Standardized packaging has been essential in the transformation of supply chains from static storage systems to modern, fast-moving systems [15].

5.1.5 *Convenience*

Convenience as a driver for packaging is influenced by the consumer and the retailer. Consumers' desire for convenience is due to the demand for instant gratitude and product availability. Packaging must play to one or more of three key central themes: save time, save money, or provide support by making things easier. The simplest smart packaging innovations are those that include the appropriate use of materials to create packaging, components of package design, without complex functionality for better convenience to fulfil consumer needs [4].

Microwave heating and cooking has resulted in a number of smart packaging innovations driven by the desire for greater levels of consumer convenience, not only in microwaveability but also in portion sizes. In the home, consumers' desire conveniently packaged food products that can be made into meals quickly without compromising on quality, hence the current flush of microwaveable products, prepared meals and salad kits at major retailer stores, including: Shoprite/Checkers, Pick n Pay, Spar, Woolworths and the Food Lovers Market. Convenience in food packaging provides consumers with more variety and allows consumers versatility in their preferences [26].

5.2 COST IMPLICATIONS OF PACKAGING IN THE SUPPLY CHAIN

5.2.1 *Improved Utilization*

Packaging impacts productivity of logistical systems and affects the cost of every logistical activity within the supply chain. At a wholesale level, unit loads of food products, are shipped by full truckload (TL) to lower cost in the supply chain. Whilst most food products are picked and distributed in mixed loads in carts and pallets to different food retailers, some are floor loaded in trailers and transported directly to the retailer without the use of pallets. There are numerous advantages to optimizing the volumetric and weight capacity of loads as storage and transportation costs are directly linked to the density and size of food packages. Recent trends show that packages are getting smaller and as lightweight as possible to improve cube utilization which helps provide logistical value. When package size is reduced by 50%, transportation efficiency doubles lowering the number of vehicles required and decreases the systems environmental impact. Packaging allows for improved utilization of vehicle space, improved transport speeds and easier or faster handling of products [4].

5.2.2 *Retail*

Retailers must account for high handling costs, related to unpacking food products this includes, the substantial amount of time and employees required to remove packaging from food products to place every single case and item of food onto the shelf. Cutting down the amount of packing used in food products provides a tremendous opportunity toward improving profit. This has prompted the shift in packaging design focus on the evaluation of productivity not only in the logistical process but also at a retail level. Increasingly, manufacturers are designing packages that add retail value to provide profitable gains and increase sales revenue. Packaging has a direct effect on the retailer's overall profitability and profitability of each product, as the gains of the retailer are directly linked to the operational costs resulting from opening food packages, displaying, and selling them.

The benefits of sustainable packaging are clear from and environmental stance; however, the financial savings that could results from these efforts often underestimated and overlooked. In June of 2019 Pick 'n Pay (one of South Africa's top retailers) opened grocery sections which did not have pre-packaged fruits and vegetables or single use vegetable bags. The package free selection offered considerable savings of up to 77% on food products such as chillies,32% savings on green beans and a 25% savings on mushrooms [27]. The retailer has implemented number of initiatives such as the, 'pick and weigh option' and reusable containers at 29 stores to reduce packaging and single-use plastic [28].

5.2.3 *Disposal*

A growing population and the increasing rate of urbanization in South Africa has led to higher volumes of waste generation, this has required the establishment of effective waste management policies. In South Africa waste management suffers from widespread under-pricing, waste disposal is preferred over other options such as recycling and reuse as the cost of waste management is not fully considered by industry and consumers. The National Pricing Strategy for Waste Management (NPSWM) developed a framework within which waste management charges can be set in South Africa. The NPSWM acknowledges that the under-pricing of waste services does not encourage waste generators and holders to reduce waste generation, rather it perpetuates the use of landfill which is regarded as the cheapest method of waste disposal. The framework suggests possible waste management charges or economic instruments (EIs) that can be enforced in compliance with the overall fiscal and taxation policy of South Africa. The objective of the economic instruments is to provide incentives for manufacturers, consumers, recyclers, and other parties involved in waste management to reuse and reduce waste production [8].

5.3 ENVIRONMENTAL IMPLICATIONS OF PACKAGING IN THE SUPPLY CHAIN

The environmental impact of packaging directly depends on the material, method of manufacture, reuse and disposal of the packaging. There are also indirect wastes created by packaging such as packaging weight and food waste, sustainable packaging helps reduce food waste since as it has greater environmental impact than packaging waste [29]. The South African Department of Environmental Affairs [7] states that, processing, packaging, distribution and retail account for 45% of wasted food (of this, 5% of is classified as the responsibility of consumers [8]).

Data on annual consumption of the different packaging material and of forecasted values of future collection from 2012-2023 are made available by Packaging SA. These values have been represented in Figure 5.

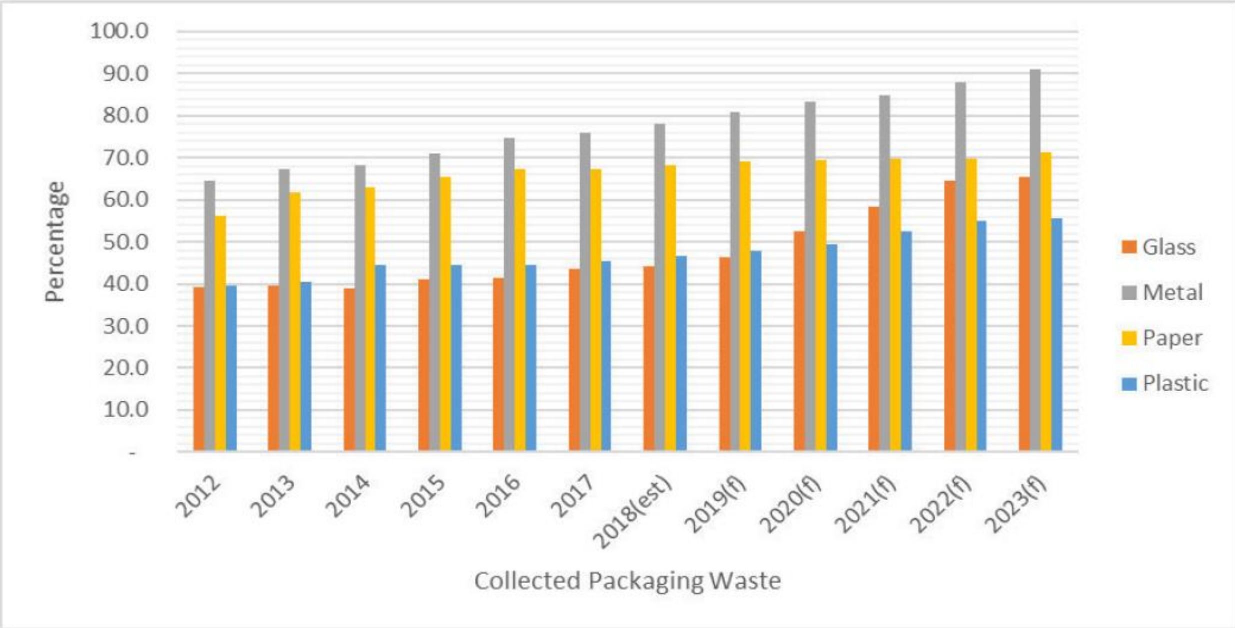

Figure 5: Collected Packing Waste [8]

From Figure 5 it can be observed that metal has the highest collection rate over the past few years, whilst having the lowest consumption for packaging. The shrinkage of metal industry can be contributed in part to the development of newer lighter materials, and in part to smaller packaging as has been observed in the non-alcoholic beverage sector (Coco-cola South Africa reduced the size of its 330 ml can to 300 ml in 2017 [30]). Nevertheless, industry leaders predict the sector will grow again due to increased government pressure placed on the plastic packaging industry to curb plastic waste in the environment.

South Africa has one of the best recycling rates in the world when it comes to plastics. Despite the lack of sophisticated collection and sorting systems, South Africa recycles more plastics than any developed country. In 2018 [8], 519 370 tonnes of plastics were collected for recycling, this was a 6.7% increase from 2017. From this volume, 352 000 tonnes were converted to raw material and recycled products, surpassing the 350 000-tonne barrier for the first time. South Africa is a world leader in mechanical recycling [31], with 46.3% of all plastic products in 2018 being recycled; in comparison, Europe recycled 31.1% of its plastic. Approximately 67% of all Polyethylene Terephthalate (PET) bottles were recycled in 2017 this figure grew by 12% from 2016. Plastics recycling has led to a 246 000 tonnes reduction of carbon dioxide emissions in 2018, equating to the greenhouse gases produced by 51 200 vehicles [8].

5.4 FOOD PACKAGING LEGISLATION In South Africa

South Africa has enforced some regulation on packaging with varying success. Plastic bag regulation has aimed to influence the recycling of plastic bags and likely motivated producers of other material types to initiate recycling programs. More recently, the Department of Environmental Affairs prompted the creation of extended producer responsibility plans.

5.4.1 *Regulation*

In May 2003, regulations were put in place on plastic bags. These regulations comprised of both design standards to increase recyclability, and a tax on bag sales to encourage reduction and reuse [3]. The third aim of the legislation was to stimulate a plastic bag recycling industry. A non-profit company, Buyisa-e-bag, was established to ease the process of collection to improve the supply from consumers and collectors to recyclers [32]. In 2018 the plastic bag levy brought in R241m revenue into the fiscus, which amounts to over 2 billion bags sold through formal retail channels (excluding the informal sector) [33]. As of February 2020, the finance minister announced, that the plastic bag levy would be increased to 25 cents, this results in increase greater than 100% [33].

A number of packaging material streams started voluntary industry initiatives to promote the recycling of valuable materials; however, Nahman [3] argues that for glass and PET (polyethylene terephthalate) the programs may have been started to avoid punitive regulations. Although the industry initiatives promote and enable recycling, they do not promote reduction or reuse and do little for the recycling of less valuable materials. Regulation seems to be necessary in cases where the material has little recycling value, as industries would not have economic motivation to initiate the recycling programs. A different regulatory approach would be to regulate high levels of recycled content into packaging to stimulate the demand for recycled material. Packaging SA states that it is impossible and impractical to regulate a high level of recycled content into packaging as there are practical limitations to the use of recycled materials [34]. Certain materials, such as paper, are highly recyclable but provide different characteristics after each cycle, requiring the introduction of virgin material. Paper has a realistic life of 5 to 7 cycles before virgin fibers must be introduced [34].

Although packaging, and its associated wastes, have an environmental impact, there is little regulation on it in terms of climate action. Packaging SA [8] states that the South African national legal framework for climate change is still relatively undeveloped and that the country is party to several international agreements, but national legislation is yet to be enacted.

5.4.2 *Industry EPR*

In 2018, Packaging SA submitted the Packaging SA Extended Producer Responsibility (EPR) Plan to the South African Department of Environmental Affairs. Packaging SA define an EPR as an environmental policy approach where a producer is responsible for the entire life cycle of its product in order to meet legal obligations. The EPR holds the producer responsible for designing its products with materials that are the least damaging to the environment and in such a way that the recycling of the product is attainable and optimised. In the EPR, Packaging SA indicates their plan to, within 5 years, increase the percentage of packaging and paper recycled from 58.2% to 66.9%. This is an increase from 2.2 million to 2.7 million tonnes of recycled packaging and paper Have they achieved this so far. The EPR commits to more than increasing recycling in the industry. It commits to dedicating 50% of the funds collected from producers and importers to 51% black owned companies/organisations, and to create 11 067 direct and indirect jobs. The EPR Plan also budgets for the development of “Packa-Ching”, which is a mobile buy-back centre program. The budget includes the establishment of 10 new kiosks annually, resulting in 10 new black owned businesses and countless community opportunities. The plan commits 90% of the EPR fees to EPR objectives; this is likely due to the financial issues of the plastic bag regulation. The plan will promote a circular economy[†] and improve national awareness and education on sustainability. The EPR includes the producers of glass, paper, paper packaging, metals, polyolefins, PET, polystyrene, vinyl, and future alternatives [8].

5.5 FOOD PACKAGING in SOUTH AFRICA: SUSTAINABLE OR NOT?

Sustainable packaging must be effective in fulfilling its core functions, primarily protection of the packaged good; efficient in use of resource; safe for the environment and human health; and circular [12]. Therefore, the sustainability of South Africa's food packaging should be evaluated on these functions. Along with these functions the industry can be evaluated in terms of the waste hierarchy. The South African Department of Environmental Affairs has implemented their waste management strategy using the Waste Hierarchy (WH) [35]. The WH identifies the waste management process of waste disposal as least ideal and recovery, recycling, reuse and prevention as increasingly more ideal. The waste management processes of prevention (reduction) and reuse are seen as waste prevention efforts. The other components of the WH are recycling and recovery which manage waste as a resource and as a last resort disposal.

In 2016 [34], 3.83 million tonnes of packaging and paper were put on the South Africa market. In the same year, 1.61 tonnes (42%) of packaging and paper were lost to landfill or uncontrolled disposal. This material will not be reintroduced into the economy despite its possible value. The packaging and paper EPR plan has committed the industry to decreasing the amount of waste disposal, but this commitment relies on the success of waste prevention and waste recovery.

When industries recognised the business case for removing valuable materials from the waste stream and re-processing them, a number of voluntary industry initiatives were established to coordinate recycling in the respective industries. Prominent examples of these initiatives are Collect-a-Can (beverage cans), the Glass Recycling Company (GRC) and PETCO which collects PET, such as soft drink and water bottles. In all three cases the materials are high-value, 100% recyclable over many cycles and are fit for many applications [3]. However, there are many material types which are not as attractive for recycling which still hold value. Packa-Ching, as introduced under the Industry EPR, accepts all waste streams and its development allows more material streams to be recycled. Through these recycling schemes and other recyclers South Africa is able to recycle a high proportion of the packaging waste it produces. Of the 3.83 million tonnes of packaging and paper produced in 2016, 2.222 million tonnes (58%) were collected for recycling and other purposes. The recycling rates per main substrate in 2016 were: glass 42.5%, metal 73.3% (beverage cans 72%), paper 67.2% and plastics 44.6% (PET beverage containers 42%) [34]. A large part of the success of the recycling industry in South Africa is due to the informal waste collection sector. This sector comprises kerbside waste pickers who collect recyclable material from household waste and waste pickers based at landfill sites. It is estimated that 80%-90% of packaging waste collected for recycling in South Africa is collected by waste pickers [31].

6 CONCLUSION

The research aimed to identify the drivers of food packaging waste South Africa and the associated economic and environmental implications, which have become a topic of

[†] A circular economy is regenerative system in which resource inputs and waste, emissions and leakage and minimised by slowing, closing and narrowing energy and material loops [8].

increasing concern as remaining landfills are on the verge of reaching capacity. An exhaustive review of literature was conducted, this helped to provide an intricate understanding of food packaging sustainability especially within a social context (job creation for thousands of waste pickers). Based on the results it can be concluded that due to the provision of low-cost waste services, waste generators are not driven to reduce waste, with disposal to landfill being regarded as the cheapest method of waste disposal. While waste legislation is expected to redivert packaging waste away from landfilling to alternatives such as recycling and composting, numerous stakeholders identify that the current legislation, restricts waste innovation and may unwittingly compromise the jobs' of waste pickers supporting the development of SA's Green Economy.

The research makes a useful contribution towards understanding the nature and practices of the food packaging industry in South Africa. Moving forward it is important that waste management strategies be guided by: the quantities and types of waste generated, what it best for the local communities and markets, job creation and available skill levels, the local policy and legislation, the local cost of technology solutions, and the local climate for business and investment.

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APPENDIX

Table 3: Breakdown of studies included in qualitative analysis

	Author	**Title**	**Type of Publication**	**Year**
1	A. Nahman	Food Packaging in South Africa: Reducing, Re-using and Recycling	Report: Government Digest	2010
2	Packaging SA	Packaging SA Extended Producer Responsibility Plan	Report	2018
3	A. Anderson	Alcohol ban sees third company pull back from planned investments	News Publication: Times Live	2020
4	E. De Stadler, J. Du Plessis, S. Eiselen, L. Feris, M. Loubser, N. Melville, T. Naudé, R. E, R. Sharrock, P. Stoop, C. van Heerden, E. van Zyl, T. Woker and J. Yeats	Commentary on the Consumer Protection Act	Book: Juta	2015
5	D. Fryer	Traceability in the food industry – why are SA producers not doing this?	News Publication: FoodStuff SA	2020
6	A. Smith, N. P. Tau, S. L. Smouse, M. Allam, A. Ismail, N. R. Ramalwa, B. D. Disenyeng, M. Ngomane and J. Thomas	Outbreak of Listeria monocytogenes in South Africa, 2017–2018: Laboratory Activities and Experiences Associated with Whole-Genome Sequencing Analysis of Isolates	Journal: Foodborne Pathogens and Disease	2019
7	Business Insider SA	Recall of pilchards at Shoprite, Checkers: 'Bloated' cans could make consumers sick," 23 February 2020	News Publication: Business Insider SA	2020
8	Food and Agriculture Organization of the United Nations	"Food Traceability Guidance	Report: Food and Agriculture Organization of the United Nations	2017
9	V. Guillard, S. Gaucel, C.	The Next Generation of Sustainable Food Packaging to	Journal: Frontiers in Nutrition	2018

	Author	Title	Type of Publication	Year
	Fornaciari and H. Angellier-Coussy	Preserve Our Environment in a Circular Economy Context		
10	D. Burrows	Beyond Plastics: Grocery Packaging in a Sustainable Future	Report: The Grocer	2019
11	Woolworth Proprietary Limited	Woolworth Packaging Position Statement	Report: Woolworth Proprietary Limited	2016
12	J. Caboz	Pick n Pay's new unpackaged food: This is how much money you'll save by bringing your own container	News Publication: Business Insider	2019
13	African News Agency	Pick n Pay introduces packaging-free zone, expands its 'nude' produce wall	News Publication: Creamer Media's Engineering news	2019
14	Z. Boz, V. Korhonen and C. K. Sand	Consumer Considerations for the Implementation of Sustainable Packaging: A Review	Journal: Sustainability	2020
15	K. Child	Smaller soft drink sizes leave bitter taste of shrinkflation	News Publication: Times Live	2017
16	GreenCape	Waste, 2019 Market Intelligence Report	Report: GreenCape	2019
17	A. Nahman	Extended producer responsibility for packaging waste in South Africa: Current approaches and lessons learned	Journal: Resources Conservation and Recycling	2010
18	Packaging SA	Design for Recycling	Report: Packaging SA	2017
19	Department of Environmental Affairs	National Waste Management Strategy	Report: Government Gazette,	2019
20	Creamer Media Reporter	SA landfill sites a ticking time bomb	Publication: Creamer Media's Engineering news	2018

	Author	Title	Type of Publication	Year
21	H. Roman	A waster research, development and innovation roadmap for South Africa (2015-2025)	Report: Department: Science and Technology,	2014
22	L. De Kock	#Budget2020: Plastic bag levy increase the new sin tax?	News Publication: BizCommunity	2020

DEEP LEARNING HARDWARE ACCELERATION FOR HIGH PERFORMANCE IN SMART AGRICULTURAL SYSTEMS: AN OVERVIEW

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ABSTRACT

The proliferation in the sizes of data and the tenacity for precision in classification or detection tasks has made machine learning techniques highly relevant other than the traditional classifiers which rely on hand-crafted features. This facilitated the advent of deep learning (DL) which has been lauded for its automatic feature extraction ability and short testing times. However, due to its large number of parameters, it is computationally intensive. Several approaches have been put forward to manage this challenge and a salient one involves the use of DL hardware accelerators such as Graphical Processing Units (GPU), Field Programmable Gate Array (FPGA) and others. To the best of authors knowledge, no significant review has been done as regards DL hardware accelerators in the agricultural domain. Hence, this research is focused on deep learning and various optimization techniques, DL accelerators with impacts and limitations. Finally, recommendations have been proffered which is geared towards improving the performance and efficiency of DL accelerators.

Keywords: Deep learning, DL hardware accelerators, machine learning, GPU, FPGA.

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1 INTRODUCTION

According to Kamilaris and Prenafeta-Boldú [1], deep learning could be elucidated as a branch of machine learning made up of several processing layers that extract and learn data representations of various features hierarchically. In recent times, deep learning has received much attention due to its ability to automatically extract features, the availability of standard pre-trained models, etc. In addition, many studies show that it outperforms traditional machine learning methods. It has recorded successful strides in solving challenges in a variety of domains such as in the health[2], financial [3], telecommunication [4], multimedia [5], agricultural [6], digital marketing [7], manufacturing [8] sectors etc. Deep learning is broadly categorized into supervised, semi-supervised, and unsupervised learning models.

Deep learning is based on the artificial neural network made up of interconnected neurons arranged in a series of layers [9]. The architecture of deep learning is made up of the input layer that receives the data, hidden layers where learning takes place, and the output layer which gives out the result. Each layer contains several neurons which maps the input, multiplied by weights and transformed by activation functions, into outputs to be used as input to nodes of the succeeding layer. These forward and back propagation steps are iterated until the weights, biases and hence the loss function are optimized. The activation functions introduce non-linearity which simplifies the computations involved in obtaining the loss function. Those mostly applied in deep learning include the sigmoid, hyperbolic tangent, rectified leaky unit and identity functions [10][11]. Figure 1 shows the deep learning architecture adapted from ref [12].

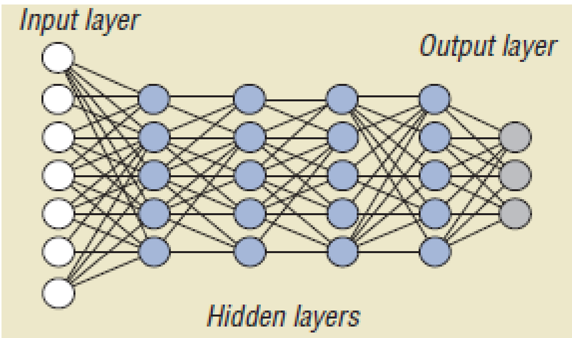

Figure 1: Deep Learning Architecture

In supervised learning models, the datasets used are labelled. They include Convolutional Neural Network(CNN)[13], Recurrent Neural Network[14], Long Short Term Memory[15]. In contrast, unsupervised learning models make use of unlabelled datasets and they include Autoencoders[16], Restricted Boltzman Machines[17], Deep Belief Network[18], Generative Adversarial Network[19].

The CNN model is widely used in agriculture for classification, recognition and detection tasks due to its equivalent representation, sparse interaction and parameter sharing capabilities [20]. It consists of the input, convolutional, pooling, fully connected and output layers. A labelled set of images are used as input to the convolutional layer. This layer extracts features from the image to produce feature maps by convolving filters (e.g. edge detection filters) over the image and computing the sum of dot products between them. An activation function especially the rectified leaky unit is applied to eliminate noise and dark regions in the image. The feature maps are then passed on to the pooling layer where the spatial dimensions are reduced. Several convolutions and pooling processes are repeated in a CNN model. Thereafter the fully connected layer takes in the output from the pooling layer and classifies it into the respective image classes based on the features already learnt. In the output layer, the softmax function is applied to select the image class with the highest probability as the predicted class for a given image. CNN models can either be trained from scratch (by initializing the weights to be optimized) or through transfer learning. Transfer learning involves utilizing weights of pre-trained models, especially in a situation of deficit in training data, in order to improve model performance and prevent over-fitting. Examples of pre-trained CNN models are ResNet, VGGNet, AlexNet, MobileNet, GoogleNet, DenseNet, Inception, etc. Figure 2 shows the architecture of the CNN model adapted from ref [21].

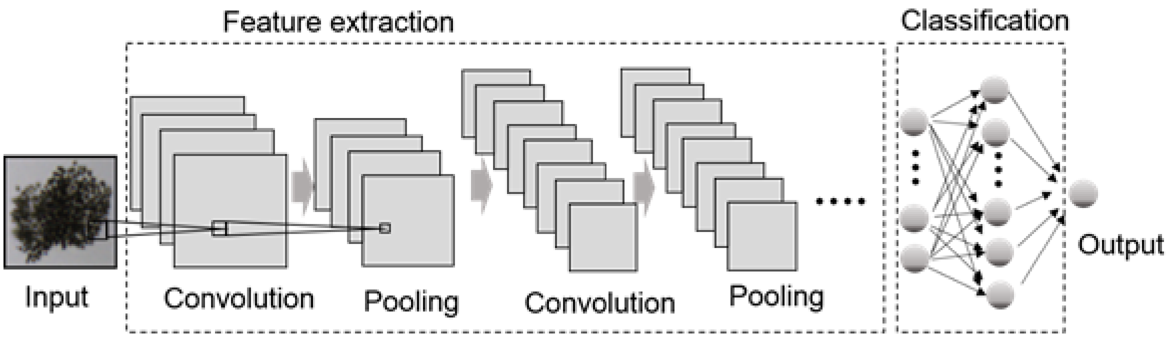

Figure 2: The CNN architecture

Furthermore, deep learning architectures are implemented on frameworks and they include Tensorflow, Keras, Theano, Caffe, Pytorch, Microsoft cognitive toolkit, Deeplearning4j, etc. However, the accuracy of deep learning comes with the drawback of being computationally intensive as it generates millions of parameters that require large matrix multiplications[22]. As this accounts for long training times and also limits real-time inference on low-power devices, several works of literature have proposed approaches aimed at mitigating this challenge.

2 OPTIMIZATION TECHNIQUES FOR DEEP LEARNING MODELS

Cloud computing is a common approach for optimizing deep learning models and it involves offloading some computations to a cloud server[23]. Nevertheless, this approach has its attendant problems such as scalability issues when the number of connected devices increases, security risk, and high latency issues[24]. Furthermore, pruning could be employed to reduce the model size by removing redundant parameters in the network which have an infinitesimal contribution to the model accuracy[25]. Quantification could also be applied to reduce storage and bandwidth requirements by converting parameters from 32-bit float values to 8-bit values[26]. In the same vein, knowledge distillation, whereby a 'student' network learns from a 'teacher' network is another approach[27]. Factorization, which involves synthesizing convolution kernels to lower tensors, could also be applied. These approaches reduce the number of parameters to a reasonable extent but at the cost of a loss in accuracy. Other approaches include the use of parameter efficient pre-trained models(such as SqueezeNet, MobileNet, etc) and also facilitating the computations with hardware accelerators.

3 OBJECTIVES

In light of the above, this research paper focuses on deep learning hardware accelerators as it concerns the agricultural domain. It sets out to:

(i) Describe the main types of deep learning hardware accelerators in use;
(ii) Review most recent research publications where hardware acceleration is applied to deep learning for agricultural applications;
(iii) Proffer noteworthy recommendations.

4 HARDWARE ACCELERATORS

Hardware accelerators are microprocessors designed to speed up deep learning computations. These accelerators are capable of low precision arithmetic, in-memory computing, and parallel processing[25]. The deep learning hardware accelerators mostly used are Graphical Processing Units(GPU), Field Programmable Gate Array(FPGA), Application-Specific Integrated Circuits(ASIC).

4.1 Graphical Processing Units

Graphical processing units are specialized flexible electronic chips comprising multi-core processors that carry out parallel processing of data and perform mathematical operations at high speed. Its high processing speed and easy programmability makes it the most commonly used accelerator for training/inferencing deep learning models. Researches conducted show that GPUs could either be used as a co-processor with a central processing unit, as a server GPU, an external stand-alone processor or incorporated in embedded devices(known as embedded GPUs). Generally, GPUs are capable of performing millions of computations in the shortest possible time but have a disadvantage of not being energy efficient. However, the embedded GPUs by Nvidia such as the Jetson TX series are more power-efficient(requiring low power) but with a lower processing capacity than conventional GPUs[28]. The Compute Unified Device Architecture(CUDA) and Open Computing Language(OpenCL) are valid examples of C language-based, parallel computing framework developed by Nvidia and Khronos group respectively. Unlike the CUDA which is limited to GPUs application, OpenCL can be used for programming a variety of hardware platforms such as GPUs, FPGAs, Digital Signal Processors[29]. Examples of GPUs are the Nvidia-DGX series, Nvidia-AI GPU series, Nvidia-HGX server framework, Nvidia-Drive, Nvidia Jetson series. Figure 3 is an example of a GPU adapted from ref [30].

Figure 3: A Typical Nvidia Jetson TX2

4.2 Field Programmable Gate Array

Field programmable gate arrays are reconfigurable integrated circuits that can be reprogrammed an infinite number of times to accelerate computationally intensive tasks[9]. They are known for their good processing capabilities and are more energy-efficient than GPUs. They are however not widely used for accelerating computations because programming an FPGA requires expertise. The FPGA architecture consists of programmable logic blocks, interconnect and input/output blocks[31]. The programmable logic blocks are connected by routing resources and are arranged in a grid. Logic functions, which are executed on the logic blocks, are connected with the aid of interconnect circuits. The input/output blocks located at the boundary of the 2-

dimensional grid can be programmed as input, output, or bi-directional pins. Unlike the GPUs which executes computational tasks on its multiple cores, FPGAs allow for deep pipeline parallelism whereby complex algorithms are split and executed concurrently. In addition, apart from being not easily programmable, FPGAs have long synthesis time for complex designs. The use of multi-FPGA cluster is not applicable and they are cost prohibitive[29]. Examples of FPGAs are Spartan-6, Microsoft's project brain wave, Stratix-10, Stratix-IV, Zynq-7000, VirtexII-600, Virtex-7, Cyclone-IV, etc. Figure 4 shows an example of an FPGA board adapted from ref [32].

Figure 4: Stratix-10 FPGA Board

4.3 Application-Specific Integrated Circuits

Application-specific integrated circuits are specialized integrated circuits designed to carry out specific algorithms such as the multiply and accumulate(MAC) operations for convolutional neural networks. They offer high efficiency, high processing speed, with easily programmable logic, and are more cost-effective than FPGAs[25]. However, because they are designed specific algorithms, a slight change in the deep learning model would render the ASIC redundant[28]. Common examples of the ASICs are the Intel Movidius Neural Compute Stick(NCS), Google's Tensor Processing Unit(TPU), Snapdragon series 6, Krin 900 series, Ascend 910, etc. The NCS is a universal serial bus device, developed by Intel, made up of the myriad vision processing unit and hardware accelerators. It is being affixed on embedded systems for recognition/detection tasks[33]. TPUs are special ASICs introduced by Google for accelerating convolutional neural network models. It is a systolic array-based accelerator that has a customized 256×256 grid of MAC units in its core. Figure 5 displays an example of an ASIC adapted from ref[34].

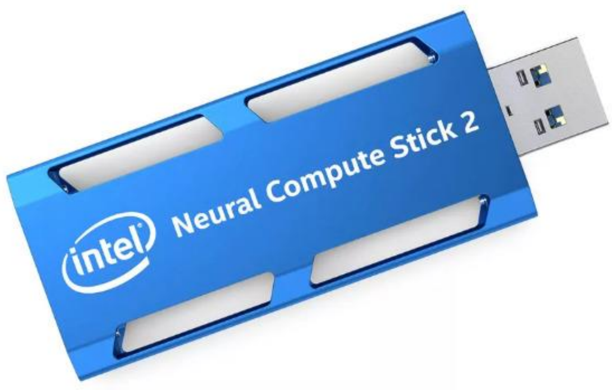

Figure 5: Intel Movidius Neural Compute Stick

5 REVIEW ON DEEP LEARNING ACCELERATORS FOR AGRICULTURAL PURPOSES

In this section we set out to review 20 research papers, published from 2017 to 2020, that applied hardware accelerators to speed up training and/or inferencing of deep learning models for both real and non-real-time agricultural applications.

Lammie et al [35] investigated on the acceleration of binarized deep neural networks(DNN) for DeepWeedX classification on FPGAs implemented using the OpenCL framework. Pretrained DenseNet-128-10, Wide Residual Network(WRN)-28-10, and ResNet-50 models were trained on an Intel DE1-SoC FPGA and Nvidia Titan V GPU. The inference time and power usage obtained were significantly lower for the models implemented on the FPGA with the DenseNet-128-10 being the most accurate and the WRN-28-10 recording the lowest inference time.

Knoll et al [36] developed a system for plant detection in organic farming by executing an FPGA-based DNN on a Terasic DE1-SoC. The classification results obtained reflected an inference runtime of 42 frames per second(FPS) and reduced consumption of power about 45 times lower than that of the state-of-the-art Nvidia GTX 1080Ti GPU.

In a bid to develop an artificially intelligent recognition system on a low-power embedded system, Li and Yang [37] developed a system that detects cotton pests. A CNN model was used to extract the features trained by the triplet loss and then implemented on a PYNQ-Z2 development board which consists of an Advanced RISC Machine(ARM) and FPGA. Even though a limited amount of dataset was used, a testing accuracy of above 95% was obtained with an inference runtime of 2FPS. The authors recommended that parameter quantization and further parallelism could be employed to improve inference speed.

A system was proposed by Shadrin et al [38] for detecting seed germination. The datasets collected were trained on a custom CNN, made up of 2 convolutional and 2 fully connected layers, for 50 epochs and a validation accuracy of 97% was recorded. The trained model was deployed on both a raspberry pi accelerated with a Movidius neural compute stick and a desktop GPU(Geforce GTX 1050Ti). Although the raspberry pi had a slower running speed of 4.5FPS, it is portable and its power consumption was significantly lower(2.5watts) than that of the desktop GPU(24.01watts).

An Internet-of-things(IoT) device, powered by solar energy, for detecting codling moth in apple orchards was developed by Brunelli et al [39]. The insect datasets obtained were utilized to train through transfer learning, a pre-trained VGG-16 model on the TensorFlow framework for 10epochs. The trained model, with a classification accuracy of about 81%, was converted to a graph model and deployed on a Movidius compute stick for accelerated inferencing. The IoT device functioned to preprocess images of insects on the raspberry pi3, carry out prediction using the Movidius compute stick, and notify the farmer, using a Long-Range Wide Area Network(LoRaWAN) protocol, when a codling moth was detected.

Zhang et al [40] proposed a global pooling dilated convolutional neural network(GPDCNN) for the identification of cucumber leaf diseases. The datasets acquired by the authors were used to train the GPDCNN on an intel@ core i7-7 7000 KCPU@4GHz X8processor; Nvidia GTX 1080Ti GPU. A classification accuracy of about 95% was obtained which outperformed the AlexNet and deep CNN models used for evaluation.

Der Yang et al [41] made use of an unmanned aerial vehicle(UAV) for real-time classification of crops. Image datasets were trained using an image semantic segmentation model, SegNet, on a cloud server accelerated using 4 Nvidia Tesla V100

SMX2 GPUs implemented on the Keras framework. Inferencing was carried out on a containerized environment of Docker on the Keras framework accelerated with Nvidia GTX 1080 graphics card. The UAV was designed to capture images from the farmland, send it via a 4G mobile network to the containerized environment for inferencing. The SegNet model performs the prediction and sends its result to both the UAV controller and the farmer's mobile phone. A classification accuracy of 89.44% and an inference speed of 0.7seconds was recorded.

Jiang [42] trained datasets using transfer learning to classify 12 weed types on the Keras framework. The weed datasets obtained from a public data source were trained for 500 epochs with the training procedure accelerated on a Geforce GTX 1080Ti. Training and validation accuracies of 98.99% and 91% were recorded respectively.

The ResNet-18 and ResNet-50 architectures were retrained by Afonso et al [43] to identify potato blackleg diseases implemented on the Pytorch framework. The datasets, which consist of images of diseased and healthy plants acquired by the authors, were trained for 100epochs on a workstation comprising the Geforce GTX 1080Ti GPU, 12 core intel Xenon E5-1650 processor. The ResNet-18 model outperformed the ResNet-50 with a classification accuracy of 94%, training time of 3minutes, and test time per image of 4.6milliseconds.

Olsen et al [44] trained 2 CNN models through transfer learning for the classification of weeds using their multiclass weed dataset known as DeepWeeds on Keras framework with TensorFlow backend. An Nvidia GTX 1080Ti GPU was used for the training procedure and the model was deployed on Nvidia Jetson TX2 for inferencing. A better classification accuracy of 95.7% was obtained for the ResNet50 model and an inferencing time of 18.7FPS on the TensorRT platform was recorded.

The attention cropping approach for processing images to be trained on a CNN model for plant species classification was proposed by Xiao et al [45]. The pre-trained ResNet-50 and Inception-V3 architectures were retrained through transfer learning, on the image datasets acquired, with 2 Nvidia GeForce GTX-1080 GPUs on top of the Pytorch framework. Better results were obtained for the ResNet-50 and Inception-V3 models trained with images pre-processed using the attention cropping approach.

Bodhwani et al [46] employed a pre-trained ResNet-50 model to classify 185 plant leaf images. The augmentation technique was applied to increase the number of the leafsnap images being used to train the model on the Keras framework for 41 epochs. The training procedure was carried out on Google's cloud server with a Tesla K80 processor GPU and this lasted for about 5 hours (as against the 24 hours it took to train 60% of the images on a central processing unit). Training and testing accuracies of 99% and 93% were obtained respectively.

A system, implemented on a raspberry pi 3B, for detecting strawberry fruit was developed by Lamb and Chuah [47]. Video data was fed as input to a sparse 3-layered convolutional classifier with optimization techniques such as input compression, application of a colour mask, etc. being employed. The training procedure was carried out on a desktop GPU- Nvidia GTX 1080Ti for 200 epochs with a batch size of 32. The trained model was deployed onto the raspberry pi3 for inferencing. An average precision and inference speed of 84% and 1.63FPS was achieved respectively.

Czymmek et al [48] proposed a system for detecting and classifying carrot weeds. The image datasets collected were used to train a You Look Only Once (YOLO) architecture on an Nvidia GeForce 1080Ti GPU; AMD Ryzen 7 1800X for 5500 iterations. A high precision rate of 89% was obtained with an inference speed of 18.65FPS. Also, an inference speed as high as 56 FPS was achieved when the input data was compressed but this lead to a significant loss in precision. The authors recommended the use of binarized CNN and devices such as the FPGA as they respectively reduce memory bandwidth and are energy efficient.

A CNN model for fish detection was proposed by Cui et al [49]. The image dataset collected from the Gulf of Mexico was trained on the GeForce GTX 745 GPU implemented on the TensorFlow framework for 700 thousand iterations. Also, data augmentation, dropout algorithm, and loss function refinement were employed to improve the training procedure and reduced training time and loss were recorded.

Zhou et al [50] built an 'improved ResNet' model for the detection of broccoli crops. The acquired datasets were trained on the TensorFlow framework with a 12 core Intel core i7-8700k CPU; Nvidia GTX 1080Ti GPU. The proposed model was compared with results obtained from the GoogleNet, ResNet, and VGGNet. Although the proposed model had a greater computation time, it achieved a better segmentation performance and grading accuracy than the other models.

Waheed et al [51] proposed an optimized DenseNet model for the classification of corn leaf diseases and evaluated the model with results obtained from the EfficientNet-BO, VGG-16Net, XceptionNet and NasNet models. The models were trained on a google collaboratory, made up of 1x Tesla K80 GPU with 2496 CUDA cores; single-core Xeon processor @2.3GHz CPU, for 47 epochs. A validation accuracy of 98.06% and a computation time per epoch of 3minutes was obtained. The proposed model outperformed the other CNN models in terms of the number of parameters and training time.

A novel INC-VGGN model, built by modifying the pre-trained VGGNet, for detecting plant diseases especially in rice and maize crops was introduced by Chen et al [52]. The training and testing procedure was implemented using the Nvidia GeForce GTX 1060 GPU; Intel core i7-8750 CPU. After 30 epochs of training, a validation accuracy greater than 91% was obtained from training the proposed model both with the acquired image dataset and a public dataset.

A residual dense network comprising a shallow feature extraction, residual dense block, dense feature, and UPNet was proposed by Liu et al [53] to enhance feature extraction from low-resolution images. Greenhouse agricultural low-resolution images were used for this task carried out on an Nvidia GTX 2080 GPU implemented on the PyTorch framework. Also, the bicubic option in Matlab was used to simulate the low-resolution images and its result was compared with that from the proposed network. The proposed model produced impressive results in being able to recover complex details from the datasets.

Finally, Uzal et al [54] proposed a deep CNN model capable of estimating the number of seeds in a soybean pod. The model was trained on a computer equipped with a GeForce GTX 970 GPU implemented on Theano and Lasagne frameworks. A classification accuracy of 86.2% was obtained and this surpassed the result from the Support Vector Machines (SVM) classifier it was compared with. Table 1 gives an overview of the reviewed studies

6 DISCUSSION/RECOMMENDATION

From the reviewed papers, three (3) of the researchers applied FPGAs, two (2) applied ASICs while other fifteen (15) researchers applied GPUs for accelerating deep learning models. The Intel Movidius neural compute stick was the prominent ASIC being applied while GPUs as co-processors and external GPUs were more prominent for agricultural purposes. The prominent GPUs in these reviews are best suited for training deep learning models and non-real-time applications due to their high throughput but high power consumption attribute and low mobility factor. Embedded GPUs are better options for real-time applications (as could be seen in Olsen et al [44]) because they are more energy-efficient than other GPU types and are easily programmable. Furthermore, the application of energy-efficient hardware accelerators (FPGAs, ASICs, and embedded GPUs) especially for onboard real-time agricultural applications is still in its nascent stages as only a few researches in literature of machine learning and autonomous systems proposed such ideas. Real-time practicability of deep learning models in areas of monitoring, pest and disease control, and weed control as well as other areas of agriculture would be a formidable avenue for improving food production. Overall, reduced training and inference runtimes were achieved through hardware acceleration and this could be applied in industrial engineering areas such as quality control, process monitoring, predictive maintenance and others. Also, it recommended that considerably combining optimization techniques such as model/input compression, quantization, parameter efficient models, etc. with hardware acceleration would further reduce computation/inference speed.

7 CONCLUSION

Accelerating deep learning models is a necessity given its large amount of trainable parameters and the need for real-time applications which is a core requirement for smart agriculture and also industrial engineering applications. This review paper surveyed deep learning hardware accelerators used for agricultural purposes. It gave a background knowledge about deep learning, optimization techniques, and further described examples of hardware accelerators. It equally highlighted the need for employing more energy-efficient accelerators for real-time deep learning applications in agriculture. Finally, it recommended that a symbiotic combination of optimization techniques with hardware acceleration would improve computation speed.

Table 1: Summary of Studies

S/N	References	Hardware Accelerator Type Used	Task Accelerated
1	Lammie et al, 2019	FPGA	Training and Inference
2	Knoll et al, 2017	FPGA	Training and Inference
3	Li and Yang, 2020	FPGA	Training and Inference
4	Shadrin et al, 2019	ASIC	Inference
5	Brunelli et al, 2019	ASIC	Inference
6	Zhang et al, 2019	GPU	Training
7	Der Yang et al, 2020	GPU	Training and Inference
8	Jiang, 2019	GPU	Training
S/N	**References**	**Hardware Accelerator Types Used**	**Task Accelerated**
9	Afonso et al, 2019	GPU	Training
10	Olsen et al, 2019	GPU	Training and Inference
11	Xiao et al, 2018	GPU	Training
12	Bodhwani et al, 2019	GPU	Training

13	Lamb & Chvah, 2018	GPU	Training
14	Czymmek et al, 2019	GPU	Training and Inference
15	Cui et al, 2020	GPU	Training
16	Zhou et al, 2020	GPU	Training
17	Waheed et al, 2020	GPU	Training
18	Chen et al, 2020	GPU	Training
19	Liu et al, 2019	GPU	Training
20	Uzal et al, 2018	GPU	Training

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A GREENHOUSE IOT APPLICATION FOR SMART AGRICULTURE SOLUTIONS

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ABSTRACT

The second goal from United Nations (UN) Strategic Development Goal (SDG) focuses on ending hunger, achieving food security, improving nutrition and promoting sustainable agriculture. South Africa is a water-scarce country, and with a growing population, farmers need to reduce waste and enhance productivity to be able to meet this SDG from the UN. IoT technologies can help farmers to monitor their fields from anywhere and also be able to use the data collected to improve productivity as they enable the farmer to obtain real-time data on their plants and fields. The use of IoT devices is expected to grow from 75 million in 2020 by 20% annually. In this paper, an IoT integrated greenhouse is presented. Sensors collect data from the greenhouse using an Arduino and send it to an online dashboard using the MQTT protocol. The dashboard can be accessed from any web browser. An android mobile app is also developed to view real-time data and control the greenhouse when one is offsite. This real-time data is used to trigger events to maintain the conditions of the greenhouse or can be downloaded for further analysis. The model was tested indoors and outdoors to simulate the growth stages of strawberries and managed to maintain the set parameters for the optimum conditions for the growth of strawberries.

Key Words: Greenhouse, IoT, MQTT

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1 INTRODUCTION:

South Africa is highly vulnerable to climate change and has been affected by climate change-related disasters like floods, storms, earthquakes, wildfires and droughts. Floods and storms occur more frequently in South Africa contributing 37.9% and 33.3% of the frequencies of internationally reported losses between 1990 and 2014 as shown in Figure 1 [1]. Even though drought contributes only 4.5% of the frequency of losses it contributes 33.4% of the economic issues. This affects agriculture and with the effects of global warming increasing every day there needs to be a solution to reduce these effects on farmers especially small scale farmers.

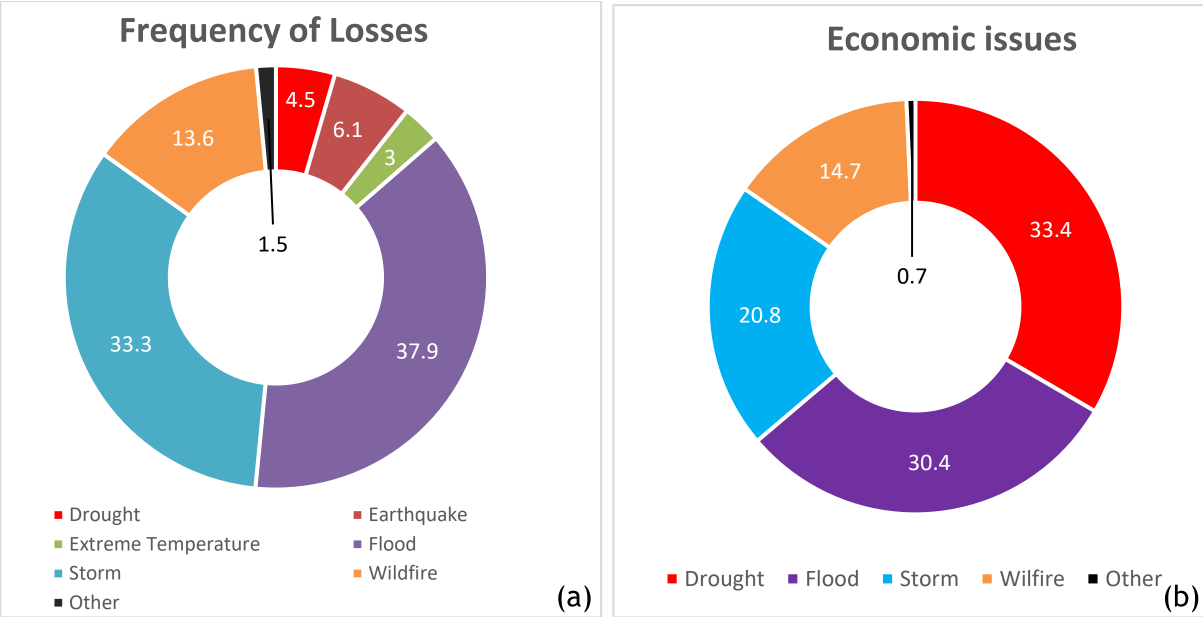

Figure 1 Internationally Reported Losses 1990 – 2014 (a) Frequency, (b) Economic issues [1]

2 LITERATURE REVIEW

Agriculture contributes 2.6% of the South African GDP [2] yet it provides employment to over 70% of the country's labour force [3] with more than a million people directly dependent on agriculture for their livelihood [4].

2.1 Temperature rise

The temperature in South Africa is warming up at a rate higher than the global average. The projected increase is 3°C at the end of the century if there is a reduction of greenhouse gases [5]. South Africa is a dry country with an annual average rainfall of less than 500 mm which is below the world average of 860 mm and about 1.3 million hectares of farmland under irrigation [4] which makes it at a higher risk of being affected by droughts associated with global warming. Even though for most of the parts of South Africa rain will remain a predominantly summer rainfall, the South-Western Cape will remain a predominantly winter rainfall area but with much less rainfall. This will affect the agricultural output of the Western Cape as it depends on the winter rainfall. Due to global warming, the rainy season will be shortened while the storm intensity will increase which will allow less time for water to be absorbed into the soil leaving more people and agricultural activities reliant to water captured in dams hence there is need for proper dam water utilisation [8].

2.2 Factors affecting Greenhouse designs

Greenhouses houses can be grouped in term of design and level of technology used i.e. low-tech or high-tech [9]. Various factors have been used in the design of greenhouses which include location [12], [13], [14] climate and economic conditions [15], physical, biological and economic factors [16]. Van Henten et al used a multi-factorial optimisation approach [17], whilst Vanthoor used a model-based approach with eight design elements [18]. When dealing with the horticultural sector in a Mediterranean climate, locally adapted strategies for different types of greenhouse design and climate control management are required to improve on the performance of greenhouses [19].

Knowledge of plant requirements at different growth stages and under various light conditions is crucial in the design of control strategies for more cost-effective and competitive greenhouses. Knowing the limit of variations from the optimum greenhouse climate without affecting production quality and yield contributes in the creation of a proper automation level for energy management, environmental impact reduction and maximising the use of natural resources [19].

2.3 Growing strawberries in a greenhouse

Growing strawberries in a greenhouse not only prevent damages from natural disasters but also provides a suitable environment for growth [20]. Fluctuations in the environment especially in temperature and light have a significant effect on the growth of strawberries hence a greenhouse helps to reduce the fluctuations [21], [22], [23], [24]. Studies have shown that temperature is the main environmental factor that affects the growth of flowers and fruit in strawberries [25], [26], [27].

2.4 Application of IoT in greenhouse control

Several strategies have been implemented to optimise the climatic conditions the design of greenhouses [28], [29]. Control strategies involving evolutionary algorithms, simulation-based genetic algorithm, natural ventilation and fuzzy logic have been implemented [29], [30], [31], [32]. The need for reducing wiring in the greenhouse and the need for many sensors to be installed in smart agriculture has resulted in many different controllers being utilised by researchers in order to control greenhouses from a remote location. The ZigBee has been used as the backbone of low cost, low power consumption, low data transmission and self-organised wireless sensor network [33], [34]. In greenhouses, the ZigBee has been mainly used for on-line monitoring in Internet of Things applications [35], [36], [37]. The LORA has been used data for processing and analysis, and control the greenhouse remotely online [38]. An Arduino with an Ethernet and a WEMOS have also been implemented [41], [42]. In this research, we are implemented an Arduino with an ESP8266 to develop a low tech, low-cost model of a greenhouse. This is so that we utilise the Arduino's input/output but give it wireless connectivity through the ESP8266 which only has two input/output pins.

3 METHODOLOGY

The need for the development of the greenhouse was mainly informed by the 2016-2018 drought that affected the Western Cape Province in South Africa which resulted in Cape Town the only metropolitan in the province almost reaching day zero. The city taps were projected to be turned off in May 2018 [34]. To reduce the effects of a future drought on horticulture and strawberry farmers in the Western Cape a low cost, low tech greenhouse adapted to the Western Cape climate is proposed. The generic product development process developed by Ulrich and Eppinger [45] shown in **Figure** 2 was followed to develop the solution.

Figure 2 Generic product development process [45]

3.1 Concept development

To understand the need 7 people were interviewed. These consisted of four farmers, two greenhouse manufacturing companies employees and a University of Technology's institutional greenhouse management were interviewed. The farmers interviewed consisted of two strawberry farmers, one horticultural farmer who has operations in the metro and the Winelands district and a farmer working on setting up a solar power irrigation system in the Karoo. Interviews were carried out with the two strawberry farmers, the institutional greenhouse management and one manufacturing company. Questionnaires were sent to the horticultural farmer and one manufacturing company.

From the interviews, the main customer needs were summarised as efficiency, accuracy, exceptional hygiene, heightened bio-security, cost-effectiveness, ease of maintenance, ability to control remotely and ease of programming for the operator. From these customer needs a House of Quality [44] was developed to turn the customer needs into engineering needs. A five-step methodology proposed by Ulrich and Eppinger [45] shown in Figure 3 was used in concept development giving yield to five concepts.

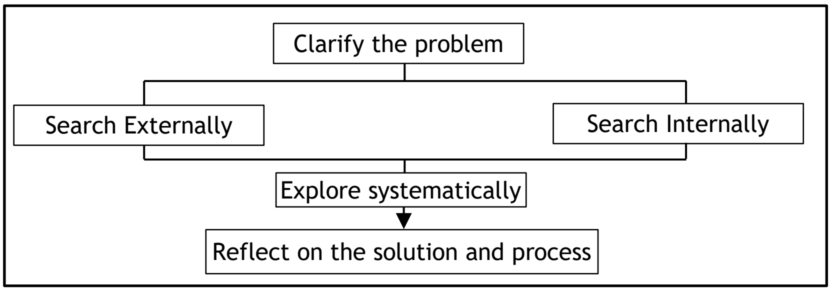

Figure 3 Five step methodology for concept development [45]

3.2 Concept selection

The Pugh concept selection [46] method was used to select the best concept. This process consists of concept screening and concept scoring. Concept screen involves the preparation of the selection matrix, rating the concepts, ranking the concepts, combining and improving the concepts selected and then reflecting on the results and process. The concept scoring process also follows a six-step methodology of preparing the selection matrix, rating the concepts, ranking the concepts, combining and improving the selection of the final concept and reflecting on the results of the selection and process.

3.3 Systems-Level Design

Once the final concept had been selected the systems engineering approach was used to develop the prototype. The Vee model [47] was utilised to decompose the system and

Table 1 System operational design parameters

		Optimum
Temperature	Strawberries	18 °C (optimum growth for roots and fruits) 25 °C (growth of the whole plant) [48],[49]
	Horticulture	18 – 30 °C [48]
Light Intensity	Strawberries	400μmol/10000 Lux [50]
	Horticulture	150 μmol [51]
Soil Moisture	Strawberries	74 – 100 %, Klamkowski [52]
	Horticulture	41 - 80%
Humidity	Strawberries	65 - 75 % [53]
	Horticulture	85 – 95%

determine the system requirements, firstly at a high level, then at a detailed design stage, finally hardware and software requirements were established. The system was verified at each level of integration and recomposition and then validated using the experts at the UoT's institutional greenhouse.

3.3.1 *Requirement analysis*

The systems requirements were developed from the literature, farmers' history records and information gathered from interviews greenhouse manufacturing companies and a University of Technology's institutional greenhouse management. The system operational parameters are shown in 1

3.3.2 *System architecture and detailed design*

The proposed design consists of a microcontroller with sensors to measure the following factors: light intensity, soil temperature and moisture, air temperature and humidity. Real time data from the green house is uploaded on the ThingSpeak server to enable remote monitoring and control using and online dashboard and a mobile app. The first level system architecture for the system is shown in Figure 4. A Raspberry Pi, Arduino and NodeMCU were considered for the control of the greenhouse. Since there was more data control than data processing the Raspberry Pi was eliminated. The Arduino was chosen ahead of the NodeMCU due to it having more input and output ports and also most of the sensors uses 5V instead of the 3.3V in the NodeMCU.

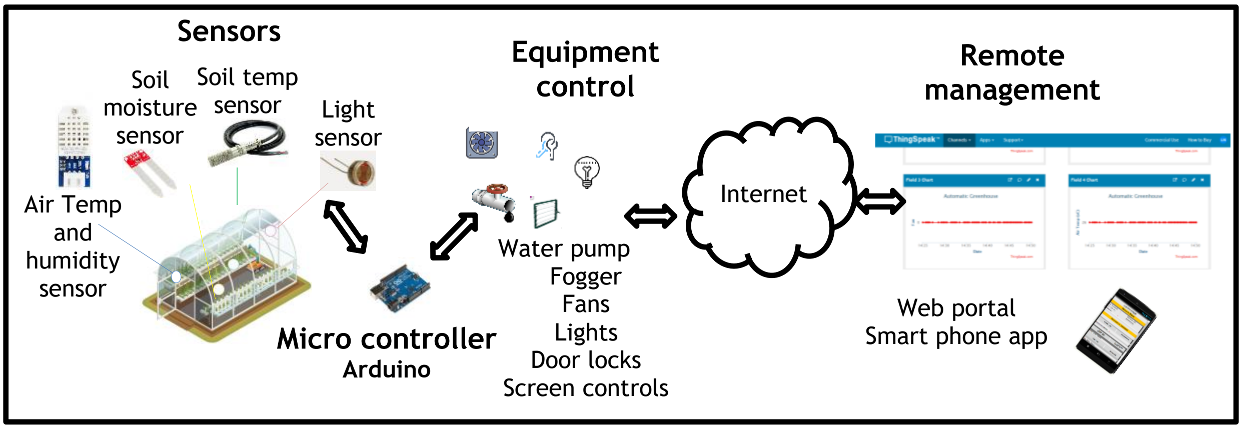

Figure 4 First level system architecture

3.3.3 *Data acquisition*

Air temperature and humidity were measured using a DHT22 module which has a measuring range from -40°C to +125°C with +-0.5 degrees accuracy. A DHT 22 consists of a humidity sensing component together with a thermistor for measuring the temperature as shown in **Error! Reference source not found.**. The humidity measuring component consists of two electrodes with moisture holding substrate sandwiched between them. The substrate is usually a salt or conductive plastic polymer. Ions are released by the substrate when it absorbs water vapour which in turn increases the conductivity between the electrodes. The change in resistance between the two electrodes is proportional to the relative humidity. Higher relative humidity decreases the resistance between the electrodes, while lower relative humidity increases the resistance between the electrodes. The thermistor used in the DHT 22 is has a Negative Temperature Coefficient (NTC). An 8-bit SOIC-14 IC is installed for signal processing, calibration, conversion of the analogue signal to digital and then split into temperature and humidity so the signal is just read by the Arduino with no need of further processing. The soil moisture sensor measures the soil's electrical conductivity. There mainly two types of soil moisture sensor that can be used with an Arduino, a resistive moisture sensor and a capacitive moisture sensor. Resistive sensors when left in wet soil tend to allow the process of electroplating which destroys the sensor. A capacitive sensor two plates positive and negative with a hygroscopic dielectric material in between them. A capacitive moisture sensor works by measuring the changes in capacitance caused by the changes in the dielectric. A DF Robot capacitive soil moisture sensor was used.

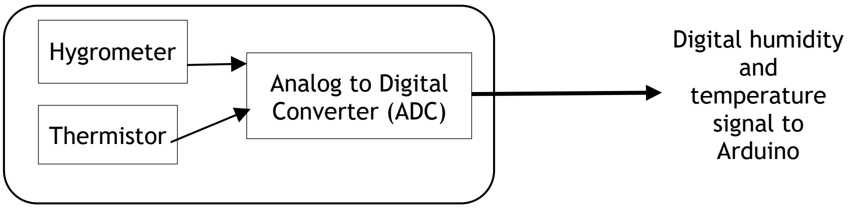

Figure 5 DHT22 construction

The soil temperature sensor was designed by creating a voltage bridge using a 100kΩ thermistor and thermistor as shown in Figure 6. The resistance of the thermistor at any given point in time is calculated using

$$R_2 = R_1\left(\frac{v_{in}}{v_{out}} - 1\right) \qquad \text{Equation 1}$$

Where $R_2$the resistance of the thermistor is, R_1 is the resistance of the known resistor (100kΩ), v_{out} is the voltage between the thermistor and known resister and v_{in} is the input voltage (5v) from the Arduino. The Steinhart-Hart equation is used to convert the resistance of the thermistor to a temperature reading in Kelvins as shown in $T = \frac{1}{A+BlnR+C(\ln R)^3}$ Equation 2

$$T = \frac{1}{A+BlnR+C(\ln R)^3} \qquad \text{Equation 2}$$

Where T is the temperature in Kelvins, R is the resistance of the thermistor at temperature T in Ohms and A, B and C are Steinhart-Hart coefficients for the thermistor, $1.009249522 * 10^{-3}$ $2.378405444 * 10^{-4}$ and $2.019202697 * 10^{-7}$respectively in this case.

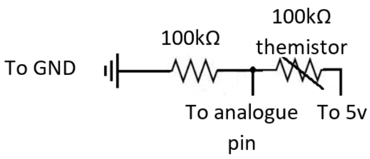

Figure 6 Circuit diagram for measuring soil temperature

To measure the light intensity of light to a Light Dependent Resistor (LDR) it is exposed to in lux (lx) the formula in $L = BR_1^m$ Equation **3** is used.

$$L = BR_1^m \qquad \text{Equation 3}$$

Where L is the light intensity in lux, R1 is the resistance of the LDR in Ω, B and m are obtained experimentally to give $1.3 * 10^7$ and -1.4 respectively.

To measure the light intensity of an LDR using an Arduino the voltage divider as shown in Figure 7 Circuit diagram for measuring light intensity. The LDR R_1 is attached to the 5v pin of the Arduino and 10kΩ resistor R_2 is attached to the ground pin with the analogue pin being common among them. The total voltage drop

$$V_{tot} = V_1 + V_2 = 5v \qquad \text{Equation 4}$$

The Arduino, with its built-in ADC (Analog to Digital Converter) converts input analog voltage from 0-5V into a digital value in the range of 0-1024. V_2, used in the calculation is equal to

$$V_2 = k * RawADC \qquad \text{Equation 5}$$

Where,$k = 5/1024$ $RawADC$ is the raw DC input voltage from the the LDR circuit.

The total resistance

$$R_{tot} = R_1 + R_2 \qquad \text{Equation 6}$$

From Ohm's law

$$\boldsymbol{V_{tot} = IR_{tot}} \quad \textbf{Equation 7}$$

$$\boldsymbol{5v = I(R_1 + R_2)} \quad \textbf{Equation 8}$$

$$\boldsymbol{I = 5/(R_1 + R_2)} \quad \textbf{Equation 9}$$

Since $V_2 = IR_2$, R_1 can then be obtained by

$$\boldsymbol{R_1 = (5.0\,/V_2 - 1) * R_2} \quad \textbf{Equation 10}$$

Since $R_2 = 10k\Omega$ we can now find the resistance of the LDR R_1.

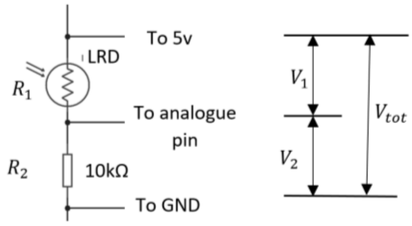

Figure 7 Circuit diagram for measuring light intensity

3.3.4 Control Strategy

To control the temperature of the greenhouse at a desired value the temperature reading from the greenhouse is compared to the threshold temperature and placed in a range. Two threshold values for maximum and minimum values are set depending on the plants in the greenhouse. If the temperature is above the maximum threshold it is placed in the hot range, the screens are opened to the maximum and fans turned on. If are the temperature is within the desired range for the plant it is placed high, medium or low range. If the temperature is lower than the minimum threshold the fans are switched off and the screens closed. The configuration of the screens and fans is determined by the range of the temperature. In the low range the fans are off with screens opened to the low level, in the medium range the fans are off with screens opened to the medium level and at high range, the fans are on with the screens opened to the high level. Figure 8 (a) shows the flow diagram of temperature control when the temperature is in the hot range. The same procedure is followed for the control of humidity. Humidity has a range of moist, high, medium, low and dry. If humidity is higher than the maximum threshold the fogger switched off and the screens opened to maximum. When humidity is lower than the minimum threshold the fogger is turned on with the screens closed. In the moist range the fogger is off with screens opened to the low level, in the high range the fogger is off with screens opened to the medium level and at low range, the fogger is on with the screens opened to the high level. Figure 8 (b) the flow diagram of humidity control when the humidity is in the moisture range.

For irrigation controls, the water moisture content is measured and compared with the threshold moisture content. If the moisture content is less than the threshold and the air humidity is less than the threshold humidity the irrigation pump is turned on as shown in Figure 8 (c). For the lights, the light intensity is compared to the threshold value. If it is less than the threshold value the light is turned on as illustrated in Figure 8 (d). The overall system flow diagram is shown in is shown in **Error! Reference source not found.**.

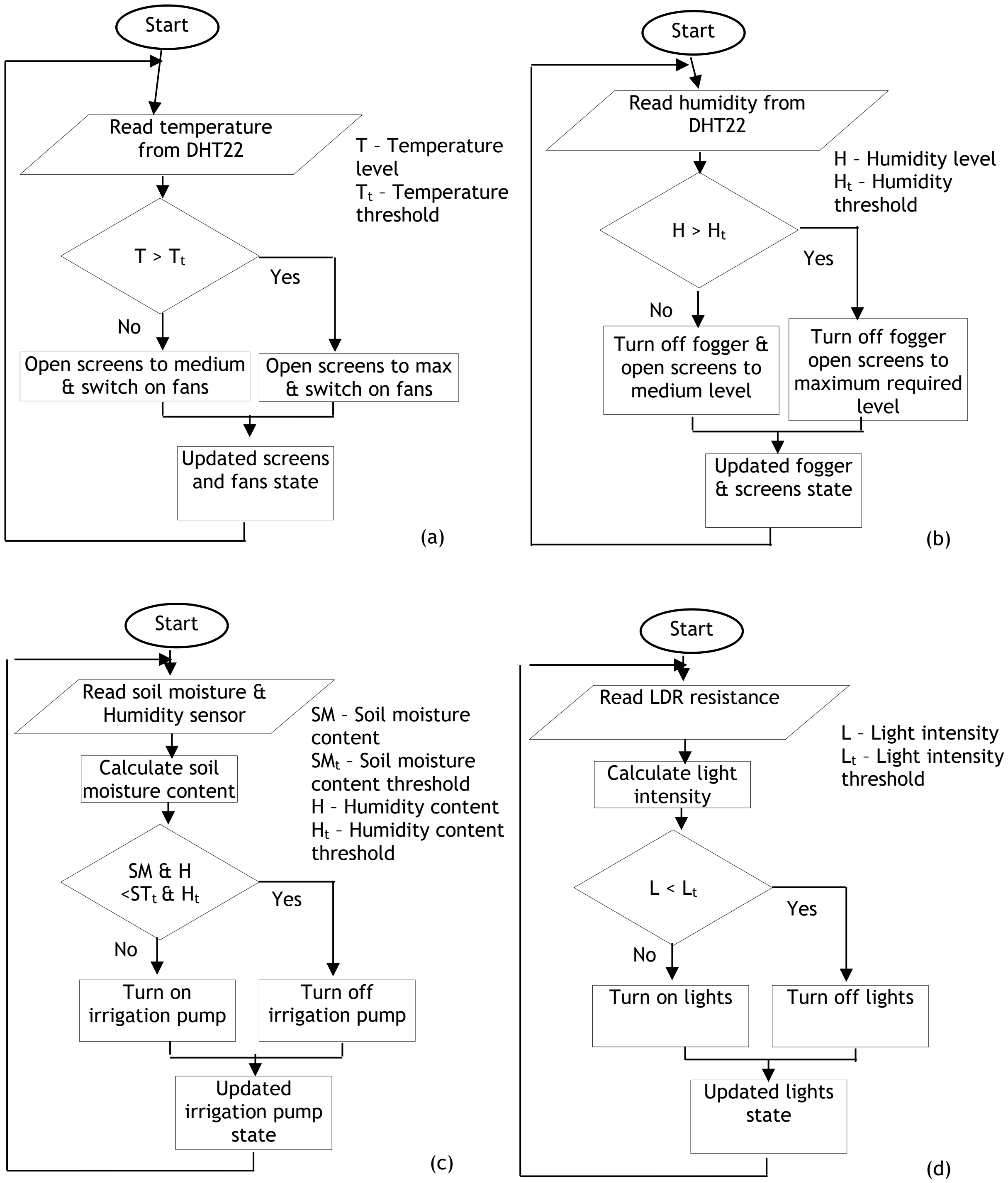

Figure 8 Subsystems flow chart (a) Temperature, (b) Humidity, (c) Soil moisture, (d) light intensity

3.3.5 MQTT protocol

The MQTT protocol in ThingSpeak IoT services is utilised to update the web dashboard and mobile app. MQTT is a publish/subscribe communication protocol that uses TCP/IP sockets or WebSockets. The ESP8266 is used to enable internet connectivity to the Arduino UNO. The Arduino becomes the MQTT client which subscribes to the ThingSpeak MQTT broker and can publish on a channel created and subscribe to updates from the channel. In order for the MQTT client and broker to communicate the client needs to subscribe to a channel feed and the

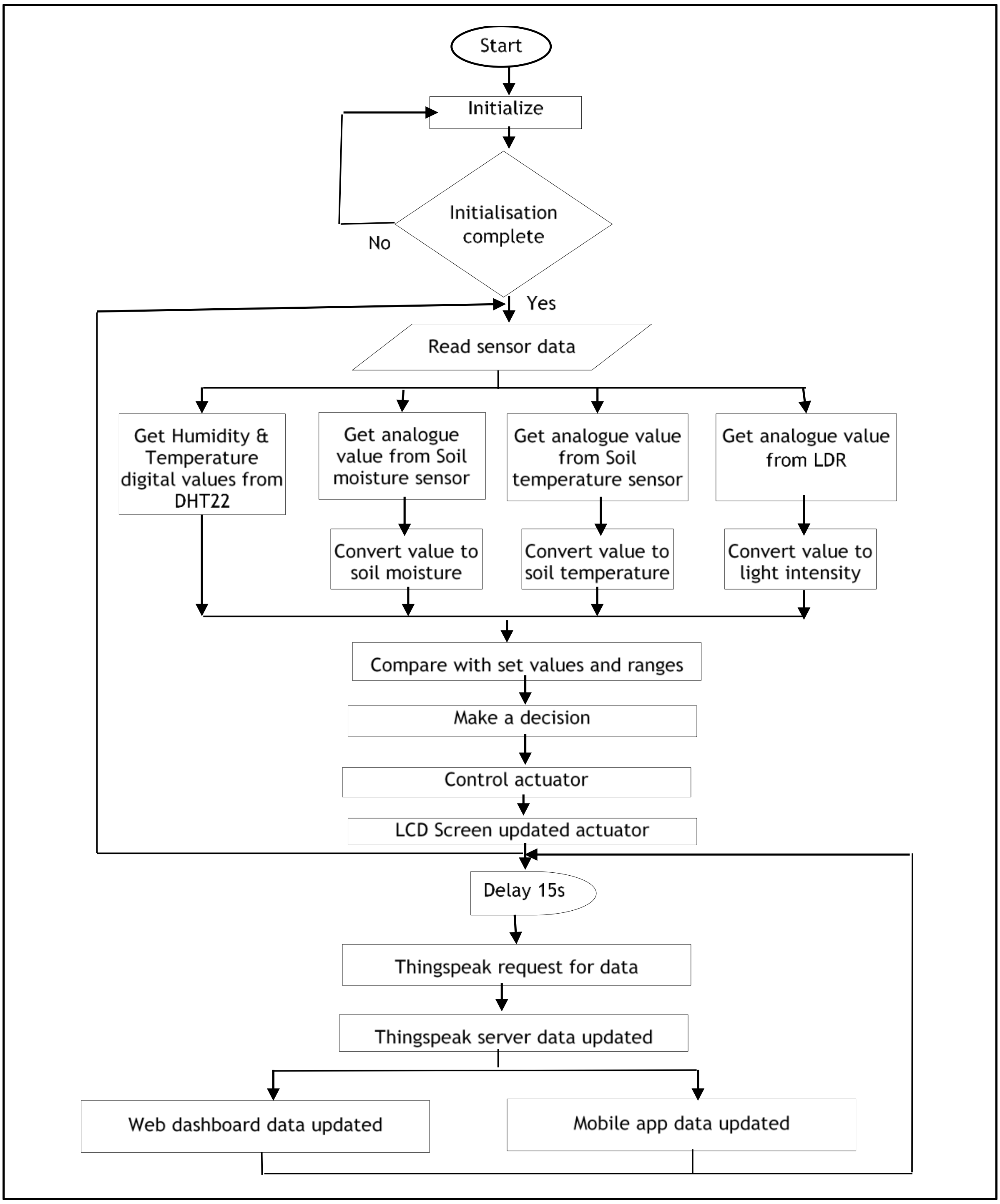

Figure 9 System Flow Diagram

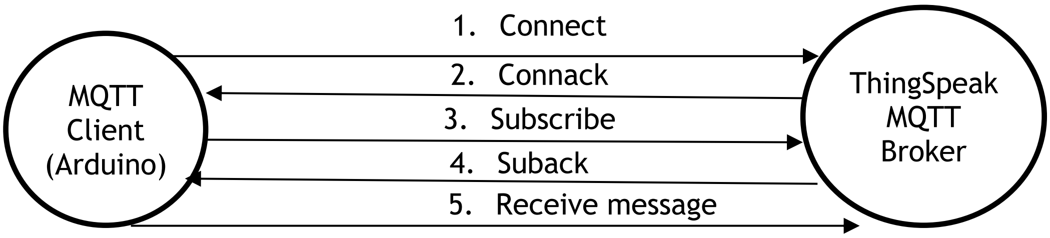

Figure 10 Communication between MQTT client and broker

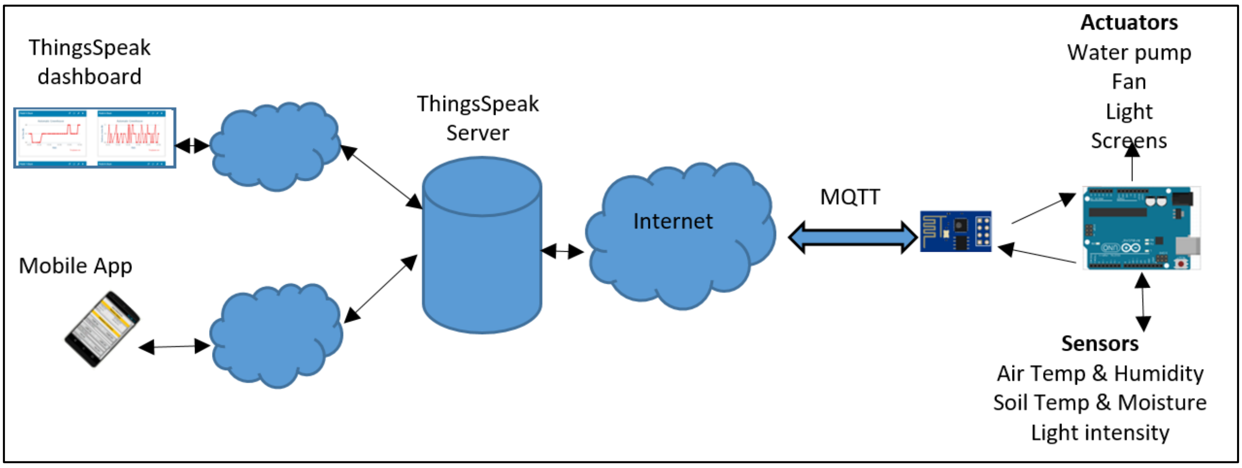

Figure 10 System communication overview

specific fields of the channel. The steps taken in order for the client to send a message to the broker are shown in Figure . Figure 10 shows an overview of the system communication. The main advantage of using MQTT is that it uses less data to send or receive information and it allows internet connectivity between sensors in an effort to create seamless connectivity among gadgets

3.3.6 System control levels

In order to avoid confusion in the control of the greenhouse, a hierarchy of the control levels was set up. The system has four levels of control, automatic control using a microcontroller (Arduino UNO), manual physical control that can override the automatic control using buttons on the control panel, online control using the ThingSpeak dashboard and mobile app. The microcontroller is used for automatically controlling the system but can be overridden by manual controls through the buttons on the systems, ThingSpeak dashboard and mobile app. The levels of control of the system are shown in Figure 11.

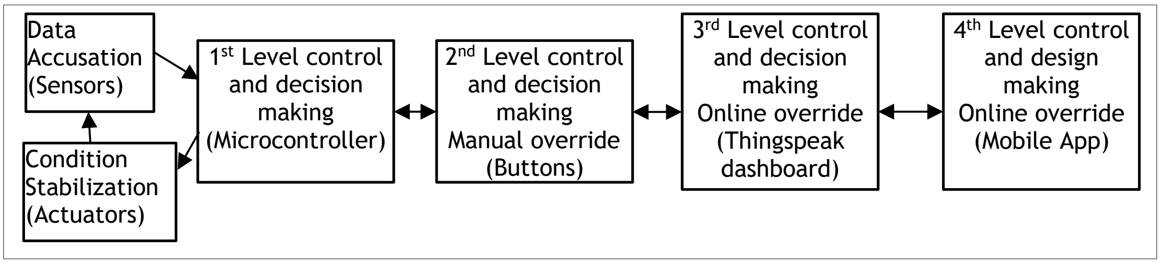

Figure 11 Levels of control

Table 2 Average recorded system parameters

Week	Air Temp(°C)	Air Humidity (%)	Soil Temp(°C)	Soil Moisture (%)	Light Intensity (Lux)
1	17.8	72.3	16.2	78.4	9852
2	18.5	70.4	17.4	76.4	9954
3	24.6	68.4	18.8	72.5	10240
4	24.5	67.5	19.4	73.2	11564

4 RESULTS

The model of the greenhouse shown in Figure 12. Conditions for the growth phase of strawberries was were set on the greenhouse and monitored for one months. The growth of the roots and fruit were simulated for the first two weeks and the growth of the whole plant was simulated for the last two weeks. The average recorded values are shown in Table 2. The model was monitored in-house for the first two weeks and last two weeks outdoor. Part of the model control circuits is shown in Figure 13.

Figure 12 Greenhouse model

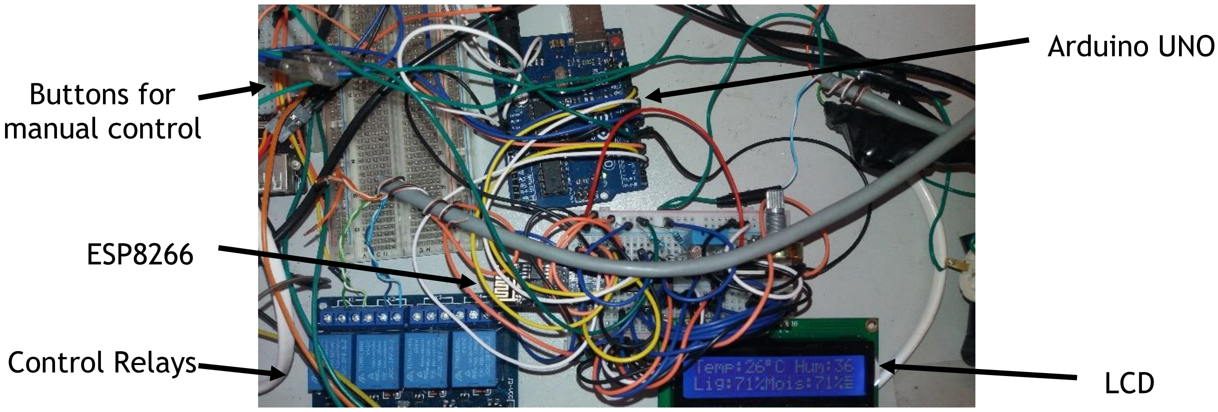

Figure 13 Model control circuits

The parameters measured are displayed in an LCD. The manual control can be used to change the threshold values and override the automatic. The ThingSpeak dashboard and mobile app are shown in Figure 14 There is a delay of 15 seconds between the values displayed on the LCD with the dashboard and mobile app values. This is due to the fact that the ThingSpeak server updates after 15 seconds whilst the LCD values are updated every millisecond. MIT App developer was used to develop the mobile app and can be downloaded to any phone running on Android.

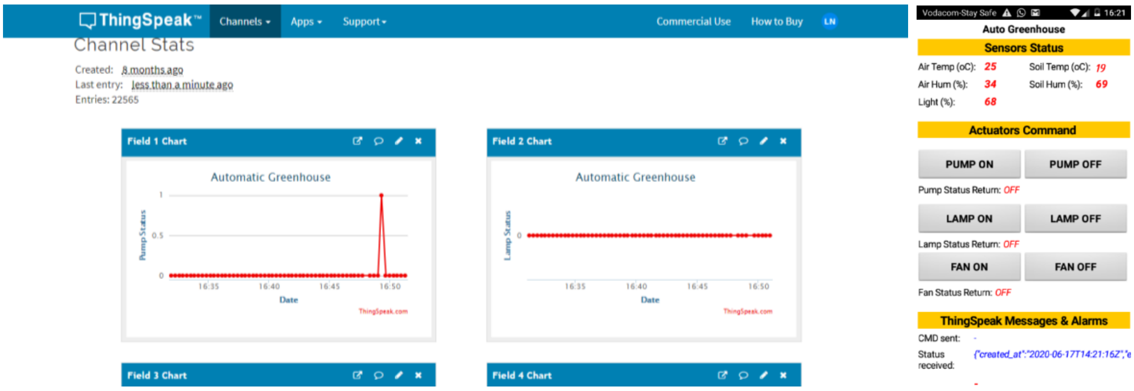

Figure 14 ThingSpeak dashboard and Arduino mobile app

5 DISCUSSION OF RESULTS

The model was validated by the agricultural experts at the UoT's institutional greenhouse. Though they liked the idea of remote control as they have to drive to the institution to reset the greenhouse systems they felt that more tests of the model needs to be done to ascertain the robustness of such a system. The other worry was on security and data protection, as security was not considered in the design of the system. The other area of the design that needs to be improved upon is the layout of the physical control system as it was felt to be a bit complicated. There was a major need for the system to be simple and user friendly. The idea is that the system assist the user to concentrate on functionality rather than the programing aspects of the system. Some of the sensors used are not that accurate as the objective was to test functionality and create a low-cost solution within a small budget for farmers to easily access this solution. These affected the accuracy of the measurements done on the system. When a full-scale model is built accurate sensors are recommended to be used.

6 CONCLUSION

In this paper, the design of an automated greenhouse model with remote online monitoring and control is discussed. As a way to conclude this paper, the author now revisits the motivations for this research: To design a way of using IoT to prepare for the future of South Africa getting drier than before. Secondly, this paper presents an initiative to save water and optimise plant production, especially in dry areas. The focus in building the greenhouse was to use low-cost technology. An Arduino was used as a microcontroller and was given access to the internet through the connection to ESP866. ThingSpeak IoT services is utilised to connect the Arduino to the ThingSpeak server. The information in the server can be observed and controlled through the online dashboard and a mobile app. Future research could include utilising Matlab Analysis and Matlab Visualisation on the ThingSpeak dashboard for analysis of the data. The use of Xbee modules to communicate information among sensors

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BARRIERS AND ENABLERS TO INTERNAL QUALITY AUDITING PRACTICES AT A SOUTH AFRICAN AUTOMOTIVE ASSEMBLY PLANT

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ABSTRACT

The purpose of this study is to investigate the barriers and enablers to internal quality auditing practices at a South African automotive assembly plant. The study is a single and cross-sectional case study. Data was collected through reviews of literature, company documents and interviews. The research participants were drawn from the different levels of the company organogram. Varying views on the purpose of internal quality audits, mismanagement of audit corrective actions and audit programme deficiencies were evident barriers. On the other hand, the participation of auditors in problem solving and risk management as well as the use of management tools enabled internal quality auditors to know where to direct their resources. These findings show the factors and their impact on internal quality auditing practices in the company. The findings can be used to further examine how the barriers can be minimised and the enablers enhanced.

Keywords: ISO 9001, Quality Management, Internal quality auditing

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1 INTRODUCTION

Managing quality in the automotive industry today requires a heightened sense of awareness of the context under which Quality Management Systems (QMSs) operate [1]. It is a context characterised by challenges such as increased customer demand, shortening product development and commercialisation cycles. These challenges present themselves amidst increasing product safety requirements, where the risk of making mistakes is high, prompting for carefully positioned and sustained QMSs [2]. To improve organisational performance and increase competitiveness, organisations have implemented and obtained certifications of their QMSs based on the ISO 9001 standard [3, 4].

When a company has obtained its QMS certification that is based on the ISO 9001 standard, it is necessary that it maintains the certification and continuously improves its quality performance [5]. Quality auditing is one of the essential practices for maintaining the ISO 9001 QMS certification and evaluating the QMS performance of a company [4, 5]. Since the introduction of the 2015 version of the ISO 9001 standard, over 878 664 organisations globally and across industries have successfully obtained their ISO 9001:2015 certification [6]. The challenge facing these organisations is the need to effectively maintain their ISO 9001 QMS certifications through periodic quality audits. There are, however, concerns with the high maintenance costs associated with ISO 9001 QMS and quality audits [5, 7]. In a global automotive industry study conducted by AIAG, it was found that organisations spend, on average, 116 working days and approximately US$100 225 annually to comply with QMS requirements through audits [8].

The effectiveness of auditing practices in driving quality improvements has also been criticised [3, 5, 8]. Quality audits should not only verify a company's conformance to the ISO 9001 requirements, but should also evaluate quality performance and identify opportunities for improvement [9, 10, 11]. Moreover, internal quality auditors fulfil a supporting function that provides quality assurance services within their organisations. It is from this perspective that the effectiveness of quality auditing be perceived and assessed. Hence internal quality audits must be flexible and their primary purpose depends on the organisation [12].

It is in this prevailing debate that this study was conducted. The study was based on a single case company, hereafter referred to as company XYZ. The purpose of the study was to examine the internal quality auditing practices at Company XYZ with the objective of determining the barriers and enablers that impact on the effectiveness of the practice.

Case study organisation

Company XYZ is an automotive assembly plant that is located in South Africa and is part of a global production network of 31 plants. During the company's 46-year production tenure, it achieved significant international recognition for producing good quality vehicles in 2002 and 2015. All the assembly plants in the production network are required to be competitive in terms of quality, operating costs as well as production volume performance. Assembly plants that maintain exceptional ISO 9001 QMS performance secure a greater allocation of production volume.

At the time that the study was conducted, Company XYZ's managers and auditees were not satisfied with the effectiveness of internal quality auditing practices. Despite an increase in the number of internal quality audits, the company observed a high number of non-conformances from external audits. It was also expressed that internal quality audit practices were insufficient to prepare Company XYZ for external quality audits. To address these concerns, there was a need to conduct this study. The identified barriers and enablers provided an understanding of how the barriers could be eliminated and enablers strengthened to encourage effective internal quality audit practices.

2 LITERATURE REVIEW

2.1 Quality Management Systems in the Automotive Industry

In the automotive industry, an organisation's QMS can be based solely on the ISO 9001 standard or it can include industry specific quality standards such as the IATF 16949. In addition to the ISO 9001 and IATF 16949 certifications, the automotive component suppliers are required to certify their QMS according to the requirements of the OEM's country of origin. Moreover, it is required that the QMS performance of OEMs and component suppliers are assured through periodic quality audits [4]

2.1.1 Classification of Quality Audits

The quality auditing practice lends its theoretical perspectives from the financial and managerial auditing disciplines and is considered a tool utilised irrespective of what is audited [13]. Therefore, internal audit literature from other disciplines was carefully considered and reviewed for this study.

An audit is a systematic, independent and documented process for obtaining compliance evidence and for evaluating the extent to which standard operating procedures are fulfilled [14].

Quality audits are classified into three categories: product, process and system audits. Product audits evaluate whether a company's product conforms to customer specifications and requirements [15]. Process audits are performed to evaluate interacting activities that transform inputs into outputs against predetermined instructions or standards. They establish whether the processes are delivering and managing the intended results effectively [16]. System audits are an evaluation of a company's QMS elements as well as its interrelated processes to determine whether they enable the company to deliver results that are consistent with its purpose and strategic direction [15].

The above categories of quality audits are further classified as either internal or external to the audited company. Internal audits are conducted by ISO 9001 trained and competent internal quality auditors. The audits are done to establish the company's QMS performance and to identify opportunities for improvement [17].

External quality audits include second-party and third-party audits. In the automotive industry, second-party quality audits are performed by an OEM organisation on its suppliers. This is done for two reasons. Firstly, to determine whether the supplier is capable of meeting the OEM's customer specific requirements. These audits are a basis for awarding a contract to a supplier. Secondly, second party audits are conducted on existing suppliers to determine whether the suppliers continue to adhere to the OEM's quality requirements [17]. Third-party quality audits are performed by an external entity for the purpose of either certifying the company's QMS or determining whether the company has plausibly maintained its ISO 9001 QMS [17]. A graphic representation of these quality audits is shown in Figure 1. In this study, the process and system internal quality audits of company XYZ were examined.

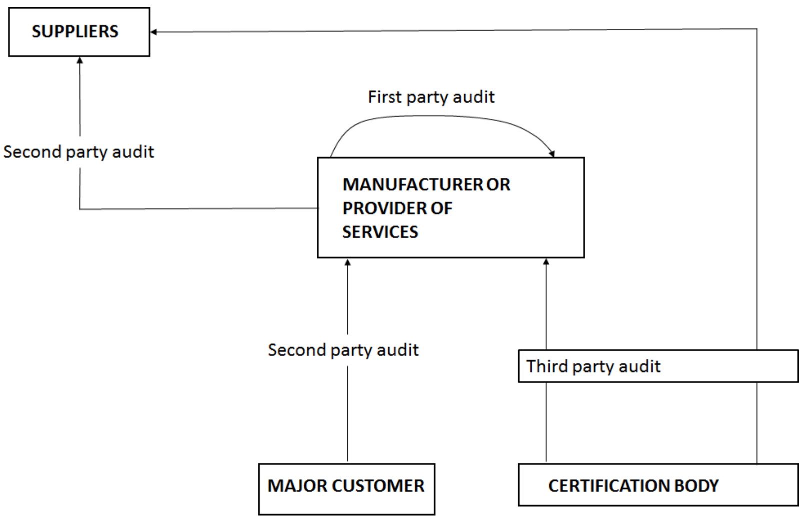


Figure 1: Types of Quality Audits Source: Chiromo & Ngobeni [38]

2.2 Theoretical framework: barriers and enablers to internal quality auditing

Previous studies on internal quality audit effectiveness had focused on frameworks that show how internal quality audit practice can be improved, how business relevance can be operationalised and how internal quality audit frameworks that can assist ISO 9001 companies measure the performance of their QMS can be developed [2, 3, 5, 18, 10].

Similar studies have focused solely on the possible factors that influence internal audit effectiveness and did not consider evaluating the impact of the practice on the company using quantifiable performance indicators [19, 12, 20]. Most of these studies were based on literature reviews. However, empirical studies concerning internal quality audit practice barriers and enablers are still considered relevant because to improve the internal quality auditing practice the factors that have an impact on the practice's effectiveness need to be determined [10, 19].

In order to determine barriers and enablers to internal quality audit at Company XYZ, the theoretical framework of Lenz & Hahn [12] was used. The framework organised the barriers and enablers into the organisational, internal quality audit relationships, internal quality audit resources, and internal quality audit processes themes. Based on the knowledge gained from other literature sources, the framework was expanded to include the performance measurement theme.

Traditionally, quality audits were conducted for the purpose of monitoring conformity [10]. However, with the introduction of the 2015 version of the ISO 9001 standard, there is more emphasis on performance [15]. Performing internal quality audits to determine whether or not a company conforms to the ISO 9001 criteria is synonymous to utilising a "conformance-based" audit approach which is no different from what external quality audits do. As a result, this could render internal quality audits as insufficient in evaluating the performance of the QMS for continuous improvement purposes. It is also argued that the extent to which the practice of internal audit adds value in a company is dependent on how effectively the practice is managed in the company [21, 20]. Based on these reasons, the theoretical framework of Lenz & Hahn [12] was expanded to include the performance measurement theme.

2.2.1 Organisational context barriers and enablers

When an organisation maintains its ISO 9001 QMS merely to conform to requirements and satisfy external quality auditors; it is a barrier. Alic & Rusjan [18] further describe organisations with low expectations as those that: 1) conduct quality audits merely to identify and eliminate nonconformities, 2) focus on maintaining ISO 9001 QMS certification with least efforts and 3) often require convincing evidence to accept auditors' findings. Organisations that are internally motivated to maintain the ISO 9001 QMS are an enabler to internal quality auditing practices because they have a goal to obtain an efficient ISO 9001 QMS beyond obtaining successful recertification [18].

In order to address issues of increasing audits, and redundancies, it is recommended that management standards are integrated through audits [21, 9, 22]. Therefore, the integration of management systems can be regarded as an enabler that facilitates efficiencies in the internal quality auditing process.

2.2.2 Internal quality audit relationships barriers and enablers

Difficulties posed by rising expectations of management towards internal quality auditors has also been cited as a barrier. Hatherell [23] argues that meeting the needs of management, auditees, and external auditors without ensuring auditor independence can present a barrier to internal auditing practices. Auditor independence ensures the objectivity of internal quality audits and allows other employees within an organisation to perform self-assessment audits of their own processes [24].

Coleman [25] also emphasises that internal quality auditors should be involved in risk elimination, management and mitigation to be able to be effective in their organisations. Knowledge in company processes and strategies enables the internal quality auditors to execute their jobs effectively. Alic & Rusjan's [18] study found that in order for the internal quality auditing function to have managerial relevance in a company, it has to be appropriately integrated within the strategic goals and direction of the company.

2.2.3 Internal quality audit resource barriers and enablers

Another important barrier noted is inadequate internal quality auditor competence. Internal quality auditing should be used as a means of improvement and to confirm compliance with the requirements of the ISO 9001 standard [26]. Thus, the audit findings should direct the attention of management to the areas where significant action is required.

Kaziliūnas expressed concern in the lack of interpersonal skills and experience shown by the internal quality auditors when they engage with top management [2]. Therefore, internal quality auditors need to be provided with opportunities to engage with top management beyond internal quality audits. As part of the advising role of internal quality auditing that is advocated by Mahzan & Hassan [27], internal quality auditors should also be able to provide advice for addressing corrective actions and this calls for auditors to be knowledgeable on company processes.

Abu-Musa [28] also found out that there is a need for the internal quality auditors to improve their skills in the use of computerised information systems. Considering the environment in which automotive QMSs operate and the emerging skills, it is important for internal quality auditors to adopt new quality monitoring and auditing approaches while leveraging on technologies for analysing, testing and reporting [29]. Acquiring skills in these technological trends, can also assist internal quality auditors in monitoring and maintaining an aligned view of significant areas of impact within their organisations so as to make informed decisions on where to direct internal quality audit resources [30].

2.2.4 Internal quality audit process barriers and enablers

Internal quality audits that are performed with the sole motive of checking conformance to ISO 9001 standard requirements are seen as a barrier because they do not stimulate auditees to seek improvement opportunities in their processes [31]. Furthermore, managing the audit programme without taking into cognisance the effectiveness of the auditing process and the audit programme is seen as a barrier to the internal quality audit practice [31].

In order to make key decisions pertaining to the processes to be audited as well as the timing and frequency of audits when establishing the audit programme, the auditors have to engage "systems-thinking" and risk-based approaches [32, 25].

When an audited organisation obtains non-conformity findings, internal quality auditors are expected to report such findings to management. When management is not receptive, is not accountable, and does not take action, this leads to a barrier known as the "deaf effect" [33].

2.2.5 Internal quality audit performance barriers and enablers

It is proposed that when taking into consideration the measurement of the internal audit function's performance the effectiveness, efficiency and economy of the function must be considered [34,12]. The evaluation of internal audit effectiveness is seen as an enabler because internal quality auditing practices can be performed efficiently and not effectively. For example, processes that are irrelevant can be audited in an efficient manner [35] cited by [12].

Internal quality audit effectiveness has been categorised based on two perspectives in literature. The first perspective is based on the internal quality auditors' self-assessment views on their effectiveness and the second perspective is based on the auditees' assessments and views of how effective the internal quality auditors are [12]. In discussing the barriers of the two perspectives, Geis [36] said that internal audit effectiveness that is based solely on auditee perceptions poses a barrier because auditees might have ambiguous or low expectations. On the other hand, investigating internal audit effectiveness based on the auditors' self-assessments may also pose a barrier of continuing audit activities with an untested or less critical view of effectiveness. Therefore, in order to enable a balanced measure of internal quality audit effectiveness, it is beneficial to obtain both the auditors' and auditees' views on internal quality audit effectiveness.

3 RESEARCH METHODOLOGY

An explanatory, qualitative and single case study research strategy was utilised for this study. The study was done in order to determine possible barriers and enablers that impact on internal quality auditing practices at company XYZ. An adaptation of the theoretical framework developed by Lenz & Hahn [12] was used. Their framework is a consolidation of the previous frameworks and literature on internal audit effectiveness. This study was conducted to determine barriers and enablers, and to organise them into organisational, internal quality audit relationships, resources, processes, and performance themes. The theoretical framework describes the micro and macro factors that influence the effectiveness of internal auditing practices. However, this study adapted only the micro factors from the theoretical framework because insufficient background information of Company XYZ was available to prompt examination of macro factors. Furthermore, the micro factors were seen as prevalent and the evaluation of internal quality audit practice effectiveness was done from the context of company XYZ's QMS. Based on the knowledge gained from other literature sources, the framework was expanded to include the performance measurement overarching theme.

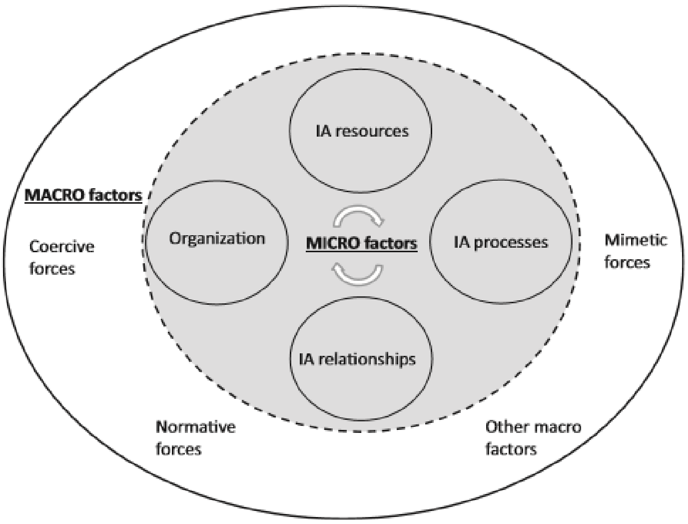


Figure 2: Lenz & Hahn [12] internal audit effectiveness theoretical framework

The data collection process encompassed virtual semi-structured interviews and analysis of company annual audit programmes and management review records from the year 2010 to 2019. Multiple sources of evidence were used to ensure validity and reliability of the evidence collected [37].

The interview protocol was drafted based on themes adapted from the Lenz & Hahn [12] theoretical framework, coupled with knowledge gained from literature review. The company document analysis served the purpose of substantiating the data that was collected from the interviews. It also ensured that there was no over reliance on one data source. The analysis of the annual audit programme and management review records focused on determining an objective view of:

- The annual trend of internal quality audits and non-conformance audit findings,
- the factors that determine the timing, frequency and scope of audits, and
- management's perception of the effectiveness of internal quality auditing practices.

The data collected was analysed using a pattern-matching analysis technique [37]. This analysis strategy was necessary to connect data collected to the overarching themes identified in the Lenz & Hahn [12] framework. Thereafter, a frequency count was performed on the annual number of audits and non-conformance audit findings from the period 2010 to 2019 with the aim of determining a possible trend graphically.

Judgment sampling was used to select the study's interview participants based on their professional judgment and the influence they have on the company's auditing practices as well as overall ISO 9001 QMS. The target population included internal quality auditors, production engineers, Integrated Management System (IMS) and QMS Specialists. The selected sample size of seven (7) interview participants was based on the availability and willingness of participants. Table 1 below shows the participants' professional background.

Table 1: Interview participants' background information

Function Title	Company Experience	Automotive Industry Experience	Respondents
Lead Internal Quality Auditor	Above 20 years	Above 20 years	1
Internal Quality Auditor	Less than 5 years	5 to 10 years	1
Quality Steering Manager	5 to 10 years	5 to 10 years	1
IMS Specialists	5 to 10 years	5 to 10 years	3
Production Engineer	5 to 10 years	5 to 10 years	1

4 FINDINGS AND DISCUSSION

This section provides empirical findings and analysis based on data collected through document reviews and interviews that were conducted in Company XYZ. The findings are presented in section 4.1 and 4.2 on the basis of the organisational context, internal quality audit relationships, resources, process, and perceived performance themes.

4.1 Internal quality auditing practice enablers at Company XYZ

4.1.1 Organisational context enablers

Both the auditors and the auditees agreed that the integration of the ISO 9001, ISO 14001 and OHSAS 18001 management systems simplified the certification processes of the management systems. Furthermore, the Integrated Management System specialist role in the company's departments was considered an enabler to balance the maintenance efforts of the management systems. One participant responded:

> *"Previously there were standards that took precedence over the others. After the systems were integrated, there is equal allocation of resources and attention to the maintenance of the standards."*

4.1.2 Internal quality audit relationship enablers

Participants agreed that beyond their usual scope of auditing responsibilities, internal quality auditors provided advice for addressing the audit findings. They were involved in problem solving, risk management and quality improvement coaching activities. This strengthened the relationship between the auditees and the auditors. The auditees were content with the joint approach to solving quality problems and risks.

The IMS specialists played an important role in enticing management to support and cooperate with internal quality audits. This is illustrated by the comment:

> *"Management seems to be generally supportive of internal quality audits and often involves auditors in management quality meetings. Each department has an IMS specialist who forms a crucial link between Auditors and Management regarding department related QMS and audit risks. That helps in that the IMS specialists assist in areas where the auditors fail to give guidance."*

4.1.3 Internal quality audit resource enablers

On the use of information systems and technical experts to analyse process data, the majority of respondents were satisfied. The auditees saw it as an enabler because it facilitated knowledge sharing among the technical experts, auditees and auditors. One auditee participant commented:

> *"When our department was audited on Test Equipment Management (TEM), the auditors were able to independently retrieve and analyse measurement system analyses for test equipment and process capability studies from the TEM electronic system. This made the audit process a knowledge sharing experience as findings raised were directly related to improving our TEM process."*

4.2 Internal quality audit practice barriers at Company XYZ

4.2.1 Organisational context barriers

The participants believed that the implementation of internal quality auditing practices at company XYZ was hindered by the organizational context barriers. These barriers included; 1) the company's externally-driven motive to maintain its ISO 9001 QMS, 2) the company's inclination to prioritise production volume demands over quality audit corrective actions, 3) the company's lack of knowledge on the ISO 9001 requirements, and 4) the lack of knowledge on the purpose of internal quality audits.

There was a strong view among participants that being able to export vehicles and demonstrate compliance to the ISO 9001 QMS requirements were the main reasons why the company maintained its ISO 9001 QMS. This was reflected by the comment:

> *"When working in an automotive company, it is crucial to be ISO 9001 certified. Without this certification the company will not be able to build and export vehicles."*

Both the Auditors and the auditees agreed that conducting internal quality audits, management of corrective actions, and providing training to the auditors were critical ISO 9001 QMS maintenance activities. The activities were necessary to improve the performance of the QMS. However, the auditees were not happy with the emphasis that was put on meeting production targets over implementing audit corrective actions.

On the other hand, auditors were concerned with the auditees' lack of understanding of 1) the purpose of internal quality audits, 2) the ISO 9001 requirements, and 3) the importance of the audit corrective action recommendations. In this regard, one internal auditor stated that:

> *"Some auditees do not understand the purpose and importance of internal audits. They do not address corrective actions on time. The auditees sometimes do not agree with the identified non-conformances even though they don't know the ISO 9001:2015 requirements."*

4.2.2 Internal quality audit relationships barriers

The auditors had reservations about addressing audit findings and on participating in problem solving, risk management and quality improvement coaching activities. This participation in activities beyond the scope of their responsibilities had created conflict in the past. One auditor responded to this by stating that:

> *"When managers of the auditees do not agree with advice given by the auditors, they usually escalate their disapproval of audit findings to the Quality Manager. The Quality Manager in turn agrees with the auditee's manager without properly consulting with the auditor. This creates conflict and affects the quality of subsequent audit results."*

Although the auditors said that the auditees cooperated during audits, they noticed that the auditees were reluctant to implement corrective actions timeously.

4.2.3 Internal quality audit resource barriers

The views regarding the industry and process related knowledge of internal quality auditors varied among auditees and auditors. The internal quality auditors said that they were adequately knowledgeable and experienced to conduct audits based on the ISO 9001 standard and company processes. Moreover, they had extensive experience in the processes of the company as well as in the automotive industry. The auditees had other views. They were of the opinion that auditors were not adequately knowledgeable in the critical processes of the company. In 2019 similar concerns were raised in the Management Review records of company XYZ. Management pointed out that the internal quality auditors were not competent to prepare the organization for external quality process audits. This was stated as follows:

> *"There is insufficient process knowledge among internal auditors to conduct audits according to the process specifications and ISO 9001 Requirements."*

4.2.4 Internal quality audit process barriers

Analysis of company XYZ's annual audit programme records and interview respondents raised barriers within the internal quality auditing process and management of the audit programme. These barriers seemed to stem from the focus of the audit programme, audit fatigue and the company's response to internal quality audit corrective actions.

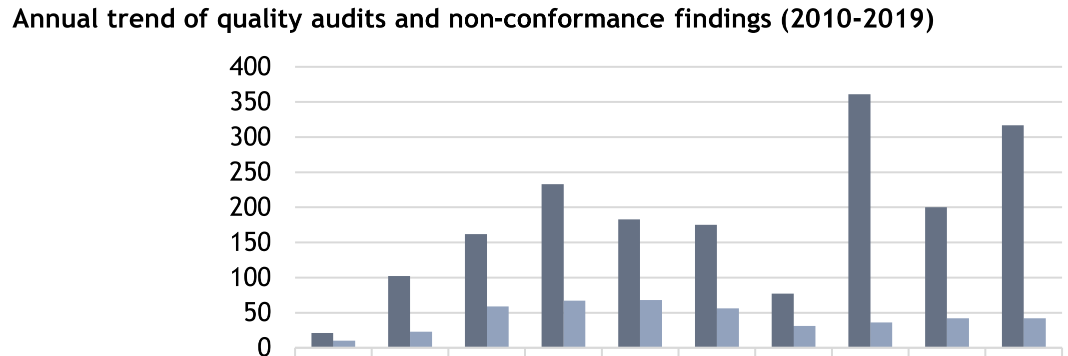
4.2.4.1 "Conformance to ISO 9001 requirements" audit programme focus

The auditees and auditors unanimously agreed that the audit programme focused mainly on conformance to the ISO 9001 requirements. This was sometimes in contrast with achieving process targets as well as influencing continuous improvement of processes and performance. In stating the reason for their views on the focus of the audit programme, one auditee said:

> *"The focus is really about verifying and confirming the level of adherence and compliance to set clause requirements of the standard more than; determining whether processes meet targets, and improving the implementation of production processes."*

4.2.4.2 Unclear premises for determining the timing and frequency of audits

When the auditees were asked if they were satisfied with the frequency and timing of planned audits, they were unanimous in expressing discontent. The emanated from the fact that improvements caused by audit findings were not noticeable. The analysis of the audit programme records and individual audit reports from the 2010 to 2019 confirmed the auditee responses. It raised questions regarding the decision-making process, the planning of the audits as well as how they were conducted. It was not clear whether the frequency and timing of audits took into consideration the importance of processes, the history of product and process performance beyond previous internal and external audit findings. Consequently, an increase in the total number of audits coupled with a corresponding increase in minor and major non-conformance findings became evident (See Figure 3).



	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Sum of total number of non-conformance findings	21	102	162	233	183	175	77	361	200	317
Sum of total number of audits	10	23	59	67	68	56	31	36	42	42

Figure 3: Annual trend of quality audits and non-conformance findings (Source: Own research)

4.2.4.3 Mismanagement of audit corrective actions

The auditors and auditees agreed that the manner in which corrective actions were managed in the company posed a major barrier. Although they had different reasons on what perpetuated inadequate corrective actions, they both agreed that the management of corrective actions was inadequate. The auditees said there seemed to be more time set aside to conduct audits than to conduct root cause analysis and implement corrective actions. On the other hand, the auditors attributed the inadequacy of corrective actions to the failure of the auditees to consider audit corrective actions as part of the departmental quality improvement activities.

Auditee response:

> *"'Quick-fixing' of audit corrective actions takes place instead of delving deep into the real root causes. Why? Well, auditees are simply overly audited. There is not enough time to do proper root cause analysis because production issues are seen to be more critical. While still preparing to address the audit findings more audits are planned to take place"*

Auditor response:

> *"Corrective actions are not sustainable because auditees see audits as burdensome in light of production matters; and do not include them as part of CIP activities within their departments."*

4.2.5 Internal quality audit performance barriers

Company XYZ's measures of internal quality auditing effectiveness were based on management review results. Management viewed the implementation of the internal quality audit programme, the audit resources, and the evaluation of audit results as adequate to effect improvements of the company's ISO 9001 QMS. The auditees' responses on the effectiveness of company XYZ's internal quality auditing practices were varied. Some auditees said the similar audit findings recurred despite increased frequency of auditing. Other auditees perceived internal quality audits as being effective because major non-conformance audit findings were identified prior to external quality audits. This was in agreement with the views of internal quality auditors.

In light of the current state of company XYZ's QMS, auditees and auditors were asked for their views on the significance of internal quality audits in the company. Both auditees and auditors agreed that current internal quality audits contributed to the prevention of external audit non-conformances in comparison to other objectives such as continuous improvement and customer focus. This was illustrated by the comments:

> *"We say we are customer focused but we are more concerned about not getting non-conformances, than by what improvement we can make to bring a natural customer satisfaction to the fore front."*

Internal quality auditors also strongly believed that frequent auditing contributed mainly to the objective of preventing external audit non-conformances.

> *"Through frequent auditing we are able to prevent some non-conformances in external audits. Our audits do not identify improvement and positive audit findings in the same capacity as non-conformance findings."*

4.3 Discussion

The results of this study show that there are more barriers that pose difficulties to effective internal quality auditing practices than there are enablers that facilitate effective practices at Company XYZ. Predominant barriers to the implementation of internal quality auditing practices were evident in the organisational context and the internal quality audit process themes.

The company's motivation for maintaining its ISO 9001 QMS, is a crucial link that can help explain how auditors relate to auditees and how the internal quality audit process is managed. The findings in this study are similar to those of Alic & Rusjan [18] in that the auditees and auditors saw the reason for maintaining the ISO 9001 QMS as exclusively for the company to be able to produce and export vehicles. This is in contrast to an intrinsic motivation that seeks to continuously improve the company's product quality and process performance. The external motivation of company XYZ toward ISO 9001 QMS maintenance seemed to have filtered through to the internal quality auditing process. The focus and approach to managing the audit programme was a mere "conformance check" of processes against ISO 9001 standard requirements [18].

A conformance-based approach to managing the audit programme and individual audits has been discouraged by various scholars who found that results from such audits do not encourage auditees to improve their processes [15, 2, 31]. With such an approach to auditing, one does not wonder why when faced with a decision between quality audits and production demands, the auditees chose the latter. At the same time, the auditors' preoccupation with accomplishing the audit programme was met with further obstacles in the company. The bases for determining the timing and frequency of audits in the annual audit programmes were unclear. The auditors were equally frustrated with the failure of the auditees to address corrective actions promptly. Among these barriers, the effectiveness of internal quality auditing practices in contributing toward the ISO 9001 QMS objectives of the company was questioned. The company mainly measures internal quality audit performance based on external auditors' perceived effectiveness. This hinders the company to have an objective measure of the impact of internal quality audit practices on continuous improvement and customer focus objectives. Consequently, this drives auditors to measure their own effectiveness based on the number of non-conformance findings found prior to external audits.

Internal quality auditors perform an advisory role, beyond their auditing mandate by providing advice on addressing corrective actions and risk management. This strengthened the relationship between auditors and auditees. However, it was evident that the varying needs and expectations of management and auditees also do affect auditors' decisions during audits, posing a barrier to their independence and objectivity.

The integration of the management system standards was found to be more desirable than managing the systems separately [9]. Audits can provide a good foundation for achieving the integration [21, 9, 22]. The findings in this study also support the integration of management systems as it simplifies the certification process and helps to balance the maintenance of the management systems. It is therefore imperative that company XYZ strengthens its integrated system by addressing barriers that hinder the company from reaping benefits from the auditing practice.

The use of information systems and technical experts by internal quality auditors for planning and performing audits was also recognised as an enabler. It facilitated knowledge sharing which in turn stimulated interest in audits among the auditees.

5 CONCLUSION

This study provided awareness of the barriers that need to be eliminated as well as enablers that need to be strengthened to improve the quality auditing practices at company XYZ. The findings are a basis upon which continuous improvement would be realised in the ISO 9001 QMS of the company. The study's findings can also be used to explore measures to address the identified barriers and improve the enablers. This will in turn enhance understanding on how internal quality audits can contribute to continuous improvement of the quality system.

Although this study was conducted based on a case organisation, organisations that are accredited to the ISO 9001 Quality Management System standard can also benefit from the findings.

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MODIFIED APPROACH FOR IMPLEMENTATION OF FAILURE MODE EFFECT AND CRITICALITY ANALYSIS: A PRELIMINARY FRAMEWORK

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ABSTRACT

The persistent variations in the outlook and complexity of today's factory and service repairable systems has mounted significant pressure on maintainability efforts. Successful adaptation by industries can be achieved by continued modification of pertinent maintenance technologies and development of proof-of-concept approaches or both. Failure Mode Effect and Criticality Analysis (FMECA) present appreciable concepts and system renewal routines within reliability and maintainability efforts in Industries. Application reports claim both process and functional improvements. This paper present a modified preliminary FMECA framework derived mainly from the status of research outputs on the field. The study rely on FMECA literature to elicit the mean global practice from component to system level. The laid down procedures were combined with some proof-of-concept proposals which was sufficient for the development of an improved framework. Successful application of the proposed method can enhance product and process safety as well as improve overall system quality and performance.

Keywords: Repairable system, reliability, maintainability, FMECA, functional improvement

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1 INTRODUCTION

Equipment and facilities employed in the operation processes of diverse entities can change from the original state in the course of time. This condition generally lead to diminishing functional properties with ultimate adverse system service decrement. Maintenance actions are required to get such equipment back to satisfactory service. Maintenance work can be planned or unplanned. Planned or preventive maintenance is organized and carried out with foresight, control and records to a predetermined plan, while unplanned or corrective maintenance follow unavoidable and unforeseen breakdowns. Predictive maintenance can form part of preventive maintenance. Failure mode effects and criticality analysis (FMECA) form a sequence of activities resulting articulated for better management, control and effective restoration of breakdown equipment. Since its inception, FMECA has been used to enhance product and process safety as well as improve overall system design process and system process design. Failure mode and effects analysis (FMEA) is a key integrated sustainability tool with the capacity to improve the reliability and safety of an optimally designed and installed production system [1]. Four common classes of FMEA include system, design, process and machinery FMEA [2]. There exist reports [3] maintaining that FMECA can broadly be divided into two aspects; FMEA and criticality analysis (CA). The presentation insists that FMEA must precede CA. This can aid the analyst with the supplementary value of a quantitative measure of system failure modes. It is at this point of inclusion of the criticality of failure that the analytical tool is considered as failure mode effect and criticality analysis (FMECA) [4-5]. The information from this approach provides managers with realistic and acceptable operational performance strategies. Important contributions to system sustainability derivable from FMECA include its ability to detect changes in trend at a very early stage, thereby keeping the industry running at its installed capacity among other things [6-8]. The importance of avoiding failure of most systems during actual operations have long been stressed [9] FMECA when correctly implemented strengthens product quality and streamline process flow by introducing research oriented decision support and modifications into the industry. Sutrisno et al. [10] describe how FMECA can support and sustain the success in creation of sustainable and reliable manufacturing practices while incorporation of possible external factors into the procedure has been suggested [11]. The study proposes evaluation of the link to customer's design and feedback (as appropriate) with a view to seeking areas of improvement as parts of correlated factors affecting good process performance practices. The impact of equipments' environmental failure and its attendant risk measures in FMECA is available [12].

Proper integration of FMECA into full process of development necessitates the creation of a structure, which establishes a functional connection between the elements to be considered, for example; the industry components, units, sub-assemblies to the system level in accordance with the parts list. Examples of the use of this method of analysis are seen in the automobile industry where automotive driver seat design and tyre production processes have received attention [13-14]. Xiaodong et al. [15] proposes a failure evolution mechanism model (FEMM) to construct the dependencies of failure progression-tests in industrial systems. The FMECA were applied at the unit level, to help track the failure progression process and derive relevant failure evolution-related evidence. New contents of failure mode/rate, were introduced to evaluate the performance of the system category studied namely; prognostic health management (PHM) systems. MA et al. [16] conducted FMECA on airborne weather radar (WXR) maintaining that the safety of the WXR would affect the safety of the whole aircraft. There is a good documentation of FMECA application to qualitative analysis of machinery component failure focusing on external factors and multi-competing failure modes [11]. The presentation suggested a combination of FMECA and failure time modeling and validated the method using a real case study of machinery component. There are reports of application of FMECA on standalone systems. For instance, water storage tank [17] and liquefied natural gas storage systems under construction [18]. The application of FMECA in reducing the overall maintenance cost was profitable in the case of Afam thermal power plant [20], located in Nigeria. The FMECA offer a means of analyzing system dependability centered on the estimates of failure initiation correlated to surrounding environment and the allowable stresses on concrete tank element [17]. The FMECA process can be as a bottom-up analysis that is broardly based on careful hierarchical breakdown of the entire system. It can also be initiated at any level if the required amount of data is available [20-21]. Obviously, criticality assessment has received credible attention capable of allowing it a distinguishing standing since its inclusion in FMEA. A vast majority of published works still deal strictly with FMEA while sparingly discussing the integration of CA into the process.

To date, opinions remain divided as to the potent FMECA procedure capable of improving system reliability and maintainability as well as design and production processes. It is expected of different parties to present different data when there are discrepancies of opinion. Basically, the practical application varies, and so does its experiences under various case studies. As presented in various literature [6, 10-14], sufficient application of the approach into the design process still favour advanced countries. Others, especially in developing countries rely on expatriates where it is in practice. Moreover, the evolution of different techniques and policies has made reinforced the barrier to a state-of-the-art assessment to causal observers. Taking of from traditional failure and repair channels, the procedure has progressed into a wide-ranging practice for the design of integrated maintenance and sustainability support systems, ranging from processes to function through remaining useful life of industrial systems. Attempt has been made to present a state-of-the-art overview of FMEA in recent past [22] including observable patents. The work summarizes results of a survey bordering on FMEA problems and shortcomings and proposes state-of-the-art of FMEA improvements. The authors lament prohibitive cost of FMECA process, though integrated approaches to FMECA costs [23-24] had been proposed. It however failed to consider criticality assessment as stand alone concept in all its aspects and over generalized failure shades and roots. The main cleavage of FMECA is to identify these shades, assess their probability of occurrence, elicit the criticality and determine suitable intervention actions (restore failed part and forestall such failures in future [25]. Successful identification of candidate failure modes, failure nucleation zones (FNZ) and failure propagation methods (FPM) and determination of causes can provide an invaluable direction to eliminating or reducing probability of failure occurrence. There is still paucity of research publications in FNZ and FPM aspects of FMECA. Availability of data in this direction would help evaluate prospective failures in a system more accurately, to delineate its immediate effects on system performance. On the contrary, the ranking of failure modes reported in vast literature are mainly offshoots of coalescing the metrics of Severity (S), Occurrence (O) and Detection (D) that produce a combinatorial parameter referred to as Risk Priority Number (RPN) [26-29]. In this combination, a likely failure mode receives some rating, which is dependent on its global effect on mission success and overall safety. Research is still ongoing in the area of reduction of failure occurrence, especially in mission critical systems, as other methods short of RPN have been proposed [30-32].

This paper gives a summary of significant traditional ideas of FMECA with special emphasis on those concepts that is amenable to the development of a global framework that can broaden the integration of the approach into the industrial spheres in developing countries, where the application so far is abysmal. We chronicle the implementation developments, some of which refine the thrust of the criticality perceptions, though others appear to have a widening effect on the scope. The study maintain some of the conventional pattern of failure, root cause, and restoration targets for satisfactory performance and highlight the essence of particular FMECA research effort not the detail. There is avalanche of case studies cited to elicit the range and impact of concrete applications. The references can guide interested readers on full methodology of each case even though the presentation present a historical FMECA standpoint. We argue that the technique is yet to receive the domesticating attention in many developing countries, and this calls for a framework targeted at domesticating the procedure in such spheres. This paper attempts a preliminary effort towards generating such a framework.

2 BRIEF HISTORICAL BACKGROUND

Proper system effectiveness paradigms have long been emphasized due to increased reliability and safety requirements of emerging industrial processes, manifested in increased complexity with rising cost of material and labour [33]. Some published works [22] trace the formalization of FMEA back to 1949, when the US Armed Forces introduced Mil-P 1629 with the mission of classifying failures in line with their impact on mission success and safety. The National Aeronautic and Space Administration (NASA) later adopted the use of FMECA in the 1960s [34]. In particular, the Apollo space program explore the technique in mitigating risk and safety leakages that can result from trifling sample sizes with emphasis on preparing for a safe trip to the moon. Towards the end of 1970s, the Ford Motor Company employ FMEA to safety and regulatory concerns of its business. It equally found application in improvement of design processes and production lines. The standardization of the structure and methodology of FMEA by the automotive industry in 1980s resulted in its extensive usage in a variety of industries today. FMECAs has developed to the point of being guided by standards. This presentation strives to outline the scope and general procedure hitherto covered by the FMECA method with a view to laying the foundation for updated robust implementation frameworks that matches its status. Expectedly, the basic FMECA combines experiences obtained from previous developments and ongoing production and uses the information as the basis for new developments.

3 MATERIALS AND METHODS

The preliminary framework of profiling the status of FMECA integration make use of both primary and secondary data. To understand how the concept has fared, on-the-site information from production and operations intensive industries, beginning from system level, down to the unit level is very essential. However, case study industries and subsystems with good data management proficiency is strongly recommended for a meaningful FMECA framework that can meet the demands of this study. The development of a healthy framework that can cater for FMECA needs of personnel with moderate experience require company visits to ascertain its status. During such meetings, archival documents can offer invaluable help as regards components or systems damage and repay history. The maintenance and operations unit of case studies can grant interviews to investigators so that their opinion on the aspects of FMECA relevant to operation improvement can be discussed properly. The industry might be so kind as to provide pertinent data relating to system failure and prediction as well as logistic issues in its everyday activities. The quality assurance and peculiar line managers with more than 15 years of working experiences can make for a robust FMECA framework. Structured questionnaires may be necessary to elicit the opinion of customers on the consistency of product quality or deviations. The secondary data can involve published peer reviewed articles obtained through tailored search of well-established repositories, to understand the latest trends in FMECA technology. Towards this direction, online materials, reliability and maintainability research books, monographs and periodicals can help elucidate the global trends in the fields and its probable future direction.

In this preliminary framework, the traditional steps in conducting FMECA for components [1], [20], [34] formed the basis. The study partly rely upon other recent techniques existing in literature to develop a preliminary modified FMECA procedure that can enhance the maintenance function and improve product or process effectiveness. This phase of the research made use of only the quantitative data sourced from reputable repositories in laying the foundations of a preliminary framework. In implementation, the framework partly enjoy suggested procedures laid down in FMECA literature and then furthers on some proof of concept aspects. The proposed framework can, apart from elucidating the real status of the global FMECA integration, lead to an FMECA programme that can improve the profitability of maintenance, product, process and operation improvement functions in Southern Africa.

3.1 Preliminary Framework

The concepts underlying the research are generally outlined in what follows. Identification of candidate system and definitions; Determination of individual failure modes and generalization into possible failure modes; Cause diagnostic assessments with related Tests and Failure effect prognostics with related Tests. Others include Synthesis of failure severity; Determination of failure probability of occurrence; Evaluation of failure criticality; Prescription of risk and safety benchmarks, results with modifications, improvement and mitigation procedure and policies.

3.2 Identification of candidate system and definitions

The identity of the system simply refers to what it is. Definitions and boundaries for FMECA are provided by a functional and physical description of the case study system. The functional description is represented as a functional flow diagram consisting of operation sequence from start to finish. This gives the "as–installed" or "as-is" description of the system with regards to how the system is being operated, its installed capacity and existing throughput as well as operational, failure and maintenance information. High and low level indenture diagrams or diagrams showing the system as whole, components, units, subassemblies and other parts of the process all assist in describing the case study system physically. In its construction, the preliminary flow chart is mostly reflect a high-level procedural step. Necessary modifications may be necessary when the new framework will evolve in detail. At the point, it will be possible to reflect susceptible failures at each level.

3.3 Determination of individual failure and generalization

The acceptable level of operational performance of the system is determined from company records or other applicable sources. This can enable the determination of candidate failure mode and generalization into possible failure modes. This generalization will categorize failure mode by function, hard ware or combination of both as the case may be. The idea of the generalization step is to break down the failure event into the perceptible modes in the first instance. Attempt is normally made to express each failure mode in terms of the operational and environmental conditions belying the event. The failure mode types categorized at this stage will be confirmed during the diagnosis to follow or placed properly if different from the actual cause.

3.4 Cause diagnostic assessments with related Tests

In cause diagnostics, abnormal performance conditions are detected, component, unit, subsystem or system that failed or failing determined and the nature or extent of the fault estimated. Lopez and Sarigul-Klijn [35] discusses various fault diagnosis steps which include data pre-processing, feature extraction and selection, classification as well as data fusion and decision making. Fault indication tests may be conducted at this stage to rule out suspicion and maintain precision in the failure modes. In delineating the root cause, it is necessary to understand the failure mechanism properly, so as to plan for their elimination in advance. The failure mechanism that is evident should be subjected to an assessment of its probable cause or causes. Factors like mechanical stress, lubrication leakages, temperature cycling, loosening of tension belts, fatigue, corrosion and substandard or defective parts can all constitute failure. Other causes may be traced to operator or maintenance induced errors. Neglect of routine practices like cooling, cleaning, belt re-tensioning can equally cause failures. Preference should be given to the standard practices of attributing each failure cause to the lowest component in the indenture, or level in the parts hierarchy, at which the failure occurs, in the event of a failure possessing multiple competing causes.

3.5 Failure effect prognostics with related Tests

Prognostics can simply stand as a fair estimate of the remaining useful life or time to failure with the possibility of a future failure born in mind. From this definition, it can be inferred that it is not enough to stop at delineating the special effects of identified failure modes present in an industrial system, the analyst can do better by diagnosing possible failure dependence of neighbouring subsystems. Appropriate degradation tests (example; impact tests on neighbouring components thought to fail soon due to the pre-existing failure event) may be conducted where necessary, to profile individual failures. The impact of the failure on operation materials, reliability and safety requirements of the entire system can be investigated. Such impact could result in complete halting of the system, injuries to personal, loss of in-process materials or could result to partial degradation with harmless effects to the system and loss of customer goodwill. A failure rigorousness action or tests can activate remaining useful life prediction and confidence interval estimation. The full FMECA research will align with a simple delineation technique: whereas identifying and failure profiling shall be in diagnostic regime to properly represent already occurred failures, prognostic procedure should concern itself with estimation of dependence failures. That is; failures initiated by a candidate failure event, despite the fact that the part might still be in suspended animation.

3.6 Synthesis of failure severity

One of the most important benefits of amalgamating the failure severity is to rank the response criteria. The very common classification methods in literature [36] involves ranking failure severity in terms of “as hazardous without warning”, “hazardous with warning”, “very high”, “high”, “moderate”, “low to moderate low”, “very low and none” [37]. Ebeling [20] uses slightly different indices like catastrophe, criticality and degree of loss on acceptable system performance. Rating systems for Severity, Detection and Occurrence are properly documented [6], [10]-[11]. The methods elaborating the use of 1 to 10 rating scale appear to be more popular. To allow for consistency and adequate tolerances in a strong FMECA framework, use can be made of existing system of categorization while other more compatible and improved methods can be explored to match the innovations in FMECA modeling.

3.7 Determination of failure probability of occurrence

The probability of occurrence is based on the expected number of occurrence of each failure mode over a specified time interval. We propose to start this step with the reliability specification and allocation experience of existing databases [37] and comparing them with parts having known reliabilities. This can prepare safe runway for computation of failure occurrence probability. The methods of using reliability block diagram to group probability estimates by component and rolling them up to units and system level may also serve as a good method of determining the probability of occurrence. A good number of researchers use methods that define a present risk state along some conditional reliability function before introducing Bayes theorem to optimize probabilistic approximations of an expected state [38-40]. Consequently, Bayesian models can apply equally well in FMECA risk analysis framework.

3.8 Evaluation of failure criticality

There is need to provide a measure of the criticality of the failure mode that combines the probability of the failure modes occurrence with its severity ranking. When standard severity categorizations have been in line with the operation process realities, the criticality index can be computed for each of the corresponding failure modes. The criticality number for each component can also be computed and rolled up to the system level, to provide a criticality matrix of guide for eliminating critical failures. This phase serves to improving the process as well as providing research oriented failure management and control. Several methods of quantifying failure criticality exists which might serve as a building block to the FMECA innovative designs [41, 17, 32, 3].

3.9 Prescription of risk and safety benchmarks

This penultimate step is integrated because of the demand of improved safety performance on industries which has been highlighted a good number of researchers [42-44]. Products and process safety are investigated as is closely related with FMECA. Operation risk is associated with the probability of component or system failure and the consequences of failure such as loss of revenue due to production loss, asset damages and health issues. Informed and applicable safety measures must be exercised in every situation that can cause injury, loss of life, severe damage to either equipment or product and possibly the surrounding environment. For example, Giardina and Morale [45] determine possible accidental events in the storage system used in the liquefied natural gas regasification plant. The proposed approach combine FMECA with hazard and operability analysis (HAZOP) methodologies. Liu [46] present a new the D number method with the intension of handling several valuations of risk factors evident in FMECA techniques. In particular, the author use a technique known as “improved grey relational analysis method” and referred to as “grey relational projection (GRP)” to decide on the “risk priority order” of the observed failure. The two methods were later combined to propose an optimal “risk priority model” for the assessment of risk in FMEA. The author maintains that criticality can stem fromb calculating the “risk priority number” (RPN) of individual failures. The RPN results from multiplying the normal scores of risk factors such as occurrence (O), severity (S), and detection (D). New methods like the “fuzzy set theory”, “fuzzy AHP method”, “Shannon Entropy and fuzzy VIKOR method” were all proposed in the presentation. Recent works have progressed the use of fuzzy based techniques [47] and “generalized multi-attribute methods” [6] in FMEA.

3.10 Function/Operation Tests

Upon completion of the forgoing steps, the system can pass through function and operation tests to ascertain whether the results represent an improvement over what obtained previously. Accelerated life tests results on innovative spare parts and relevant failure metrics can be compared with standard results on alternatives. The test can be the bedrock of defining a go-no-go basis for the newly designed system. Sequential tests can be run on deserving systems or subsystems. Successful adaptation of an innovative FMECA procedure can require implementation of any resultant test(s) that might not be contemplated at the start of the design. The collated and compared results, if finally accepted, can be reported in the form of improved FMECA framework for the case study system, subsystem, unit, product or process. The installation of the framework as the new maintenance order in the concerned area should be done with care. Proper sensitization of the maintenance and production crew as well as change management experts might be necessary, to obtain the gains of the entire process. A more detailed methodical framework for FMECA is proposed and described in Figure 1.

3.11 Operational variables

There are certain operational variables that can affect impressive implementation of the modified FMECA framework. Effort should be made by the production department or incharge to ensure that these parameters reach optimal values prior to the FMECA programme. Ozor et al. [49] list some of these variables, which have been modified for the particular nature of this study.

3.11.1 *Proficiency of Operating Personnel (POP)*

This metric measures the competence of the operating personnel in administering the tenets of FMECA. Use of proficiently trained personnel is fundamentally important to ensure that technical specifications are followed. The training of FMECA personnel should transcend hands-on-the-job and include fundamental Engineering and Analytics experience. The crew should possess good observation and recording abilities, so that accurate data can be obtained on specific components. The data can be statistically analysed to obtain results that are useful for future and improved FMECA administration.

3.11.2 *Administrative Delay (AD)*

While planning for the FMECA programme, the nature of delays that are probable should be contemplated and adequate plans of containment made. This study propose a predefined timeline for the FMECA administration. Hence, logistic and administrative deferrals should have been conceived so that an idea of when the system will return to use will be known at the beginning. This step, apart from streamlining operation processes, can enhance supply chain management as regards spare supplies and inventory.

3.12 Maintenance variables

The maintenance variables that can affect practical implementation the proposed framework include strength of the service or maintenance crew and repair times- that is, the time it takes to get a failed system back to operation. The availability of spare parts as well as the competence of the service men can significantly affect the final results of a FMECA process.

3.12.1 Service Crew Strength (SCS)

The strength of the service crew must be proportionate to the FMECA level specified for correction of a failed part or system. Inadequate number of personnel can generally lead to fatigue and loss of goodwill on the part of few repair men. It is possible to observe Industry management attempting to save cost by using inappropriate service crew. Conversely, over populating the service crew can lead to redundancy, which does no good to the enterprise. All that is required is to establish an optimal policy in the number or strength of service crew vis-à-vis the warranted FMECA criteria.

3.12.2 Repair Times (RP)

Repair times are better set from analysis of repair times data observed on components over a long period of time. Therefore, FMECA administrators should pay attention to recording of the repair time for components, sub-systems or entire systems so that accurate data can be documented for the purpose of obtaining repair time estimates.

3.12.3 Spare Parts Availability (SPA)

Since FMECA is part of breakdown maintenance intervention. There are significant chances that a percentage of parts of repairable equipment will need replacement. Lack of spare parts or delay in procurement effort can extend the reinstallation date of the equipment. This underscores the need for profitient inventory management in all Industrial concerns already implementing or contemplating the use of FMECA.

3.12.4 Efficiency of Maintenance Personnel (EMP)

An original spare part installed in defiance of the installation conditions can fail upon commissioning just as it will take a longer time for incompetent personnel to accomplish a repair task. The competence of the maintenance crew is crucial to implementation of effective FMECA programme. This can be achieved through training and retraining of FMECA personnel. The basic thing is to ensure that the maintenance crew possess adequate technical expertise to perform a proper FMEA.

4 CONCLUSION

The preliminary framework of the integration of failure mode effect and criticality analysis technique was undertaken. Reports from industrial applications claimed both process and functional improvements, so enormous as to invite incredulity. The research has so far exposed the need to provide a resume of the approaches employed in delineating criticality of the failure mode that 1); combines the probability of the failure modes occurrence with its severity ranking. 2); Provide an updated robust implementable matrix of guide for eliminating critical failure with a view to improving the entire process that is informed by research oriented failure management and control. The implementation results show that the technique can heterogeneously reduce the spate of hitherto several commercial failures globally. Yet, there is still opportunities for achieving a healthy streamline framework to further expand its application.

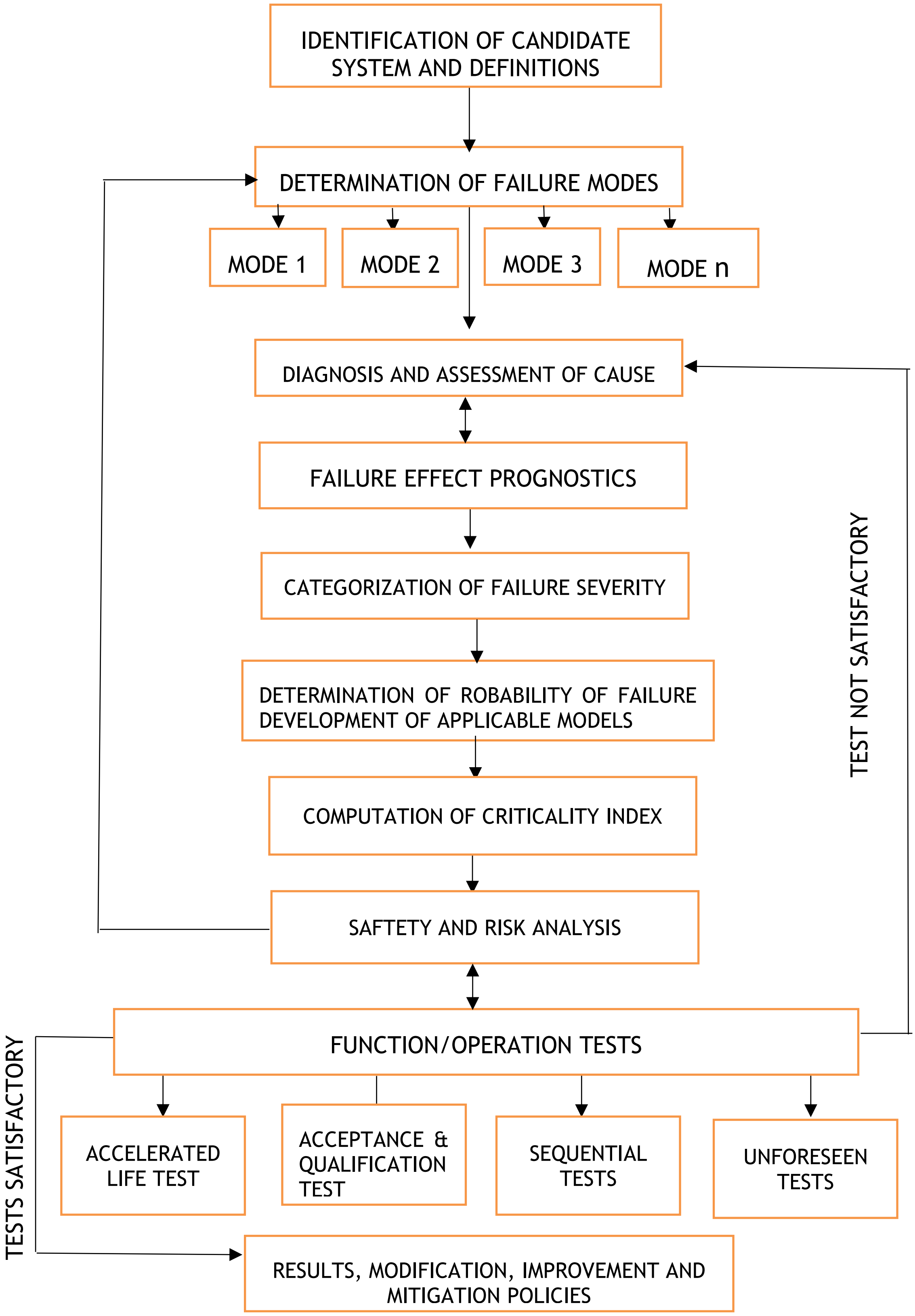

Figure 1: Block diagram of the methodological framework

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A CRITICAL REFLECTION OF TEACHING AND LEARNING IN AN OPEN DISTANCE LEARNING ENVIRONMENT: AN ENGINEERING PERSPECTIVE

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ABSTRACT

The Open Distance Learning (ODL) pedagogy forms the basis of teaching and learning culture at an open distance learning institution. The ODL pedagogical culture is mirrored through discourses that are evident in the institution. Interrogation of these discourses enables the institution to keep abreast with the latest improvements in a global context, thus enabling a deeper insight into change in behaviour regarding teaching and learning. This encompasses not only the development of a multiskilled leader but a person that embraces sustainability as a primary objective. COVID 19 enabled a learning revolution that would redefine the citizen of the future in functioning effectively in a complex world. This paper critically analyses teaching and learning in an ODL context through a case study application in an engineering environment with the objective of critique and reflection of current processes to enable process engineering and re-engineering.

Keywords: teaching and learning, engineering, open distance learning

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1 INTRODUCTION

The open distance learning (ODL) pedagogy forms the basis of teaching and learning (T&L) culture at an ODL institution. The ODL pedagogical culture is mirrored through discourses that are evident in the institution. Interrogation of these discourses enables the institution to keep abreast with the latest improvements in a global context, thus enabling a deeper insight into change in behaviour regarding teaching and learning. Social structures influence human experience in a given society which impact the development of an individual. Socialisation may be experienced as a developmental process where people integrate perception, knowledge, attributes and skills that create an enabling environment to function optimally in a given society [1]. The agency is the personal and psychological attributes that all individuals bring to the workplace to where learning takes place [2]. Structure, culture and their interplay, can be either enabling or constraining in the way it creates conditions that affect and influence the actions of agents. This study aims to reflect on current practices in important areas of teaching and learning at an ODL institution.

In this case, the experience of students and the engagements with the learning process provides vital information as to the effectiveness of current practices in higher education. In addition, the past system instilled experiences that have caused animosity towards the education system which is believed to be colonized education [3]. This may be one of the reasons for the student unrest experienced which culminated in the current dialogue, “decolonization of the education system.”

2 LITERATURE REVIEW

A fundamental definition of ODL pedagogy is premised on deciding the what, the how, the technology and strategy proposed in teaching. Choices are informed by a multitude of denominators which include the African context, student profile, competencies, attitude and behaviour, values, prior knowledge and skills, professional body requirements and so forth. An ODL pedagogy may be described as the application of teaching strategies that enable students to learn in an open distance environment [4]. These strategies and delivery of teaching are flexible, multidimensional, integrated, holistic and linked to specific disciplines. The engagement of staff and student enable the transfer of appropriate skill-sets to the student.

Effective functioning on the ODL platform empowers the development of an ODL culture that creates the dispersion of education and enables staff and students to envelope and develop required talents. The list below provides imperative guiding principles to enable teaching and learning to occur.

- Empathy – understanding the student
- Clear messages –avoid ambiguity
- Pace of work – guarding against overload
- Education as development - determined by student and lecturer commitment
- Inquisitiveness – of lecturers and students
- Effective plan and execution – enhancing the process
- Assessment – planned and thoughtful assessment opportunities [4]

Garrison[5] postulated deliberations and reflections of ODL pedagogy and mentioned that innovation and technology impact the delivery of teaching and learning [6];[7];[8]. Otto [9] focussed on the transformational process. This influenced academia and students with regards to knowledge transfer modalities, curricula and instructional diversities on academia and students over decades. Teaching strategies encompass epistemological principles that guide the process of learning that ranges from the view of teaching as transmission, becoming transactional and then transformational. Learning theories such as constructivism, connectivism, behaviourism, rationalism, cognitivism, constructionism, social constructivism, and other hybrid models of learning theory are embedded in the transmission, transactional and transformational frameworks.

The ODL philosophy attempts to assimilate characteristics from the spheres of learning, that is andragogy (adult learning), heutagogy (self-determined learning) and pedagogy (science of teaching) [9]. Knowles [10] argues that critical analysis of adult learning premised five assumptions that differentiate adult learning from child learning, that is self-concept, experience, readiness to learn, orientation to learn and motivation. The notion of heutagogy is based on competencies and outcomes that are pertinent to current students.

Michael [7] analysed the mechanisms of independent learning and recommended that dialogue is imperative for transactional distance education [8]. The concept emancipated self-directedness and accountability as important variables in the teaching and learning process. The discussions emanating from ODL pedagogy views the different generations of distance education as proposed by a range of authors such as [5]; [6];[11]; [12]. Heydenrych and Prinsloo [13] also allude to the importance of applicable technology where a wealthier picture on the different generations of distance education interrogate how curricula, pedagogies, delivery, storage and ownership changed over these years. The choice of teaching strategies are based on epistemological beliefs and assumptions with regard to how learning takes place. The aim is to reconsider and re-engineer the teaching and learning process so as not to denigrate any of these learning theories [12];[14];[15].

ODL learning occurs on different platforms. It may occur on any type of engagement that the student chooses. Students are seen to be in a community within the teaching and learning platform where specialised discourses occur in varying degrees. Knowledge is built on shared meaning where participation is vicarious. Students participate as listeners, readers, participants, speakers and writers within a system of shared value [8]. Students share their insights on a particular subject matter.

Insights into how learning occurs has influenced the focus on research in higher education. Therefore, a deeper insight on how learning occurs is important in planning meaningful learning experiences. Entwistle and other authors agree that knowledge and skills are important for professional performance, but are convinced that mere knowledge and skills are insufficient for skilful practices and for the transformation of the self that is integral to achieving such practice [11];[12];[16]. The rational question in education should be “What should students know?” and “What should they be able to do?” in terms of being and becoming [3]; [10]. This is imperative from an engineering perspective as the Engineering Council of South Africa (ECSA) implemented graduate attributes (GA) in determining whether students are competent in the various engineering disciplines.

The clearest trend emerging from analysis of strategies is that, considering both current and proposed teaching and learning practices, it is no longer viable to adopt one-size-fits-all approaches to pedagogy or systems. The colleges within the university have ambitious plans for moving from the traditional one-size-fits-all approach of paper-based distance education delivery that has characterized much of past pedagogy to an ODL model [13]. Diversification of teaching and learning strategies is being driven by, amongst others:

- Recognition of the educational limitations of historical models of distance education delivery (described by one College as requiring a paradigm shift from purely transmission styles of teaching and learning to interactional styles involving critical interactive learning where students are encouraged to engage and interact with content on a much deeper level);

- Expanded teaching and learning options available, largely driven by developments in use of information and communication technology (ICT) in higher education globally;
- A need for greater flexibility to accommodate the divergent requirements of teaching different disciplines, as well as varying characteristics of students enrolled across different programmes [4].

In providing a rationale for expanding the range of teaching and learning strategies, colleges generally place strong emphasis on the importance of developing student 'graduateness' [4]. The expectation is that more diverse teaching and learning strategies will create richer opportunities for building self-awareness, deeper approaches by student to their learning, development of the skills of critical understanding and problem-solving, and interaction of different kinds [12]. It is also noted that there is a growing expectation that university graduates should be ICT literate, which is driven by changing expectations in the workplace. Nevertheless, it is clear that there is a strong shift from ICT being understood as a support function towards it now being required as a key enabler of core teaching and learning functions [4].

3 METHODOLOGY

This study is qualitative in nature and uses a case study research methodology to investigate open distance online learning as a means of teaching and learning. Ebneyamini and Sadeghi [17] proposes that a case study is an empirical inquiry. It investigates a contemporary phenomenon within its real-life context and this is what sets it apart from other methodologies. It copes with the technical distinctive situation in which there will be many more variables of interest than data points.

A case study methodology is appropriate for this research as it enables an empirical inquiry at hand and investigates a phenomenon that is currently experienced in the higher education sector within a real-life context. Case studies provide insight into phenomena at hand that enable the exploration of underlying situations. The methodology enables the gathering of information over a period of time from multiple sources. In this case, information was gathered through engagements in meetings, informal discussion with staff and students, as well as through secondary literature in the form of journal articles.

The current experience with COVID 19 has propelled all organisations, and in particular higher education to rethink the way it operates in the delivery of teaching and learning. The organisation in case has provided an opportunity to delve deeper into online learning and therefore provides an opportunity for holistic, in-depth investigation. The paper is therefore a critique and reflection that would enable re-engineering of processes that enhance sustainability to a larger extent, through a case study methodology.

4 FINDINGS AND CRITIQUE

Table 1 provides a synopsis of the student process from registration through to graduation.

Table 1: Critique of current student process

Step	Critiques of Current T&L Model
Student Receives Pre-Registration and Counselling	• Currently there are no means to assess all students' readiness on an individual basis either through internal processes or through self-diagnosis. Although there is a unit dedicated to counselling and support, students either have to initiate this service for themselves or be referred by an academic.
Student Registers and Receives study package/ information about support	• The supply of print-based materials using postal and courier services often leads to delays and backlogs in students' receipt of materials: this has proved particularly challenging in a semester model, however, a significant number of students still request print-based resources. • Students often experience delays in sourcing prescribed textbooks which are not supplied as part of the study package. • This is a major concern as Post Office strikes and other problems prevent the progress of students. The university has instituted couriers to deliver study material, however the student address is incorrect or the student is not there. Millions of rands is being "wasted" in the process which is not warranted.
Student is prepared for learning: Introduction to College/ Literacies training and development	• Students can request training on various issues of the ODL pedagogy at Regional Centres or at the central campuses. In the past, Regional Centres, arranged regional orientation workshops but these were not always well-supported by academic staff. • Students can also request to be linked to a contact-based tutorial sessions at a nominal additional fee. However, such tutorial groups can be established only if a viable number of students request the service and were additional to and not an integral part of the learning programme offered. • Critique – This requires student active engagement and quite often they are not active.
Student learns: Individual learning Facilitated learning Social learning Learning through formative assessment Workplace learning	• Typically students complete two formative assessments which contribute 10-30% of their final mark and receive feedback on these. There has been an increased use of MCQs for this purpose which allows for a quick marking and return process but which typically provides limited feedback and does not necessarily create competences. • In the past, deadlines for these formative assessments were set at an institutional level but with increasing numbers of students submitting assignments online, the system is unable to cope and deadlines are required to be staggered. • A routing system for managing the flow of digital assignments and to facilitate onscreen marking was implemented. • All modules have a site which includes an open forum and provides the possibility of adding additional features such as additional self-assessment options. However, use of the platform is variable among both staff and students. In addition, there is limited training for both staff and students on the learning management system (LMS).

Step	Critiques of Current T&L Model
	• Firewalls, as well as bandwidth constraints, have prevented large scale use of social media in the support of learning, although there are several instances of innovative practice which are limited. • Workplace learning is an integral and integrated component of some programmes, e.g. teaching and counselling, however, managing this effectively on a national scale, and assuring equivalence of experience across borders, remains a challenge. • A tracking system for at-risk students is operational.
Summative assessment takes place	• Although there are some examples of alternative summative assessment strategies, venue- and module-based written examination papers remain the primary means of summative assessment. This requires huge logistical planning to ensure that venues are available offering the right circumstances at the right times for the right numbers of people. • After writing examinations, large numbers of paper scripts are moved from decentralized examination centres to the centre for distribution to marking groups, and then collected back, marks captured, and scripts archived all in a very short space of time. • As a general rule, exit-level and post-graduate scripts are subject to external moderation, which adds to the time needed and the potential for losses and errors and for internal moderation feedback. Time is a limiting factor and places major strain on all academics.
Remedial action for students who have failed but may write supplementary examination	• Support offered is highly variable. If students are still registered for other modules, which may not always be the case, they may be able to access past papers and online. In general, remedial sessions are not offered for repeating students. If they do contact lecturers for advice, they are most likely to be advised to revise selected sections of their study materials/ prescribed textbooks.
Graduation	• Typically students who successfully complete a qualification will be invited to participate in a graduation ceremony three to four months later. Graduation ceremonies are held at decentralized venues around the country. Some departments operate a 'grow-your-own-timber' initiative to recruit the best graduates as tutors or faculty but this practice is variable.

5 DISCUSSION AND RECOMMENDATION

The discussion and recommendation of the paper is based on themes.

Note. For the purposes of this paper, the most pertinent issues are discussed

5.1 Theme 1- Study Materials

a) Regardless of method of delivery, the packages of learning materials supplied (particularly at undergraduate level) should, wherever possible, be **sufficiently**

comprehensive to enable module/programme completion without a need to purchase additional resources. The library has a major role to play in helping to create access to needed resources through virtual library services.

b) Significant growth is expected in the requirement to incorporate **multiple media in learning packages**: print/text, video, audio, and computer-based multimedia. In most instances, this will demand higher levels of digitization of materials delivery.

c) For some modules and programmes, printed materials will remain an essential learning requirement, even if one can assume that all students have access to ICT and the Internet. Thus, decisions to phase out print should be based on **pedagogical need not technological pre-determinism**.

d) **Video and audio requirements** will be highly variable, according to purpose and length, thus requiring a range of production options and distribution of creation facilities (with some centrally located and other based in colleges).

e) Several disciplines are highly visual, requiring **effective integration of graphics** and careful visualization in materials design. Some departments also require use of special characters and symbols in materials.

f) As more use is made of online teaching and learning strategies, it is essential to ensure that the **Learning Management System** (LMS) is usable and easy to navigate, with a specific focus on ODL delivery. Different LMSs may be required for different disciplines. It is also becoming important to focus the LMS platform on tuition only, removing all administration functions in order to reduce clutter and complexity in course presentation, as well as to limit customization of third-party software applications.

g) **A split between content storage and content presentation** is becoming increasingly important in online course delivery to enable the same content to be presented in more than one module and via more than one student interface (for example, both an LMS and a mobile app).

h) **Seamless integration** with third-party educational materials, online library facilities, online journals, databases, reference and other research tools is of growing importance. Referrals to Massive Open Online Courses (MOOCs) and open educational resources (OERs) may help with supplementary learning and to enable students to master 'pre-knowledge' required for studies (including development of ICT skills).

i) Some disciplines are required to provide students accessed to specialized, **industry-specific software** packages as part of the learning experience (Ramdass, 2016).

5.2 Theme 2 - Student Support

Several types of student support are essential to provide an effective learning experience which is not the case at present. These will include:

a) **Student announcements**, which are anticipated to become increasingly electronic: emails, short message service (SMS), social media postings (MXit, Facebook, Whatsapp, and so on), and postings on the LMS require a robust and reliable system.

b) **Face-to-face tutorials and interactions**, which remain a requirement for many modules and programmes, regardless of the level of ICT integration available.

c) Some disciplines require **practical sessions**, either in physical or (in some cases) virtual laboratories.

d) Direct communication links with academics and e-tutors, which may be through telephone, SMS (and related platforms like MXit), social media platforms, instant messaging, VOIP applications such as Skype, real-time synchronous chat rooms, or LMS interactivity features (such as discussion forums);

e) **Direct communication links with fellow students**, which may be face-to-face or through SMS platforms like MXit, social media platforms, instant messaging, or LMS interactivity features (such as discussion forums);

f) Video-conferencing or virtual classrooms.

g) A **Student Relationship Management System** (SRMS) is required to track student queries regardless of their origin (email, telephone, SMS, social media, or face-to-face), both to ensure that queries are routed automatically to the right person for resolution and to enable monitoring of successful resolution.

h) Improved **use of learning analytics** is required to enable analysis of student activities and subsequent improvement to affect the design of programmes and modules.

5.3 Theme 3 - Student Assessment

a) In many cases, increased use of **diagnostic assessments** (low-stakes tasks that enable students to assess their preparedness) with automated feedback can help students to determine whether or not certain courses of study are appropriate before they commence, thus helping to reduce dropout rates.

b) Increased emphasis on formative assessment is expected across all colleges, with growing diversification of the range of **formative assessment strategies** used by individual programmes and modules, according to pedagogical need. Where appropriate, it will be useful to enable assessment of competencies as and when they are attained, rather than according to set timetables (but within framework of maximum time limits for study to prevent high levels of dropout).

c) There is a growing need for **computer-marked, individualized assignments** for formative assessment and self-assessment.

d) **On-screen marking** and automated routing of assessment artefacts from students to assessors is problematic and will assume growing importance.

e) Diversified use of **assessment tools** will require proper integration with the Student Information System or SIS (automated importing of assessment data) to ensure data integrity and centralized storage of assessment data.

f) There is growing demand to **enable non-venue based assessments** and examinations. This will require secure online facilities to manage non-venue based assessment and to verify student identity (including possible use of biometric technologies and/or webcams).

g) **Growing use is expected of e-portfolios**, reflective journals/diaries, learning logbooks, and case studies, as well as peer-reviewed assessment tasks and group projects.

h) As growing use is made of electronic assessments, **software tools are required to detect plagiarism [17]**.

5.4 Theme 4 - Student diversity

Notwithstanding the above pedagogical drivers for changes, colleges reflect strong awareness of the diversity of the student population. Students are geographically scattered, with some (although a declining minority) who live in areas where there is no or inadequate connectivity available. More importantly, students cover a wide economic spectrum, from those who have limited or no means to afford technology access to those who live in ICT-saturated environments. In addition, a key demographic trend has been growth in the number of students of school-leaving age, many of whom have not had any prior exposure to the rigours of independent study or whose schooling background has inadequately prepared them for the learning demands of higher education (especially where high degrees of rote learning have characterized their school career). From this perspective, several colleges highlight the importance of providing students access to learning opportunities to prepare themselves effectively for university study, including provision of Foundation Programmes, MOOCs focused on epistemological access, and diagnostic tools providing automated feedback to enable students to assess their readiness for specific programmes of study before enrolment [17].

5.5 Theme 5 - Improving student engagement

Related to this is a concern in the critique that many proposed College strategies place heavy emphasis on establishing direct channels of communication with students, to overcome the effects of ‘distance’. This is laudable to the extent that it clearly focuses on improving engagement and deepening learning. This would characterize social construction of knowledge through engagement between: the learner and the facilitator; the learner and the content; the learner and peers; the learner and the context; and the learner and the technology in the educational process. However, the shift to a blended learning model should not be confused with a slow drift towards models of teaching and learning more suited to face-to-face universities. The institution remains an ODL institution in its mission and operations.

5.6 Theme 6 - Financial and HR implications

Clearly, it will become increasingly important to analyse the financial and human resource implications of introducing new teaching and learning strategies, particularly those that enable direct contact between students and university personnel (tutors, academics, or administrators). Some College strategies do note that introduction of greater interactivity will require more human capacity, but seem to assume that this will be a given, rather than proposing more structured and rigorous processes of analysis in which choices are explored and some are ultimately excluded because their cost is too high or their educational return on investment is considered inadequate to justify their use. Importantly, financial analysis should serve to avoid this slow drift towards modes of learning more suited to face-to-face universities, which will undermine the economic logic of the functioning as an ODL institution [17].

5.7 Theme 7 - Support Services (a major component in the ODL strategy)

College pedagogical strategies made several observations about the importance of support services in implementing a blended teaching and learning model. This was augmented by discussions with various support units. From this perspective, it is instructive to begin by analysing some of the key constraints that affect the ability of support departments to provide effective services to support implementation of colleges’ pedagogical strategies.

Support services may be categorised as follows:

- ICT
- Library
- Disability Unit
- Counselling
- Academic literacy
- Department for the despatch of study materials

The high level of administrative bureaucracy, a problem noted in most discussions conducted, impedes collaboration and coordination, as well as reducing productivity. Several systems and processes (for example, procurement and appointment of human resources) move very slowly which negatively affects planning and coordination. Likewise, the manual nature of several institutional processes means that there is often significant repetition in reporting and documentation, which reduces the available time to provide effective support. Related to this is the problem that support workflows are not underpinned by ICT systems that help to automate and coordinate support operations. Finally, the high frequency of meetings within the organisation significantly adds to workload pressure, as it removes significant amounts of productive time from the working weeks of staff. This problem is discussed again in the section on Decision-Making below.

Testing of innovations of different kinds becomes problematic within this context, as there is no scope for structuring the process of testing new approaches or technologies, measuring their relative effectiveness, and then systematically widening their use should they prove successful. Instead, innovations tend either to be tested in the absence of mechanism to scale them should they prove successful or innovations are scaled too rapidly with no structured plan to accommodate growing demand. A more structured approach to testing innovations, based on identified priorities within colleges, is thus required.

5.8 Theme 8 - Ensuring ICT Access for Students

As an ODL university, students require access to ICT’s in the teaching and learning process.To support this process, baseline research is required on students and their current levels of access to technology, so that this can inform future planning. The design of this research should take specific account of the reality that students are widely spread, to ensure that sampling is representative of the full range of student circumstances. As an ODL institution, the use of ICT’s for all educational and communications is essential as many programmes have gone ‘fully online’. Therefore ICT access to all students is imperative.

5.9 Theme 9 - Streamlining Decision-Making

The organisation is large and complex, which inevitably creates a certain level of complexity in terms of structure, culture and agency where decision making is problematic and takes months. However, it remains important to pursue simplicity whilst retaining the rigour that will ensure good governance and effective decision-making. There needs to be a delicate balance that would ensure agility without loss in rigour with regard to decision making. Furthermore, it will enable the University to effectively pursue its strategic objectives in implementing its objectives. Given the analysis of these structures, it is proposed that a consultative committee review process be undertaken with the intention of simplifying, as well as verifying, decision-making policies, procedures, and processes.

6 RECOMMENDATION AND CONCLUSION

As an academic in a dynamic space where changes and challenges are the norm, there is always better ways of performing effectively. This is where industrial engineering practices and sustainability come into play in re-engineering and simplifying methodologies. The first step is engaging the colleagues in the department with mini-conferences on topics such as quality, teaching and learning, curriculum and so forth. The first industrial engineering conference took place in 2019 with quite a positive response from higher education institutions. This impacted teaching and learning, to an extent. However, more effort is required for the university to embrace quality as a driving force and industrial engineering as a discipline that would improve current practices.

The proposed discussion on the T&L agenda may lead to improvements in learning outcomes that are relevant for all stakeholders. With the potential for the development of partnerships between teachers and students and access to the digital landscape, there is the possibility of natural attraction to learning. The endeavour is to create an environment where there is active participation from all stakeholders. Student engagement on learning tasks would enable new learning partnerships in the learning environment, thus empowering the construction of new knowledge in the real world.

The teaching and learning policy is required to drive pedagogical capacities of teachers that embrace learning outcomes. There needs to be a learning revolution that would define the citizen of the future in functioning effectively in a complex world.

The challenge is clear, but so too is the opportunity. The institution is in a unique position to effect an organisational transformation that is both broadly agreed and urgently needed. The commitment to make the shift is abundant, and this paper reflects the opportunities and challenges that can drive strategic direction on a systematic and sustained level. If it can be done successfully, the institution would transform not only itself for the better but redefine ODL in the higher education landscape in South Africa. Unless this shift is accompanied by serious focus of financial and human resources on implementation of improved strategies, the likelihood of change is limited.

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THE STATUS OF RAILWAY INFRASTRUCTURE AND OPERATION IN SOUTH AFRICA – AN OVERVIEW

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ABSTRACT

In Africa, the rail industry is poised to be a frontier in the transportation sector, hence, many countries with fast-growing economies across Africa are investing massively on the rail infrastructure in order to promote local transit and regional trade. The South African rail transportation system and network has been regarded as one of the best in Africa, hence, this study conducts a holistic review of the railway manufacturing technology developments in South Africa highlighting the strength and challenges of the sector. The findings of the review conducted show that some of the challenges that are peculiar to the rail sector in South Africa include: poor maintenance, skills shortages, poor rail infrastructure and the use of some obsolete technologies. These challenges can be mitigated with the deployment of emerging technologies such as the Internet of Things (IoT), cloud computing, the use of smart sensors which is supported by advanced analytical capabilities such as the big data platform to provide enhanced asset utilisation, advanced fuel management systems for energy efficiency, predictive maintenance, automatic railcar control, capacity management and infrastructure maintenance. In light of this, recommendations were made to promote the sector with the use of these emerging technologies and digital solutions.

Keywords: emerging technologies, digital solutions, rail infrastructure, rail industry

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1 INTRODUCTION

The railway system is poised to represent the future of Africa's transportation system. Hence, many countries with fast-growing economies across Africa are investing massively on the rail infrastructure in order to promote local transit and regional trade. The poor condition of rail infrastructure in many African countries has continued to mitigate the effective use of rail systems with a negative impact on the economic development [1]. According to the report of the United Nation (UN) [2-3], Africa's population is expected to increase by 1.3 billion by 2050, thus, accounting for more than half of the total global population growth. This implies that there would be an increase in the transport demand due to the increasing population. In other words, the increasing number and size of the African metropolitan cities will also require new urban mass transport systems, with the railway system being one of the most suitable systems to meet such requirement. This will also open up some landlocked cities or countries with poor connectivity to the seaport. The economy of the African countries have been projected to grow over the next three to four decades with the Gross Domestic Product (GDP) of Africa also estimated to grow from a base of $1.7tn in 2010 to more than $15tn by 2060 [1, 3]. This estimate is in line with the UN Sustainable Development Goal (Goal number 9) which relates to industry, innovation and infrastructure. Therefore, in order to meet the needs of Africa''s growing population and the estimated domestic product, there is a need to revamp the existing rail infrastructure. This is because, the potential for Africa's economic growth, will require new demands for transportation and improved infrastructure. For instance, South Africa is reputable for mining activities, thus, new mining developments involving high-volume outputs will require a supporting transportation infrastructure which is capable of handling the mined bulk volumes. Also, in South Africa, the revamping of the rail sector is already underway and it is paying off with the transformation of the sector as well as the industrial sector through the creation of new business opportunities and revenue models which can sufficiently leverage the investment made on the rail infrastructure [4-5]. The development of the railway sector will assist in harnessing the dividends of the population growth of the African continent through the creation of business opportunities, as well as local and regional trade. Nowadays, the regional and global supply chain is becoming increasingly complex and competitive which demands improved digital and integrated logistics or solutions, hence, a functional rail transportation system will promote the effective operation of the supply chain [5]. This research paper focuses on the appraisal of rail infrastructural and operational challenges and finally proposes some strategies for effective mitigation of the identified challenges.

1.1 Overview of rail transportation in South Africa

The rail transportation system forms a critical part of the South African transportation infrastructure. At present, nearly all the major cities in South Africa are connected by rail, and South Africa's railway system has been rated as one of the most successful in Africa [1]. The rail transport industry was reorganized in the 1980s along business lines into a government-owned corporation called Transnet. At present, due to increasing complexities and demand, some small portions of the rail system have recently been privatized [6-7]. The Passengers' Rail Agency of South Africa (PRASA) has the mandate to deliver commuter rail services in the metropolitan areas of South Africa while the Rolling Stock Renewal Program (RSRP) was also set up by the South African government to drive government's initiatives towards the digitalization of the rail infrastructure. Some of the mandates of the program are to: invite domestic and international manufacturers to submit a bid for building rail coaches, revitalize the local rail engineering industry, create or improve skills, create jobs and develop a new generation of skilled railway workers from the craftsmen to engineers [8-10]. The program since inception has strengthened South Africa's local manufacturing base and has contributed immensely to the long term competitiveness and prosperity for the country with the procurement of new fleets, building of rail coaches, as well as creation of direct and indirect jobs. The RSRP has also contributed to the South African government's Industrial Policy Action Plan (IPAP2) by promoting product localization and manufacturing, skills acquisition, development and job creation. Furthermore, the program has also aligned procurement initiatives to the SA's government primary objective for localization (high-level local content relative to import content). This has assisted in the creation of local industries that can sustain local production with a focus on manufactured and non-manufactured areas such as engineering, technology transfer, design and components manufacturing. Through the program, the skills development and transfer for local labour to sustain local production has been rapid with a commitment to stimulate local economic development [11-12]. The railway manufacturing technology development relates to a number of critical factors such as the development of the rail engineering industry with the appropriate measures to design, manufacture, and export rail components. The development and implementation of digital technologies will promote the development and operation of an efficient and reliable passengers' and freight rail operations, with the capacity to link the supply chain and the industry of suppliers. It will also enhance the development of human capacities with appropriate rail skills (training and development). The implementation of findings from the Research and Development (R & D) will also foster the development and maintenance of modern rail technology, and the overall economics of rail transport. As part of the PRASA's effort to revitalize the rail transportation system, the Gibela Rail Consortium was launched and empowered in 2014 to lead the revitalization of the South African railway sector and become a catalyst in PRASA's endeavours to elevate commuter rail as an efficient transport mode of choice for people in the metropolitan cities. Since inception as the first train manufacturing plant in Africa, the Gibela company has delivered on the mandate of job creation, skills initiatives and development, the development and use of local contents, development of new, safe and reliable rail transportation for daily rail commuters in line with the best global practices [13]. The company employs modern technologies and equipment for the manufacturing operations such as the use of seven-axis welding robots capable of producing 22,000 welds and two railcar profiles in a day. It also has a 20 m drawbench, ceiling integration tooling system as well as the mechanical and electrical rotating fixtures for improved ergonomics and speed during the manufacturing operations amongst others. The use of the scissors lift table has also been deployed to replace the traditional overhead cranes to promote safety, operational efficiency and precision. The company has delivered on the development of modern trains for transportation in the metropolitan cities having the following features:

1. Railcar with a capacity of up to 1 200 passengers in six cars. The modular design allows for adjustment depending on the periods of higher and lower demand.
2. Railcar with a length of 21.5 m and 131.5 m for the whole train.
3. Railcar whose travelling speed ranges between 120 kmph to 160 kmph.
4. Incorporation of the latest international safety features, including the anti-crash system designed to protect drivers and passengers.
5. Railcar system with a lightweight structure, using South African stainless steel (local content), consuming significantly less energy than the standard trains.
6. Incorporation of several other energy-saving features such as the regenerative braking system which permits a 30% reduction in energy consumption. The energy generated by braking is directed into the train's power network, thereby, promoting energy efficiency, environmental friendliness via carbon emission reduction and reduction in other associated costs.
7. Railcar components that are 90% recyclable.

8. Railcar having six wide double doors per coach, for easy commuters' access, for all and sundry including those who are mobility challenged, the elderly and mothers with prams, strollers etc.
9. Railcar with spacious interiors for easy movement.
10. Railcar with large exterior windows providing lots of natural light, supported by various LED lighting options.
11. Wide, unobstructed gangways, to ensure uninterrupted views down the train to enhance safety and security.
12. Large ergonomic toilets on board.
13. Other special features such as functional air-conditioning systems, CCTV, Wi-Fi internet access [13].

1.2 The development of rail transportation in South Africa

The development of the rail transportation network is critical to trade and economic development as well as commuters' transportation. Poor maintenance, skills shortages, poor rail infrastructure and the use of some obsolete technologies for the operation of the rail sector have been identified as some of the factors hindering the profitability of the rail operators [1, 4-5]. This has also contributed to extensive delays in the movement of passengers with consequences on the productivity of the passengers. While accelerated rail investment and expansion can be noted across South Africa, the need for emerging technologies and digital transformation which characterises the modern rail systems should also be emphasized. With the increasingly complex nature of businesses in South Africa, emerging technologies hold immense possibilities for good transportation models that are capable of supporting the increasingly complex needs of consumers and business in a digital environment.

2 METHODOLOGY

The method used in this study was the literature survey and the analysis of the reports from the organisations saddled with the responsibilities of handling and revitalization of the rail industry such as the Passengers' Rail Agency of South Africa (PRASA) and the Transnet. From the literature review the following aspects require enhancements:

2.1 Revitalization of the rail engineering industry as well as the upgrade of the existing rail infrastructure and fleet [4-5].

1. There is a need for an increase in the running speeds of the railcars (ranging from 160 km/hr-200 km/hr.).
2. Revitalization of long-distance rail services.

2.2 Investing in human capacity, acquisition and development of human skills.

There is a need to also define the developmental objectives to include rural development, access for the rural and urban, employment creation and sustainable economic development.

2.3 The use of appropriate technology and systems digitalization.

The existing system capabilities should be enhanced with the incorporation of smart technologies with capabilities for Internet of Things (IoT), cloud computing, smart sensors and advanced analytical capabilities such as the big data.

2.4 Expansion of the rail network

This includes the linking of the rail transport system to the airports and other transport systems, the development of new railway lines, linking the developed and undeveloped regions of the country, as well as the acquisition of a new and modern rolling stock fleet.

According to PRASA [14], some identified links are:

1. Johannesburg – Durban high-speed rail
2. Moloto rail corridor (high-speed rail)
3. Bara rail link
4. Daveyton rail extension
5. Hammanskraal (Rehabilitation of the existing rail line)
6. Motherwell rail extension
7. Johannesburg – Queenstown – Mthatha rail project
8. Cape Town International Airport rail link

2.5 Capacity enhancement projects:

1. Umlazi – Durban - KwaMashu
2. Mamelodi doubling of the line
3. Station upgrades
4. Accelerated rolling stock program
5. Light-rail and High-speed rail

2.6 Preventative maintenance program

This involves the use of preventive algorithm and models for preventive maintenance activities to forestall sudden breakdown, interruptions in operations and unplanned maintenance activities.

2.7 Operational efficiency

This involves enhancing the nature of operations, amongst others, through the development of effective traffic control systems, speed gates, biometric ticketing systems and telecommunication systems. This is to ensure:

i. Service excellence and operational reliability.
ii. Prioritizing passenger services on the rail network.
iii. Safety and security.

3 RESULTS AND DISCUSSION

The findings from the review show that the use of emerging technologies in the design, manufacture and operation of the railcar, rail tracks and rail networks in South Africa is a requirement. It also shows the propensity of the South African railway system to align with the global best practices in terms of technology and operation over time. However, some of the challenges that are peculiar to the rail sector in South Africa at present include poor maintenance, skills shortages, poor rail infrastructure or the use of obsolete technology. These challenges can be mitigated with the full deployment of emerging technologies such as the Internet of Things (IoT), cloud computing, the use of smart sensors which is supported by advanced analytical capabilities such as the big data platform to provide enhanced asset utilisation, advanced fuel management systems for energy efficiency, predictive maintenance and automatic railcar control. The technologies have the capacity to also enhance capacity management and infrastructure maintenance if fully deployed. A system with good predictive capabilities can be employed to improve the effectiveness of maintenance activities on key rail assets. This will assist in the reduction of maintenance and the operating costs. Others include the use of automatic control system which will enable the railcar to stop or navigate ahead of obstructions as well as the automatic inspection system which can be employed for monitoring the integrity of the rail tracks including the curvature, alignment, grade, ballast amongst others. The deployment of the emerging technologies and digital solutions will also foster effective communication between the railcar drivers, operators and the track equipment personnel for effective tracking of the movement and positions of the railcar. This will also enable the operators to determine the trends in the passengers' movement and predict when and where additional capacity is needed. At present, the South Africa government and railway system regulators are supporting the digital transformation of the rail systems with substantial investment in the sector to promote the use of emerging rail technologies that will bring about improved performance in the sector in line with the global best-practices.

3.1 Railway manufacturing technology developments in South Africa

The South African railcar regulators, manufacturers and operators are taking giant strides to develop modern fleets and gradually embrace digital solutions in order to promote operational efficiency. The technology is emerging, hence, time is a critical factor required for the full implementation of digital solutions and emerging technologies. However, the emergence of modern railcars in South Africa has witnessed the use of some of these technologies with improved performance. The use of digital onboard inspection technologies will enhance continuous and more frequent inspection and data collection that will inform quick decision making, maintenance and planning. In addition, the automation of railcar operations has the potential to promote both safety and network efficiency, thereby, improving the railcar productivity. The automation has the capacity to enhance the transportation of more goods and people by rail. This will reduce the demand on highways with improved energy efficiency and a significant reduction in emissions. When deployed, the precise location of all railcars operating across the network as well as their distances for safe operation can be tracked. This will promote safety, management and improve the scheduling activities, thereby, increasing the number of railcars on tracks with improved safety and network velocity [16-17].

3.2 Safety of the South African railway

Safety and ride comfort are also critical factors that determine the level of development in the railway sector. In South Africa, there has been significant improvement in the operational and safety-related incidents during the 2015/2016 year. According to the Transnet report [17], in 2015, the total number of operational occurrences was 4250 as compared to 4,632 experienced in 2014. This accounts for 8% reduction in the operational related occurrences between 2014 and 2015. Similarly, there was a marked reduction in the safety-related occurrences from 6,222 in 2015 to 5,520 in 2016, accounting for 11% reduction [17]. The overall safety performance and the overall injury and fatalities occurrences in the South African Railway industry are shown in Figures 1 and 2 respectively while Figure 3 shows the security-related occurrences in the South African Railway industry.

The results imply that over years, there have been marked improvements in the overall safety performance of the railway sector in South Africa, however, the cases of the operational and safety-related issues can be further minimized with the use of emerging technologies and strict adherence to standard and global best practices. Such standard practices include the use of an automatic control system that can detect obstructions ahead on the track. Instead of the numerous rail signalling system which characterizes the traditional rail system, a single robust signal control and communication system can be installed both on the trackside and on-board. This promotes the overall speed and safety of the system by ensuring that the railcar does not exceed the safe speed limit and a safe distance from other railcars in order to avoid a collision. The control system will also enable the railcar to either stop or navigate automatically under normal operations or ahead of impending danger. In addition, the use of improved data analytics software can allow the acquisition of critical data trends and its application to detect faults at an early stage in order to enhance safe and uninterrupted operations. The gathering of data through inspection technology such as smart sensors and the analysis through analytic software can reduce catastrophic failure and fatalities related to human factors or errors.

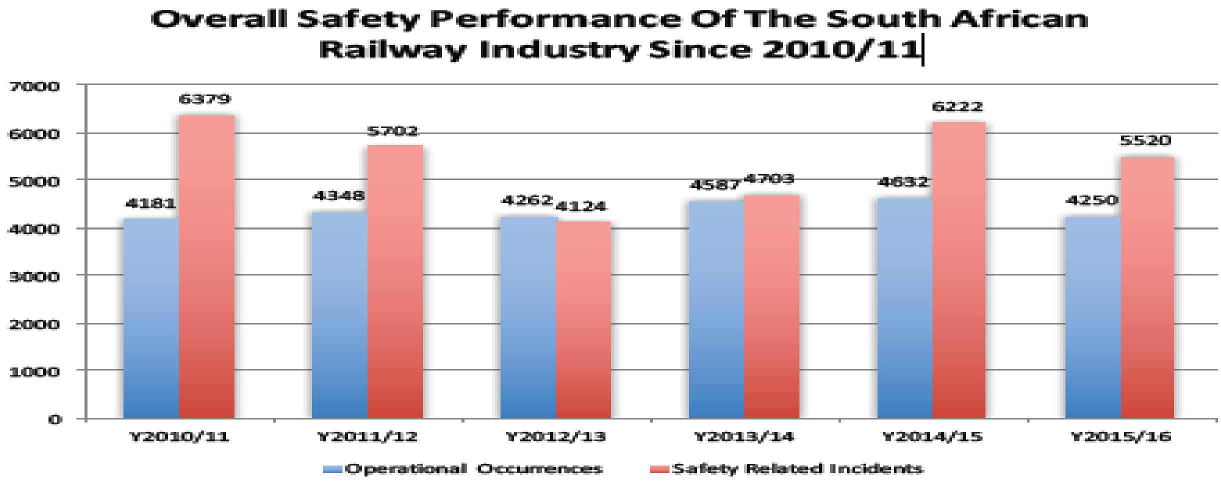

Figure 1: The overall safety performance of the South African Railway industry [17]

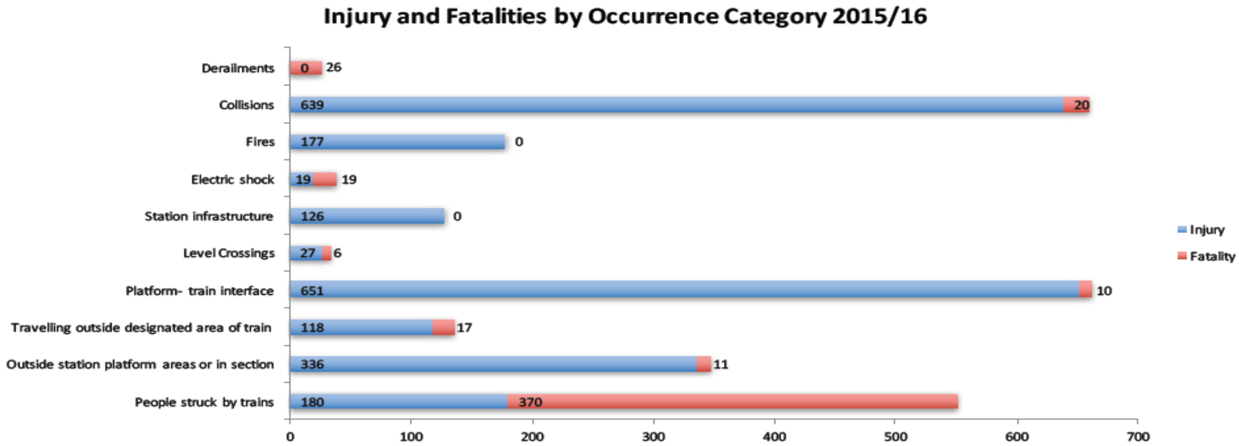

Figure 2: The overall injury and fatalities occurrences in the South African Railway industry [17]

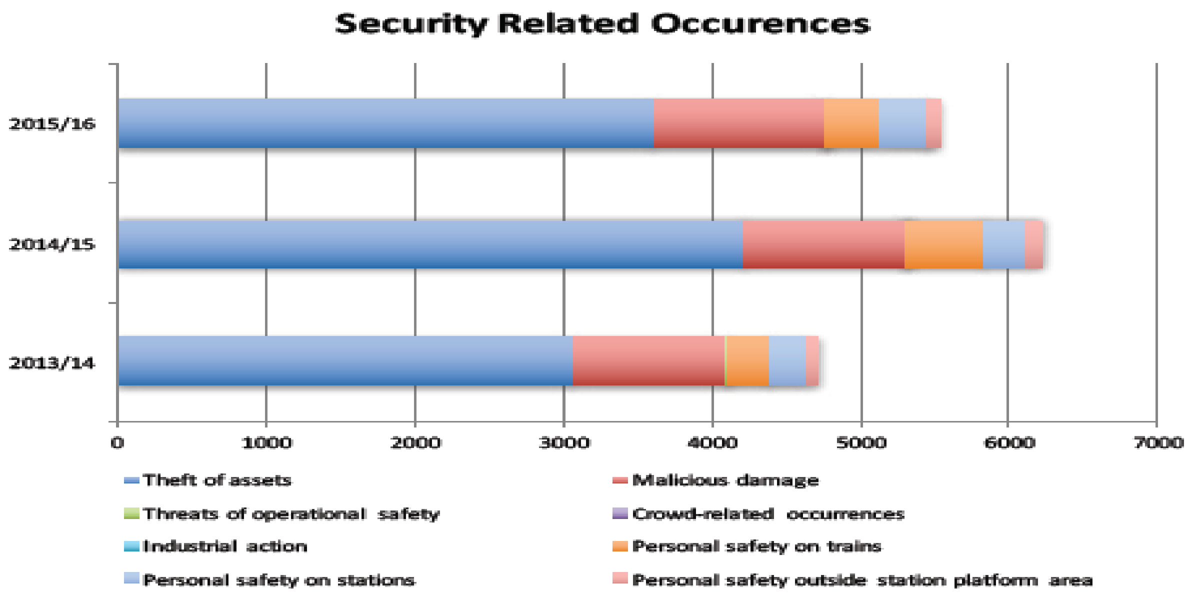

Figure 3: The security related occurrences in the South African Railway industry [17]

4 CONCLUSION

The strength and challenges, as well as the performance of the rail industry in South Africa, were examined in this work through the literature survey. The South African rail transportation system and network continues to be one of the most successful rail transportation systems in Africa. The use and development of the emerging and digital technologies in line with the Fourth Industrial Revolution geared towards the revamping of the sector will be of great benefit. The findings from the review highlight some effort of the South African government and the regulatory agencies in the revitalization of the sector. It also shows some areas of strength which require consolidation and some areas of challenges that require revitalization so that the operation of the South African rail transportation system can conform to the global best practices. In light of this, recommendations were made to promote the sector.

5 RECOMMENDATIONS

The following is recommended:

1. The full deployment of emerging technologies and digital solutions.
2. Adjustment of business model to incorporate the technologies and other social, economic and environmental considerations in the transition to technology integration and adoption in the transport sector.
3. Need for sound policy frameworks coupled with investment in the research and development geared towards the development of the rail sector.
4. To reduce risks associated with job displacements, there is a need for human capacity development for necessary skill acquisition and upgrade.
5. Adequate funding of the rail sector which may involve expansion of the funding sources.
6. Expansion of the rail network to foster interconnectivity between the rural and urban areas in order to promote local transit as well as regional trade.
7. The development and use of high-speed trains to foster interconnectivity within the metropolitan cities and regional countries.

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A PRACTICAL PERFORMANCE MEASUREMENT FRAMEWORK FOR SMES IN A SOUTH AFRICAN CONTEXT

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ABSTRACT

A correctly designed and fully implemented business performance measurement system (PMS) can improve the chances of success of South African SMEs. Unfortunately, existing performance measurement frameworks were found to be of limited practical use for SMEs in a South African context, because they are either too complex or too resource-intensive to implement. In this study, a practical framework, the "Business Development Scorecard for SMEs" (BDSC), was developed.

Design requirements were developed based on literature and used to extract elements from existing frameworks, which were then used to design the proposed framework. In principle, the BDSC is an adaption of the Balanced Scorecard but far more resource-efficient to implement, requiring only the assistance of SME accountants. The BDSC framework is generic and applicable to SMEs in any industry and specifically addresses the South African context.

The validity and implementability of the proposed framework were demonstrated through personal semi-structured interviews with 20 potential users.

Keywords: SMEs, performance measurement, balanced scorecard, basic literacy, South African SMEs

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1 INTRODUCTION

Small and medium enterprises play an important role in the economy but have an extremely high failure rate [1-3, 8-12, 17]. The importance of performance measurement in a business as a critical enabler of success has also been established [4, 5, 6, 7]. However, internationally, performance measurement in small and medium enterprises (SMEs) has been hampered by a lack of research about performance measurement system (PMS) solutions in SMEs [8, 9, 10]. Literature and research on PMSs for SMEs in a South African (SA) context is particularly scarce [11, 12]. Additionally, the PMS field is very wide and fragmented [13, 14] making it difficult for SME owners to obtain the required knowledge to implement a modern and meaningful PMS [15, 16]. Consultants in this field are also scarce and very costly [15, 17], putting their services out of reach of most SMEs. A performance measurement framework (PMF) that will enable an SME owner to implement a modern PMS in the business will therefore contribute to addressing this problem.

SMEs differ greatly from large businesses and so do their PMSs [6, 8-10]. Many frameworks are used successfully in larger organizations; however, to the best of this author's knowledge, there is no PMS framework for SMEs in use that fits the requirements of SMEs [8-10] – and certainly none in SA [11, 12]. Existing SME PMS frameworks are mostly once-off case studies [8-10] or mostly of academic importance [8-9]. It is against this background, that the following objectives will be addressed in this paper:

- Developing a practical, implementable framework specifically suited to enable SME owners/managers in SA to implement a PMS for their businesses.
- A secondary objective that preceded the main objective, was identifying the actual requirements/attributes of a PMS for South African SMEs.

2 APPROACH/METHODOLOGY

A comprehensive literature study was used to crystalize requirements, and analyze existing frameworks as to their adherence to these for specifically SMEs in South Africa. These requirements formed the basis of the framework development. The researcher also drew on his own experience as an SME owner. The literature study covered four (4) main areas:

- Performance measurement system principles;
- Existing performance measurement frameworks;
- Characteristics of SMEs; and
- The South African business environment perspective.

The design procedure for the proposed framework entailed the following steps:

- Identifying the design requirements of the framework from literature;
- Analyzing existing frameworks from literature against requirements as a source of input for a newly-designed framework;
- Proposing an improved approach by drawing logical conclusions based on the literature; and
- Validating the proposed solution through a survey of potential users.

A comprehensive literature search was done, and relevant sources selected by starting with an internet search in general, and the Stellenbosch University electronic library in particular.

A problem in the PMS field is that it is very wide and fragmented, with many different viewpoints held and frameworks in use, resulting in duplication in the effort as well as unmanageable diversity in the PMS field [8, 13, 14, 16, 18]. Also, there is no universal body of knowledge available for performance measurement systems [13, 14] and a 'general theory' of performance measurement has not yet emerged [13, 16].

Taticchi, Tonelli, and Cagnazzo [18] analyzed 6 618 papers mentioning "performance measurement" and identified the four most-cited researchers as R.S. Kaplan; A. Charnes; A. Neely; and R. Banker. These findings were used as a point of departure.

A narrower search by the researcher containing the term "performance measurement frameworks" narrowed these down to relevant sources for this study, focus on two of these authors, i.e. Kaplan and Neely. This finding also correlates with research by Carlyle [8], in that Kaplan and Norton were the most cited authors, and Neely the author of the most papers in the PM field.

Specifically searching for the terms "performance measurement in SMEs" and narrowed down further to also include the word "framework", identified several relevant papers from other authors as well. The list of references shows a wide variety of interests and backgrounds, supporting the earlier statement that the field is extremely wide. It also supports the authority of sources.

Recent research papers concluded that there is no existing PMF for SMEs in use that fits identified requirements [8-10] and specifically none in use in SA [11, 12], the author, therefore, did a detailed analysis of only a sample of existing frameworks, those regarded somewhat subjectively as the most relevant ones as discussed below. The objective of the analysis was to gain input from a variety of designs and possibly to identify components of frameworks that could be used as input in developing a new framework more suited to address all the requirements.

Frameworks used by many large corporates included the, according to citations, 5 most popular frameworks, as well as the EFQM framework based on TQM, and the Dynamic Multi-dimensional Performance (DMP) [19] framework for its different approach. The researcher did not find many SME PMFs during the literature study but selected a sample of seven frameworks all representing a different approach to PMS design [6,8-11,18,20].

Perspectives of some small business consultants [63,64] were then included to gain a practical perspective, better insight into SME characteristics, and reasons for failure and success among SMEs.

Validation of the proposed framework was done through personal semi-structured interviews with potential users. A sample of 20 participants, either SME owners themselves or accountants, as the most frequently consulted advisors to SMEs [20, 21] and therefore most likely to be facilitating the implementation of a PMF in SMEs.

Participants were selected according to the following criteria:

(a). All participants: Based in the Southern Cape, because of logistical constraints.
(b). SME participants:

- Minimum of one (1) participant from each of the five (5) industry sectors [22, 23] in which most SMEs operate
- A spread of SME participants according to size.
- Minimum five (5) years'- experience as owner/co-owner of an SME.
- The selection was randomly chosen from local business directories in the geographical area.

(c). Accountant participants:

- More than 50 percent of their clients must be SMEs.
- Minimum five (5) years' experience as a practicing accountant.
- The selection was random from the South African Institute of Chartered Accountants (SAICA) – Southern Region membership list.
- Participation was in a personal capacity as an accountant – not representing the practice were they worked.

The final sample consisted of eight (8) accountants and twelve (12) SME owners, based on their willingness to participate. The interviews were in the form of a questionnaire. Participants were asked to express their level of agreement with elements of the proposed framework, using a 5-point Likert scale. The elements were statements about general business problems openly discussed in the public domain.

3 LITERATURE REVIEW

3.1 Business goals, strategy, and PMS frameworks

Performance measurement implies that there is a goal/objective, i.e. a measure of success. The general view among authors [24] of what exactly is seen as overall 'performance' or success in a business, can be summarised by the view of Michael Porter [25] that "the fundamental goal for a business is the long-term return on invested capital" (ROIC).

Achieving the interest of all stakeholders has become important, including for instance – the interests of environmental groups and local communities [16, 26].

Several authors note that smaller businesses regard survival, endurance, and positive cash flow as their measure of success – more important than profitability [11, 27-31]. SME success differs substantially from that of big business, being much more linked to the personal income and lifestyle needs of the owner. The author proposed the following definition of SME success that sums up the literature and which was validated together with the proposed framework.

> *SME success means to have a profitable business that sustains the owner's desired standard and quality of living.*

The measures in a PMS should drive the fulfilment of this goal.

Analyzing all the factors and inter-relationships among objectives that influence a business's performance is a complex and very resource-intensive process [30]. PM frameworks generally simplify this process by guiding the user to first identify the critical objectives of the organization [5] and then translate these into measures that will support evidence of the degree to which an objective is fulfilled. Most frameworks derive the critical objectives from the overall organizational vision and strategy [6, 32]. The initial analysis of a business's overall vision/goal and unique strategy to achieve it contributes significantly to the complexity and resource intensity of the PMS design process. Some researchers note that skilled external consultants are in most cases required to design and implement PMSs [7, 15, 16].

Bäuml [33] found that strategic performance measures only start to have a significant effect on firms reaching a size of 45 to 55 workers. Small- and micro business in SA (representing more than 95 percent of all businesses in SA as well as internationally) have less than 50 workers [2], which implies that for the biggest SME population by far strategic measures in a PMS are much less relevant than commonly portrayed in literature. Furthermore, SMEs change strategy often and quickly, which is not good for traditional PMSs [34, 35]. Indeed, Rompho [35] found during a case study of a failed PMS implementation that frequent strategy changes were the primary cause of PMS failure in SMEs.

3.2 Characteristics of SMEs

SMEs have attributes that differentiate them from large businesses. A survey of relevant literature [5, 6, 13, 36-40] highlighted the following characteristics:

- Personalized management, with little devolution of authority;
- Lack of management skills and formal business training;
- Management systems and processes are informal and personal /or vague;
- Strategic processes are informal, dynamic, and either not structured or even completely lacking;
- Lack of management- and human resources;

- Lack of financial resources/cash flow to absorb shocks;
- Lack of training or limited investment in training;
- Failure rate very high;
- Growth is normally much more uncontrolled than in bigger businesses.

Also, the aspects that the SA context brings to SMEs, contribute to SA SME owners having more distractions than many of their global peers which result in them having less time to focus on their business, putting even more strain on management resources [2, 22, 41-46]:

- Critical skills shortages and relatively uneducated workforce;
- Low levels of basic literacy and numeracy of the workforce;
- High level of labour intensity in SMEs;
- Difficulty in competing for skilled labour;
- SA SMEs have an abnormally high failure rate compared to most other countries;
- Burdened by over-regulation and inept bureaucracy;
- Hostile unions and rigid labour laws;
- Many SME owners lack the skills to run a business;
- Language and cultural differences leading to communication difficulties and misunderstanding.

The abnormal high failure rate of SMEs in SA as mentioned in literature can be attributed mostly to management and finance-related causes as well as low profitability [3,41, 42, 47]. Table 3 in Results section 4 shows a summary of the causes of SME failure and problems encountered in SA.

3.3 Characteristics/requirements of a “good” PMS

A “good” PMS will meet most if not all the requirements that a PMS should have, as stated in PMS literature. Here researchers highlight the importance of specific types of objectives and measures that SMEs should have in their PMSs in certain areas – a bottom-up characteristic. Some researchers [48, 49] have proposed PMS frameworks with basic essential measures that any SME should have. This is in contrast to the general PMS literature, which mostly relates to big business, and where reference to PMS requirements are made mostly for the system in general and in non-prescriptive, general terms – leaning towards a unique design of every business’s PMS – a top-down characteristic [6, 50, 51].

3.3.1 Specific measures regarded as essential to SMEs

Cash and liquidity. Several researchers note that cash- and cash flow measures are of paramount importance to SMEs; not only for business survival but also for credit providers (mostly banks) [27, 29, 31, 37, 40, 49]. Banks’ credit decisions are based on the balance sheet as security and liquidity measures for affordability [21, 31].

Human resources. Hudson, Smart, and Bourne [37] stated that, because of the flatter organizational structure and therefore many roles and more responsibilities of employees in SMEs, the human resource dimension is critical. A multi-skilled workforce is therefore very important in SMEs [52]. The SA SME environment especially demands thorough workforce training because of the skills shortage [2, 43].

Customer dimension. SMEs tend to have fewer customers and are therefore more at risk when losing even one customer [37, 49, 52]. SMEs excel at meeting customers’ needs and create value for the customer from the bottom-up. SMEs, therefore, need to have basic customer satisfaction measures in place.

Productive/profitable operations. Garengo et al. [6] emphasized that operational aspects are most critical to SMEs’ success. The productivity of operations, quality, and cost control/reduction is considered as important areas for SMEs to excel in and are noted as essential, basic areas of measurement [36, 37, 48, 49]. These measures could all be described as having the attribute of 'driving profitable operations'.

3.3.2 Requirements for an SME PMS in general

The general "top-down" requirements for a good PMS in general, were described comprehensively by especially Garengo et al. [6]. These requirements are discussed below with the input of more authors. The SME and SA perspectives were added where applicable.

Strategy alignment. It implies that measures should be derived from the business's strategic objectives [5, 24, 53]. The PMS should link high-level strategic goals with operational measures – thereby operationalizing strategy [50, 54]. Frequent strategy changes are a feature of emergent strategies as they are developed by an iterative process. A PMS for SMEs will therefore have to accommodate frequent strategy changes as well [35, 54, 55].

Based on the findings of Bäuml [33], strategic measures should only be brought into a PMS for SMEs on a contingent basis when:

- The SME's management and financial resources can handle the process [56]; and
- The SME has grown to a critical size of more-or-less 50 employees [33]; and
- The strategy of the SME has become more stable [35].

Strategy development. The mutual relationship between strategy development and PMS is noted by some researchers [5, 6, 53]. PMS for SMEs especially should support the development of and the unveiling and mapping of existing strategy [13].

Focus on stakeholders. SMEs do not have the luxury of catering for the needs of a diverse range of stakeholders [6]. In sync with the success vision of SMEs, the primary goal of SME shareholders almost certainly revolve around the survival of the enterprise. As banks are the primary provider of financing for SMEs, they need to be treated as important stakeholders [21, 27, 57]. The shareholders and the bank (credit provider) will therefore be the main stakeholders that initially really matter for most SMEs. In the SA context of massive un-employment [42] and high SME failure rates [2, 3], measures that drive SME survival are of particular importance.

Balance. Modern PMSs measure performance from various perspectives – not only the financial perspective. The most popular are those of the Balanced Scorecard framework [5, 6, 24]: financial, customer, internal processes, and capabilities/learning. Intangible assets, such as human capital, brand value, and systems. represent a much bigger percentage value than traditional tangible assets such as land, buildings, and stock. The management and measurement of intangibles, especially human capital, has therefore become increasingly important [5, 6, 24]

Dynamic adaptability. This refers to the capability of a PMS to react on and adapt to changes in the business's external and internal environment [6]. SME owners and management are close to the 'action' and sense internal and external changes. It will be 'in their minds' in the same way as the strategy [17, 58].

Process orientation. PMSs should change from having functional performance measures to process performance measures. In smaller businesses, a process-orientated PMS is simpler than in larger ones, because here processes are more visible [6].

Clarity and simplicity. For SMEs, it is especially important that the PMS is simple and focussed, with the minimum number of measures (though still balanced). SMEs do not have the management resources for a complex system [54, 55].

Causal relations. A PMS must contain (lagging) measures that represent results, but also (leading) measures that represent the determinants of those results, i.e. logical causal relationships amongst drivers and outcomes [4-6, 16, 24, 53].

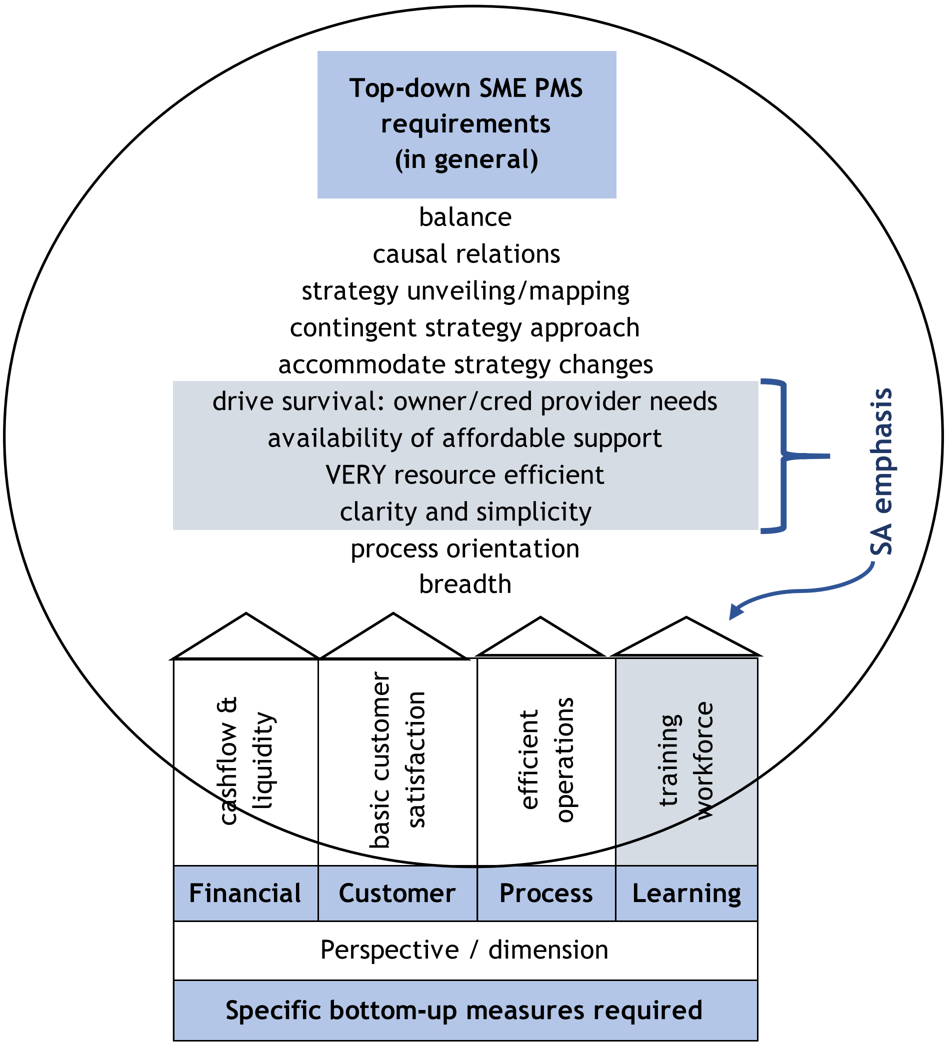

Figure 1: Requirements for a PMS for SA SMEs

Depth and breadth. Several researchers agree that businesses should initially focus on achieving breadth in their PMSs to establish a balanced, integrated PMS. SMEs require only broad, simple systems because of their flat, simpler organizational structures [6, 48, 49].

Resource-efficient implementation is a primary requirement in SME PMS frameworks, especially in SA, due to severe resource shortages (management in particular), management skills, and lack of knowledge about PMS. Dalrymple [59] observed that *time and management effort* are the *scarcest* of all SME resources. Hudson-Smith and Smith [54] summed up the importance of this requirement best by stating that PMS implementation will in fact *not be viable* in an SME if it is not resource-efficient. The author can confirm this strongly from his own experience.

Availability of affordable support for implementation. Most SME owners lack the knowledge to implement a PMS without specialist assistance [10, 16]. External PMS consultants are very expensive and scarce worldwide [15, 60, 61]. In SA the consulting fee of these consultants would be out of reach for the vast majority of SMEs [17]. Because of the close relationship between SMEs and their accountants, these would be the ideal specialist assistant for the task, but they are generally not equipped with such knowledge [20, 21]. Based on these facts, the author concludes that a PMS framework would probably only be used by SMEs if competent affordable support for implementation is readily available.

The requirements for a PMS for SMEs and in a SA context specifically, is summarised by Figure 1. The circle contains all the requirements: firstly the requirements for the system's measures in general - a top-down characteristic. It highlights the special importance of survival driven, resource efficiency, support, and simplicity from the SA perspective. From the bottom-up, the requirements of specific measures in certain dimensions are shown. Workforce training is highlighted as of special importance from a SA perspective.

3.4 Comparison of existing PM frameworks

Table 1 shows the sample frameworks with an indication if they fully comply (2 points awarded) or partially comply (1 point awarded) compared to the requirements listed in Figure 1. The total score of each framework is shown, and the frameworks are ranked (top to bottom) from lowest to highest score. It shows that 'the small business pyramid' has the best and 'the SMART pyramid' the lowest scores. The representation of characteristics/requirements in the frameworks is ranked (left to right) from lowest to highest. It shows that 'balance' is the best represented and 'strategy unveiling' the least. The small frameworks on average have indeed a better score than the big frameworks – as would have been expected.

A variety of principles and approaches emerged from these frameworks to address some of the requirements that generally present a problem to SME PMSs:

(a). Resource efficiency
- An incremental approach to implementation [54].
- Prescriptive measures to reduce the amount of analysis and design required [49, 59, 62].
- Simple decision-support rules to identify measures [19].

(b). Strategy development
- Unveiling and mapping existing strategy [55].
- Suggestion/prompting of strategy through comparison with benchmarks [59].
- Suggested drivers of financial outcomes [62].

(c). Strategy changes/Volatile environment
- Do not take strategy into account [49, 59, 62].
- Comprises of a dual system: a stable component plus a variable component that changes in sync with strategy [34].

As can be seen in Table 1, none of the existing frameworks, for any size business, fulfills all the requirements identified in Figure 1 for a SA SME PMF. Most of the PMFs are not practical for use in SMEs because of the skill level of consultant and the management- and financial resources that would be required for implementation.

4 RESULTS

4.1 A proposed solution – the Business Development Scorecard for SMEs (BDSC): a combination of three existing frameworks

A solution is proposed by combining the strengths of two of the three best-scoring frameworks in Table 1, i.e. the Balanced Scorecard (BSC) (using the circular methodology of Garengo et al. [6, 55]), and the Small Business Performance Pyramid (SBP) [49]. A third framework, the Flexible Performance Measurement (FPM) [34] system, combines the first two frameworks.

The logic of these three frameworks can be described briefly as follows:

The Balanced Scorecard (BSC) [5, 24] is by far the most widely-used PM framework worldwide [5]. Strategic objectives in four perspectives (financial, customer, processes, and learning) are derived from the strategy of the business. The objectives are graphically portrayed in a strategy map in causal relationships over all the perspectives — visualizing how the strategy

Table 1: Comparison of some existing PMS frameworks

SIZE	No	PERFORMANCE MEASUREMENT FRAMEWORK	AUTHOR AND PUBLICATION DATE	REQUIREMENTS OF A GOOD PMS FOR SMEs											PMF TOTAL SCORE
				STRATEGY UNVEILING	CONTINGENT STRATEGY	DRIVW SURVIVAL	SUPPORT AVAILABLE	RESOURCE EFFICIENT	CAUSAL RELATIONS	STRATEGY CHANGES	CLARITY& SIMPLICITY	PROCESS ORIENTATED	BREADTH	BALANCE	
big	1	The SMART Pyramid	Lynch & Cross, 1991						1		1		1	1	4
big	2	The Results and Determinants Framework	Fitzgerald *et al.*, 1991						1	1			1	1	4
big	3	EFQM (European foundation for quality management's business excellence model)	EFQM, 1991							1			1	2	4
small	4	The performance measurement and management framework	Jamil & Mohamed, 2011			1			1				1	2	5
big	5	The Performance Measurement Matrix	Keegan *et al.*, 1989			1		1		1	1		1	1	6
big	6	The Performance Prism	Neely *et al.*, 2002						2			1	1	2	6
small	7	Continuous strategic improvement process for SMEs (CSI)	Hudson *et al.*, 2001, 2006	1	1			1		1	1	2			7
small	8	FPM - Flexible PM system for SMEs	Pekola *et al.*, 2016		2		1	1	1	1	1	1		1	9
big	9	The Balanced Scorecard (BSC)	Kaplan & Norton, 1992	1			1		2		1	1	2	2	10
small	10	The Business Process Benchmarking approach	Dalrymple, 2004	1	1		1	1		1	1	2	1	1	10
small	11	PMM for SMEs: a Financial statement-based system	Bahri *et al*., 2017			1	1	1	1	1	1	2	1	1	10
small	12	BSC using Circular Methodology for strategy development in SMEs	Garengo & Biazzo, 2012	2			1		2		1	1	2	2	11
big	13	DMP - The Dynamic Multi-dimensonal PM framework	Maltz *et al.*, 2003		2	1	1	1		2	1		1	2	11
small	14	The Small Business Pyramid (SBP)	Watts & McNair, 2012			2	2	2		2	2	1	1	1	13
		TOTAL SCORE PER PMF REQUIREMENT		5	6	6	8	8	11	11	11	11	14	19	

LEGEND: fully compliant 2 partly compliant 1

will be executed. The BSC needs a relatively stable strategic environment, requiring a redesign with every strategy change. Measures are then chosen to support each objective to populate a scorecard. Using the circular methodology of Garengo et al. [6, 55] with the BSC can assist in unveiling the existing business strategy and thereby simplify this resource-intensive process.

The Small Business Performance Pyramid (SBP) [49] is a very simple framework that prescribes specific measures in three areas (business sustainability, liquidity, productivity). The SBP is not fully balanced, does not take strategy into account, and is therefore not affected by changes in strategy or the business environment. It is very resource-efficient to implement.

The Flexible Performance Measurement system (FPM) [34] is specially designed for the turbulent business environment that SMEs operate in. It is a two-part framework that has a stable, essential set of core financial/profitability measures plus a set of supporting measures that change according to a changing strategy and business environment. The FPM is a very resource-efficient PMS to start with — but with financial measures only. This results in a very unbalanced system until strategic measures are also incorporated.

Table 2: SME PMF solution = integration of three existing frameworks

PERFORMANCE MEASUREMENT FRAMEWORK	AUTHOR AND PUBLICATION DATE	REQUIREMENTS OF A GOOD PMS FOR SMEs											PMF TOTAL SCORE
		STRATEGY UNVEILING	CAUSAL RELATIONS	BREADTH	BALANCE	CONTINGENT STRATEGY	DRIVE SURVIVAL	SUPPORT AVAILABLE	RESOURCE EFFICIENT	STRATEGY CHANGES	CLARITY& SIMPLICITY	PROCESS ORIENTATED	
Business Development Scorecard for SMEs (BDSC)	**The author, 2019**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**1**	**21**
Balanced Scorecard with Circular methodology (BSC)	Garengo & Biazzo, 2012	**2**	**2**	**2**	**2**			1			**1**	**1**	**11**
Flexible PMS for SMEs (FPM)	Pekkola et al., 2016		**1**		**1**	**2**		**1**	**1**	**1**	**1**	**1**	**9**
The Small Business Pyramid (SBP)	Watts & McNair-Connolly, 2012			**1**	**1**		**2**	**2**	**2**	**2**	**2**	**1**	**13**

LEGEND: fully compliant 2 partly compliant 1

The BSC and SBP frameworks have opposite attributes. Table 2 illustrates that the weaknesses of the one are compensated by the strengths of the other, and *vice versa*. The only requirement that cannot be fulfilled by either of the two frameworks, is the ability to accommodate strategy on a contingent basis. This is where the FPM contributes with its dual system composition. Table 2 shows how the best characteristics of each framework have been combined in the new framework.

The proposed solution, the ***"Business Development Scorecard for SMEs" (BDSC)***, is therefore a two-part PMS (as in the FPM) with a stable prescriptive component (as in the SBP) plus an adjustable strategic component (as in the BSC).

In light of the universal vision of success of SMEs of survival/endurance, it was appropriate that Phase 1 consists of measures that would drive survival. Added to these, measures that are regarded as essential for SMEs were added, to create a set of stable and generic measures for Phase 1. The new PMS starts with the stable and generic Phase 1 and adds unique strategic measures in Phase 2 when the SME has grown to a critical size, or when management resources are deemed sufficient. The generic measures of Phase 1 would make implementation very resource-efficient.

The proposed solution in the format of the BDSC framework is shown in Figure 2. The structure of the BSC framework is retained for the BDSC and the Phase 1 objectives are generated within a BSC framework – thereby combining the SBP with the BSC. These stable, generic measures can be accommodated in the structure of a BSC, but not *vice versa* for the dynamic measures of a strategy-driven BSC. Phase 1 is therefore a BSC that contains only generic essential and survivalist measures. Because Phase 1 measures are already in a BSC structure, the new system can seamlessly 'grow' into Phase 2 when strategic measures need to be added. When proceeding eventually to Phase 2, strategic objectives can be identified with the aid of the circular approach [55] (or even standard BSC methodology [5, 24], depending on available support).

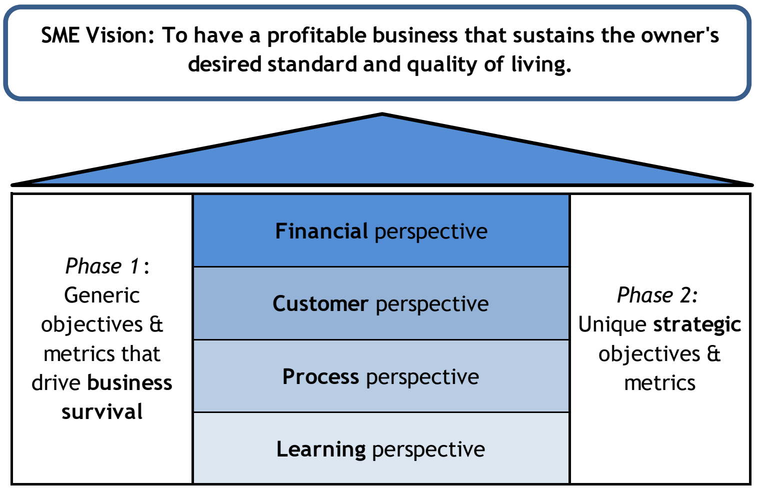

Figure 2: The logic of the BDSC in a Balanced Scorecard framework

4.2 The development process of the BDSC

4.2.1 Generating objectives

The generic, stable objectives that will drive SME survival, was developed by generating some counter objectives that would address the '*common causes of failure and other factors that impact negatively on SA SMEs'*, plus objectives and measures from the literature that fall in the category of '*essential measures that any SME should have*' (the bottom-up measures), as shown in Figure 1. Table 3 lists the causes of failure and negatively impacting factors for SA SMEs, as extracted from literature [3, 41, 42, 47] - each showing a set of typical counter objectives that could address it. A specific counter objective can be applied to more than one cause of failure, as indicated in Table 3. The counter objectives were developed from the literature study and confirmed by the author's own experience as an SME owner. Some of the counter objectives may require further motivation and are discussed below.

Lack of access to financing can be countered by making the SME more "finance-able".This equates to having a healthy balance sheet, acceptable profitability, and good cash flow management [21, 27, 57].

Poor profitability can start to be addressed by just regularly and (more importantly) timely determination of the actual profitability of the business ("what gets measured, improves"). What is proposed is some leading measures of profitability — not the lagging financial statements. The term "operational profitability" is probably the best description of what needs to be measured and in line with the findings of Jarvis et al. [31] about what mature SMEs measure. Garengo et al. [6], noted the example of "control cost measures" that could predict profit. Watts and McNair-Connolly [49] mentioned value-added cost which essentially boils down to operating margin.

The questions that therefore need to be answered on a daily/weekly basis to determine total operational profitability, include:

- Are we selling enough to operate above breakeven?
- Are our variable costs within budget?

Poor management*, *shortage of management resources and worker skills*, *over-dependence on the owner, *and* ***uncontrolled growth*** can all be addressed by putting standard systems and procedures in place and training personnel and supervisors accordingly [10, 13, 56, 63, 64]. Good management systems will also facilitate the owner's exit strategy [63, 64].

Table 3: Suggested counter objectives to causes of SME failure in SA (with validation results)

CAUSES OF FAILURE and PROBLEMS IN SA SMEs	TYPICAL COUNTER OBJECTIVES
1. lack of strategic planning	a
2. lack of access to finance	c, d
3. cash flow problems	b, d
4. lack of structure and formal systems	f, g, h
5. poor management in general	f, g, h
6. entrepeneurial, lack formal business training	a, d, e, f, g, h
7. shortage of management resources	f, g, h
8. too dependent on owner/manager	f, g, h
9. poor profitability	a, e
10. poor financial control & planning	e, f, g
11. low investment in training personnel	f, g, h
12. uncontrolled growth	d, e, f, g, h
13. external factors with no control	a, c, d
14. skills shortage	g
15. un-educated work force	I, j
16. rigid labour laws	I, j
17. hostile unions	I, j
18. cultural and language differences	I, j

COUNTER OBJECTIVE		
Description		Validation
do proper, regular strategic planning	a	88%
improve business profitability	b	94%
improve strength and liquidity of balance sheet	c	88%
do thorough cash flow planning & management	d	92%
know/determine profitability, key costs, breakeven	e	94%
develop and improve standard systems and processes	f	88%
do training in standard systems and processes	g	84%
do supervisor training and development	h	85%
do basic literacy education in Eng/Afr and local indiginous African language	i	78%
do basic numeracy & financial literacy training	j	69%

VALIDATION: Percentage survey participants that either agree or fully agree that an objective will be a counter measure to a cause of failure/problem. The score represents an average score for the objective.
Scoring on a 5-point Likert scale

External factors that the SME has no control over, such as a recession or entry of strong new competition, can be faced much better with a "war chest" of good cash flow and access to financing as well as strategic planning. A healthy balance sheet and good cash flow management are critical in this regard.

A hostile, uneducated, illiterate labour force can be addressed much better if there is a mutual understanding of cultural differences and language. There are probably a few things that will create more goodwill and mutual respect than if management and workers from all population groups can communicate in English/Afrikaans as well as the prevalent local indigenous African language. Nelson Mandela is quoted as once saying: "if you speak to a man in a language he understands, it goes to his head. If you speak to him in his language, it goes to his heart" [65].

Basic literacy and numeracy education will prepare uneducated, illiterate [41-45] workers for training in the business processes and systems and it will make them more "trainable". It is also very much in line with the SA government's broad-based black economic empowerment (BBBEE) goals [2].

Quality and customer satisfaction objectives were the only essential measures (Figure 1) judged not to be already covered in the survival objectives and were added in addition to the list of objectives shown in Table 3.

4.2.2 The Performance Map

Following standard Balanced Scorecard (BSC) design procedures [5, 24, 53], the objectives were linked to demonstrate cause-and-effect in "strategy map" format as depicted in Figure 3. It shows strategic objectives added as a 2nd phase alongside the 'business development' objectives. The lower level objectives drive the next level of objectives - all combining to support the success vision of business endurance and survival. The basic literacy objectives act as enablers of the other objectives in the learning perspective. The author, therefore, proposes that the basic literacy objectives be accommodated in a separate, 5th perspective named "basic literacy" - acting as a total 'system enabler'. The map is re-named as the "performance map" to distinguish it from the standard BSC's strategy map.

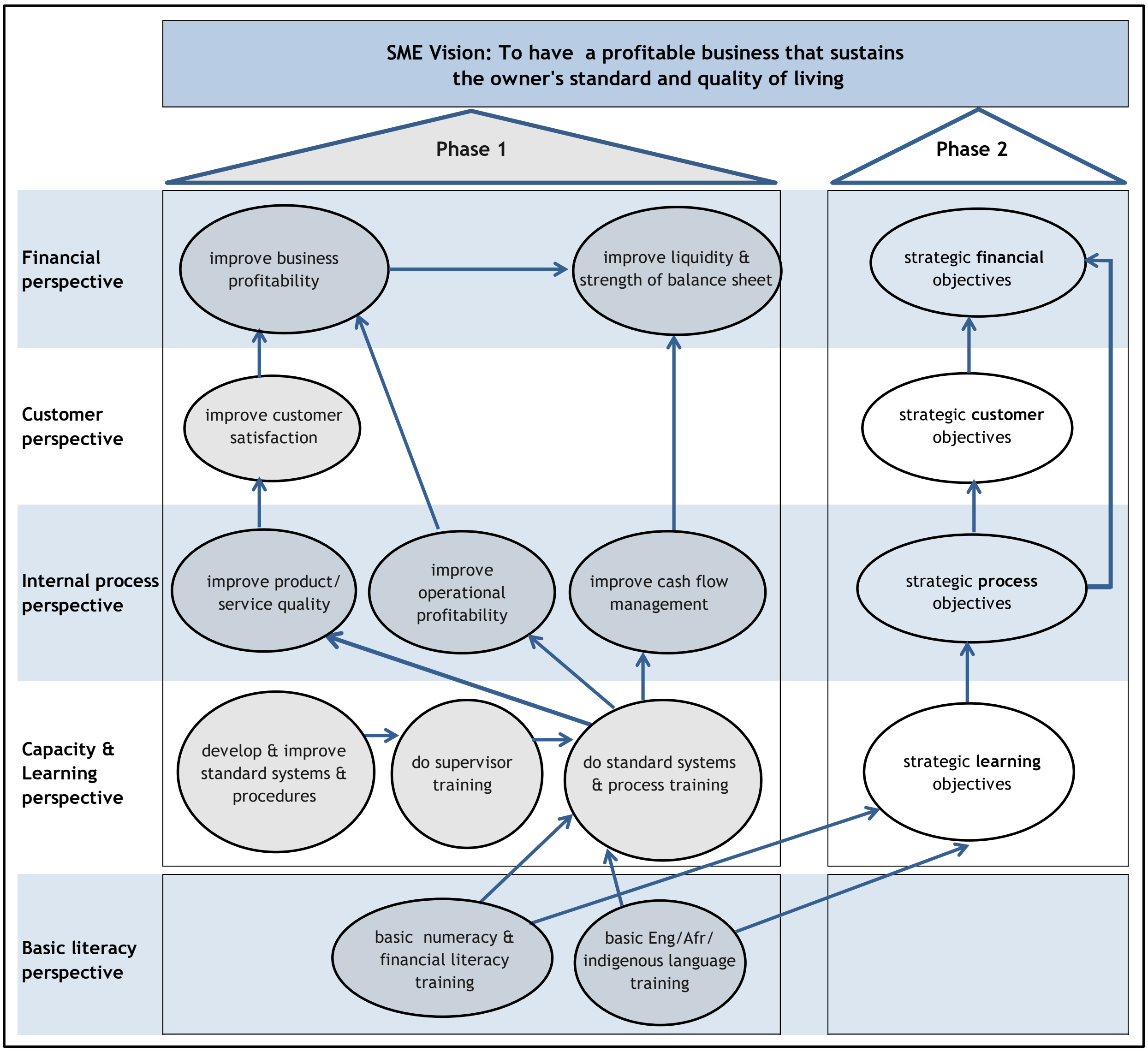

Figure 3: The Performance map of the BDSC framework with 'basic literacy' perspective added

4.2.3 The scorecard

These generic objectives were then translated into suggested typical supporting measures that populate the scorecard of the new framework as shown in Table 4. Users could start their PMS with these sample measures and change to more appropriate ones if required.

4.2.4 The BDSC framework

Phase 1 of the proposed new PMF, therefore, consists of **(i) a *performance map*** (Figure 3) containing generic objectives linked in general cause-effect relationships, and **(ii) a *scorecard*** of suggested typical measurements to support these objectives (Table 4).

4.3 Validation of the BDSC

The vision of success, objectives, and measures was then validated for general acceptability through the survey of 20 potential users.

The vision of success that drives the BDSC **was validated** by asking participants to express their level of agreement that for an SME owner success is "*to have a profitable business that sustains the desired standard and quality of living of the owner(s)*". All participants (100%) either agreed or strongly agreed with this statement.

Objectives were validated by asking whether the proposed objectives were effective counter objectives, within the control of the SME owner, for addressing specific causes of failure and problems faced by SMEs. The results are shown in Table 3. The causes of failure with typical objectives to counter each is listed on the left. On the right, the objectives are described and the corresponding validation 'score' (percentage of respondents either agreeing or strongly agreeing) is shown.

All objectives show a high percentage validation, with the lowest score of 69% and the majority of objectives scoring more than 80%. The results confirm that the objectives of the BDSC are drivers of SME success.

Each ***measure was validated*** for ease of implementation, i.e. that an SME owner would be able to administer (implement) a specific measure on the scorecard with only the assistance of his/her accountant – if assistance was required. Table 4 lists the objectives of the scorecard with corresponding suggested typical measures to support each objective. The results in Table 4 again show strong validation, with only one out of 19 measures scoring 59% and the rest more than 80%, confirming that the BDSC is very resource-efficient to implement.

5 DISCUSSION & RECOMMENDATIONS

With the development of the BDSC, some shortcomings of existing frameworks were addressed. Firstly, existing literature focuses mainly on large corporations – this is never explicitly stated, but in most of these, it is implicitly assumed that the company looking at implementing a specific model has the required skills and/or resources to do so, either themselves or by using implementing agents. SMEs do not have that luxury, and in reality, the owners/managers need to "do the work" themselves. By testing the BDSC with SME owners from various industries the approach and final design of it found not only general acceptance but also maybe more importantly, most agreed that they would be comfortable starting to implement it themselves.

Secondly, SMEs specifically in South Africa have additional needs not broadly addressed in existing frameworks. These centre around the huge skills shortage, both as far as the management/financial background of the owner is concerned as well as the lack of even basic levels of language and maths skills. In this regard it is noteworthy that five (5) of the eleven (11) phase 1 objectives are training/human resource-related, emphasizing the growing importance of intangibles such as human capital.

The management systems development nature of the 1st phase lays the foundation of the SME to grow. Systems and procedures together with well-trained employees will free the owner to concentrate more on strategic matters.

The author believes that because of the generic nature of objectives and measures in the BDSC, it will apply to any type and size of SME in any industry.

Table 4: Objectives and suggested measures for the scorecard of the BDSC (Phase 1)

PERSPECTIVE	OBJECTIVES		SUGGESTED MEASURES (evidence)			
	No	Description	No	valdation	Cycle	Description
FINANCIAL	1	improve business profitability	1	100%	month	profit % and -value as per financial statements
			2	100%	month	breakeven sales
	2	improve health & liquidity of balance sheet	3	94%	month	debt:equity ratio
			4	88%	month	fire ratio
			5	100%	month	nett current assets
CUSTOMER	3	improve customer satisfaction	6	82%	week	% overall customer satisfaction on a 5-point Likert scale
PROCESS	4	do thorough cashflow planning & -management	7	94%	week	cashflow projection- next 6 weeks
			8	82%	month	cashflow projection- next 12 months
			9	94%	day	total cash and cash facilities available
			10	94%	week	% debtors overdue
	5	improve total operational profitability (as leading indicator of business profitability)	11	94%	week	accummulated sales contribution vs budget &breakeven
			12	94%	week	monitor key variable cost items vs standard
	6	Improve product/sevice quality	13	59%	week	monitor % quality defects: products/services
LEARNING	7	develop and improve std systems & procedures	14	82%	month	number of processes documented or revised
	8	do supervisor training	15	88%	6 month	% supervisors pass relevant training courses
	9	do training in std systems & procedures	16	94%	6 month	% workers competent in relevant systems and procedures
BASIC LITERACY	10	do basic Eng/Afr/Indigenous language literacy training	17	94%	6 month	% workers that can speak Eng/Afr/ indiginous language
	11	do basic numeracy- & financial literacy education	18	94%	6 month	% workers pass basic FINANCIAL LITERACY test
			19	88%	6 month	% workers pass basic NUMERACY test
	Validation: Percentage survey participants that either agree of strongly agree that a measure can be implemented with only the assistance of an accountant. Scoring was on a 5-point Likert scale					

The limitations of this research were the relatively small sample size of 20 participants in the validation survey which was also not composed to fully reflect the proportional contribution of each industry sector and SME size, or a complete geographical representation. The generic objectives that drive SME survival also cannot be claimed to be a complete list.

Future research possibilities that can build on this research, are:

- Research on a complete list of generic objectives and measures that will drive SME survival.
- The types and nature of basic literacy training in SA SMEs that will have a significant positive effect on their performance.

6 CONCLUSION

The contribution of this research was (i) the identification of the requirements of a PMS specifically for South African (SA) SMEs and (ii) the development of a framework to implement such a PMS.

The proposed new framework, the "Business Development Scorecard" for SMEs (BDSC) can be implemented by any SME, requiring only resources available to all SMEs.

The BDSC is a 2-phased system, with the 1st phase consisting of generic objectives that drive the survival of the SME, emphasizing training and liquidity objectives, and the 2nd phase adding unique strategic objectives and measures.

The SA context of the BDSC is highlighted by the inclusion of a "basic literacy" perspective of measurement that drives better "trainability" of the very low skilled SA workforce.

"Measurement drives performance", and the objectives and measures of the BDSC drive SME survival and endurance. The author believes that this new framework can contribute to a higher success rate amongst any type of SME worldwide, and specifically in SA.

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DESIGNING A LEAN AND GREEN FRAMEWORK FOR GHG REDUCTION IN THE SOUTH AFRICAN MANUFACTURING INDUSTRY

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ABSTRACT

Lean and Green is an emergent field of research focused on promoting operational efficiency and environmental performance. One of the environmental measures within this paradigm, is greenhouse gas emissions (GHGs) – an ever-present threat to society. The aim of this study is to design and evaluate a literature-based Lean and Green framework for GHG reduction in the South African manufacturing industry. Surveys were distributed to Subject Matter Experts to test and design a refined Lean and Green framework for GHG reduction. By incorporating Design Science Research, various design elements and themes belonging to the framework were evaluated. Participants voiced the relevance and potential for GHG reduction, but also provided additional elements from the literature-based framework obtained from a Systematic Literature Analysis and Applied Thematic Analysis. The refined framework from this study allows future researchers to develop GHG methodologies by means of Lean and Green.

Keywords: Lean and Green, South Africa, GHG emissions, Lean philosophy, Systematic Literature Review, Applied Thematic Analysis, Survey

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1 INTRODUCTION

The South African manufacturing industry contributed an average of R325 Billion to its Domestic Product (GDP) between 1993 and 2019 [1]. This nourishes our domestic economy, sustains employment and ensures societal relief. Unfortunately, this industry embraces numerous challenges. One of which is the high demand, productivity requirements, competitors, and environmental obligations they must abide to.

South Africa has one of the highest CO2 emissions per capita and is the largest energy consumer on the continent [2]. It is a well-known fact that GHG emissions are an overwhelming threat contributing to global warming [3]. As with other countries, South Africa is forced to abide to various environmental regulations and policies. In 2019, the South African Carbon Tax Act (No. 42483 of 2019) was introduced, pricing emissions at R120 per CO2 equivalent above a prescribed threshold [4]. The manufacturing industry is confronted with reducing its Greenhouse Gas (GHG) emissions and a need exists to develop a method to assist with this task. Lean and Green presents itself as a resolve.

Lean is a process improvement philosophy aimed at reducing inefficiencies (waste) in order to promote higher levels of productivity [5]. Lean categorises 8 forms of waste (Inventory, Motion, Waiting, Over-production, Over-processing, Defects, Transportation and Un-used employee intellect) [6, 7].

Lean was initially developed for the manufacturing environment, first appearing in a 1988 article by Krafcik [8]. However, Lean has been implemented in a wide variety of industries which include healthcare, construction, systems design, IT and other service sectors [9, 10, 11, 12]. In addition, Lean can be used to simultaneously reduce environmental effects [13].

The Green philosophy is concerned with the reduction of the environmental affects posed by anthropogenic activities [14]. According to Zokaei et al [15], the 8 forms of Green waste are air emissions, energy consumption, land contamination, water discharges, water usage, noise, physical waste and lost human potential. This has been used to assess supply chain management among other applications [16, 17].

Lean and Green strives to simultaneously increase productivity (by means of lean principles) and reduce the environmental effect (by incorporating green principles). Farias et al [18] suggests best sustainable practices and criteria from a framework which identifies the relationships and concepts of Lean and Green performance. The suggested practices are VSM (Value Stream Mapping), Kaizen, 5S, SMED (Single Minute Exchange of Die), JIT (Just in Time), Cellular manufacturing, TPM (Total Productive Maintenance), EMS (Environmental Management System), 3R (Reduce, Reuse, Recycle), DFE (Design for Environment) and EEC (Environmental Emission Control). In order to show the overlap between these two paradigms, **Figure 1** compares these respective traits.

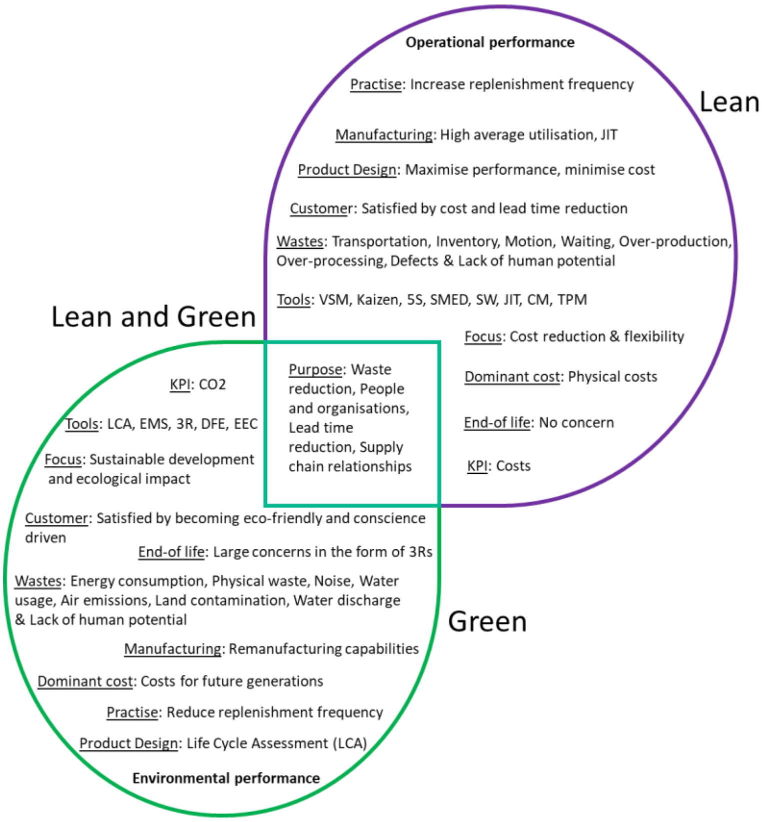

Figure 1: Lean and Green overlap adapted from Dües et al [19] and Zokaei et al [15]

Despite the trait differences listed in Figure 1, Lean and Green holds a shared purpose to achieve waste and lead time reduction, recognise people and organisations, but maintain supply chain relationships [15, 19]. For any institution to fully harness the potential of Lean and Green, the relationship between the two philosophies must be recognised. One way of doing so, is by outlining the two paradigm relationships intertwined across different levels of learning maturity.

The levels of Lean and Green maturity have been depicted in **Figure 2**, as adapted from Zokaei et al [15]**.** The initial representation of the Lean and Green relationships was categorised according to innocence and degree of knowledge realised. This approach substantiates this relationship, but can be further enhanced using the learning maturity stages discussed by Bradley [20]. These levels include unconscious incompetence, conscious incompetence, conscious competence & unconscious competence. Using these learning maturity levels; the variated representation of the relationship more accurately depicts the expected stages levels of learning when embracing Lean and Green.

Stage of learning maturity	**Unconscious incompetence:** Not knowing what you don't know	**Conscious incompetence:** Knowing what you don't know	**Conscious competence** Not knowing what you do know	**Unconscious competence** Knowing what you do know (2nd nature)
Relationship	**Conflicting**: Polarity between Lean and Green	**Benign**: Both may co-exist, but are non-complementary	**Synergetic**: Positive relationship perpetuated	**Symbiotic**: Lean and green form part of the same strategy
Example	Frequent deliveries rising emissions, whereas lowering emissions reduces productivity	Lean team pursues economic goals whereas green teams pursue environmental goals independently	Reducing product waste reduces green impact simultaneously	L&G strategy for reducing loss imparted to society during entire production life cycle

Figure 2: Lean and Green maturity stages adapted from Zokaei et al [14]

As illustrated in **Figure 2**, various companies may function within different stages of lean and green maturity. In the primal stage, companies pursue independent lean and green initiatives which counteract one another. Organisations which fall victim to this stage are those who pursue lean improvement projects under environmental regulations, unaware of this relationship. During the next stage, an organisation may become aware of the association between these two facets and begin separate initiatives non-complementary in nature. The next two stages recognise the relationships and aims to improve productivity and environmental performance. One can argue that green is dictated by legislature, which can ultimately be resolved by continuous improvement in accordance with Lean principles. In summary, this figure represents the innate relationship shared between Lean and Green respectively.

However, little guidance is provided in literature on how to apply or implement this approach within organisations. Moreover, no methodology exists for reducing GHG emissions with Lean and Green. As a steppingstone towards such a methodology, a framework must first be developed.

Therefore, the aim of this paper was to design and evaluate a literature-based Lean and Green framework for GHG reduction in the South African manufacturing industry.

2 RESEARCH METHODOLOGY

In a qualitative research study, new concepts and theory are created [21, 22]. For this reason, a design science research (DSR) paradigm was followed. This involves multiple stakeholders during the development of a state-of-the-art artefact [23, 24]. The research methodology has been encapsulated in **Figure 3**.

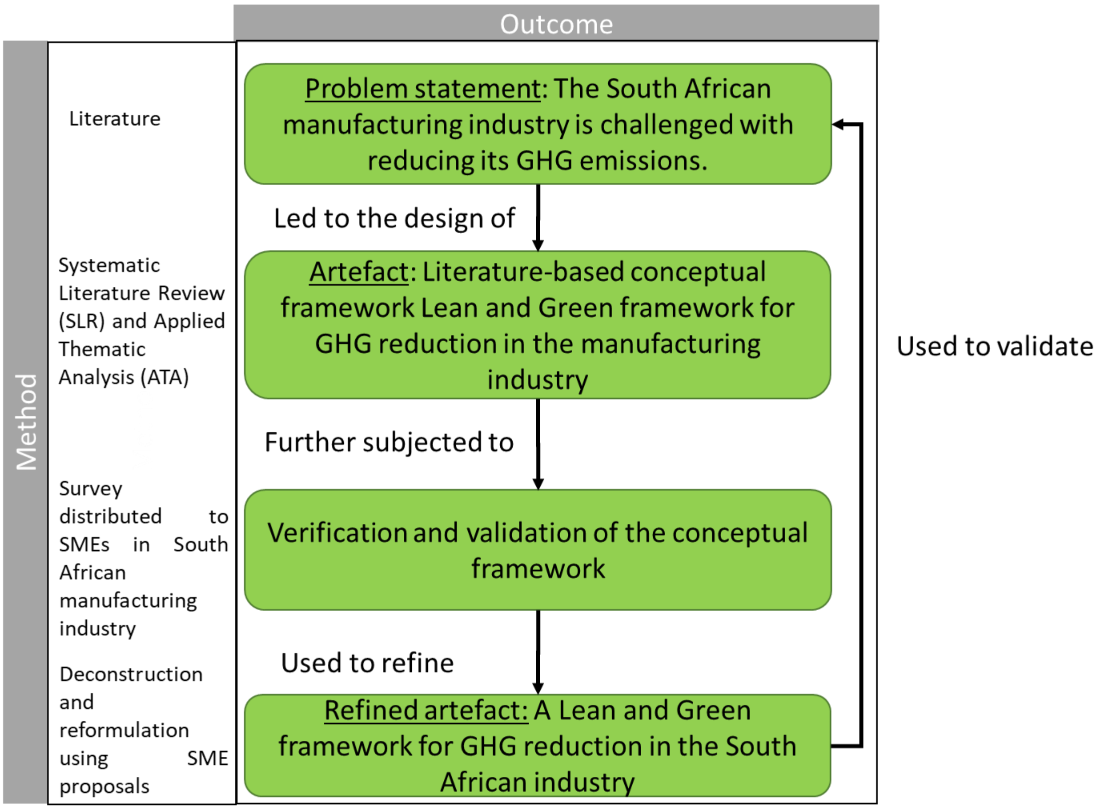

Figure 3: Research methodology

2.1 Systematic Literature Review and Applied Thematic Analysis

By following a systematic literature review (SLR) and an applied thematic analysis (ATA), a conceptual literature-based Lean and Green framework for GHG reduction was developed.

A SLR was used to screen and identify 56 publications from an initial set of 464 publications from scientific databases. The keywords Lean, Green, framework, model, tax, South Africa and emissions were used to search between 2015-2019. An ATA was used to formalise the essential design elements and themes recommended by academic scholars. This data was consolidated by coding in ATLAS.ti.

2.2 Survey

A survey was used to evaluate the literature-based conceptual Lean and Green framework.

2.2.1 Survey design

The survey had the following objectives:

1. Validate that the South African manufacturing industry is challenged with reducing its GHG emissions
2. Verify the established design requirements for the framework
3. Verify that all design elements and themes of the literature-based framework are appropriate for GHG reduction
4. Verify that all potential design elements and themes are identified
5. Verify the associations between the design elements
6. Verify the associations between themes
7. Validate that the framework addresses the research problem

According to Al-Ghamdi [25], an average more than 3 on a 5 point Likert scale indicates a higher level of success (agreement). In this study, a consensus rate of 60% (3 on a 5-point Likert scale) was used. By factoring the results for each of the survey statements (Table 1: Summary of survey design requirements, statements and questionsTable 1 in Annexure A) and suggestive commentary, a refined Lean and Green framework is proposed (section 3.2.6).

Demographic information was also incorporated in the survey, outlining the participant's industry and years of experience. This survey was designed as a Google Form, accompanied by an explanatory 5-minute video on the conceptual framework.

The survey design relied on the objectives of this study and specifications outlined in the table located in Annexure A. This table provides a summary of the objectives, survey design requirements, specifications, survey statements and questions. The right-most column of this table provides the survey results. A Likert scale was used to evaluate the degree by which participants agree or disagree with the survey statements, and a dichotomous scale (yes or no response) for questions posed. Questions which prompted participants to elaborate further (Q2 & Q4) are discussed in section 3.2.2-3.2.5.

2.2.2 Participants

The survey was disturbed to Subject Matter Experts (SMEs) within the South African manufacturing industry using a purposive sampling technique: snowballing. SME's included environmental engineers, managers or practitioners learned in operational and environmental efficiency.

3 FINDINGS

3.1 Systematic Literature Review and Applied Thematic Analysis

During the SLR and ATA, five themes categorise 41 design elements extracted from 56 research publications. The results of the SLR and the ATA lead to the formulation of a conceptual literature-based Lean and Green framework for GHG reduction, as depicted in **Figure 4.**

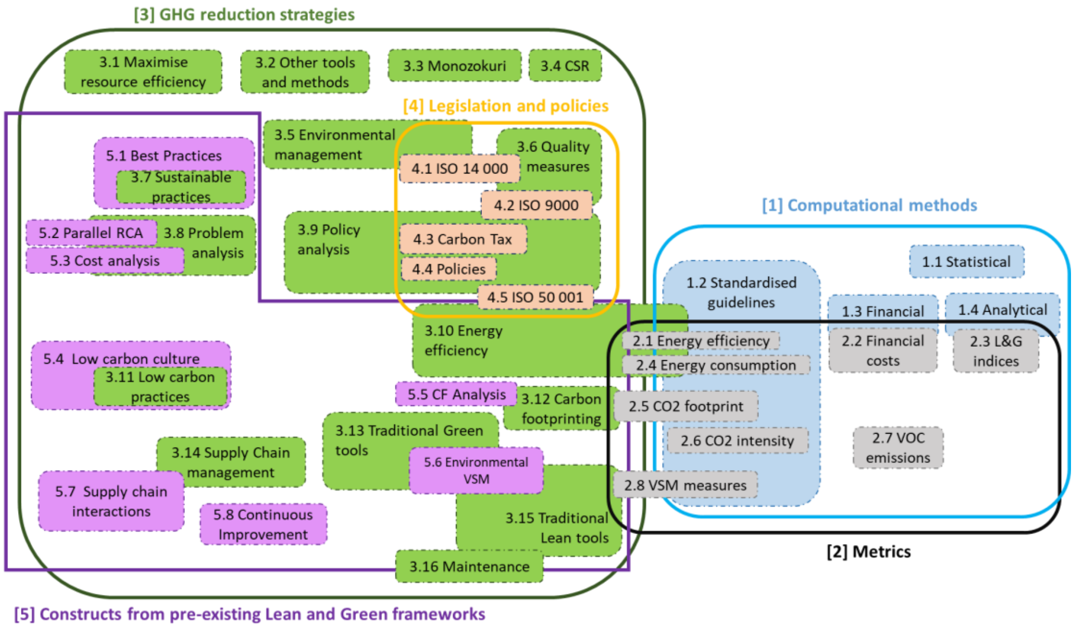

Figure 4: Literature-based Conceptual Lean and Green framework for GHG reduction in the manufacturing industry

Each element is colour coded and numbered, incrementing left to right from the top and bottom of each bordered line (theme). The overlaps of each bordered line depict their relationship amongst each other. Similarly, the overlap of various design elements illustrates mutual inclusion or exclusion between respective traits.

On the right-hand side, the framework stipulates GHG computation methods (in blue) which can be used for further analysis. One approach may be a statistical approach by means of simulation modelling or experimental design studies [26, 27]. A more popular approach is through standardised guidelines for energy, CO2 and value stream mapping performance measures using Greenhouse gas guidelines, carbon foot printing or environmental value stream mapping [28, 29]. Other methods include a financial approach by means of cost-profiling [26], envelopment analysis [30] or the use of an analytical method involving optimisation models, structural equation modelling (SEM) and state space modelling [31, 32].

From a strategic standpoint (top left-hand corner in green), organisations can maximise their resource efficiency using a resource-based view, reduce material consumption or increase resource consumption. Monzokuri is a Japanese term symbolising creative and balanced manufacturing of products, in harmony with nature and society [33]. Other Lean and Green tools and methods include 5 Why, Ishikawa diagrams, TRIZ (Theory of Inventive problem solving), Affinity Diagrams and PDCA [34, 35, 36]. Some of these strategies are associated with certain forms of legislature, policies, or international standards (middle centre in orange). These prompt higher compliance with tax regulations and environmental reporting ranging from energy audits to GHG reporting. These resources guide strategies concerning environmental management, quality, policy analysis and energy efficiency.

The last theme in the bottom left-hand corner (constructs from pre-existing Lean and Green frameworks in purple) was used to conceptualise the nature of the proposed framework in Figure 4. Best practices are associated with those which are sustainable. An in-depth analysis on the operational efficiency and environmental performance can be achieved through parallel root cause-analysis, cost and carbon footprint analysis. Additional elements include managing supply chain interactions, invoking continuous improvement, maintenance or instilling a low carbon culture. This framework identifies environmental value stream mapping as the preferred tool for GHG reduction [18, 29, 37]. Therefore, any such methodology aimed at GHG reduction must incorporate this tool to map out, identify and improve on environmental performance.

Collectively, this framework provides the elements needed for GHG reduction in a manufacturing industry. While the design elements and themes included in the conceptual literature-based framework represented manufacturing industries across the world, a further need existed to verify the elements of the framework for the South African manufacturing industry. This verification process was fulfilled by means of a survey.

3.2 Survey findings

3.2.1 Participants demographics

Survey participants stemmed from the South African manufacturing industry. The representation of this industry is embodied in **Figure 5**.

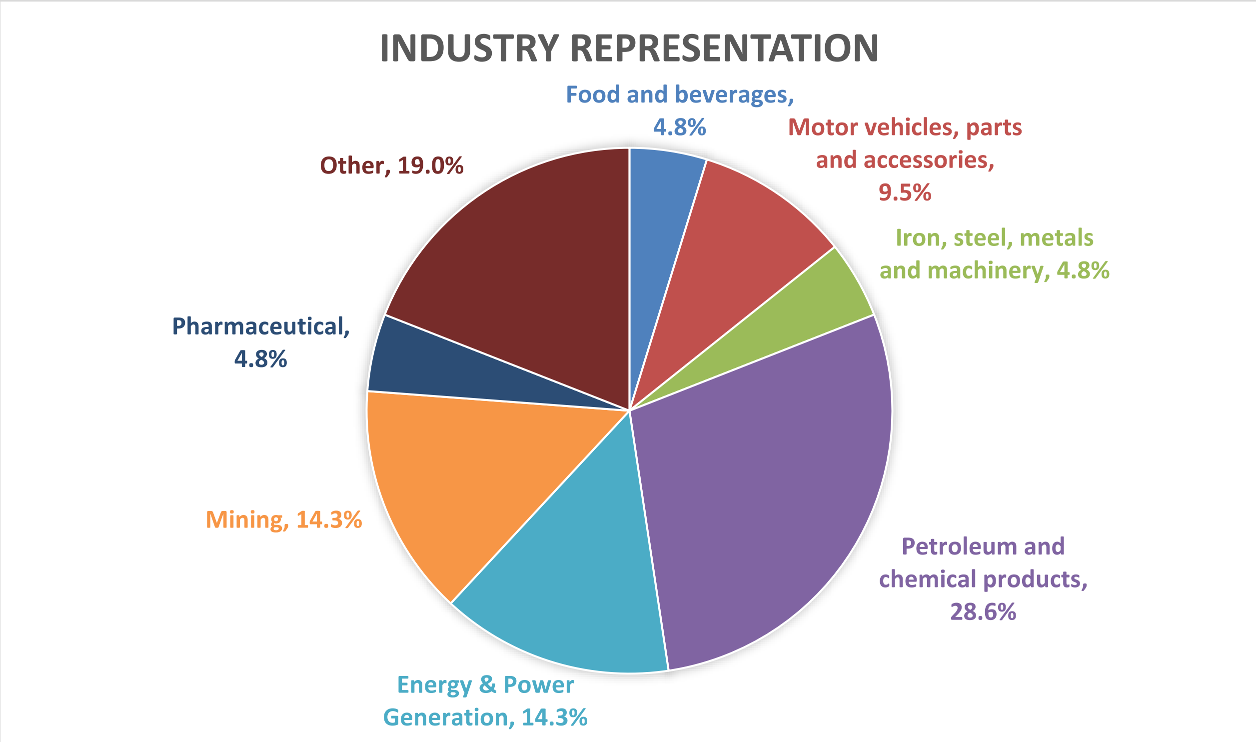

Figure 5: Industry representation of survey participants

Based on the industry representation, the majority of participants work in the petroleum and chemical production industry. This spread of various manufacturing industries shows the unbiased nature and shared experience of this research problem. The degree of industry experience is a vital statistic to include in a qualitative study [22]. A distribution of the years of experience belonging to survey participants is illustrated in **Figure 6**.

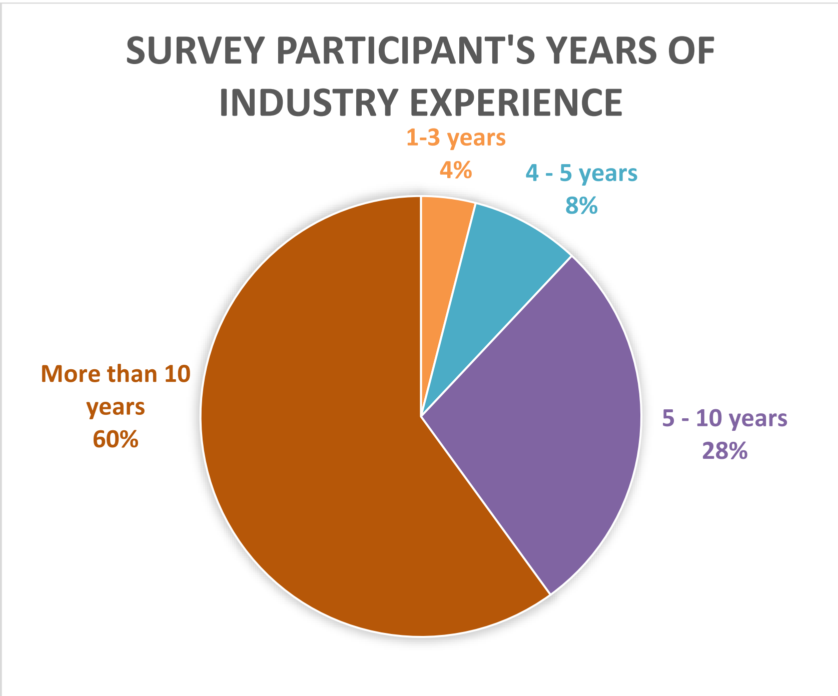

Figure 6: Survey participant years of experience

As illustrated in Figure 6, the level of participant's experience predominately exceeds 10 years. It is probable that these SME's have a higher job position, suggesting that they fulfil a supervision or managerial role in their place of work.

The survey statements and results from the study are provided in

Annexure A. An elaboration on the results and suggestions from participants is further discussed in sections 3.2.2-3.2.5.

3.2.2 Objective 1 - Research problem

The identities of each participant are anonymised, denotated P1 to P25 for the 25 survey respondents. Survey participants felt strongly that the research problem is indeed an issue this industry faces (4.32 average).

There is often a mismatch and uncertainty within manufacturing organisations (P8). Companies require incentives or local government legislature to enforce environmental practices (P19). Interestingly, enforcement is a critical factor from regulatory bodies (P11). This is crucial since environmental specialists experience low buy-in from operational functions in an organisation. This could be improved by ensuring such institutions correctly enforce environmental policies, procedures and legislation.

Several organisations perceive GHG reduction as an additional cost to company (P8, P19). It has a large capital investment with what is believed to be a low return when efficiency improvements are overlooked. Manufacturing companies are pressured to become carbon neutral, which P15 believes is inherently impossible. This argument is also made in literature [38, 39].

South Africa is faced with socio-economic difficulties (P9), cleaner technologies could result in job loss. Due to shareholder pressure, profit margins are at risk when GHG emissions are reduced (P21). Although renewable energy sources and leaner technologies mitigate CO2 emissions (P14), they threaten job employment and may require extreme modifications to existing energy infrastructures (P8, P9). Existing infrastructures do meet air quality emission standards (P11) and legacy-infrastructures will be difficult to upgrade accordingly (P8).

P19 argues that organisations unmotivated to adopt Lean production may lag in their competitive environment. Methods to encourage or adopt Lean manufacturing must be further investigated in South Africa [40].

P25 believes that South Africa is on its way to a greener society already reliant on non-renewable energy sources. The awareness of GHG emissions is still low (P8, P12), and a larger effort should be made to enlighten organisations.

3.2.3 Objective 2 - Design-requirements

The framework design requirements yielded an average score of 3.57. Participants found that the conceptual framework should be further simplified (P10, P16, P3). To achieve this, the pre-existing constructs from Lean and Green frameworks from the conceptual model are modified into strategic elements. Since frameworks are used to guide strategic decisions, the elements from pre-existing frameworks embody the Lean and Green GHG reduction strategies. These modified strategic design elements will thus feature in the refined Lean and Green framework for GHG reduction.

Additional changes included an overlap simplification (P16, P20), footnote (P12, P14, P21) and rotation about the y-axis (P3, P15).

3.2.4 Objective 3 to 6 - Survey questions, design element and theme associations

Majority of participants believe the design elements are appropriate with an average score of 3.9 and 3.88 for design element, theme appropriateness and associations. P19 argues that all are essential. However, 84% of participants believed that certain elements or themes can be omitted from the framework.

P7 and P8 feel that the framework is logically assembled but could be further simplified. Forms of simplification include costs and regulations (P5) and cost analysis (5.3) vs financial costs (2.2) by P8. The analysis of financials must begin with a prescribed method. For this reason, these two elements now share an association. Carbon footprinting strategy (3.12) and carbon footprint analysis (5.5) was consolidated into a new design element "Carbon footprinting & CO2 intensity" with analysis (P8).

32% of participants identified additional design elements or themes which could be incorporated. P17 suggests frame monitoring and control strategies to measure the effectiveness of an organisation's adaption to Lean and Green. For this reason, "Control measures" become an additional strategic design element. Similarly, change management (P7), GHG procedures, and incentives (12B,12L & 12l) for legislation and policies (P10) were also included as a new design element. Since renewable energy sources are a means to mitigate emissions (P14), renewable energy sources became a new strategic element.

P17 advises that ISO 18 001 is also included as it increases full stakeholder participation and an essential element to deploy this framework. ISO 18 001 is an international standard for health and safety systems [41]. Since occupational health and safety is crucial for any organisation, it can be used for active decision-making [42].

3.2.5 Objective 7 – Capability of literature-based framework

In summary, the participants believe that the conceptual Lean and Green framework could reduce GHG emissions in the South African manufacturing industry. This is made evident by the 3.96 average obtained in the table provided in Annexure A. An average score of 4.12 stresses that the five themes could address the problem, while an average of 3.8 suggests that the conceptual framework in itself will do so.

3.2.6 Refined Lean and Green framework for GHG reduction

By incorporating the feedback from the various subject matter specialists, a newly refined framework was designed (**Figure 7**).

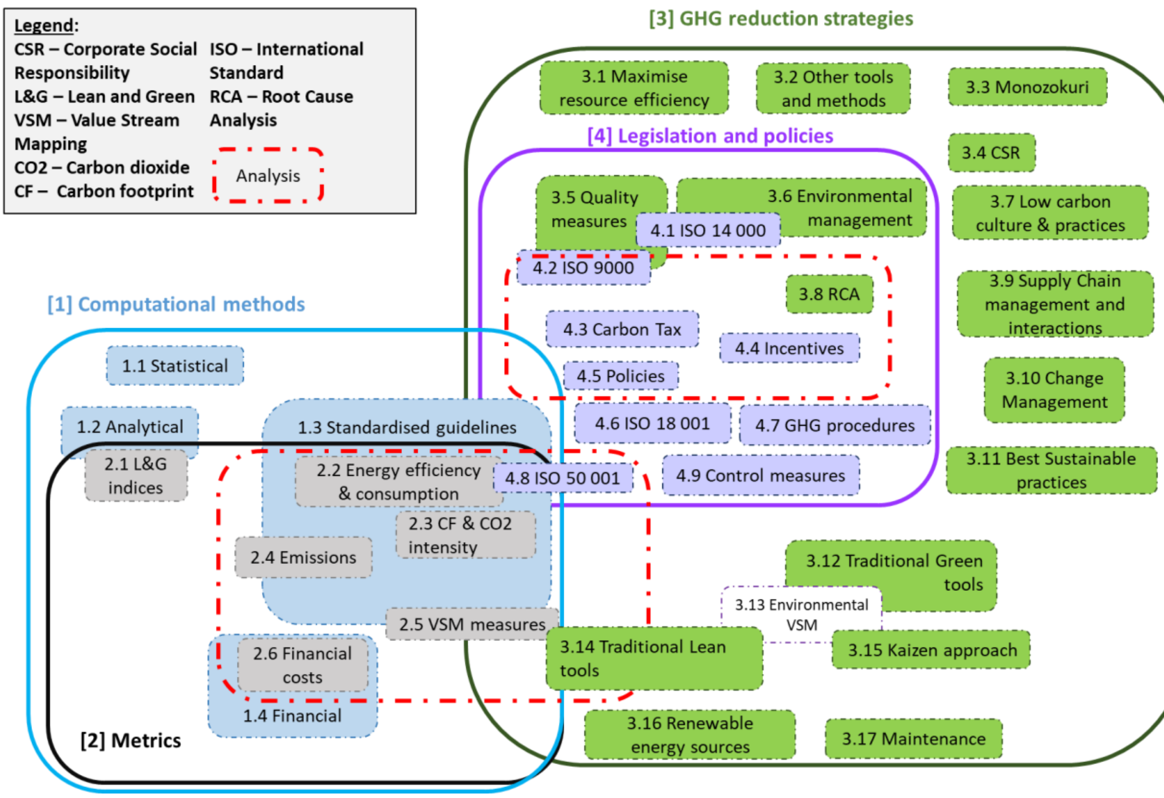

Figure 7: Lean and Green framework for GHG reduction in the South African manufacturing industry

The modifications made to the initial framework has a more intuitive appeal, higher degree of legibility and visual distinction between the various design elements and themes. With the conceptual framework designed, the next research steps must be undertaken. Conclusions and future recommendations are discussed in section 4.

4 CONCULSIONS AND FUTURE RECOMMENDATIONS

Based on the survey results and refined framework, a means to GHG reduction in the South African manufacturing industry can be achieved using the framework proposed in this study. By deploying Design Science Research in this study, the refined framework was thus designed.

Several survey findings were not included in the refined framework. P7 argues whether Monzokuri should be incorporated in the model. However, Monozkuri is a core principle pertaining to Lean and Green [43]. It is also referred to as "the older sister of sustainable manufacturing" [15]. P8 recommends optional or essential design elements which can be used for objective analysis in industry. With the combination of Lean and Green part of a new field of research, and GHG emission reduction by means of this principle sailing uncharted waters, more research is required. For now, all design elements in the framework are considered essential until it is physically implemented in industry, or by means of a methodology developed.

"It is very difficult to predict the usefulness of a framework without testing it on real world case studies to get actual results" (P14). In correlation with this comment, Authors [44, 45] advise that the iterative use of the framework and expert opinion in industry will further validate that the theory in the framework provides the best available explanation (solution) for the problem using literature. This coincides with principles of construct validation. Thus, the practicality of the designed framework will be realised and validated in industry when used in case studies.

Based on the survey results, the framework has been validated. The same can be said for the framework design requirements, relationship and relevance of each design element and theme. This framework outlines the essential design elements and themes applicable to the manufacturing industry of South Africa. Furthermore, these are considered to holistically represent the principles of Lean and Green.

Considering that Lean and Green is still in its infancy stages, it is yet to be fully realised and implemented in South Africa. Despite the use of lean for sustainable practices, the application of this newly coined paradigm has yet to take form. Therefore, a deep understanding of Lean and Green implementation strategies is needed. For this reason, future research could analyse the implementation factors for Lean and Green in South Africa, followed by an implementation model for Lean and Green similar to David SM [46]. In addition, a methodology could be developed to assess the levels and degree of paradigm integration.

A noteworthy research cause can further contextualise Lean and Green in the South African context. Moreover, Lean and Green can be defined within other sectors in South Africa. One could also consider the effects of future carbon trading and pricing strategies. The strategies recommended by Alton et al [47] suggest that modifications to carbon taxes that include carbon adjustments and appropriate carbon tax revenue recycling can ensure that environmental regress is compensated with a fair economic benefit.

With the current COVID-19 pandemic, new ways of configuring processes, procedures and systems become essential. According to Cohen [48], the need for sustainable practices may be of greater need than ever. This pandemic may serve as an experimentation for downsizing the consumer economy and promote sustainable consumption transitions. Lean and Green may assist in shaping the new society and strategies organisations can turn to.

Higher levels of economic development have proven to decrease energy consumption intensities [49]. Furthermore, energy consumption and CO2 emissions share a unidirectional causality. Hence, strategies, business models or innovations which spur economic development can indirectly reduce CO2 emissions in South Africa. The relationship and environmental gain from these activities can be further investigated.

Despite the need for greening processes, industries must constantly re-evaluate aspects for the most beneficial outcome. These decisions ultimately shape our society and must therefore be taken in the right direction, in the most careful and calculated manner possible. Lean and Green may become a new field of research that can deliver an environmentally conscious, productive, innovative and strategically driven society benefiting oneself and our environment.

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ANNEXURE A

Table 1: Summary of survey design requirements, statements and questions

Objective	Design Requirement or Subject matter specifications	Survey statement (ST) or Question (Q)	Avg. result (5)
1. Verify the research problem	Convert research problem into survey statement	ST1: The South African manufacturing industry is challenged with reducing their GHG emissions.	4.32
2. Verify the established design requirements for the framework	The framework must co-ordinate elements within each theme using a standard approach	ST2: A standard approach (in the form numbering and colours) is used to formalise, categorise and compartmentalise each element in a theme.	3.84
	The framework must be simple in structure	ST3: The framework is simple in structure.	3.28
	The framework must be legible	ST4: The framework is legible.	3.68
	The framework must be intuitive	ST5: The framework is intuitive to follow.	3.16
	The framework must provide a visual distinction between various elements	ST6: The framework separates and merges different elements	3.68

Objective	Design Requirement or Subject matter specifications	Survey statement (ST) or Question (Q)	Avg. result (5)
	The framework must holistically detail elements associated with Lean and Green	ST7: The framework formalises, categorises & compartmentalises elements relevant to Lean and Green	3.8
	The relationship amongst the five themes must be defined using visual distinctions or overlaps between the design elements	ST8: By viewing the overlaps between the elements, the relationships between the 5 themes can be understood.	3.56
3. Verify that all design elements and themes are appropriate for GHG reduction	Ensure all design elements are relevant	Q1: Are there any elements or themes within the framework which should be omitted? Q2: If yes, please elaborate	84% Yes 16% No
4. Verify that any potential design elements and themes are identified	Accept suggestions on outstanding elements or themes which were not identified in the literature	Q3: Are there any outstanding elements or themes which you can identify? Q4: If yes, please elaborate	32% Yes 68% No
5. Verify the associations	Ensure that the appropriate direct and	**(ST9-22) State the level by which you agree or disagree with the association and layout design for the following elements:**	

Objective	Design Requirement or Subject matter specifications	Survey statement (ST) or Question (Q)	Avg. result (5)
between the design elements	indirect relationships between each design element are made		
		9. Standardised guidelines with energy efficiency, energy consumption, CO_2 footprint, CO_2 intensity and VSM measures	4.08
		10. Financial costs and financial computational methods	3.88
		11. Lean and Green indices and analytical methods	3.75
		12. Carbonfootprinting strategy, Carbon footprint analysis and CO_2 footprint metric	4.08
		13. Environmental VSM with Traditional Green tools and Traditional Lean tools	3.96
		14. Traditional Lean tools and Maintenance	3.71
		15. Supply chain management and interactions	3.79
		16. Low carbon practices and a low carbon culture	3.88

Objective	Design Requirement or Subject matter specifications	Survey statement (ST) or Question (Q)	Avg. result (5)
		17. Problem analysis strategy with parallel root cause analysis and cost analysis	3.92
		18. Best practices and sustainable practices	3.92
		19. ISO 14 000 with environmental management and Quality measures	3.75
		20. ISO 9 000 with quality measures and policy analysis	3.75
		21. ISO 50 001 with policy analysis and energy efficiency	3.88
		22. Policy analysis with carbon tax and policies	4.04
6. Verify the associations between the themes	Ensure that the appropriate direct and indirect relationships between each theme are made	**(ST23-25) State the level by which you agree or disagree that the following themes share an association:**	
		23. GHG reduction strategies with legislation and policies, constructs from pre-existing Lean and Green frameworks, metrics and computational methods	3.88
		24. Metrics with computational methods and constructs from pre-exiting Lean and Green frameworks	3.88

Objective	Design Requirement or Subject matter specifications	Survey statement (ST) or Question (Q)	Avg. result (5)
		25. Legislation and policies with GHG reduction strategies and constructs from pre-existing frameworks	3.88
7. Validate that the framework addresses the research problem	Validate the themes and framework against the research problem	**(ST26-27) State the level by which you agree or disagree that:**	
		26. The five themes could address the research problem.	4.12
		27. The framework could address the research problem.	3.8

IMPROVING VEHICLE SERVICE SCHEDULES AT AN AUTOMOBILE COMPANY

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ABSTRACT

The scheduling of vehicle appointments for services and repairs at automobile service organisations has an impact on overall efficiency and customer service. This paper describes the challenges of service scheduling and the implications that this has on technician utilisation, availability of spare parts, costs and customer service. Requirements are then developed that define the efficiency and effectiveness of a scheduling system drawing upon literature from other industries. A solution is proposed that integrates information and optimises the scheduling of vehicles to improve the performance of the scheduling system. The solution is tested and shows that efficiency, technician utilisation and customer satisfaction are likely to improve if the solution is implemented.

Keywords: appointment scheduling, vehicle maintenance, customer service

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1 INTRODUCTION

1.1 Context

This paper discusses a study that was conducted at the service and after-sales department of an automobile company that specializes in premium-brand, luxury vehicles. This department is responsible for managing maintenance, repair, quality control and complaints and installing new features in vehicles. The quality of service provided by this department is seen as a potential key differentiator in the marketplace and as a result, the department needs to enable high levels of customer satisfaction while remaining efficient and cost-effective. While automotive sales are an imperative part of automobile dealerships, the servicing of vehicles has the potential to generate a substantial portion of revenue and profit. After-sales departments can generate up to 80% of the company's profit [1] and the service market of a vehicle may generate over three times the turnover of the purchase price during the vehicle's lifecycle [2].

1.2 Background

The service division within the after-sales department under consideration currently generates far less profit than their theoretical potential with an average annual efficiency that is 30% below the OEM's benchmark. This study aims to increase the efficiency of the service and therefore the overall after-sales department by interrogating the technician utilisation and appointment scheduling system that is used. The scope includes the process of scheduling vehicles for repairs and services at multiple dealerships of the automobile company.

Currently, there is no standard approach for the scheduling of repairs and services which results in high variability between the approach followed by dealerships. Some dealerships schedule vehicles using a predetermined number of cars per technician per day. Therefore, neither the job that must be done on the vehicles, which determines the expected time that the technician will spend working on the vehicle nor the number of available working hours in a day is taken into consideration. As a result, technicians are frequently either over- or underutilised on different days as the time it takes to complete a certain number of vehicles varies from one day to the next. An analysis of historical data showed that technician utilisation, when measured as booked hours over available hours, ranged between 25% and 150% for 15 technicians over two weeks. Another factor that affects technician efficiency is that in some dealerships, customers are assigned to specific technicians to facilitate relationship building which complicates the scheduling of vehicles on any particular day. Also, at some dealerships, part availability is not taken into consideration at the point of scheduling vehicles which can lead to delays and higher variability in job time.

1.3 Research Aim and Objectives

This study aims to develop an improved system design for the scheduling of vehicles to improve technician utilisation and customer service. The resulting objectives are to:

- Gain a thorough understanding of the current scheduling systems at the different dealerships using a current state and root cause analysis
- Conceptualise appointment scheduling principles and approaches
- Identify key decisions of the scheduling system
- Design an improved scheduling system
- Evaluate whether the new scheduling system leads to better technician utilisation
- Establish the impact of the (new) scheduling system on the down-stream processes at the dealerships.

1.4 Method

This study started with an investigation of the as-is process by collecting data over five weeks at two different dealerships of the automotive brand. Data was collected through observation, document analysis and interviews with the area manager, service managers, technicians and admin and bookings clerks. This data was used to understand the current processes and issues and the key factors that affect vehicle scheduling. After gaining a thorough understanding of the problem, root causes were analysed followed by a literature review to aid in the design of an improved scheduling system by analysing the work of other authors who have examined or solved similar problems. System analysis, based on the V-model [3] was then completed to study the system and identify key variables. Different concepts were considered and a final integrated system design was developed. A simulation model was also developed to illustrate how the system will work and to test the final design. The testing compared the new system design against the as-is process over a week. An implementation plan and risk analysis of the new system was also developed.

2 CURRENT STATE OF SCHEDULING AT THE COMPANY

2.1 Process Overview

Vehicles are generally booked for services or repairs using a manual system. This system is triggered when a customer calls the company to make a booking. These calls are handled by a booking clerk who, if available, asks the customer several questions and then completes the booking with the information provided by the customer. The clerk then creates a job card that is given to the relevant service advisor. The clerk also informs the customer of any important information.

An online scheduling process is also currently available for customers. For this process, the customer completes an online schedule request. The bookings clerk then receives a system-generated email informing them of the request. They then call the customer back to complete the booking for the service or repair as per the manual process.

The information that is needed from the customer to complete a booking includes full name, contact details, customer identification document number and the vehicle registration, identification number and current mileage. The customer will also be asked which service the vehicle is being booked in for and if some other repairs or issues need to be attended to. Key customer information is stored in a database and is verified each time a customer schedules a booking with the dealership.

2.2 Findings and Observations

2.2.1 The Booking Process

Booking clerks at the company are not technically trained. As a result, they do not always have insight into the services or repairs that are required. This can lead to customer frustration and miscommunication of issues and required repairs to the technicians. In a previous study conducted at the automobile company, low employee skill levels were found to be one of the root causes of low productivity and efficiency [4].

One of the dealerships previously attempted to implement a system where the scheduling of vehicles was not based on the number of cars per technician per day, but rather on the number of hours of work content and available hours per day. This initiative was not a success and was abandoned. From the interviews, it was established that some of the reasons for this included a lack of technical knowledge and skills to make scheduling decisions at the booking point and ineffective change management.

Typically, therefore, it was found that the number of cars scheduled per technician varied significantly between dealerships and that the job duration is not considered when allocating cars per technician. Other observations were that bookings clerks could forget to inform the customers of all important information which can lead to customer dissatisfaction and failure demand in the process.

2.2.2 Part Availability

When a vehicle is booked in, if the parts needed for a specific service or repair are not available, the job on the vehicle cannot be completed which can result in inefficient technician utilisation and customer inconvenience. Not all parts are stocked at the dealerships, due to inventory policies and although the OEM manages fast-moving parts, this can become a concern for vehicle repairs where required parts cannot always be predicted or for older or rare vehicle models. The available information on vehicles scheduled for servicing is therefore not always compared with the dealer's parts availability, which adds to delays and therefore inefficiencies.

2.2.3 Unscheduled Vehicle Work

At times, vehicles can be towed in due to breakdowns. These vehicles bypass the booking process and as a result, booking clerks do not factor this work into the job schedule. Often, unscheduled clients arrive at the dealership requiring work on their vehicle. To retain good customer relationships, these customers are generally attended to. There are also instances when customers have additional requests or problems when they bring the vehicle in for a repair that they did not mention to the booking clerk. According to Nandalall [4], a root cause of low productivity for the automobile company is late job distribution and job disruption of technicians which can result in delays when acquiring the tools and parts required to complete work on vehicles. Therefore, all of these instances affect scheduling, technician utilisation and customer satisfaction.

2.2.4 Shuttle Services

The automobile company offers a shuttle service to customers. However, they do not always have an indication of which customers want to make use of the services nor where they need to be taken. This necessitates that the information is collected each morning once customers arrive meaning that the driver can only establish a route on a specific day once all information is collected. The result of this is that the shuttle frequently leaves the dealership late, which results in customer inconvenience. An analysis of two weeks of data showed that customers waited, on average, 19 minutes longer than expected for the shuttle with a maximum wait time of 49 minutes.

2.2.5 Specialist Technician Skills

Only some technicians have been trained in diagnostic skills to determine a fault when it is unclear what the problem on the vehicle is. Currently, when appointments are made, this is not taken into consideration. Ultimately, this means that when an assigned technician cannot determine the problem on a vehicle, a technician with diagnostic skills intervenes. As this diagnostic work is not considered in the schedule, the technicians with diagnostic work can become over-utilised on any particular day resulting in delays in vehicles that were assigned to them.

The findings from the initial current state analysis indicate that the current scheduling system can be improved. There is currently no defined strategy for vehicle bookings, approaches used inherently lead to high variability which impacts on technician utilisation and customer service.

3 LITERATURE

This literature review provides an overview of appointment scheduling and distinguishes between different decision levels, scheduling strategies, relevant performance measures and methods for solving scheduling appointment problems. The scope of this review does not include the management of the after-sales department. Therefore, topics such as the estimation of job duration and business process re-engineering are excluded.

3.1 Appointment Scheduling and Planning Systems

Appointment scheduling and planning systems are used in service operations to regulate the daily activities of the organization [5]. Appointment scheduling is directly related to improving client satisfaction and reducing operational cost [6, 7].

Many similarities exist between hospital Operating Room (OR) scheduling and vehicle scheduling. For both scheduling types, allocated time slots and variable procedure times exist. In these scenarios, the variability of service times depends on service type and customer characteristics [5]. These stochastic service times may increase the company's idle time and overtime as well as uncertainty and customers' waiting times [5,6]. The performance of operating rooms are principally affected by the scheduling and planning policies that are used [8] and an effective appointment scheduling system should increase the utilisation of the resource centre involved [9].

In some service systems, when customers make an appointment, there is a pre-existing match between the customer and the individual provider of the service, that is, each provider has their own customer queue, a single-provider system. When customers can be seen by any available service provider, this is known as the multiple-provider system [5]. In the latter case, the customer queue is shared among the service providers.

3.2 Decision Levels

Some authors classify decision levels for appointment scheduling and planning systems. Zhu *et al.* [8] classifies the decision levels for OR scheduling and planning as Strategic Level (involving capacity planning, case-mix and capacity allocation), Tactical Level (involving master service scheduling and workload distribution) and Operational Level (for short-term schedule or customer-level decision making). Similarly, Guoxuan and Demeulemeester [10] propose a solution methodology that includes the case-mix planning phase, the master schedule phase and the operational performance evaluation phase. In contrast, Cardoen *et al.* [11] deliberately chose to avoid classifying the decision delineation into these three classical levels. They argue that there are no clear definitions for these three decision levels and that various authors classify different problems into the same class. There is however consensus that scheduling and planning systems need to be fit for purpose and operate at a considered level.

The process of scheduling and planning may be decomposed into two phases, advanced scheduling and allocation scheduling [12]. Advanced scheduling is mainly used to assign a date [8,11,13] while allocation scheduling is used to determine the start time of service tasks and the allocation of resources [11]. Zhu *et al.* [8] suggest that the primary goal of the scheduling process is to create a feasible work plan for every day.

3.3 Scheduling Strategies

There are three scheduling strategies that are typically considered for the Operating Room (OR) scheduling problem. These include a block strategy, an open strategy and a modified block strategy.

3.3.1 Block Scheduling Strategy

When using this strategy, the schedule is organised in blocks that are assigned to specialities. A periodic schedule is then created and resources can be apportioned into slots or blocks for a stipulated duration [8]. This strategy reduces the complexity of the schedule but the schedule is inflexible, when one block is not used, it is not reassigned or available.

3.3.2 Open Scheduling Strategy

In an open strategy, a greater degree of freedom exists in that any case may be scheduled into any room [14]. With the open scheduling strategy, surgeons have the freedom to choose to operate on a patient in any available room on any workday. No surgeons must reserve a block time in advance [8]. With the open scheduling strategy, the First-In-First-Out (FIFO) strategy is followed. The open scheduling strategy can lead to more flexible schedules but due to dynamic patient arrival times and stochastic process times, waiting times can be increased and the schedules can be more difficult to manage and more inconvenient for surgeons. The OR utilisation rates can also be lower [8].

3.3.3 Modified Block Scheduling Strategy

The modified block scheduling strategy is a combination of the block and open scheduling strategies [15]. This strategy supports block scheduling in that it checks underutilisation by instigating policies to modify it. The block can be opened to other surgeons if it is seen that the underutilisation of an upcoming block is likely to happen [8]. According to Fei *et al.* [15], the strategy of block scheduling can be modified by reserving and releasing some blocks a relatively short-time in advance to improve flexibility.

3.4 Performance Measures

Any schedule needs to be measured to determine schedule effectiveness and efficiency. For this study technician utilisation, customer waiting time and service throughput are introduced.

3.4.1 Technician Utilisation

Since the utilisation of the technicians was identified in the aim of the study, it is an important performance measure. The utilisation rate of technicians is an indication of technician productivity (how much time they are spending on value-adding time vs. non-value adding time and waste). The utilisation rate of employees is also key to the profitability of the automobile company since the customers pay for the time technicians work on their vehicles. Therefore, there is a positive correlation between revenue and technician utilisation as underutilised workstations and technicians denote unnecessary costs. In contrast to this, workstations and technicians that have a very high utilisation rate, without any time buffers in their schedule, exhibit high uncertainty and may be unstable. This is because the slightest change, like a walk-in customer or an unexpected problem on the vehicle, may cause a disruption in the schedule and lead to overtime and client dissatisfaction.

3.4.2 Waiting Time

According to Cardoen *et al.* [11], one of the most frequent complaints from customers are long waiting lists. Therefore, a decrease in the waiting list of some of the technicians will be beneficial (some technicians have waiting lists and others do not). An effective Scheduling and Planning system can decrease waiting lists by optimising allocation and use of resources [14].

3.4.3 Throughput

Throughput refers to the number of vehicles that are completed (services and repairs) at the end of a workday. It is possible to have more equal technician utilisation, that is, less under- and overutilisation, but have lower throughput. This is not ideal and therefore it is important to concurrently consider the throughput of the after-sales department as a performance measure.

3.5 Approaches for Solving this Problem

3.5.1 Queuing Models

Queuing-based studies have considered queuing-based approaches to schedule surgery patients [16], however, in queuing literature, authors assume stationary service and arrival times as well as an infinite time horizon, which is not necessarily the case in scheduling environments [17]. Queuing models may offer beneficial insights on scheduling decisions regarding the effect of uncertainty, however, they have limitations when it comes to the environment of scheduling. Queuing models also typically require strong assumptions such as exponentially distributed procedure durations which are not always realistic [17].

3.5.2 Mathematical Programming and Optimisation

Optimisation techniques are popular for solving scheduling problems. Deterministic and stochastic optimisation has been used by researchers for scheduling strategies [17]. Deterministic models will be briefly described in this section, and stochastic models will be discussed under heuristic models. Ozkarahan [18] proposed a block-booking scheduling strategy where she designs a goal programming model for scheduling surgeries.

3.5.3 Simulation

Erdogan and Denton [17] indicate that although simulation models do not provide a closed-form of solutions like queuing theory models do, simulation models are more flexible. This is because the assumptions on the probability distributions of procedure durations may be more flexible. Simulation tests may also be performed to provide supplementary information on the performance of proposed models [8].

3.5.4 Heuristic Models

Some researchers have addressed surgery scheduling problems with heuristic models. This is because the combinatorial and stochastic nature of these problems can result in challenging optimisation models [17]. It is often stated that heuristic approaches are indispensable to solve real-sized or practical problems efficiently. However, Cardoen *et al*. [11] propose that several exact methods appear in literature that seem to be powerful enough to solve realistic problems, even when multiple criteria are considered. In a similar vein, Fei *et al*. [15] developed an integer programming model that assigns elective surgeries with deterministic intervals into several operating rooms. Their objective was to minimize the weighted sum of underutilisation and overutilisation of operating rooms and they solve various cases optimally by using a branch-and-price algorithm.

3.5.5 Stochastic Models

Operating Room scheduling and planning problems may be solved in a deterministic way where the duration of the procedure is assumed to be without fluctuation and is deterministic. This simplifies the problem at hand. However, Zhu *et al*. [8] indicate that in real situations there is inherent variation in service times, even when the same person is doing the same work. Therefore, this problem may be regarded as a stochastic problem. Vogl [19] formulates a two-stage mixed-integer stochastic program and suggests a set of solution heuristics for computing operating room schedules that are realistic, practical and easy to implement. They also show that a minimal sequencing rule based on the duration variance of the surgery may be used to produce significant reductions in the total waiting, overtime and idling costs.

3.6 Conclusion

Various approaches to solve this problem exist analytically. From a mathematical point of view, the problem may be abstracted as a combinatorial optimization model for assigning a given amount of resources while considering objectives [8]. The objectives for this paper may be to either minimize the service costs and overtime or to maximize the utilisation rates of the technicians.

4 DESIGNING THE SYSTEM

4.1 Design requirements

The scheduling system is required to determine the following:

- The number of technicians required at every dealership
- The workload distribution of the technicians
- The allocation of clients (Will they be allocated to technicians/workstations using a shared queue or specific timeslots?)
- The starting time for each procedure
- The choice between a single provider system or a multi-provider system with one queue

The number of services on vehicles that can be performed is already known. The duration of services is not known with certainty. However, there is a standardised time based on the scope of work that the motor vehicle company prescribes for every service and repair which can be used in this study. The aim will be to maximize the utilisation of the technicians and their workstations.

4.2 Design Considerations

Several considerations are unique to this study that need to be incorporated into the design.

4.2.1 Uncertainties

Many factors can affect the performance of an appointment system. This includes service time variability, customer preferences, the experience level of the scheduling staff and the available information technology [20]. When customers do not have a service plan or insurance, they must pay cash. Before the technician may start with the service on their vehicle, the technician should get approval from the customer first. At times, the customer declines and no services are performed on that specific vehicle. Uncertainty exists regarding the service times, cancellations, no-shows, and customers declining the quote they are given which affects variability, revenues and technician utilisation and introduces additional complexity when designing an appointment system.

4.2.2 Customer preferences

Customers have different degrees of loyalty concerning their “assigned” technician. Some customers prefer a particular technician, even if this leads to extra waiting time, whereas other customers will switch to alternate technicians. Some customers prefer an appointment as soon as possible. Other customers prefer a specific day of the week and do not mind waiting. Incorporating customer preferences will result in a model that is computationally challenging and mathematically complex [21]. Customer choice patterns are unpredictable at times and difficult to obtain from currently available data.

4.3 Designing the Appointment System

A block scheduling strategy will be used for this study. The reason is threefold; firstly, the block scheduling system does not have as many relevant disadvantages when compared to the open scheduling system. Secondly, the scheduling strategy for the Automobile Company does not need to be flexible, since there are no "emergency operations" that will need to take place. Lastly, one of the requirements from the Industry Partner of this study was that this report should aid in creating an online scheduling system where users will be able to book their motor vehicles in themselves. A block scheduling strategy will enable the motor vehicle company to take the system designed in this report and implement it into a user-friendly website.

Within the automobile setting, a customer can generally make an appointment for their vehicle the next day. Therefore, advanced scheduling will not be the primary focus because the lead time of the Automobile Company is not very large. However, advanced scheduling may be of assistance during peak times or at dealerships that have a lead time of a few days. Allocation scheduling may be beneficial for a leading-edge appointment scheduling system in the automotive industry.

Cayirli and Veral [22] state that the appointment schedule design may be broken down into a series of decisions. This includes the appointment rules and adjustments made to reduce uncertainty.

The appointment rules that will be used to schedule customers may be described in terms of the following variables:

- The Block Size (n_i): That is, the number of customers that can be scheduled to the i_{th} block.
- Appointment Interval (a_i): Lehtonen; *et al.* [23] state that there is no remarkable difference between using half-hour or hourly-based block intervals. However, they found that by using half-hour blocks, the productivity increased and as a result, half-hour block intervals are used.
- Duplicate Block: The number of customers given an identical appointment.
- Every Technician has eight available working hours (the number of hours that may be booked on the system) in a day. (Technicians with an apprentice may have more available working hours)

Offline scheduling is currently being used but results in inefficient technician productivity. With online scheduling, a model can be designed to ensure that the demand per technician is scheduled optimally, but Zhang; *et al.* [24] investigated patients' initial acceptance and ongoing use of a standard and simple online scheduling service and found that 89% of the interviewed patients revealed a reluctance to adapt to the online service.

Therefore, an integrated scheduling model is proposed where the current offline scheduling system is improved with an online scheduling system. This will be a more efficient solution and less prone to errors, especially since variables such as part availability will also be included in the final design. Another advantage is that more than one person will be able to work on it at the same time. However, customers will still have the option to call the scheduling staff and make their appointment. The scheduling staff will use the same system that will be used by customers that book their appointments.

5 THE FINAL DESIGN

The final design consists of the system architecture, use case diagram and a database. Thereafter, a simulation model with a mock dashboard was created in Microsoft Excel to determine whether the new system will address the problem.

5.1 System Requirements

The user interface of the appointment scheduling system will allow customers and booking clerks to communicate with the database and to navigate the system. The inputs to the system will be captured through the user interfaces employing a registration form, an appointment booking form and information the booking clerk will have to keep updated. Inputs that are required when designing the initial system includes the different vehicles of the Automobile company, required times to do services and repairs and the parts required for every service.

The inputs that are required with each booking include customer information, vehicle information, customer preferences, technician availability and part availability.

This data is processed and stored in the database. A scheduling algorithm is used to minimize the non-value-adding time in a technicians' day. The output of the system is a schedule, a job card for every appointment and updated part quantity and technician availability information.

5.2 System Architecture

A two-tier architecture was designed that can run on the client's browser. These tiers are the server-side and the client-side which is based on the Zhang *et al*. [25] three-tier system architecture. A representation of the system architecture is shown in Figure 1. In the first tier, the client-tier, customers and booking clerks can make appointments and access appointment information with any web-browser on the internet. The two tiers connect using web services to ensure efficient information exchange. In the second tier, the server-tier, all requests and inputs are processed by the various servers. A web server is used to connect to the internet. The web server will also handle the static content (such as static images and HTML files) and HTTP requests. The application server manages and delegates the dynamic HTTP requests and manages the appointment scheduling services including multiple technician scheduling, searching for available appointments, rescheduling appointments, and appointment cancellation and confirmation. The results from the application server will be converted through the web server into an HTML format and will be displayed in the HTML web page. The portal server is used to process customer registration and login requests. A database will be used to store all data that is retrieved.

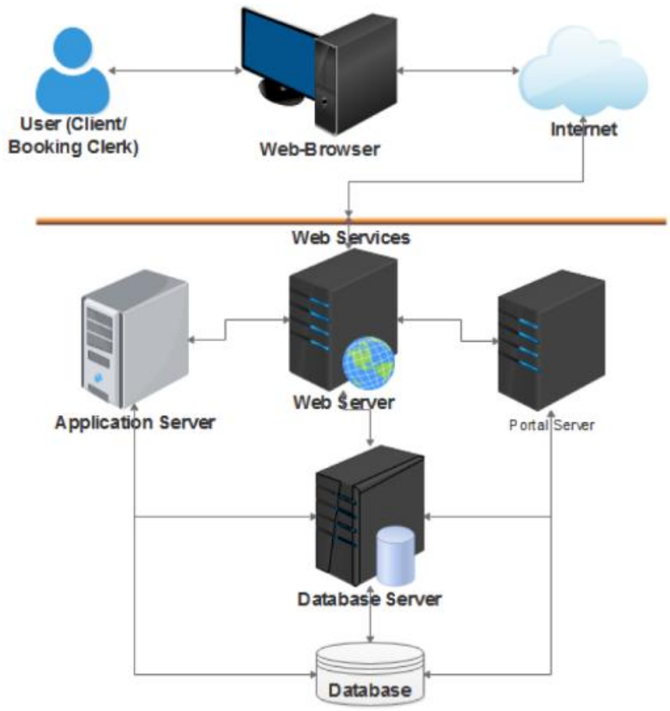


Figure 1: System Architecture

5.3 Database Design

There are seven entities within the database for the appointment scheduling system that was created using MySQL workbench. An Entity Relationship Diagram (ERD) of the database design is shown in Figure 2. The CUSTOMER entity contains all the information of the registered customers. The CUSTOMER entity has a one to multiple relationships with the VEHICLE and APPOINTMENT entities respectively, since one customer may own many vehicles and make many appointments. The APPOINTMENT entity will store all relevant information regarding the appointment. This includes the type of job to be done, the day and time of appointment, parts needed for the job to be completed and the technician assigned to the vehicle. The relationship between the APPOINTMENT entity and the JOB entity is one to multiple because although a job can only be performed once on a vehicle during an appointment, several types of jobs may be performed during an appointment (i.e. 75 000 km service and a windshield repair). The VEHICLE entity will store information regarding the vehicle which includes the service history to prevent rework. A further refinement of the system could be to add the skillset of technicians to the technician entity so that these skills can be taken into consideration when checking and assigning technicians. The TECHNICIAN entity has a one to multiple relationships with APPOINTMENT, as an appointment can only have one technician assigned to it but a technician can be assigned to various appointments. The JOB entity will contain all the different types of services that can be completed at the Automobile Company, including an estimation of the duration of the specific job as well as the parts that will be needed for that job. The PART entity will contain all the information regarding the part availability of the Automobile Company. For dealerships that allow customers to choose their technician, a further relationship would need to be created between the customer and technician entities.

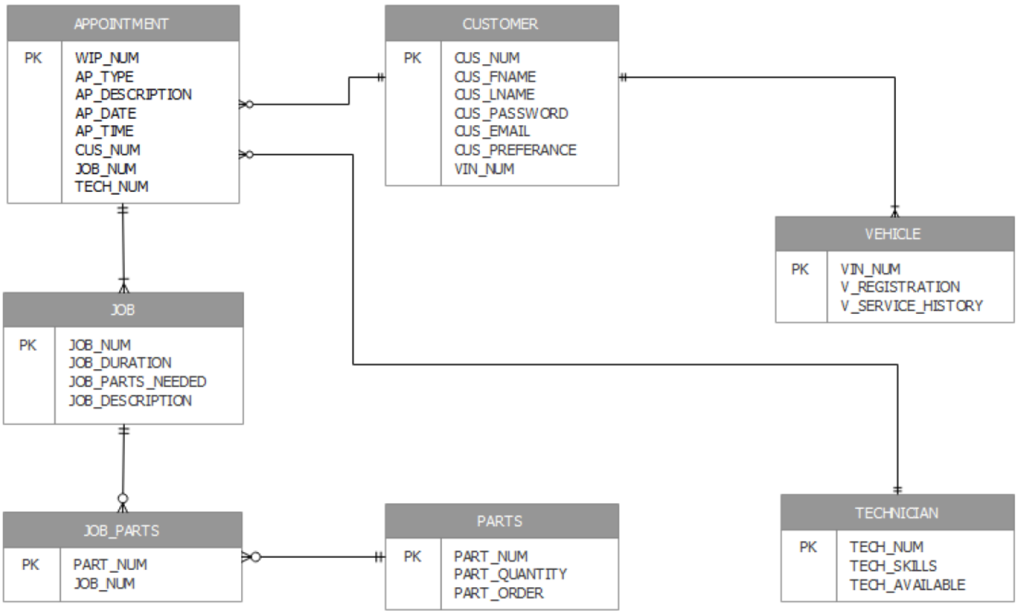


Figure 2: Entity Relationship Diagram

5.4 Simulation

To simulate and test the appointment booking system, a simulation model was created in Microsoft Excel. The appointment scheduling system aims to minimize the total unutilised time of the technicians. Test data can be entered via a series of spreadsheets. The output of the simulation is displayed on a dashboard, Figure 3(a-c), that shows information regarding technician utilisation, part availability, part demand and customer information for a specified day. The dashboard also displays the number of customers that wanted to make a booking but could not due to parts not being available. Furthermore, information regarding shuttle service requirements is also included.

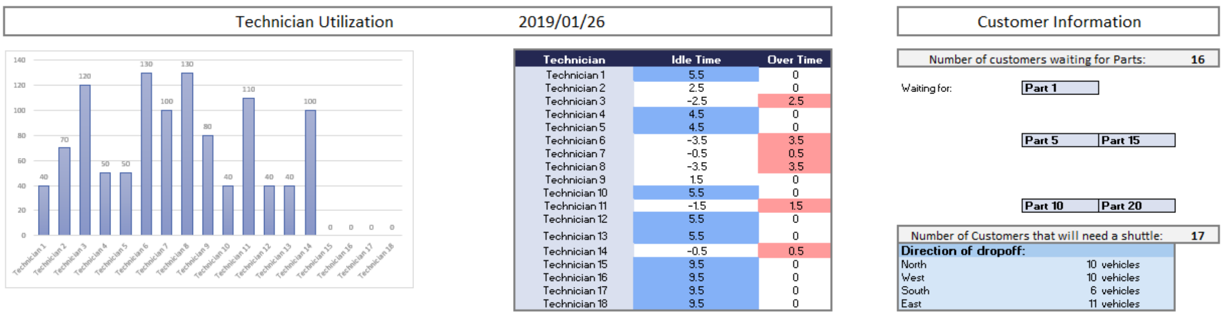
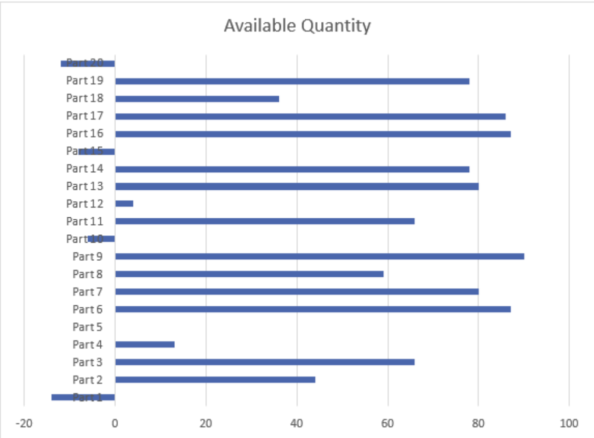


Figure 3a: Dealership Dashboard

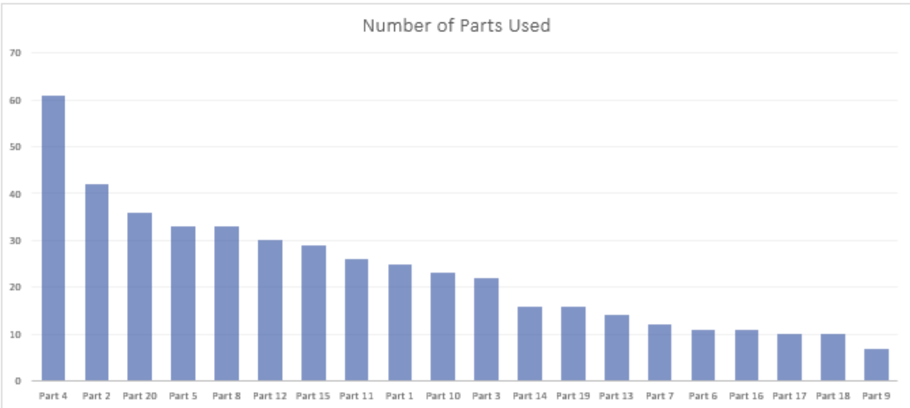
Part Availability



Part Type	Available Quantity	Order more
Part 1	Very Low	Yes
Part 2	Medium	No
Part 3	High	No
Part 4	Low	No
Part 5	Low	Yes
Part 6	High	No
Part 7	High	No
Part 8	High	No
Part 9	High	No
Part 10	Low	Yes
Part 11	High	No
Part 12	Low	No
Part 13	High	No
Part 14	High	No
Part 15	Low	Yes
Part 16	High	No
Part 17	High	No
Part 18	Medium	No
Part 19	High	No
Part 20	Low	Yes

Figure 3b: Dealership Dashboard

Part Demand



Parts Needed for this day:

Part Type	Number
Part 1	7
Part 2	8
Part 3	6
Part 4	13
Part 5	10
Part 6	2
Part 7	4
Part 8	6
Part 9	1
Part 10	8
Part 11	5
Part 12	9
Part 13	3
Part 14	3
Part 15	5
Part 16	2
Part 17	2
Part 18	2
Part 19	3
Part 20	6

Figure 3c: Dealership Dashboard

5.5 Results of the Simulation

The simulation model was run for a typical day using actual data from one of the dealerships. The actual (or current) booking system and technician utilisation is shown in Figure 4 and Figure 5. The optimised (or new) output as a result of running the scheduling algorithm is included in Figure 6. By comparing these diagrams, it is clear that the technician utilisation has reduced variability and that technicians are more evenly loaded with no technicians being over utilised.

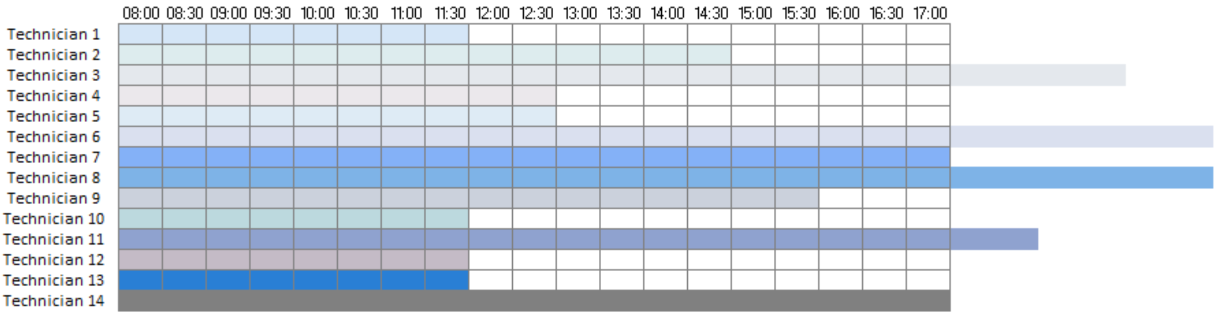


Figure 4: Schedule – Current Appointment Booking System

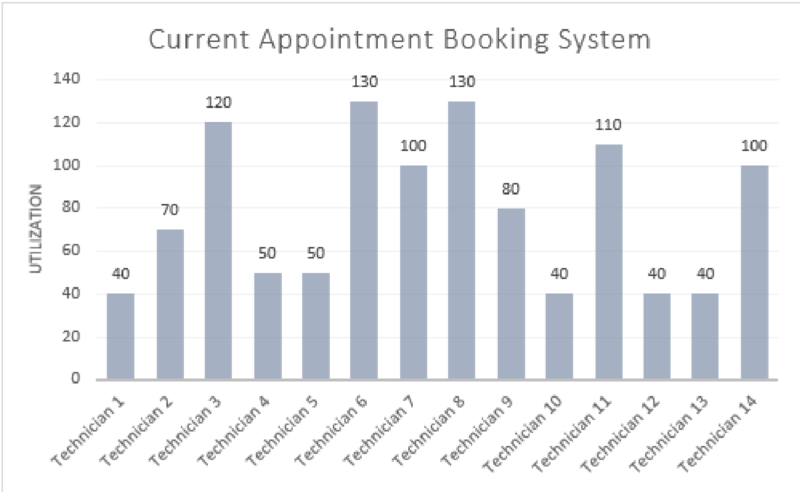


Figure 5: Technician Utilisation – Current Appointment Booking System

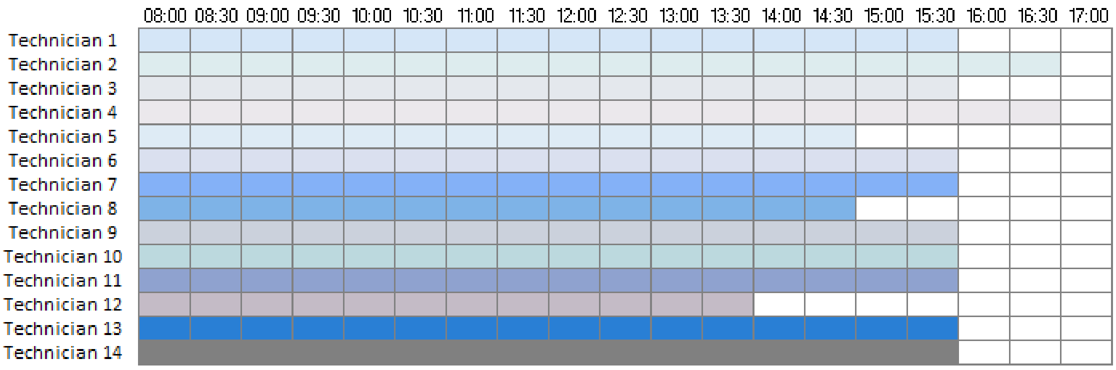


Figure 6: Schedule – New Appointment Booking System

5.6 Risk Analysis and Implementation Plan

A risk analysis was done to identify and create awareness of possible risks associated with the project. This may potentially help to avoid project delays, disruptions or even failure in further stages. The risk analysis with mitigations can be seen in Table 1. The success of the implementation of this project depends on various internal and external factors. This includes a well-established project team and the effective monitoring of the progress, changes and risks of the project. A high-level overview of the implementation plan is illustrated in Figure 7.

Table 1: Risk Analysis

REF	RISK	RISK SEVERITY	RISK LIKELIHOOD	RISK LEVEL	MITIGATIONS
1	Executives fail to support the project	INTOLERABLE	IMPROBABLE	HIGH	Have enough data to support project and build a solid burning platform beforehand.
2	Change management overload	TOLERABLE	IMPROBABLE	LOW	Implementation Plan: Ensure that there is not many changes happening at the same time.
3	Project team misunderstand requirements	UNDESIRABLE	POSSIBLE	MEDIUM	Have regular meetings where requirements are discussed and have someone who oversees the project to ensure that a gap does not develop between the expectations, requirements and what actually happens.
4	Under communication	UNDESIRABLE	POSSIBLE	EXTREME	Have regular meetings as well as a clear communications strategy
5	Impacted individuals aren't kept informed	TOLERABLE	POSSIBLE	MEDIUM	Define a communications strategy and have regular meetings.
6	Training isn't available	INTOLERABLE	IMPROBABLE	MEDIUM	Plan beforehand
7	Training is inadequate	UNDESIRABLE	POSSIBLE	EXTREME	Ensure the training program is adequate.
8	Team members with negative attitudes towards the project	INTOLERABLE	POSSIBLE	HIGH	If possible, separate the toxic person from other team members. Take a closer look at their behaviour and what's causing it and try to help them. Give them direct feedback and explain the consequences of their behaviour.
9	Failure to integrate with business processes	INTOLERABLE	IMPROBABLE	MEDIUM	Ensure that adequate planning is done beforehand to prevent this.
10	Project disrupts operations	INTOLERABLE	POSSIBLE	EXTREME	Implementation Plan: Ensure that during the implementation, no business operations are disrupted.
11	Service duration estimates are inaccurate	UNDESIRABLE	POSSIBLE	HIGH	Have time buffers, continually monitor the duration of different services and update the system if needed.
12	The user interface is low quality	INTOLERABLE	IMPROBABLE	MEDIUM	Incorporate adequate time for planning, design, testing, bug fixing, retesting, changes, and documentation, and properly account for nonworking time such as weekends, holidays, and staff vacations.
13	Poor software quality	INTOLERABLE	IMPROBABLE	MEDIUM	Use formal tools to track software discrepancies including resolution, Plan for enough time for testing and bug fixing, Require walk-throughs and inspections, Insist on validating requirements and design specifications.
14	Users resistant to change	ACCEPTABLE	POSSIBLE	LOW	The integrated system ensures that they may still make a booking by following the same process they have always followed.
15	Overly optimistic schedule	TOLERABLE	POSSIBLE	MEDIUM	Have time buffers, Set a realistic schedule that is approved by someone with experience

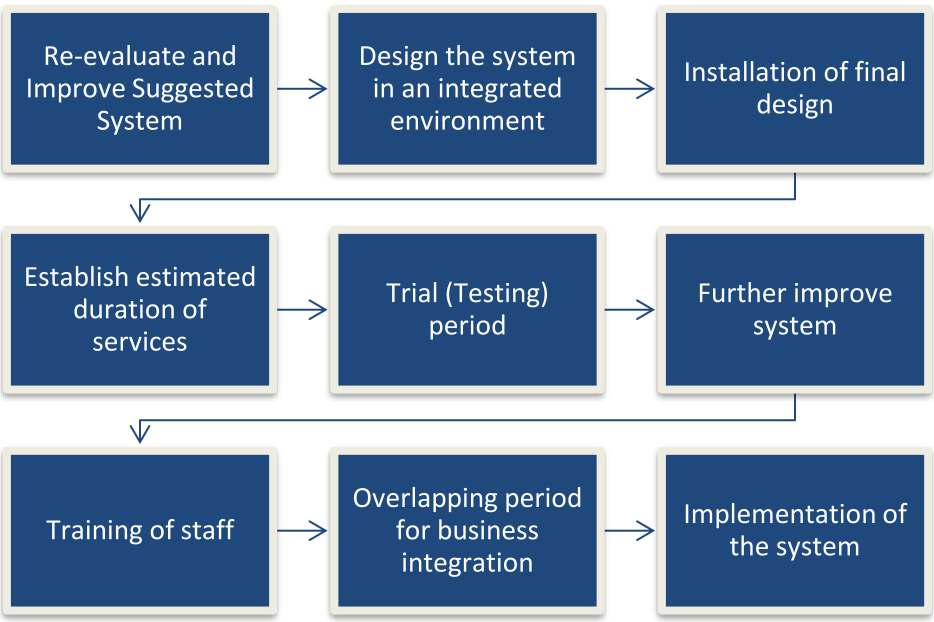


Figure 7: High-level Implementation Plan

6 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

For the company under consideration, the factors affecting technician utilisation include the current appointment booking system, scheduling integration with spare part planning and the effectiveness of data collection at the booking point. This paper discusses an integrated appointment scheduling model that could be used for online and offline bookings. It is recommended that variables such as special tools, part availability, special skills of technicians and contingencies are taken into consideration when appointments for services and repairs are made. A simulation was run to compare technician utilisation, including idle time and overtime, using the logic of the proposed model. It was shown that efficiency, technician utilisation and customer service can be improved using the proposed system. Using an integrated appointment booking and scheduling system has the additional benefit of enabling data collection that could be used for decision making, customer relationship and performance management in future.

6.2 Recommendations

If actual performance history is built into the database, the database can be the valuable source for future optimisation of time, performance and actual parts consumption. In future, the company can consider designing a mathematical model to optimise technician utilisation. Such a model would, however, require detailed stochastic service times of vehicles and the no-show rate of customers. This model could also then consider a multi-provider system with one queue which could reduce the effect of service time variability. Dealerships could also use this model to evaluate the impact of pairing customers and technicians on technician utilisation.

This model focuses on optimising technician allocation to service jobs but assumes that there is limited waste and inefficiencies within the service times and processes that are undertaken to complete each job. It is expected that there is significant waste within these processes and this would be a separate study that would affect technician productivity and utilisation as well as the variability and length of service times.

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RELATIVE ACCURACY OF TIME SERIES FORECASTING METHODS EVALUATED IN RAIL FREIGHT RESOURCE DEMAND FORECASTING

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ABSTRACT

Demand forecasting plays a critical role in operational and tactical planning. Planning in a stochastic and dynamic setting is complex. The longer the planning horizon, the greater the degree of uncertainty. In rail freight operations, resource allocations and despatch is done well before the actual demand is known. Accurate forecasting is critical to optimized resource allocation and movement of freight. In this paper, we evaluate the relative accuracy of two-time series forecasting methods in a stochastic case, for both in-sample and out-of-sample data, over a four year period. The results are encouraging. For the freight rail demand forecasting case, a more accurate forecasting method is identified. The results are generalizable to the freight transportation industry and help institutional planners identify more accurate forecasting techniques. The cost savings are potentially significant.

Keywords: Demand forecasting, rail freight, time series, transportation planning, seasonality and non-stationary

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1 INTRODUCTION

Demand forecasting is crucial to business success. Forecasting impacts strategic, tactical and operational planning [1-2]. Resource utilization efficiency and customer demand satisfaction levels are critical business operational metrics heavily dependant upon demand forecast accuracy [3].

Predictive analysis provides vital guidance for present and future operations and the macro-to-micro control can be strengthened significantly by improving the accuracy of short-term planning [4]. Long term planning in an uncertain market remains a challenge.

Lwesya [5] evaluated Exponential Smoothing and Auto-Regressive Integrated Moving Average (ARIMA) models relative to alternative time series models for the short-term horizon. We argued that companies applying more accurate forecast management methodologies are relatively more competitive. The search for and development of more accurate forecasting tools is important. In this paper, we evaluate the relative accuracy of the Holt-Winters and ARIMA forecasting models in a stochastic setting. Secondary data from a rail freight terminal is applied in the models.

2 MATERIALS AND METHODS

Liquid fuels provide energy for a wide variety of economic processes and activities. Storage at points of consumption are limited. Efficient bulk transportation and timeous availability is critically important to the economy. Planning is a function of forecast accuracy. Demand forecast accuracy, logistical planning processes and associated transport resource utilization efficiencies determine timely availability of fuel energy.

2.1 Dataset

We consider monthly fuel demand data for a selected freight rail network terminal. We use secondary data. The time series data covers a four year period from April 2012 to March 2016. The time series plot is illustrated in Figure 1 below.

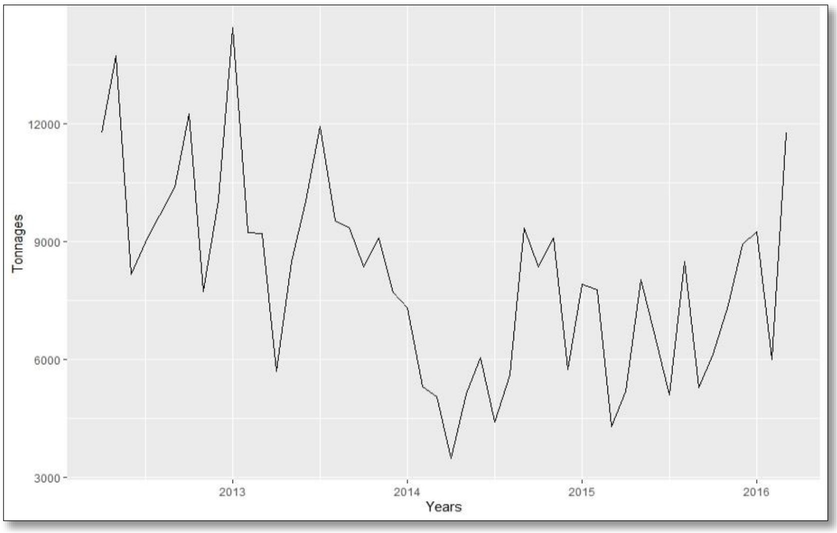

Figure 1: Monthly fuel demand from April 2012 to March 2016

2.2 Methodology

The in-sample and out-of-sample forecast accuracy of two exponential smoothing methods namely the additive and multiplicative Holt-Winters seasonal models are determined and compared against three variants of ARIMA models. Four forecast error measures were applied and these include Root mean square error (RMSE), Mean absolute percent error (MAPE), Mean absolute error (MAE), and the Bayesian Information Criterion (BIC). The objective was to determine/select the most accurate forecast method for the given case and inturn enhance planning accuracy.

2.2.1 Holt-Winters Model

Exponential smoothing methods are useful for short-term forecasting. The method assigns exponentially decaying weights as the observations get older [6].

According to the Box–Jenkins methodology, a time series can be characterized as seasonal or non-seasonal. Non-seasonal models generate forecasts when less seasonal time series exists when compared with seasonal models that offer more accurate forecasts when a strong seasonal variation is present in the time series [5,7]. Seasonality arises when the time series is non-stationary [8]. Trend also results in non-stationary time series. Senyefia [9] defines stationary properties as when the mean and variance of the variable are not time-variant and there is no trend in the series.

The Holt-Winters seasonal model has three smoothing equations that allow the data to be modeled based on the level, trend and seasonal factor in which all are updated by exponential smoothing [10]. The model has three smoothing parameters, α, β and ɣ. The Holt-Winters seasonal model has two variants namely, the multiplicative and additive.

Multiplicative Holt-Winters Model

The multiplicative seasonal version is appropriate for use in a time-series when the amplitude of the seasonal pattern is changing proportionally to the level of the series [2,11].

$$L_t = \alpha \frac{x_t}{S_{t-C}} + (1-\alpha)(L_{t-1} + T_{t-1}) \quad \textbf{(1)}$$

$$T_t = \beta(L_t - L_{t-1}) + (1-\beta)T_{t-1} \quad \textbf{(2)}$$

$$S_t = \gamma \frac{x_t}{L_t} + (1-\gamma)T_{t-C} \quad \textbf{(3)}$$

Where

L_t = estimate of smoothed level

T_t = estimate of smoothed trend

S_t = estimate of smoothed seasonal multiplicative factor

x_t = recent actual value

C = seasonal period (C = 12 months)

α, β and ɣ smoothing parameters for level, trend and seasonality respectively, (0< α, β, ɣ < 1). Forecasts at the end of period t, the forecast Ft, k for period t + k is formulated as follows:

$$F_{t,k} = (L_t + kT_t)\, S_{t+k-c} \quad \textbf{(4)}$$

Additive Holt-Winters Model

The additive seasonal version is appropriate for use in a time-series when the amplitude of the seasonal pattern is roughly constant to the level of the series [5].

$$L_t = \alpha(x_t - S_{t-C}) + (1-\alpha)(L_{t-1} + T_{t-1}) \quad (5)$$

$$T_t = \beta(L_t - L_{t-1}) + (1-\beta)T_{t-1} \quad (6)$$

$$S_t = \gamma(x_t - L_t) + (1-\gamma)T_{t-C} \quad (7)$$

Where L_t and S_t are the smoothed level and trend as defined above in Equation (1 &2) and S_t is the estimate of smoothed seasonal additive factor.

Forecasts at the end of period t, the forecast Ft, k for period t + k is computed by:

$$F_{t,k} = L_t + kT_t + S_{t+k-c} \quad (8)$$

2.2.2 Seasonal and Non-seasonal Autoregressive Moving Average Models

Louvieris [12] describes ARIMA model as primarily concerned with iteratively building a parsimonious methodology that can accurately represent both the past and future patterns of a time series.

Autoregressive (AR) models are used to capture autocorrelation in a series similar to a linear regression and to improve forecasts generated for short-term. AR models are dependent on a weighted linear sum of its previous values (lags) $Y_{t-1}, Y_{t-2}, Y_{t-3\dots} Y_{t-n}$ of Y_t and white noise ε_t. The model is formulated as follows:

$$Y_t = \beta_0 + \beta_1 Y_{t-1} + \beta_2 Y_{t-2} + \beta_3 Y_{t-3} + \cdots + \beta_p Y_{t-p} + \varepsilon_t \quad (9)$$

Where

Y_t = observed time series value at time t

ε_t = white noise (randomness)

$\beta_0, \dots \beta_p$ = the constant and the model parameters

Moving average (MA) models use past forecasts errors in a regression-like model [6]. Instead of using previous values like in the AR model, the MA model uses only the error terms $(\varepsilon_1, \varepsilon_2, \varepsilon_3 \dots \varepsilon_2)$ for forecasting. MA models are dependent on the random error terms which trail white noise, where Y_t is a function of $(\varepsilon_t, \varepsilon_{t-1}, \varepsilon_{t-2}, \epsilon_{t-3}, \dots)$. The MA model depends on q, of its past values defined as MA(q), where MA(q) represents the order of the model. The model is represented as follows:

$$Y_t = \varepsilon_t + \emptyset_1 \varepsilon_{t-1} + \emptyset_2 \varepsilon_{t-2} + \emptyset_3 \varepsilon_{t-3} + \cdots + \emptyset_q \varepsilon_{t-q} \quad (10)$$

Where

Y_t = observed time series value at time t

$Y_{t-1} + Y_{t-2} + Y_{t-3} + \cdots + \varepsilon_{t-1} + \varepsilon_{t-2} + \varepsilon_t$ = previous values and forecast error

$\beta_0, \beta_1, \beta_2, \beta_3, \dots, \emptyset_1, \emptyset_2, \emptyset_3 \dots$ = constant and the model parameters

ARMA (p,q) models are more appropriate for stationary time series. Stationary time series are common in models like AR (autoregressive), MA (moving average) and ARMA (autoregressive moving average) which are regarded as stationery processes [13].

The Box-Jenkins methodology recommends transformation of seasonal (non-stationary) time series to non-seasonal (stationary) equivalents before modeling. The transformation is effected through differencing. The seasonal ARIMA model is formulated by including additional seasonal terms in the existing non-seasonal ARIMA model and is denoted by ARIMA (p,d,q) (P,D, Q)s [6]. Where (p, d, q) represents the non-seasonal terms of the model, (P, D, Q) signify the seasonal terms of the model and s is the period of a seasonal pattern repeated in the series. The formula is further expressed as follows:

$$\varphi_P(B^s)\beta_p(B)(1-B^s)^D(1-B)^d Y_t = \omega_Q(B^s)\emptyset_q(B)\varepsilon_t \quad (12)$$

Where

$$\beta_p(B) = 1 - \beta_1 B - \beta_2 B^2 - \cdots - \beta_p B^P = \text{Autoregressive part of order p (AR(p))}$$

$$\varphi_P(B^s) = 1 - \varphi_1 B^s - \varphi_2 B^{2s} - \cdots - \varphi_P B^{Ps} = \text{Seasonal Autoregressive part of order P (SRA(P))}$$

$$\emptyset_q(B) = 1 + \emptyset_1 B + \beta_2 B^2 + \cdots + \emptyset_q B^q = \text{Moving Average part of order q (MA(q))}$$

$$\omega_Q(B) = 1 + \omega_1 B^s + \omega_2 B^{2s} + \cdots + \omega_Q B^{Qs} = \text{Seasonal Moving Average part of order Q (SMA(Q))}$$

$$(1-B)^d = \text{differencing of order d (I(d))}$$

$$(1-B^s)^D = \text{differencing of order D (SI(D))}$$

The Box-Jenkins methodology is achieved in a three-phased approach namely, model identification, parameter estimation and model diagnostic checking.

(1) Model Identification

The first step is to determine whether the series is stationary or non-stationary. The Box-Jenkins methodology is only applicable to a time series that contains stationary variables. Graphical representation of Autocorrelation Function (ACF) and Partial Autocorrelation Function (PACF) can assist in determining the presence of stationarity in a series. ACF is used to measure the correlation between current observation (Y_t) that are linear dependent to the past observation of period p, (Y_{t-p}) separated by a lag k [14]. PACF is used to measure some form of correlation associated with some degree between (Y_t) and (Y_{t-p}) where intermediate lags are not considered since they have no effect. The Augmented Dickey-Fuller Test (ADF) can also be used to ascertain whether a time series is stationary or non-stationary [15]. When the time series is non-stationary, transformation by differencing should be done.

(2) Parameter Estimation

Seasonal and non-seasonal ARIMA parameters (p,d,q) (P,D,Q) are estimated and used to select the appropriate ARIMA model.

(3) Model Diagnostic Checking

Once the model has been built, it is important to perform diagnostic examination. This is achieved by checking how accurately the model fits the time series. The residuals from the fitted model are examined against adequacy. Graphical representation of the ACF/PACF function can be used to determine the goodness of fit of residuals from the fitted model. The Ljung-Box test may also be applied to examine model goodness of fit. The Ljung-Box test is valid when the residuals of the fitted model bear resemblance to white noise signifying no autocorrelation [9]. When the tests are assessed and found to be statistically invalid then the fitted model has to be re-specified [12]. However, if the model is found to have passed the diagnostic check tests and is statistically valid, then it can be used for forecasting.

In the event a number of alternative models exist, the model that yields the highest accuracy level is selected. Several measures of accuracy are available for comparison purposes.

2.2.3 Forecast Error Measures

In order to identify the most suitable model, the following measures of accuracy have been adopted in this study: Root Mean Square Error (RMSE), Mean Absolute Percentage Error (MAPE), Mean Absolute Error (MAE) and Normalized Bayesian Information Criterion (BIC).

2.2.4 Model Application

Two stages were applied in performing forecasting for the selected models. The first stage was based on separating the dataset into two parts, in-sample and out-of-sample data. The in-sample data of 36 months was used to determine the best fit of the forecasting model. The second stage was applying the selected model in stage one to forecast the monthly demand of fuel tonnages for the next 12 months. The generated forecasts were then compared to the out-of-sample data of 12 months identified in stage one. The prediction methods employed in this paper were the exponential smoothing method and the Box-Jenkins method for building the Holt-Winters and ARIMA models respectively.

3 RESULTS

Summarised below are outputs of the different models under consideration.

3.1 Holt-Winters Model

Tables 1 and 2 below illustrate that the Additive Holt-Winters model has generated relatively lower RMSE, MAPE, MAE and Normalized BIC when compared with the Multiplicative Holt-Winters model. The results suggest that the Additive Holt-Winters model is more appropriate in rail freight demand forecasting.

Table 1: Model statistics results for fitted Additive Holt-Winters model

Model	Model Fit Statistics			
	RMSE	MAPE	MAE	BIC
Additive Holt-Winters Model	1780.708	16.703	1396.326	15.268

Table 2: Model statistics results for fitted Multiplicative Holt-Winters model

Model	Model Fit Statistics			
	RMSE	MAPE	MAE	BIC
Multiplicative Holt-Winters	2002.31	19.453	1541.858	15.503

To further validate the selected model, a diagnostic assessment for the Additive Holt-Winters model was performed to assess the significance of the autocorrelation coefficient for the model fit residuals. Figure 2 below shows that the residual autocorrelation coefficient is non-significant indicating that the fitted additive model is satisfactory.

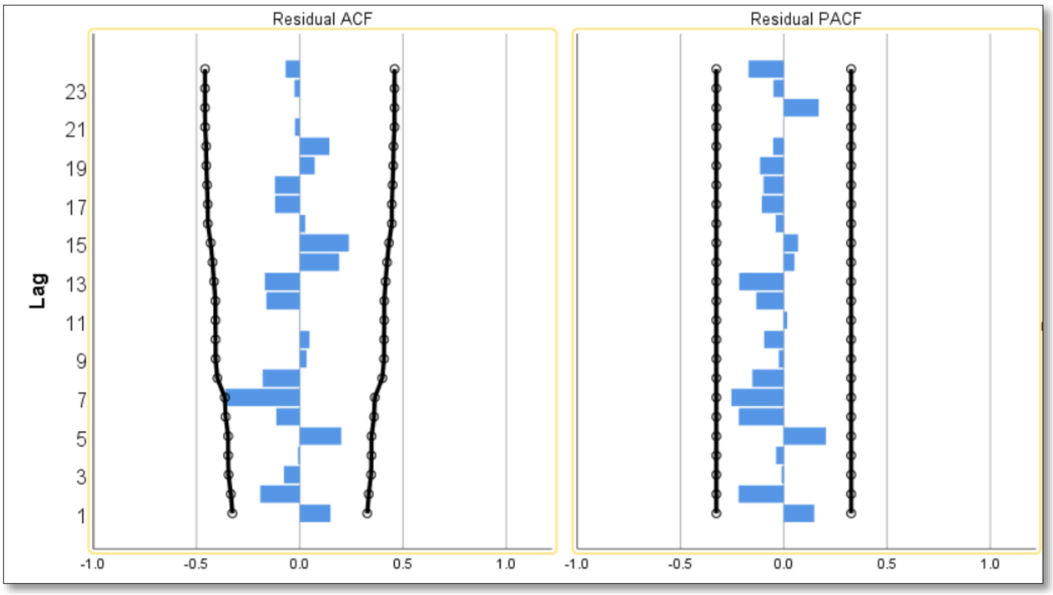

Figure 2: Additive Holt-Winters model residual autocorrelation of the fitted model

3.2 ARIMA Model

The Box-Jenkins methodology was followed to select the most appropriate ARIMA model. The first step is to determine whether the time series is stationary or non-stationary. To determine this, ACF and PACF of the time series were evaluated as shown in Figure 3 and 4 respectively.

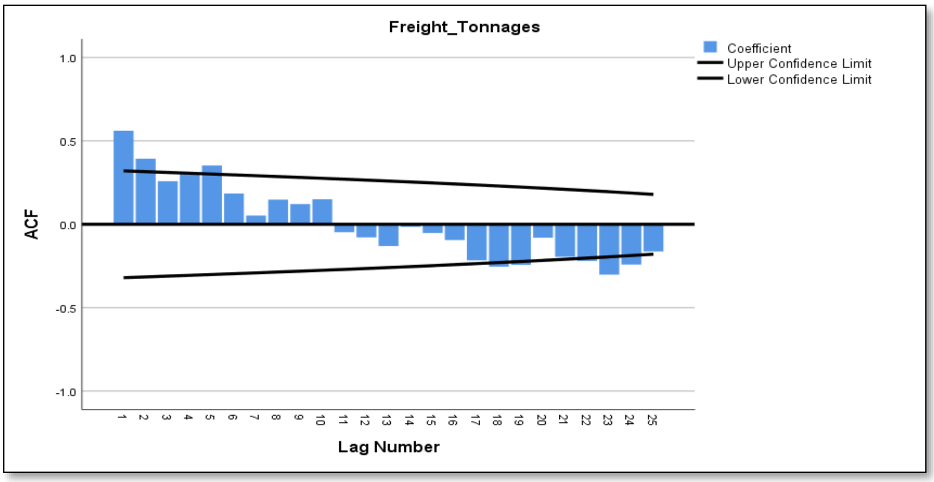

Figure 3: Autocorrelation Function plot

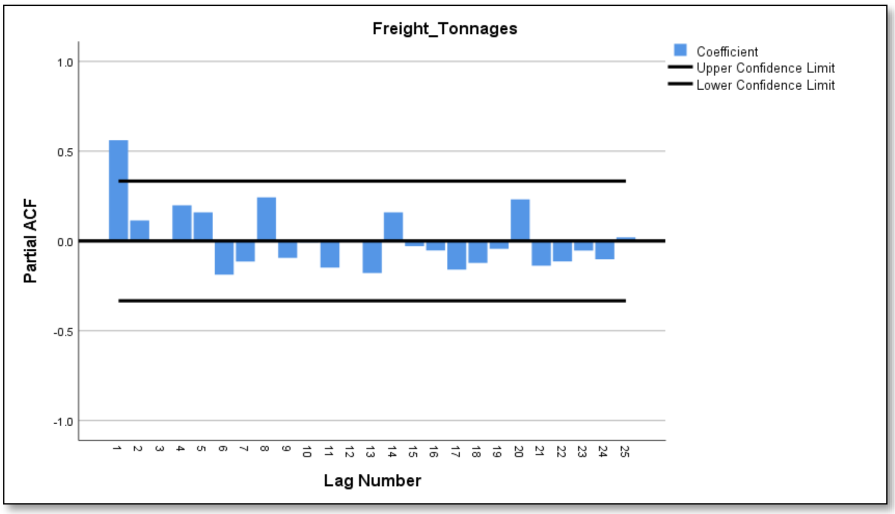

Figure 4: Partial Autocorrelation plot

The ACF and PACF plots show that there are values outside the control limits of the insignificant areas. The ACF plot shows higher values at lag 1, 2, 5,18, 23 and 24 while the PACF plot shows a higher value at lag 1. The plots confirm that the series is non-stationary.

Differencing was performed to transform the series as shown in Figure 5 below. The plot shows that the series is now around the constant mean and variance indicating stationarity. The series was differenced once suggesting that to carry out forecasts the original time series of the observed data should be differenced at least once when forecasting.

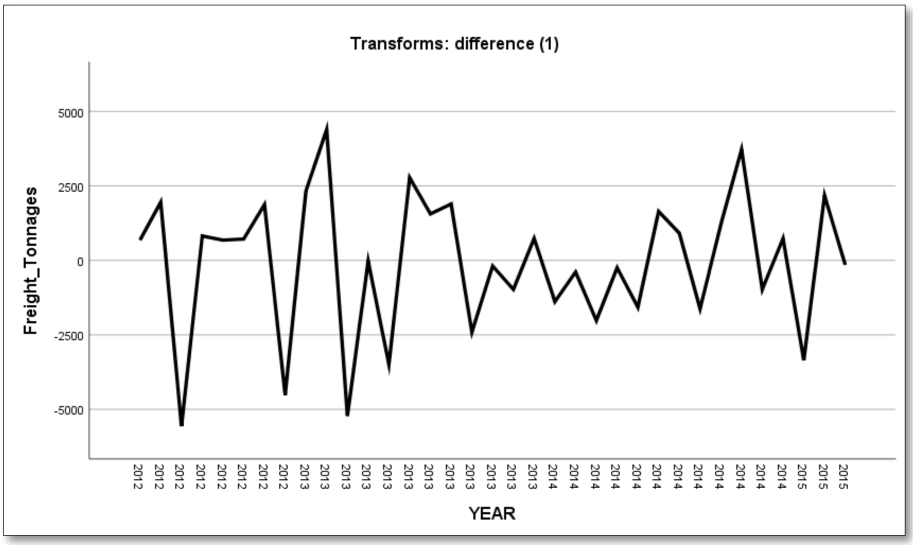

Figure 5: Differenced plot of Freight Tonnages series

The next step was to identify the seasonal and non-seasonal ARIMA parameters of (p,d,q) (P, D,Q) for the ARIMA model and selecting the prospective model using the measures of accuracy.

Table 3: Model results for ARIMA

Model	Model Fit Statistics			
	RMSE	MAPE	MAE	BIC
ARIMA (0, 1, 0)(0,0,0)[12]	2385.212	23.689	1861.757	15.656
ARIMA (0, 1, 1)(0,0,0)[12]	2165.799	21.667	1676.853	15.564
ARIMA (1, 1, 0)(0,0,0)[12]	2285.126	22.820	1816.310	15.672

Table 3 above, shows the summary of competing ARIMA models. It was observed based on the measures of accuracy that the non-seasonal ARIMA (0,1,1) yielded relatively better accuracy measures of RMSE (2165.799), MAPE (21.667), MAE (1676.853) and Normalized BIC (15.564) when compared with the other ARIMA models. Lastly, diagnostic checking was carried out for non-seasonal ARIMA (0,1,1) on residuals from the fitted model. The ACF and PACF plots in Figure 6 below, show that there is no significant autocorrelation between residuals and that the residuals represent white noise at different lag intervals. Also, the p-value of the Ljung-Box test (significant when $p < 0.05$) was observed to 0.658 indicating that the model is statistically valid and the residuals are random.

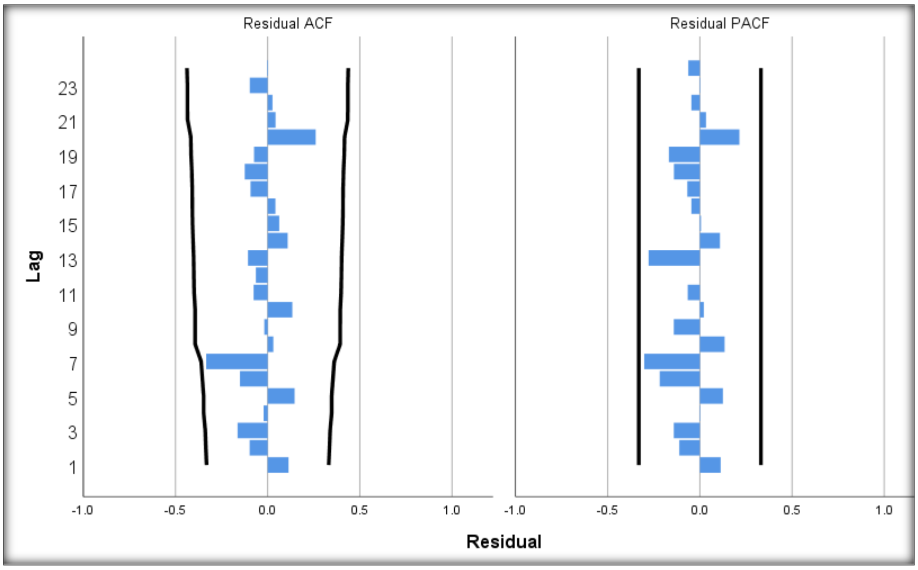

Figure 6: ACF and PACF plots

3.3 Comparison of Models

The final stage in the methodology was to perform a comparison between the two models identified from the exponential smoothing and ARIMA models and selecting the appropriate model with the best level of accuracy. The accuracy level improves as the error approaches zero.

Table 4: Comparison between Additive Holt-Winters and Non-seasonal Arima models

Model	Model Fit Statistics			
	RMSE	MAPE	MAE	BIC
Additive Holt-Winters Model	1780.708	16.703	1396.36	15.268
ARIMA (0, 1, 1)(0,0,0)[12]	2165.799	21.667	1676.853	15.564

Table 4 above, indicates that the Additive Holt-Winters model generated lower values of RMSE (1780.708), MAPE (16.703), MAE (1396.36) and Normalized BIC (15.268). The Additive Holt-Winters method based on the best of fit has outperformed the Non-seasonal ARIMA (0,1,1). The seasonal additive Holt-Winters model is selected as the most suitable forecasting method for our case.

3.3.1 Forecast Results with the Additive Holt-Winters model

The Additive Holt-Winters model was used to generate forecasts of fuel demand for the mid-term period as shown in Figure 7 below. The smoothing parameters alpha, gamma and delta are 0.3, 3.095E-06 and 3.697E-05 respectively.

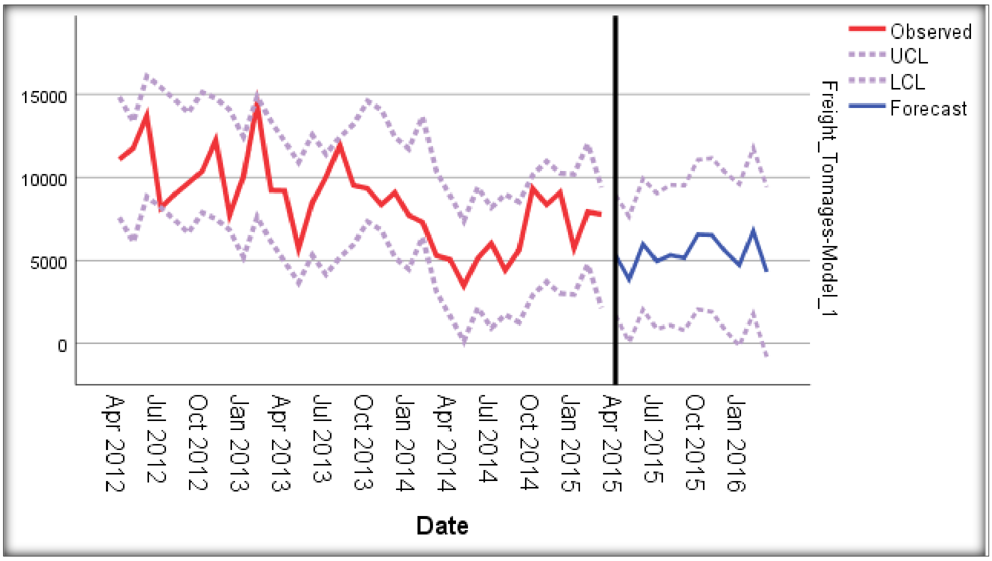

Figure 7: Observed and forecast fuel demand – Holt-Winters Model

Table 5: Actual and forecast values of fuel tonnages

Year	Months	Actual	Forecast	LCL	UCL
2015	April	4283	5328	1705	8951
2015	May	5194	3865	83	7648
2015	June	8033	5989	2054	9925
2015	July	6572	4959	876	9042
2015	August	5100	5321	1096	9547
2015	September	8479	5145	782	9508
2015	October	5290	6562	2065	11058
2015	November	6136	6535	1909	11162
2015	December	7386	5520	768	10272
2016	January	8925	4718	-156	9593
2016	February	9246	6777	1782	11772
2016	March	6005	4312	-800	9423

Table 6: Additive Holt-Winters model accuracy at different time intervals

Forecast Accuracy Measures	Forecast Periods			
	3 Months	6 Months	9 Months	12 Months
RMSE	1531	1862	1702	2096
MAPE	25	24	22	25
MAE	1473	1598	1458	1791

Table 5 above, shows a comparison of the actual and forecasted values for a 12 month period, wherein Table 6 it was identified that the selected model relatively generated lower values of the MAPE (22%) and MAE (1458) during the 9th period indicating that at this interval the model generated reasonable forecasts according to the MAPE judgement Lewis [16]. Across the other months, it was observed that the model continued to offer reasonable forecasts with the MAPE of 22-25%.

4 CONCLUSION

The relative accuracy of five variants of forecasting methods as applied to fuel demand have been evaluated both in-sample and out-of-sample. Established forecast accuracy measuring technics have been applied. The seasonal additive Holt-Winters method yielded the best results in our case. The result is generalizable to freight demand forecasting where-in the observed time series data exhibit seasonal characteristics. Improved forecast accuracy positively impacts operational planning and associated resource utilization efficiencies.

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IMPROVING HOSPITAL THEATRE ELECTIVE PATIENT ALLOCATIONS BY INCORPORATING A SYSTEMATIC MODELLING APPROACH

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ABSTRACT

Hospital theatres comprise elective and non-elective patients. The nature of patient arrivals is of such an extent that unscheduled occurrences are always a possibility. A typical scheduling approach is a first-come-first-serve basis with a minimum 'redundancy' for non-elective patients. It is, furthermore, not uncommon for an entire theatre to be allocated for non-elective patients or that a surgeon prefers to only operate during certain available time allocations. Resource utilisation in terms of efficiency is typically not the drive during scheduling. However, from a business perspective resources should be utilised with efficiency to ensure profitability. This paper presents a systematic modelling approach in order to solve for theatre patient allocations with increased utilisation availability. From the results it is demonstrated how the incorporation of this model yields fewer time wastages, allowing hospitals to improve time management.

Keywords: block scheduling, elective patients, hospital theatre, modelling algorithm, time utilisation.

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1 INTRODUCTION

Theatre scheduling can be a challenging task due to various factors such as the uncertainty of surgical duration and arrival uncertainties that include non-elective patients. Each patient requires an allocation with regards to a surgeon within a specified field of expertise. Furthermore, a suitable operating theatre is required for the execution of the required medical procedure.

The theatre schedule is critical in managing surgical units. The main purposes of a theatre schedule are reductions in the waiting time of patients, the cost of overtime and, wasted time potential through sufficient utilisations of theatres [1].

Different surgery scheduling strategies can be incorporated in health care institutions. Well-known strategies are open scheduling, block scheduling or modified block scheduling [2]. With an open scheduling strategy approach, each surgery is scheduled as an individual case not dependant on a block allocated for a specified field of expertise or. This scheduling approach is often also referred to as the first-come-first-serve approach [2].

Block scheduling is a strategy where patients are allocated to a specific predetermined time slot or block with regards to a surgeon within a specified field of expertise [3]. Modified block scheduling is a scheduling approach that combines the open- and block scheduling strategy. This can be applied by allocating certain time slots or blocks to a surgeon within a specified field of expertise where unused time slots or blocks are then identified. The open scheduling approach is then applied to the unused time slots or blocks. According to Rafaliya [4], block scheduling and modified block scheduling approaches are used most frequently in health care institutions.

Health care literature refers to two types of patients. These types can be categorised as elective patients and non-elective patients. Elective patients comprise surgeries that can be planned and scheduled well in advance. These surgeries are known as elective surgeries. Non-elective surgeries are for patients where, nor the planning, nor the scheduling could occur in advance due to the emergent and unforeseen nature thereof [5].

During the scheduling of the operating theatres, the scheduler should keep in mind that there is a possibility of non-elective patients arriving, therefore different allocation policies are known as the flexibility policy, dedicated policy, and hybrid policy should be considered [6]. With a flexibility policy, all surgeries, both elective and non-elective, are grouped together. The flexibility policy has two possible options: (1) The full capacity of the operating theatre schedule is filled to a certain fraction. By doing this some capacity is left at the end of the schedule as a safety net for unexpected events such as non-elective patients arriving. (2) The schedule is planned in such a way that a certain time frame within the schedule is allocated for unexpected arrivals of non-elective patients [6].

The dedicated policy ensures that operating theatres are dedicated to serve specific categories of patients. The dedicated policy is used to help reduce the variability of flow going through the operating theatres. This also helps to reduce rescheduling and cancellations. The hybrid policy is a policy that consists of a combination of characteristics from the flexibility policy and the dedicated policy.

2 PROBLEM DESCRIPTION

For the health care institution, from here on referred to as *Institution X*, under consideration a dedicated block schedule is used and repeated weekly. Certain time slots or blocks are allocated for different types of elective surgeries only. Note, due to practical managing considerations of Institution X, these blocks may not change. Further importance is that even though non-elective surgeries can occur, sufficient theatre space is specifically dedicated for these occurrences. As a result, non-elective surgeries fall outside the scope of this study, where the focus will only be on elective surgeries that can be planned.

Elective surgeries at Institution X are typically scheduled according to patient preference and availability. This entails that surgeries are allocated 'by hand' within available time slots on a first-come-first-serve basis. Implementation of this methodology allows for patients to have their surgeries 'immediately' scheduled in a future date; however, this might result in low utilisation of Institution X's theatre capacity. Consider the following example.

A block is available from 09:00 to 12:00 (180 minutes). There are three surgeries to be scheduled, say S_1, S_2 and S_3 with the total expected procedure and change-over times of 45 minutes, 45 minutes and 75 minutes respectively. Assume the patient allocated to surgery S_1 opts for 10:00 to 10:45. Following this, S_2 is scheduled at a later stage from 11:00 to 11:45. Surgery S_3 cannot be scheduled within this block, even though a total of 90 minutes is available (60+15+15). Note, however, that the three surgeries require a combined time of 165 minutes, and yet, cannot be accommodated given the pre-fixed time preferences.

The above mentioned example depicts a typical occurrence at Institution X. This scheduling method results in wasted potential theatre utilisation. From Institution X's managerial perspective, available theatre times are a resource. Higher utilisation of this resource will yield increased profits. Furthermore, increased utilisations will imply that future surgeries can be scheduled on earlier dates. Therefore, the average waiting times for elective surgeries, i.e. date of consultation with the surgeon to schedule theatre appointment will decrease.

This paper proposes a scheduling model formulation that can be incorporated by health care institutions. The proposed model can be coded within any programmable language, so that no specific software capabilities require procurement. The authors acknowledge that a linear programming (LP) model can be formulated to solve for maximum time utilisation. This, however, will require a health care institution to acquire suitable software and programmers proficient in LP formulation and coding.

3 THEATRE CONSIDERATIONS

Prior to the model formulation, some practical considerations are required.

Health care institutions typically comprise multiple operating theatres. Each theatre is divided into surgery blocks. These blocks are then numbered in chronological commencing order.

Take note, only one patient may be in an operating theatre at any time. Therefore, surgery allocation times may under no circumstances overlap within any theatre. Further importance, following each surgery, time is required to clean and ready the theatre for the next patient. This time will be referred to as a surgery's '*change-over-time*'.

It is not uncommon for institutions to plan for time redundancy. Every surgery has an expected procedure time associated with it. However, unforeseen complications may result in any surgery exceeding the planned time duration. If a surgery goes over-time and no redundancy was planned for, the institution is at risk that the block time will be exceeded.

Time redundancy is typically incorporated by institutions to provide a buffer for unplanned circumstances. For instance, assume a block is from 07:00 to 19:00 (12 hours) and the institution allows an hour redundancy. Surgeries are then allowed to be scheduled, and end, no later than 18:00. If any unforeseen circumstances do occur, an extra hour is available before the block ends.

Depending on when a block ends and if it is directly followed by another, the change-over-time of the last surgery may be allowed to occur within the allocated redundant time. The expected surgery time, however, is never allowed to be scheduled within the redundant time interval.

It is typical for elective surgery blocks to be scheduled from 07:00 to 19:00. The model formulation, however, will accommodate blocks of any time intervals.

4 MODEL DESCRIPTION AND FORMULATION

The model aims to allocate surgeries to scheduling blocks within operating theatres with an objective of maximising overall utilisation, subject to constraints. Surgeries are orderly distributed into various scheduled blocks, from here on referred to as a *block*. Blocks are continuous time intervals with a fixed start and end points. Important to note, no two blocks are required to be of equal time length. Further note, block numbering is chronological, therefore block$_{(i)}$ will either start either at the same time or prior to of block$_{(i+1)}$.

A block allocation lower limit (positive integer number) is determined. The model's objective is to schedule surgeries within this block lower limit. If scheduling cannot be achieved in this timeframe, the lower limit is increased by adding the next available block. The solving process is repeated with this increased lower limit. The model comprises two stop criteria, i.e. either when a solution is obtained or if the maximum allowable blocks are exceeded. For the latter, a zero solution is provided and either the available block quantities need to be increased or the number or surgeries reduced.

Blocks can be assigned surgeries as long as the time constraints are adhered to. Utilisation is maximised up to the second last block. As a result the last block's utilisation can potentially be minimised, yielding more available time should additional surgeries arise.

Data are sorted within the model from the highest expected surgery times to the lowest in chronological order. Note that change-over-times need to be taken into consideration. The scheduling is performed from a top-down approach. This entails that a surgery with a larger expected time will be allocated to a block before one with a lesser time.

4.1.1 Model formulation

Let the index set of all blocks be denoted by $B = \{1,2,\ldots,|B|\}$. The index set of listed surgeries is given by $S = \{1,2,\ldots,|S|\}$. Surgery $s \in S$ has an expected procedure time t_s and requires δ_s change-over time to ready the theatre afterwards. Let ID_s denote the name or identifier of the patient assigned to surgery $s \in S$.

Block $b \in B$ comprises an allowable time length allocation of l_b and a redundancy of r_b. If the change-over time, only, from the last surgery in block $b \in B$ may allow the total time to be greater than $l_b - r_b$, then $c_b = 1$, otherwise 0.

Let T denote the total combined time of all the expected surgery and change-over times. Let $N \leq |B|$ be the number of blocks' lower limit. Define a binary variable z, where $z = 0$ indicates that a time allocation has not yet been determined and $z = 1$ otherwise.

If surgery $s \in S$ is allocated to block $b \in B$, the binary variable $d_{sb} = 1$, otherwise 0. The allocated time utilisations from surgeries in block $b \in B$ is denoted by u_b. The pseudo code of the model formulation follows with explanations:

```
z = 0
T = Σ_{s∈S}(t_s + δ_s)
x = 0
y = 0
b = 1
no_solution = 0
while x = 0
  y = y + l_b − r_b
  if T ≤ y then
    x = 1
    N = b
  else b = b + 1
  if b = |B| + 1
    x = 1
    no_solution = 1
```

The preceding code is used the determine the blocks lower limit. If this limit is higher than the number of blocks available, no solution can be achieved.

```
for s = 1 to |S − 1|
  for i = s + 1 to |S|
    if t_i + δ_i > t_s + δ_s
      δ = δ_s
      ID = ID_s
      ID_s = ID_i
      δ_s = δ_i
      ID_i = ID
      δ_i = δ
```

This code is used to sort the surgeries from the top-down, i.e. in descending order with regards to expected time utilisation.

```
while (z = 0) or (no_solution = 0)
  max_c = 0
  for n = 1 to N
     u_n = 0
     for s = 1 to |S|
       d_sn = 0
  for s = 1 to |S|
```

$allocation = N$

for $n = 1$ to $N - 1$

if $(u_n + t_s + c_s\delta_s \leq l_n - r_n)$ and $(u_n + t_s + \delta_s \leq l_n)$

$allocation = n$

$n = N - 1$

This determines the first eligible block where the next surgery can be allocated to. If none are found, the last block is used by default.

if $allocation < N$

for $n = allocation$ to $N - 1$

if $(u_n < u_{allocation})$ and $(u_n + t_s + c_s\delta_s \leq l_n - r_n)$ and $(u_n + t_s + \delta_s \leq l_n)$

$allocation = n$

If any of the blocks from 1 to N-1 are eligible to receive the current surgery allocation, the least utilised unit is identified.

$u_{allocation} = u_{allocation} + t_s + \delta_s$

$d_{s,allocation} = 1$

if $d_{s,N}\delta_s > max_c$

$max_c = \delta_s$

if $u_N > l_N - r_N + c_N max_c$

if $N < |B|$

$N = N + 1$

else $no_{solution} = 1$

else $z = 1$

If the allocation is within limits, the scheduling will stay as determined and the program terminates. Given scheduling could be reached, either the lower bound is increased and when this is not possible the program will terminate with the message below.

if $no_{solution} = 1$

*message feedback that the model cannot obtain a solution with current parameters.

else print($lists$)

The model formulation will now be demonstrated with real-life data.

5 DEMONSTRATING THE MODEL'S WORKING ABILITY

As previously mentioned, Institution X under consideration comprises a fixed block schedule that is used weekly. Therefore, the working ability of the model requires a demonstration from only one surgical group.

The institution uses four operating theatres, where blocks are allocated according to the specified field of expertise. An operating theatre is available from 07:00 to 19:00 (720 minutes). The model is demonstrated for procedures within the surgical group 'General Surgery' classification.

<table>
<tr><th>DAY</th><th colspan="3">THEATRE 1</th><th colspan="3">THEATRE 2</th><th colspan="3">THEATRE 3</th><th colspan="3">THEATRE 4</th></tr>
<tr><th>TIMES</th><td>07:00
13:00</td><td>13:00
16:00</td><td>16:00
19:00</td><td>07:00
13:00</td><td>13:00
16:00</td><td>16:00
19:00</td><td>07:00
13:00</td><td>13:00
16:00</td><td>16:00
19:00</td><td>07:00
13:00</td><td>13:00
16:00</td><td>16:00
19:00</td></tr>
<tr><th>MONDAY</th><td colspan="3">D</td><td colspan="3">General Surgery D1</td><td></td><td colspan="2">B</td><td colspan="3">A</td></tr>
<tr><th>TUESDAY</th><td colspan="3">A</td><td colspan="3">General Surgery D2</td><td colspan="2">B</td><td></td><td colspan="3">A</td></tr>
<tr><th>WEDNESDAY</th><td colspan="2">B</td><td></td><td colspan="3">General Surgery D3</td><td colspan="3">A</td><td colspan="3">D</td></tr>
<tr><th>THURSDAY</th><td colspan="2">C</td><td></td><td colspan="3">General Surgery D4</td><td colspan="3">A</td><td colspan="3">A</td></tr>
<tr><th>FRIDAY</th><td colspan="2">C</td><td></td><td colspan="3">General Surgery D5</td><td colspan="2">B</td><td></td><td colspan="3">A</td></tr>
</table>

Figure 1: Block Schedule of Institution X

Figure 1 depicts the block allocation for General Surgery. Note that five blocks are available weekly from 07:00 to 19:00 (720 minutes). An arbitrary week (*Week 1*) is chosen for demonstration and the scheduling thereof is provided in Figure 2. Note that this scheduling was performed 'by-hand' without the use of any surgery allocation model.

Physician Specialities	Block		Patient ID	Start	End	Expected Duration [Minutes]	Elective Surgery / Change-over / Idle
Week 1 Block (D1)							
General Surgeon	07:00	19:00		07:00:00	07:45:00	45	Idle
			P001	07:45:00	09:00:00	75	Elective Surgery
				09:00:00	09:30:00	30	Change-over
			P002	09:30:00	10:45:00	75	Elective Surgery
				10:45:00	11:30:00	45	Change-over
			P003	11:30:00	12:00:00	30	Elective Surgery
				12:00:00	13:30:00	90	Change-over
			P004	13:30:00	14:00:00	30	Elective Surgery
				14:00:00	14:15:00	15	Change-over
						255	Idle
Week 1 Block (D2)							
General Surgeon	07:00	19:00		07:00:00	08:00:00	60	Idle
			P005	08:00:00	09:15:00	75	Elective Surgery
				09:15:00	09:30:00	15	Change-over
			P006	09:30:00	10:30:00	60	Elective Surgery
				10:30:00	10:45:00	15	Change-over
							Idle
Week 1 Block (D3)							
General Surgeon	07:00	19:00		07:00:00	09:00:00	120	Idle
			P007	09:00:00	11:45:00	165	Elective Surgery
				11:45:00	12:15:00	30	Change-over
			P008	12:15:00	14:00:00	105	Elective Surgery
				14:00:00	14:15:00	15	Change-over
							Idle
Week 1 Block (D4)							
General Surgeon	07:00	19:00		07:00:00	08:15:00	75	Idle
			P009	08:15:00	09:45:00	90	Elective Surgery
				09:45:00	10:00:00	15	Change-over
			P010	10:00:00	12:15:00	135	Elective Surgery
				12:15:00	13:00:00	45	Change-over
			P011	13:00:00	14:30:00	90	Elective Surgery
				14:30:00	14:45:00	15	Change-over
			P012	14:45:00	16:45:00	120	Elective Surgery
				16:45:00	17:00:00	15	Change-over
			P013	17:00:00	18:15:00	75	Elective Surgery
				18:15:00	18:30:00	15	Change-over
			P014	18:30:00	19:00:00	30	Elective Surgery
				19:00:00	19:15:00	15	Change-over
Week 1 Block (D5)							
General Surgeon	07:00	19:00		07:00:00	09:00:00	120	idle
			P015	09:00:00	11:00:00	120	Elective Surgery
				11:00:00	11:15:00	15	Change-over
							Idle

Figure 2: Block Schedule - Elective Surgeries Week 1

Expected surgery times are known and a minimum of 15 minutes change-over is incorporated. Institution X aims to plan with a 30 minute redundancy; however, note in Figure 2 how block D4 was scheduled for the final surgery to end at 19:00. Further note, the first surgery at block D4 starts 75 minutes into the allowed time. If any complications arise, the block D4 will be at risk to go into the evening hours.

The expected surgery duration, together with change-over times are 1665 minutes. Five blocks are available, resulting in 3600 (720x5) minutes. A minimum total time utilisation is therefore 46.25% (1665/3600). As a result, if it is possible to not waste a single minute, an additional 1935 hours can potentially be available, either if new elective surgeries arise or for non-elective patients. Important to note, utilisation cannot be penalised due to a lack in surgeries. For instance, if there was a zero surgery demand utilisation will be 0%. This cannot be interpreted as either poor scheduling or time management, rather than a 100% availability.

It is, however, important to note that even though a schedule is set up, elective patients can still arise thereafter. If an elective patient can be accommodated within a week where a schedule has already been drawn up, potential time at a future is freed due to the surgery that already took place. The more time economical surgeries scheduling, the higher additional potential utilisation will be available.

Define available utilisation as the summation of unscheduled time. Define these times as availability of at least an hour of uninterrupted surgical time. From Figure 2 it follows that 1260 minutes are available for utilisation over eight different time intervals. Therefore, 35.00% utilisation is available, resulting in 19.75% of time wastage during the week.

The planned surgeries are now scheduled by means of the model formulation for Week 1, incorporating a 30 minute redundancy. Change-over for the last surgery in each block is allowed to utilise redundancy and a 15 change-over is incorporated. Note that even though the original schedule utilised more than the allowable allocation for D4, it is not allowed for the model.

The scheduling results are provided in Figure 3. Note how change-over times are not exceeded and that surgeries commence at 07:00. Further note how block D*1 is scheduled with no wasted utilisation and block D*2 with only 15 minutes of wastage at the end.

Block D*3 is available for 9.25 hours and the full blocks D*4 and D*5 are available. Therefore, 31.25 hours (1875 minute) are available for additional utilisation, divided in three time intervals. As a result, 52.08% is additionally available, compared to the 35.00% of the by-hand scheduling method. Provided the same surgeries were allocated, the scheduling model yielded 48.81% more available time utilisation.

Incorporation of the scheduling model will allow for better utilisation of time, and therefore, will allow for improved management. The current theatre capacity is over designed, however, as the town's population increases over time by-hand scheduling will result in even larger utilisation losses. The incorporation of the scheduling model, however, will allow to always increase potentially available utilisation but the elimination of unrequired change-over-times.

Physician Specialities	Block		Patient ID	Start	End	ExpectedDuration	Expected Duration [Minutes]	Elective Surgery / Change-over / Idle
Week 1 Block (D*1)								
General Surgeon	07:00	19:00	P007	07:00:00	09:45:00	02:45:00	165	Elective Surgery
				09:45:00	10:00:00	00:15:00	15	Change-over
			P015	10:00:00	12:00:00	02:00:00	120	Elective Surgery
				12:00:00	12:15:00	00:15:00	15	Change-over
			P009	12:15:00	13:45:00	01:30:00	90	Elective Surgery
				13:45:00	14:00:00	00:15:00	15	Change-over
			P001	14:00:00	15:15:00	01:15:00	75	Elective Surgery
				15:15:00	15:30:00	00:15:00	15	Change-over
			P002	15:30:00	16:45:00	01:15:00	75	Elective Surgery
				16:45:00	17:00:00	00:15:00	15	Change-over
			P013	17:00:00	18:15:00	01:15:00	75	Elective Surgery
				18:15:00	18:30:00	00:15:00	15	Change-over
				18:30:00	19:00:00	00:30:00	30	Redundancy
Week 1 Block (D*2)								
Physician Specialities	**Block**		**Patient ID**	**Start**	**End**	**ExpectedDuration**	**Expected Duration [Minutes]**	**Elective Surgery / Change-over / Idle**
General Surgeon	07:00	19:00	P010	07:00:00	09:15:00	02:15:00	135	Elective Surgery
				09:15:00	09:30:00	00:15:00	15	Change-over
			P012	09:30:00	11:30:00	02:00:00	120	Elective Surgery
				11:30:00	11:45:00	00:15:00	15	Change-over
			P008	11:45:00	13:30:00	01:45:00	105	Elective Surgery
				13:30:00	13:45:00	00:15:00	15	Change-over
			P011	13:45:00	15:15:00	01:30:00	90	Elective Surgery
				15:15:00	15:30:00	00:15:00	15	Change-over
			P005	15:30:00	16:45:00	01:15:00	75	Elective Surgery
				16:45:00	17:00:00	00:15:00	15	Change-over
			P006	17:00:00	18:00:00	01:00:00	60	Elective Surgery
				18:00:00	18:15:00	00:15:00	15	Change-over
				18:15:00	18:30:00	00:15:00	15	Idle
				18:30:00	19:00:00	00:30:00	30	Redundancy
Week 1 Block (D*3)								
Physician Specialities	**Block**		**Patient ID**	**Start**	**End**	**ExpectedDuration**	**Expected Duration [Minutes]**	**Elective Surgery / Change-over / Idle**
General Surgeon	07:00	19:00	P003	07:00:00	07:30:00	00:30:00	30	Elective Surgery
				07:30:00	07:45:00	00:15:00	15	Change-over
			P004	07:45:00	08:15:00	00:30:00	30	Elective Surgery
				08:15:00	08:30:00	00:15:00	15	Change-over
			P014	08:30:00	09:00:00	00:30:00	30	Elective Surgery
				09:00:00	09:15:00	00:15:00	15	Change-over
				09:15:00	18:30:00	09:15:00	555	Idle
				18:30:00	19:00:00	00:30:00	30	Redundancy

Figure 3: Block Schedule – (Model Output: Week 1)

6 CONCLUSION

This paper presented a novel scheduling model to be used in the health care industry. Comparison with real scheduling results demonstrated how the model can be incorporated to reduce time wastages within the health care industry, with regards to elective patient scheduling.

Results showed how almost 50% additional utilisation was available during a single week's scheduling.

7 FUTURE WORK

Future work will include modelling of non-elective patient arrivals for theatres that are not only dedicated to elective patients. Different scheduling approaches will be simulated that will include how non-elective arrivals affect each scenario. These will, furthermore, be incorporated for varying block time lengths.

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A CONTRIBUTION TO THE DEBATE ON THE ACID MINE DRAINAGE PROBLEM IN SOUTH AFRICA

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ABSTRACT

The key to understanding mining consequences such as Acid Mine Drainage (AMD) on the environment is a consideration of the sources that produce AMD. The flow of AMD can cause contamination of water sources, damage to the environment and eco-systems, threatening human health, groundwork and custom sites. There have been reports of serious pollution hazards caused by AMD at different sites. High levels of metal concentrations and sulphate flowing towards a stream or river degrades water quality of the stream. Tools and techniques such as MRPP (Mining Risk Prevention Plan) have been established to help the control of environmental risk within a mine. MRPP helps to estimate and draw risks that are linked to pollution caused by old mining activities. South African Department of Water Affairs and Forest has developed different policies for limitation of water hazards in the mining sector. List of Best Practise Guidelines (BPGs) have been developed for water management tools. The BPGs outline and file best practises for water and waste management. It would be much better if acid mine drainage can be prevented, however, AMD cannot be prevented, so it must be treated. Acid mine drainage can be treated using Lime neutralization (most common), biological redemption (e.g Wetland and Sulphate reducing Bacteria), permeable reactive barriers etc. All these methods generate a large amount of Sludge which require monitoring, storage and disposal. This research focuses on available solutions to AMD and how these solutions have been used to address the problem of AMD in South Africa. The paper shows that although South Africa has introduced some far-reaching solutions to the problem of AMD in recent years, yet more needs to be done to properly fix the problem.

Keywords: AMD, treatment, South Africa, metal concentration, mining, aggregate, pervious concrete.

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1 INTRODUCTION

While mining is a central income generating industry, numerous environmental concerns are related to it. The development of a metal concentrated acid solution known as Acid Mine Drainage (AMD) is a main environmental concern of some mining operations. In most cases it is desirable to prevent AMD, however, since this is not always possible, treatment of AMD will mostly be required. Since water is a scarce resource in South Africa, persistent water pollution caused by the flow of acid mine drainage to rivers and streams raises concern on how this pollution can be controlled.

1.1 Acid Mine Drainage

Acid Mine Drainage (AMD) occurs when Sulphide minerals combine with oxygen and lose hydrogen to form acid mostly at abandoned mining sites, resulting in acid water that contaminates other water sources in the environment. Figure 1 shows a typical result of acid mine drainage. Some of the main causes of AMD are drainage from concealed mine shafts, runoff and release from open quarries and mine excess dumps and tailings. Drainage from uncontrolled concealed mine shafts into external water systems may occur as the mine shafts are filled with rainwater. The chemistry of AMD differs from place to place and depends on geological conditions. For this reason treatment of AMD needs great attention. The composition and behaviour of AMD must be analyzed and tested before finding new treatment solutions or improving on existing treatment technologies.

Figure 1: Typical results of AMD, culled from Saving Water website [1].

1.1.1 Problems Associated With Acid Mine Drainage

Some problems associated with AMD are listed here:

- The flow of AMD destroys aquatic life and it affects human health see example in Figure 2 [2].
- Even if the mine is no longer operating, the formation of AMD continues centuries causing long term environmental damage.
- The flow of AMD results in ecological damage and it contaminates rivers (drinking water) by Sulphuric acid and dense metals [3 - 6].

- AMD has an economic impact as the government spends money on water purification.
- Left unresolved acid mine drainage can leave sources of drinking water, and agricultural farms that are allocated downstream dead zones for decades, if not centuries, see Figure 2.

Figure 2: Aquatic life destroyed by Acid Mine Drainage [2].

2 ACID MINE DRAINAGE IN SOUTH AFRICA

South Africa is rich in minerals, more especially gold, which has created economic development, employment and wealth. Gold mines produce uranium, silver, pyrite, and osmiridium [3]. Although production of Gold in South Africa has a positive impact on economic growth, it also causes negative impact such as civil turbulence, commercial variation, community evacuating, contamination, negative fitness, and ecological damage [4, 7]. Since water is a scarce resource in South Africa, persistent water pollution caused by the flow of acid mine drainage to rivers and streams raises concern on how this pollution can be controlled. The map shown in Figure 3 displays the delivery of coal and Witwatersrand Basin gold deposit.

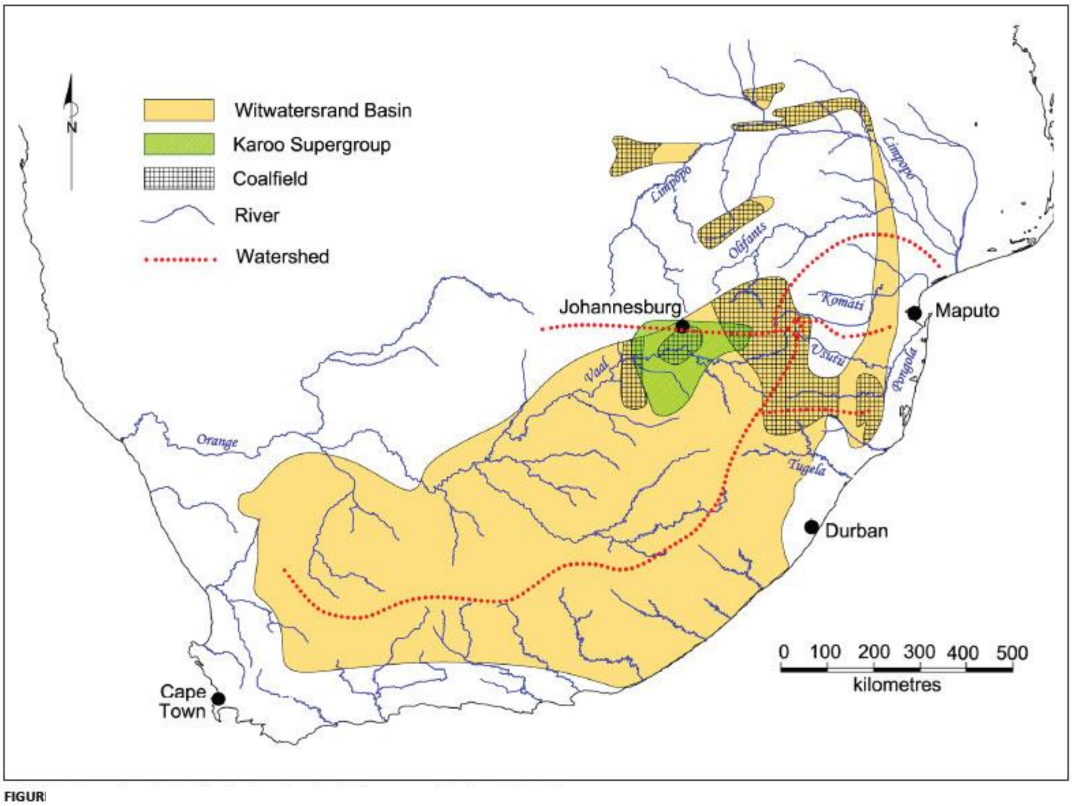


Figure 3: A map displaying the delivery of coal and Witwatersrand Basin gold deposit [8].

There is currently Acid Mine Drainage flowing to the streams that are connected to Vaal River and Crocodile River for example. Areas that are affected by AMD in Johannesburg alone include:

- West Rand,
- Wonderfonteinspruit,
- Tweelopiespruit,
- Tudor Dam and
- Robinson Lake near Randfontein.

The Tweelopiespruit is part of the Crocodile River system and the Limpopo River catchment area. Grootveil mine that is run by Pamodzi Gold has stopped working. Acid Mine Drainage is expected to flow into the groundwater systems in the near future.

2.1 The Response of South Africa to the AMD Problem

To find solutions in response to AMD, University Professors, Scholars, Mining houses, private institutions and Government departments have conducted wide-ranging research on AMD. However, their researches focus on isolated solutions to individual interest in the treatment process of AMD [9]. Examples are Neutralization and toxic element abstraction with original and improved limestone and cost savings through the use of reagents [10]. In all the research that is completed and proposed, the threat of AMD continues. In areas like Wonderfonteinspruit in Carletonville, Gauteng province in South Africa, there is a warning sign written in three languages warning people about contaminated water from old mining areas, Figure 4.

An Acid Mine Drainage Inter-Ministerial Committee (IMC) has been established in 2016 to define a strategy of action and to develop a government reply. Despite technologies that have been implemented for the treatment of AMD, with lots of protective measures that have been established, AMD continues to contaminate streams and rivers [10].

Figure 4: Informational warning signs for polluted water in three languages [10].

Every time a mine closes in Witwatersrand and stops pumping, water fills up the void and flows to the neighbouring mines because of high levels of connectivity. Then it will be the responsibility of the neighbouring mines to pump that water, thus there is a pumping subsidy introduced by Government to assist mines to pump this additional quantity of water [9]. The former Minister of Water and Sanitation, Nomvula Mokonyane, recently confirmed that a new AMD plant has been opened in Springs outside of Johannesburg [11]. This plant is to respond to the contamination of clean water and control the level of AMD underground so it cannot leak to the surface. Central basin in Germiston and Western basin in Krugersdorp has been operating for years. Building the new AMD plants has cost South African government R10 billion to R12 billion [11]. Solutions of AMD are extracted from mine voids and sent to treatment plants, then all the treated water is sent to nearby water sources such as streams, rivers and dams. Production of clean water increases water supply to the Vaal River. Kromdraai AMD treatment plant, Figure 5, was developed by Aveng group and mounted at coal mining major Anglo American Thermal Coal's Kromdraai open cast mine. The plant is currently commissioned to treat 5000m^3 of AMD per day.

The plant produces safe and clean water for the environment and it is capable of producing drinking water that meets South African National Standards (SANS) for drinking water. The AMD plant treatment process starts with pre-treatment where particulates are removed and scale forming contaminants such as Calcium, salts and metals are retained. The next following step in the AMD treatment process is Reverse Osmosis (RO) which function in a double pass mode, with the first pass in acidic condition and the second pass takes place under pH-neutral conditions for further extraction of inorganic compounds found in AMD. The last step is water polishing which requires very clean water, a mixed bed ion exchange to ensure low total dissolved solids. The Western basin in Krugersdorp and Central basin in Germiston have been operational for a few years. The plants are one of the government's plans to clean AMD.

The South African government has invested in different options in the treatment of AMD, like EPSE solutions, a new technology to treat AMD, launched in July 2016 in Johannesburg. The name EPSE is an abbreviation for Eco-Process Services, a company

[4583]-5

based in Finland. The EPSE specialises in treating Acid and Industrial wastewater and solve the problem of metal pollution in mining and heavy metal industries. Their final product is purified water and raw materials (in the form of precipitates), converting soluble metals contained in AMD to harmless insoluble metals that can be used in the production of several other processes. According to EPSE, the polluted water is passed through a boring acid reactor, then the next step is the pH-modifying reactor and the last step is Clarifier. Clarifier produces insoluble precipitates and clean water. The last step takes longer than the other steps because heavier metals have to sink, so that clean water can float to the surface. For further removal of the remaining sulphates in AMD solutions, EPSE recommends processing the clean water through sulphate-specific technology thereby producing portable water. The EPSE claims that its solution is cost-effective and it removes metals completely from AMD solutions, resulting in insoluble precipitants. Soluble precipitants are classified as hazardous waste which is required to be stored in a special storage place which requires thus more cost for storage. Figure 6 shows the schematic process flow of EPSE [11].

Figure 5: Kroomdrai water treatment plant [6].

One of the advantages of EPSE technology is that it is effective with a low and high concentration of metals, which is difficult for current technologies to extract metals from low metal concentrated solutions. The EPSE technology also generates heat that is used in mining and treatment of industrial waste and it is effective with almost all the metals, with the ability to extract all the metals at the same time, whereas current technologies are selective. As stated previously, EPSE solutions are capable of producing purified water. Purified water is water that is mechanically treated to remove contaminants and makes it useable. Treated water can be used in science, engineering laboratories, production of medication and in industries.

The content of minerals dissolved solids in water determines whether water is suitable for use in households and industry. The Water Act of 1956 protects our limited water sources from pollution. For wastewater to be used for Agricultural purposes it must not contain any poisonous or harmful constituents in the concentration [12]. Table 1 shows South African Bureau Standard for drinking water supply. It also shows the maximum permissible concentration of certain constituents in drinking water. Comparing EPSE solution results for mine effluent in Figure 7 to the South African Bureau standard in

Table 1, clearly shows that the EPSE solution meets the minimum requirement for clean water, however, the higher concentration of Sulphate is further removed in a Sulphate – Specific technology thereby producing potable water.

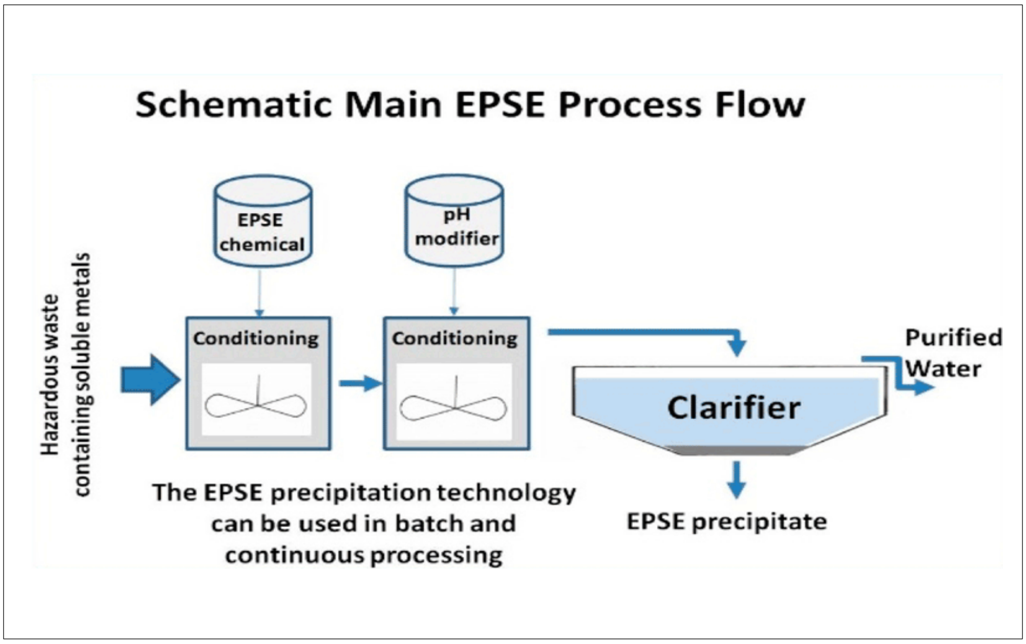
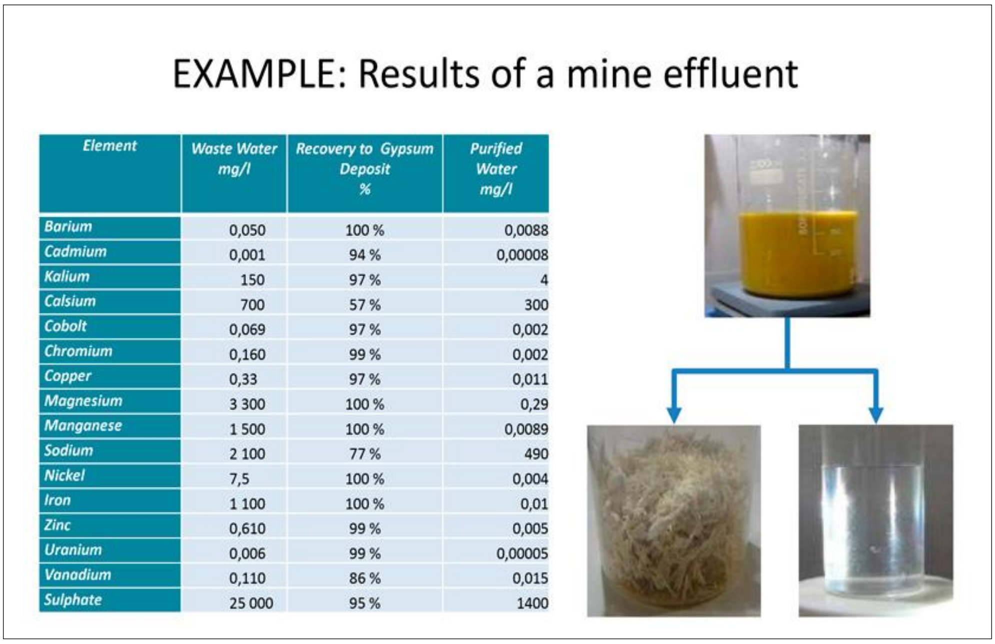


Figure 6: Schematic main EPSE process flow [8, 11].


EXAMPLE: Results of a mine effluent

Element	Waste Water mg/l	Recovery to Gypsum Deposit %	Purified Water mg/l
Barium	0,050	100 %	0,0088
Cadmium	0,001	94 %	0,00008
Kalium	150	97 %	4
Calsium	700	57 %	300
Cobolt	0,069	97 %	0,002
Chromium	0,160	99 %	0,002
Copper	0,33	97 %	0,011
Magnesium	3 300	100 %	0,29
Manganese	1 500	100 %	0,0089
Sodium	2 100	77 %	490
Nickel	7,5	100 %	0,004
Iron	1 100	100 %	0,01
Zinc	0,610	99 %	0,005
Uranium	0,006	99 %	0,00005
Vanadium	0,110	86 %	0,015
Sulphate	25 000	95 %	1400

Figure 7: Chemical results of mine effluent (AMD) for EPSE solution [8].

The report from the Department of Water Affairs website states that the then Finance Minister, Pravin Gordan, allocated R3.6 billion for water and infrastructure services in December 2011, this includes treatment of Acid Mine Drainage that can include active and passive treatment solutions.

Table 1: South African Bureau standard for clean water

Chemical Composition	South African Bureau Standard	
	Max. desirable	Max. permissible
pH	6.0-9.0	5.5-9
Total Solids	500	2000
Hardness ($CaCo_3$)	20-200	1000
Cyadines (CN)	0.01	0..2
Chloride (Cl)	250	600
Chromium hexavalent (Cr)	0.05	0.05
Fluoride (F)	1.0	1.5
Copper (Cu)	1.0	1.5
Iron (Fe)	0.3	0.7
Manganese (Mn)	0.1	0.4
Magnesium (Mg)	100	150
Zinc (Zn)	5	15
Phenols	0.001	0.002
Sulphates (SO_4)	250	400

2.2 Active and Passive Treatment Solutions

The treatment of AMD is divided into two categories namely; Active Treatment Technologies and Passive Treatment Technologies. Active treatment technologies are the most effective technologies where chemicals are added to AMD and they need lots of maintenance and routine monitoring because they use machines and electricity. Active treatment technologies are mostly used in active mines and they are more expensive as compared to passive treatment technologies. Active treatment technologies include neutralization, Aeration, chemical prediction, ion exchange and biological sulphate removal. Passive treatment technologies take advantages of nature, it focuses on biological treatment and chemical treatment technologies. Passive treatment technologies are mostly used in closed and abandoned mines. Passive treatment technologies include Anoxic limestone drains, electrochemical covers, Open/Oxic Limestone drains Aerobic and non-aerobic wetlands and Permeable reactive barriers. Table 2 highlights the differences between Active and Passive treatment Technologies.

Table 2: Difference between Active and Passive AMD treatment technologies

Active treatment technologies	Passive treatment technologies
Used in active mines	Used in closed and abandoned mines
Involves the use of chemicals and machinery.	Rely on natural chemical, physical removal processes and biological reaction.
Requires a lot of maintenance and routine monitoring	Requires less maintenance [13].
Considered for high flow rates	Considered for low flow rate [14].
Requires power or energy to operate	Does not need power or energy to operate.
Effective and reliable continuously meet water-quality based discharge criteria [14].	May not meet strict water-quality-based discharge criteria.

The main advantage of both passive and active treatment technologies is that they help to upgrade the contaminated water by lowering acidity and poisonous metal absorption and increase pH. Active treatment technology includes the following:

- Aeration – Is the process that removes dissolved carbon dioxide, which is commonly present in mine water coming from underground [15].
- Neutralization – Dosing of AMD with chemicals to produce required water chemistry [16].
- Chemical precipitation – Is the method for removing dissolved minerals from wastewater containing toxic metals.
- Ion exchange - This process is used to soften the AMD water.
- Biological sulphate removal – Is used to treat industrial waste in addition to sulphate metal removal and neutralization.

Passive treatment technology includes the following:

- Permeable reactive barrier – Is a medium that allows some but not all materials of AMD to pass through, they are made up of emplacement of responsive materials in front of and upright to the flowing polluted groundwater [17]. See figure 6.
- Slag leach bed – Is a slag check dam, or barriers containing fine-coarse slag aggregates
- Aerobic and non-aerobic wetlands – They are used to counteract acidity and eliminate metals from acid mine drainage, Wetlands are mixtures of physical, biological, and chemical interactions among plants and microorganisms [17].
- Open/Oxic Limestone drain – Is the process in which ditches are filled with gravel, to dissolve Limestone as AMD passes through the gravel.

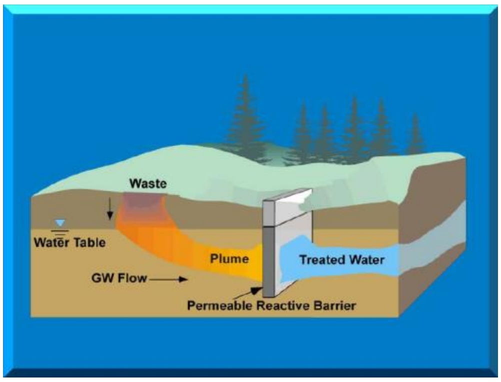


Figure 8: Permeable Reactive Media [18].

The environmental circumstances in the different passive treatment structures will dictate the metal removal instruments and due to exceptionality of each mine site and their water chemistry, a complete understanding of mine water chemistry is required.

3 CONCLUSION

AMD cannot be prevented but can only be mitigated. The use of Active or Passive Treatment technologies will depend on the mine condition. As the mining industry is a pillar of South Africa's economy, there must be laws that compel mining companies to protect the environment and be accountable. These laws must be established by the Government to preserve the environment and heritage sites. The authors are investigating the repositioning and segregation of mine waste that may result in AMD and their prevention from rejoining with water. This often includes segregating the waste from contact with under-groundwater by stirring the waste beyond the water table, handling it, and covering it with a layer of resistant material to keep out of contact with surface water. The current paper shows that SouthAfrica is on a good path to remediate AMD from some of its many abandoned mines. However, more needs to be done to properly fix the problem of AMD in South Africa.

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CAN WASTE=POWER?

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ABSTRACT

There exists an opportunity to reduce crude oil usage for virgin plastic production, consequently reducing greenhouse gas emissions from fossil fuel usage and plastic pollution in South African communities. The method used to develop this circular system of reusing, recycling, and using pyrolysis to recover energy from plastics was adapted from the work of the Ellen MacArthur Foundation. The aim was to assist the government in the initiative to reduce single-use plastics and plastic waste.

This paper can be used as a basis to further investigate how to practically roll out a circular economy initiative while observing policies across the Department of Trade and Industry and the Department of Environmental affairs. The author used interviews and a survey as tools to map out the current state. The circular economy framework was applied to the current plastic lifecycle and a new method was recommended and validated. The expected reduction in plastic waste is 30%.

Keywords: waste to energy, pyrolysis, circular economy, waste management

1 INTRODUCTION

1.1 Background

Waste is increasingly becoming a substantial part of our lives. International bodies including the World Bank have conducted studies and anticipate the growth of waste worldwide to be around 70% by 2050 if no controls are put in place [1]. Waste is any substance, that is unwanted, rejected, discarded, whether, or not such substance, material or object can be reused, recycled, or recovered [2]. On the other hand, power is defined as the ability or capacity to do something. It can be in the form of influence, money, or energy [3].

1.2 Problem statement

South Africa's increased pollution has resulted in land being used for dumping, lower air and water quality, and potential loss of value in the form of money and energy. The current method of dealing with waste is inefficient and possesses no monetary benefit to the users [2].

1.3 Design objectives

- To determine effective and efficient ways of drawing power from plastic waste.
- Design a process that has measures to assist in increasing plastic recycling and re-using.

1.4 Design delimitations

- The design will only consider South Africa and not the rest of Africa or the world.
- The study is set to focus on plastic waste and no other forms of waste.

2 LITERATURE SURVEY

2.1 Plastic Material Flow in South Africa

Figure 1 below is a graphical representation of the flow of plastic compiled by the author, using an understanding of the plastic life cycle and recycling statistics reports of how plastic travels from virgin feedstock to the point where it is considered waste, with an astounding 55% being used in packaging (single-use purpose) [4]. The plastic life cycle includes stakeholders such as the Department of Trade and Industry, suppliers of raw material and plastic manufacturers or converters in the production stage, retailers and consumers in the usage stage, municipalities and material recovery centers in the collection stage, and recyclers, Department of Environmental Affairs in the disposal stage.

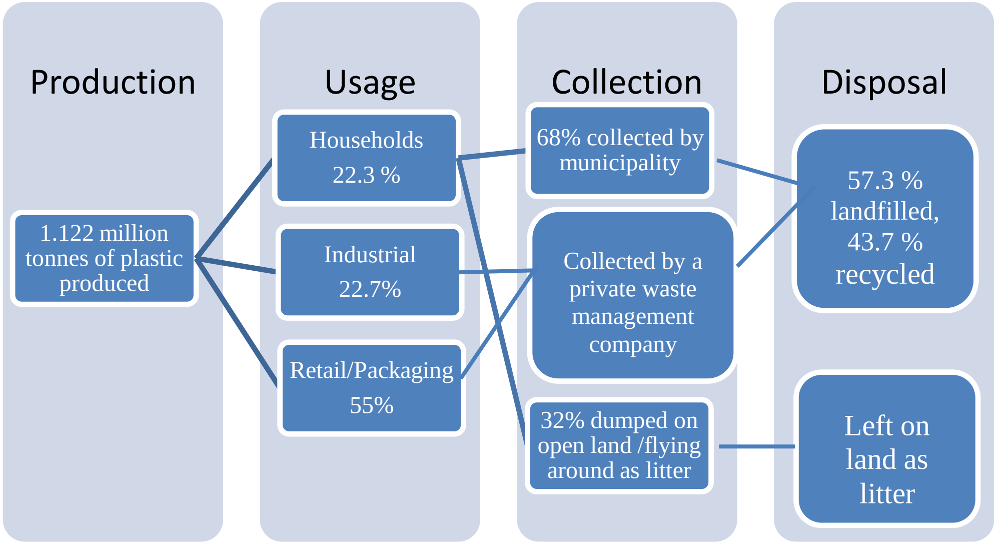

Figure 1: The four phases of the plastic life cycle

2.2 Recycling

Waste management has proven to be an issue in South Africa, with the country being 11th on the list of countries with mismanaged plastic waste [2]. There are however initiatives attempting to better manage plastics and draw some economic and social value from the material. Plastics SA reports that South Africa currently recycles 21% of plastics consumed in the country (including plastics exported for recycling), while the remainder is disposed of in landfills [4].

The challenges around recycling have been the following:

- Not all plastics are ideal for recycling, so a significant amount is left undealt with [5].
- Most recycling schemes require a feedstock that is reasonably pure and contains only items made from a single polymer [6].
- Only 64% of households in South Africa have formal waste management [7].

2.3 Raw material recovery

The raw material that stands to be recovered from plastics is in the form of fuel or syngas. Hydrocarbons composing plastic waste naturally break apart when exposed to heat. High-temperature pyrolysis in the absence of oxygen induces this breakdown that creates new products: gases, liquids, and solids [8].In the context of South Africa, the technology of producing syngas and biofuel from plastics has not yet materialized on a large scale due to lack of financial investments.

2.4 Circular economy in plastics

A circular economy is a new way of looking at product life cycles and how we consume raw materials. Plastic is a product with raw materials as inputs and it also has a life cycle as indicated in figure 1. This section introduces the terminology of slowing, closing, and narrowing resource loops. To distinguish circular economy models from linear models, we categorize the design and business model strategies according to the mechanisms by which resources flow through a system [9]. The main categories used to describe circular economies are outlined in Table 1 below.

Table 1: Common models of circular economies

Model	Description
Classic long life	Products are grounded on durability and long-term use.
Hybrid	Products are long term durable items but they have short-lived consumables.
Gap exploiter	Using the functional leftover value in products or components,
Access model	Sharing access instead of ownership. This model minimizes the demand for raw materials.
Performance model	Delivers product performance, not the product. Pursues 4 goals: product-life extension, long-life goods, reconditioning, and waste prevention.

3 DESIGN METHODOLOGY

The project then followed the DMAIC process. Although commonly known in manufacturing as a method of improving quality, the author saw an opportunity to use it for process improvement due to the wide scope of details it allows one to explore. Figure 2 represents the steps followed. Omitting the control step as implementation is pending.

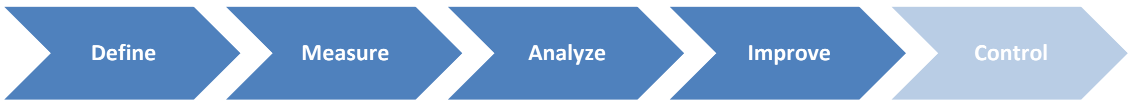

Figure 2: DMAIC framework Investopedia [10]*

3.1 Phase 1: Define (Background)

To clearly define the problem and issues surrounding it, background research was necessary. It validates the presence of a problem or disputes it and allows the investigator to identify the root cause. A desktop study was done and interviews were carried out as a form of descriptive investigation.

3.2 Phase 2: Measure

Semi-structured interviews were carried out with industry experts to determine the operation of the plastics industry and the challenges and opportunities [11]. Furthermore, a survey was carried out to identify consumer behaviour when it comes to their interaction with plastic as a material. The survey was distributed online via email and social media, using the platform “Survey Monkey”. The results were interpreted using descriptive statistics and graphs were formulated on the same platform (survey monkey).

* IDEI methodology cited in Investopedia, 2019 in 2020.

3.3 Phase 3: Analyze

A gap analysis was also used to map the current state, future state, and quantify the difference that will assist in setting objectives for the solution. The tool used to identify gaps was the Ishikawa diagram. A cause and effect diagram often called a "fishbone" diagram, can help in brainstorming to identify possible causes of a problem and in sorting ideas into useful categories [12].

3.4 Phase 4: Improve

This section will involve using Industrial Engineering tools to design a system that will ensure the circulation of the plastic material and drawing value at each step of its life cycle. It will explore the improvement of the current state.

3.4.1 *Designing circular economies*

Out of the five circular economy business models, the **gap exploiter model** was identified as the most relevant as it addresses the usage of "*left-over*" value in products, i.e plastic. The loop strategy is used to map circular economies and it includes a butterfly model having 7 loops (3 on the biological side and 4 on the technical side) as shown in Figure 3. The biological side requires the designer to look at how the material can get cascaded through various applications before it is returned to the earth in the form of nutrients [13].

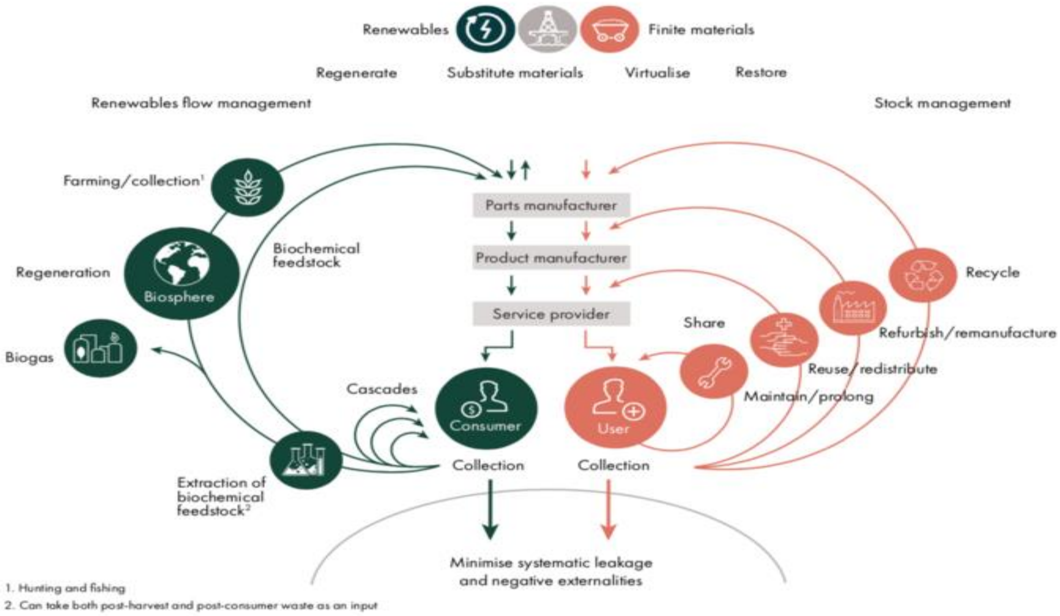

Figure 3: Development of Gap exploiter model for creating a circular economy [13][†]

3.5 Phase 3: Execute

A detailed cost analysis and concept validation will be carried out to ensure the feasibility of implementing the solution chosen.

[†] Standard circular economy design cited from Ellen Macarthur foundation, 2019

3.6 Phase 4: Implementation (Relies on approval from the government)

The project will be presented to the Wits School of Mechanical Industrial and Aeronautical engineering and to the Department of Trade and Industry as a critical stakeholder to assist in the implementation of the proposed solution.

4 CURRENT STATE

This section looks at the results obtained during the investigation phase of the project. The tools that were used to frame the current state and outline the root cause of the problem before designing a solution included the following.

Interviews were conducted with industry experts to outline and determine challenges that contribute to the inefficient recovery of power from plastic waste. Interviews as a tool were chosen due to the nature of the data that can be collected from them. The author needed in-depth information to supplement the literature and contextualize the problem and issues around it.

Table 2: Stakeholder evaluation in the plastic lifecycle

Candidate	Stakeholder Type	Challenges	Opportunities
PlasticSA-Annabe Pretorius (Polymers expert)	Federation	• Balancing interests of members in the plastics value chain • Anti-plastic lobbyists, inaccurate data	• Front-runners in research and development of better performing plastics.
DTI-Thokozani Masilela (Director)	Policymaker	• Assisting upcoming entrepreneurs to overcome barriers to entry in the reprocessing. • Reaching common ground with The Department of Environmental Affairs about the validity of banning plastic products. • Funding projects for circular economy initiatives. • Looking after the interests of waste pickers	• Creating policies that drive new economies and entrepreneurship in South Africa. • Formalizing waste pickers in SA, thus ensuring the continuation of the much-desired circular economy.
Nampak (Engineer)	Packaging (Brand owner)	• Recycled packaging material, could compromise the strength of the material. • Consumers are influenced by popular culture, putting pressure on packaging practices	• The innovation of improved plastics through continuous research and development.

4.1 Survey

A consumer-centred survey was designed and distributed to a sample of 200 participants to determine the behaviour of consumers and how it contributes to the loss of resources in plastic waste. 124 responses were received. Figure 4 shows that a large proportion of people do not recycle plastics, this accounts for 48.39% of survey responses. While a growing number recycles either weekly or daily.

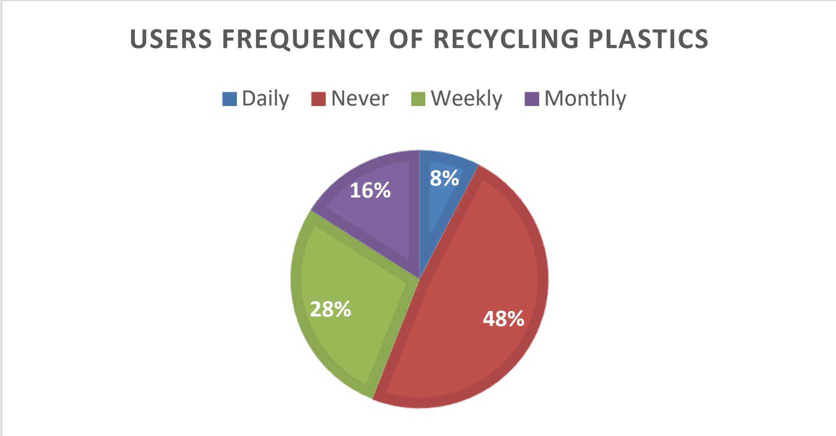

Figure 4: Frequency of recycling by plastic consumers

Figure 5 gives some insight into why a large proportion of users dispose of plastics after single-use. About 50% of people would make the most out of plastic if they knew the power/value that still lies in it after a single-use.

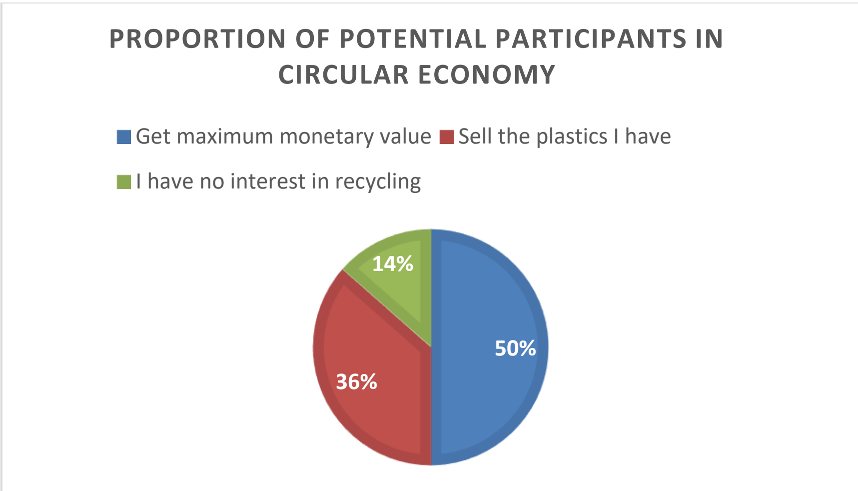

Figure 5: Potential secondary value derivation from plastic

An Ishikawa diagram was used as a main tool for the root cause analysis. It allowed the designed to drill down on the root cause s contributing to the observed effect of inefficient extraction of value from plastic as a material. This can be seen in Figure 6 below.

4.2 Root Cause Analysis of value extraction from plastic as a material

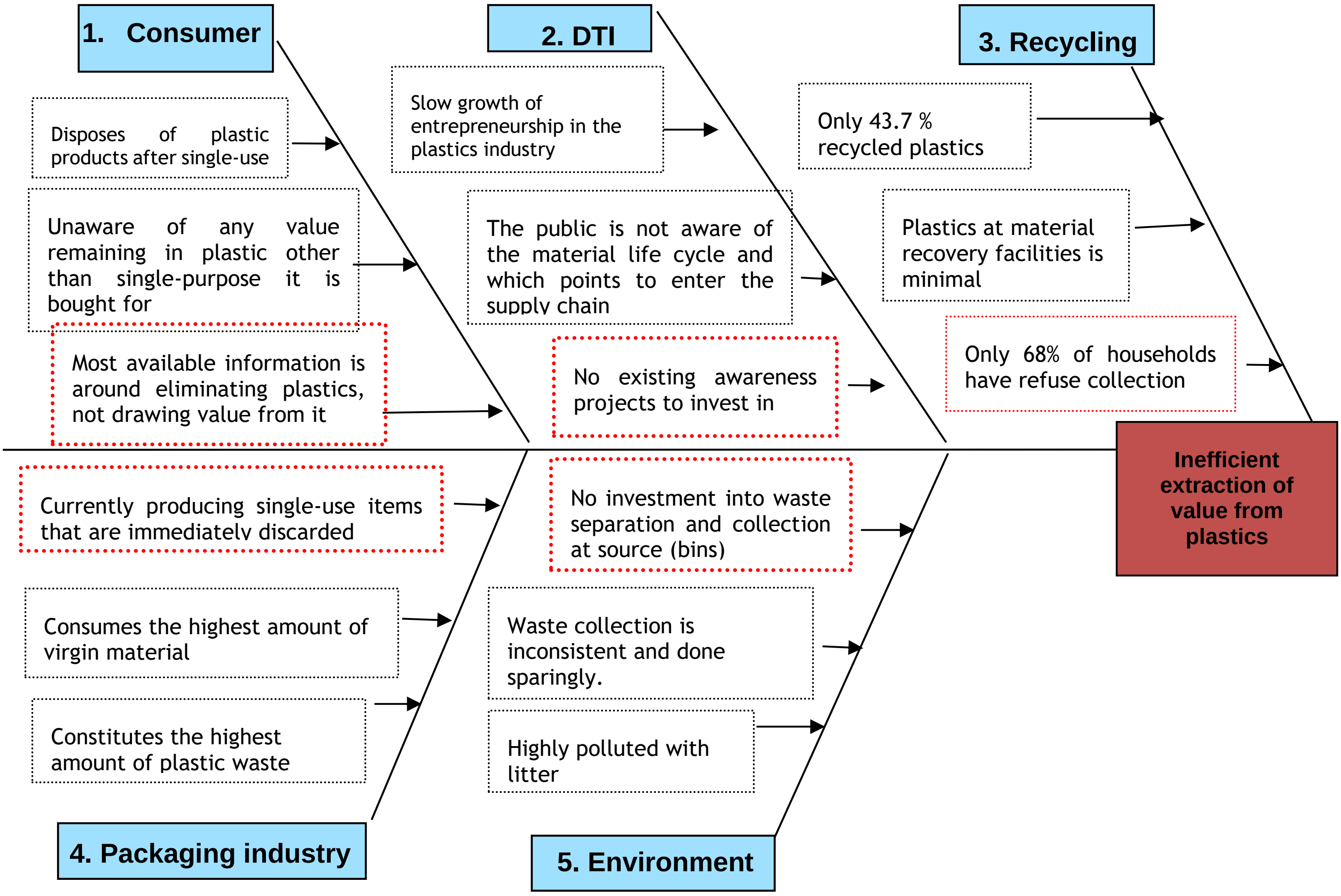

Figure 6: Fishbone diagram exploring root causes of the inefficient extraction of value from plastics

5 PRODUCT REQUIREMENTS SPECIFICATIONS

5.1 Requirements

- The design must provide awareness to the consumer about the power in plastics and increase the number of people who make the most out of plastics to 65% contrary to the 50% that is not aware of the power in plastics.
- The solution must reduce waste in the environment in the form of litter by 50% within the first six months of implementation addressing the core issue identified in Figure 7.
- The design must improve the recycling of plastics by 30% by the next PlasticSA survey year in line with increasing the current percentage of 43.7 %.
- The proposed solution must foster entrepreneurship in waste management to support the effort of the DTI as outlined in point 2.1 of Figure 6.

5.2 Constraints

- The solution must not eliminate existing markets without alternatives that give economic benefit to those involved.
- The design must fall within environmental legislation around carbon emissions into the environment according to the Integrated Resource Plan as outlined in

South Africa's low emission development strategy 2050 and address the sub-problem as identified in section 5 of Figure 6.
- The solution is dependent on policy adaptation and amendment by the DTI.

5.3 Specifications

- The design will create opportunities in the formal and informal waste management, involving more people in the plastics value chain and addressing unemployment and easing barriers to entry to support DTI attempts in section 2.2 of Figure 6.
- The solution will result in less plastic pollution in rivers and land.

6 PROPOSED SOLUTION

The proposed concept is an integrated solution with a human-centered approach. Involving the consumer and educating them about; the role of plastics in our general existence, the value in plastics, and opportunities in waste management.

The waste found in landfills can be collected and used for pyrolysis purposes, while the waste from the compartmentalized refuse bins will be reserved for waste collectors, each person will pick a refuse bag relevant to their line of recycling to be delivered and sold to Material Recovery Facilities, where sorting and cleaning will not be tedious. Furthermore, the incorporation of labelled plastic products will be required. All plastic products need to be given a number depending on how often they have been recycled. The items that have been recycled more than twice will then qualify for incineration. The benefits and challenges of this system have been explored in Table 3 below.

Table 3: Benefits and challenges of the proposed solution

Benefits	Challenges
Sustains recycling value chain	Difficult to guarantee strict implementation
Bin system allows for separation at source to improve recycling process efficiency	The sorting process is still required to determine which plastics will undergo pyrolysis
Public awareness will be created	High cost
Financial gain for people directly involved in the supply chain (waste picking, recycling, recycled oil selling)	A long period of implementation

6.1 Idea evaluation

The red lines in Figure 7 define the ideal performance as stipulated by the Product Requirements and Specifications, prioritizing public awareness, dependability of solution, sustainability, and flexibility in implementation. The black lines are an evaluation of how each concept fares against the desired system performance. Flexibility assessed the solution against section 5.1.1 requirements. Sustainability of the concept was benchmarked based on section 5.1.1 requirement of waste reduction and 5.1.2 sustaining existing markets. Public awareness proved to be critical due to its ability to be a driving lever in the implementation of any of the solutions and the system ideal was rooted in sections 5.1.1 and 5.1.3. Lastly, the dependability was plotted based on the probability of achieving waste reduction goals and gaining public interest.

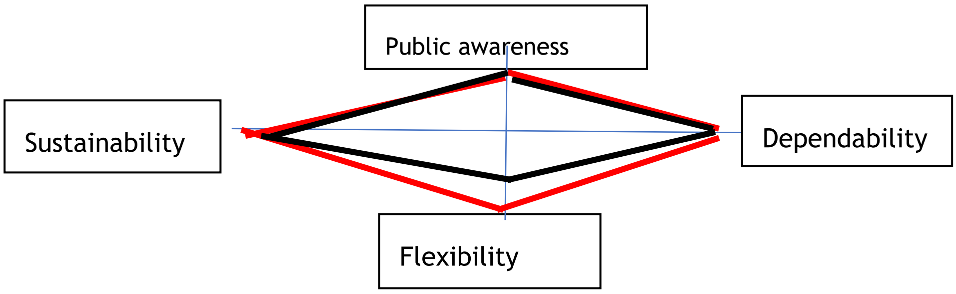

Figure 7: Polar evaluation of the proposed concept

The red outline (ideal) shows that flexibility does not matter as significantly as sustainability and dependability. This is because there is an extensive budget set aside for dealing with plastic waste and environmentally green innovations; so, flexibility or the costs associated with it are not a challenge when looking at it from the DTI's perspective and that of the global community and private entities. Sustainability and dependability are critical because of the impact of potential solutions on climate change, its reduction of appropriate controls.

6.2 Design Specification

Figure 8 is a flow diagram showing how the proposed solution would be set up in the real world, with the key players and associated activities. There is a reduction in demand of raw virgin materials as each plastic produced is intended to complete 3 cradle to cradle cycles before exiting the system (cradle to grave). Principles of circular economies as described in section 3.2.1 outline reusing as the second loop of the technical side and recycling as the outermost loop, both of these have been incorporated in the design shown in Figure 8.

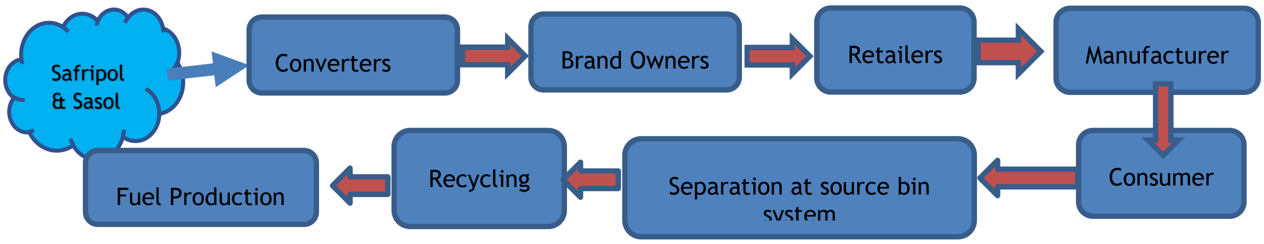

Figure 8: Proposed system of approach for a plastic circular economy

6.3 Future State

Figure 9 is a representation of the desired future state, cash flows circularly as consumers now see material recovery firms and pyrolysis units as customers, therefore creating a financial loop for the customer (outgoing when purchasing plastic items for use) and incoming when participating in recycling and oil recovery from the plastic.

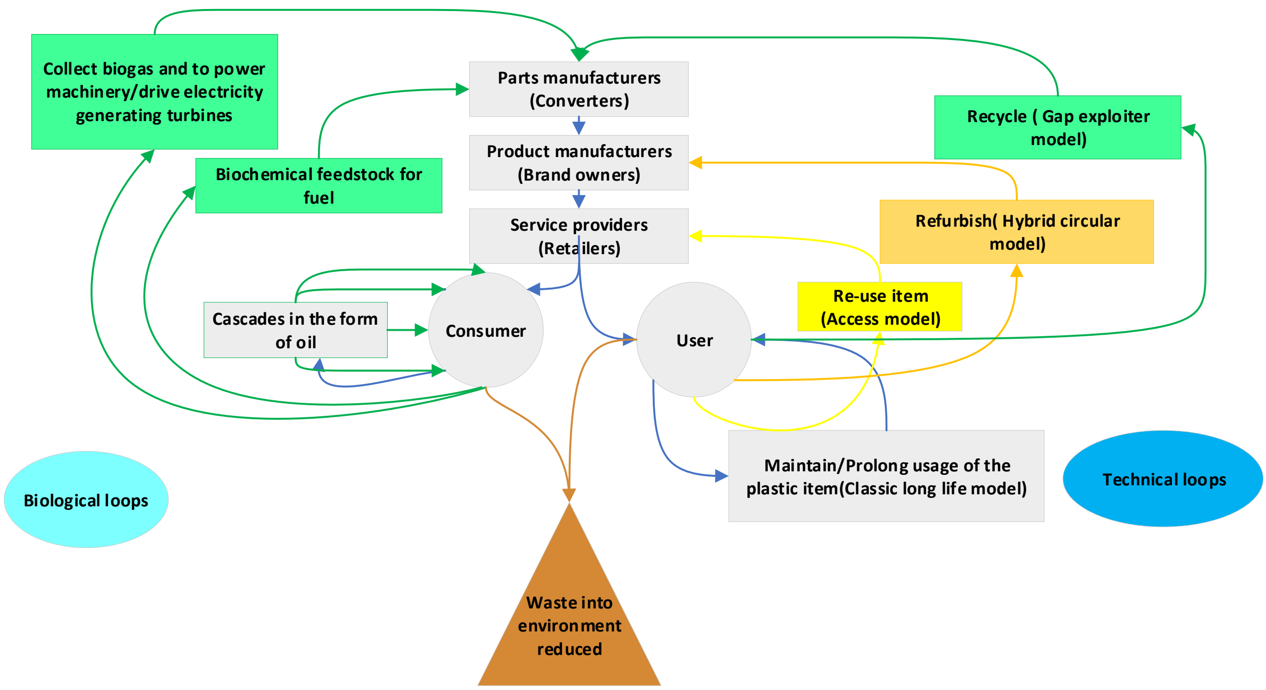

Figure 9: Plastics circular economy using the gap exploiter model, [13]‡

The loop strategy was used to map the plastic circular economy and it includes a butterfly model having 7 loops (3 on the biological side and 4 on the technical side) as shown in Figure 9. The biological side reflects how the plastic is cascaded and returned to the earth in the form of oil, the second biological loops consider bio-chemicals that can be extracted from the product- e.g. fuel oil from plastics and loop 3 the product returning to the biosphere as biogas. The inner technical loop is designed into the system for re-use of plastics, the second loop is refurbishment (product goes back to service provider) it is not applicable in this case, the third loop represents remanufacturing (product goes through the manufacturing process-to repurpose) and the outer loop is for recycling (plastic goes back to materials processor-converters).

7 CRITICAL ASSESSMENT OF DESIGN

The total population of South Africa is 58 152 066 people. Working with the assumption of 4 individuals per family unit, the municipalities would need to purchase 14 538 017 compartmentalized refuse bins. The government stands to spend R150 for each bin. Resulting in a R2 180 700 expense to the government. This is a significant amount; however, it will be rolled out over a period of 5 years. This is the primary step in the implementation process because energy recovery is considered as the last resort (outer loop) in the plastic's circular economy. The costs related to obtaining a pyrolysis plant is R112 000. One for each of the 226 local municipalities in South Africa, this would result in a cost of R 25 312 000.

7.1 Design Limitations

- High implementation costs. Cost per pyrolysis plant versus how many are needed which is currently unknown.

‡ Method of development adapted from Ellen Macarthur, 2019

- Usability of the pyrolysis unit- This will require extensive training as it is unfamiliar technology in South Africa.
- Legislation- Extra certification is needed and there currently are no existing bodies relevant for such. If pyrolysis oil is used for (subsidized) renewable energy generation or biofuels production, the oil should be certified according to a voluntary certification scheme recognized by a country's commission.

7.2 Design Validation

Designs may be validated by comparing with similar equipment performing similar purposes. This method is particularly relevant for validating configuration changes for existing infrastructure, or standard designs that are to be incorporated in a new system or application. **Case**: The city of Kraaifontein's Integrated Waste Management Facility (KIWMF) has a new plant that converts waste into energy. The plant has the potential of converting approximately 500kgs of plastic waste to 500 litres of oil per day [14].

8 CONCLUSION AND RECOMMENDATIONS

The findings of this study can be used as a basis of further investigation of how to practically roll out a circular economy initiative while observing policies across the Department of Trade and Industry and the Department of Environmental affairs. This investigation would also then look into the legislature that would govern the public and private waste collection and the operation of the community pyrolysis units. There would be an opportunity of creating oil from plastics and this would open up a new market in the South African fuels industry. There are fuel providers that would be affected by this shift as people become less reliant on buying fuel. This is mitigated by the fact that plastics that are incinerated in the pyrolysis unit are limited to those that have already been recycled. The disadvantage of this particular method is that, when operating the pyrolysis unit, it will be hard to monitor whether people are incinerating single used plastic or recycled plastics or both.

- Calculations and mapping of ideal locations for the community pyrolysis units. This process would need to be extensive to ensure that the units are placed near the areas with high plastic usage; increasing daily oil output and ensuring the seamless continued operation of the units.
- Investigations into using recycled High-density Polyethylene as raw material to make bins instead of using virgin material. This recycled plastic will make a meaningful contribution to increasing the volumes of recycled plastic material and therefore decreasing plastic waste in the form of litter from a functionality point of view and manufacturing.
- Simulation of the functionality of a reduced (size) reactor to determine feasibility and possible functionality and profitability for users and the government. The pyrolysis units need to be such that, the funds generated from it, contribute to maintenance and running costs. As outlined in section 6.3, 0.3 of the fuel produced daily will contribute to the running costs of the unit.

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FOURTH INDUSTRIAL REVOLUTION AND SUSTAINABLE IMPACT IN AUTONOMOUS FLEETS FOR EFFECTIVE SUPPLY CHAIN NETWORK IN MANUFACTURING SYSTEMS

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ABSTRACT

Industry 4.0 is a radical transformation and innovation through technology which is gaining so much attention in virtually all sectors of the economy. Manufacturing operations at inbound and outbound settings require the optimization of resources and logistics at all levels, to enable an intelligent flow of products from source to destinations within a defined network. Autonomous robots and computer algorithms of the future is required to achieve the task by ensuring timely delivery via the shortest route. Supply chain models for effective distribution of products using unmanned aerial vehicles and autonomous ground vehicles have been developed. The developed model can assist supply chain and operations manager if tested, will facilitate product delivery efficiently and optimally within the distribution network. The use of autonomous systems as a distribution agent will enable timely delivery of products, reduction in prices of products, reduced risk of accident as a result of human error, and finally, the environment will be cleaner and greener.

Keywords: Fourth Industrial Revolution, Computer algorithm, Unmanned Ariel Vehicle, Autonomous Vehicles, Supply Chain.

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1 INTRODUCTION

The complexity of the business environment requires advanced technological innovation. A paradigm shift from the traditional supply chain to the use of global best practices is necessary as a robust strategic weapon to ensure sustainable performance in manufacturing settings. Information Technology Systems are at the centre of the rapid developments of modern supply chains. As such, Min and Zhou [1] suggest that these systems be considered as the backbone of every supply chain. The internationalization of markets and the growing need for flexibility and automated systems across supply chain operations have made the development of autonomous vehicles necessary. Autonomous vehicles are mobile entities that are made of hardware and software applications able to aggregate data downstream of the supply chain to ensure the promotion of visibility, assistance with operational planning, and decision-making process. These vehicles are generally equipped with adequate computational power to handle operational activities and optimization of daily supply chain activities [2].

Recent advances in Information Technology (IT) systems have impacted many aspects of our daily life. One of the noticeable changes is the shift from computers to smart electronic devices linked to infrastructure services based on cloud computing. Hence, wireless Internet could be used to integrate computer-based automation and ubiquitous computing systems. These advances have made virtual interconnection between human beings and machines but also direct communication between machines possible [3]. The implementation of these interconnections within the production and operations environment is referred to as Industry 4.0. A significant number of solution that promotes the digital transformation of the supply chain stakeholders is provided by Industry 4.0 and the Internet of Things [4]. Several economic benefits could be derived from using Autonomous vehicles, Bechtsis et al. [5] itemized four relevant benefits as:

- Improvement of the capacity to function on a 24/7 basis;
- Reduction of the labour and maintenance cost;
- Enhancement of the level of precision in daily activities and
- Improvement of safety within Industrial facilities.

Hence, drawing autonomous vehicles and the Internet of Things in the supply chain ecosystem would improve the efficiency and effectiveness of operations [6]. Industry 4.0 is affecting many aspects of supply chain management namely collaboration between suppliers, manufacturers, and customers, and transparency of product management from dispatching to end-of-life. A description of the impact of Industry 4.0 on the supply chain as a whole is done in the following section.

2 FUNDAMENTALS OF INDUSTRY 4.0

Industry 4.0 brings along a radical shift in the manner production shop floors operate. Digitalization and the internet are at the core of the global transformation expected in the manufacturing industry. These changes affect positively the design and manufacturing processes/operations on one side and the services of manufacturing products/systems on the other side. Though the concept Industry 4.0 originated from Germany, it is referred to as the smart industry, smart factories, or Industrial Internet of Things.

The concept of smart factory implies that digital technology such as robotics combined with artificial intelligence, high-technology sensors, management and processing of data using cloud computing, interconnection via the internet of computing devices (to send and receive data), capturing and analysis of data, manufacturing is driven by digital data, software licensing and delivery model centrally hosted, mobile devices, algorithms platforms to control motor vehicles, etc. are embedded together in a global value chain [3]. Industry 4.0 facilitates the connection between human beings and computer systems controlled and monitored by computer-based algorithms. These new systems improve the readiness level of industry faced with rapid changes in shopping patterns [6].

In essence, the use of Big data, the Internet of Things, and Artificial Intelligence are promoted as one in the context of Industry 4.0. Smart machines can communicate with one another to ensure that the production lines are autonomous, to assess production issues, and proactively address them. Though Industry 4.0 benefits affect manufacturing industries mostly, sectors such as service providers, retailers, and operation companies can equally take advantage of it.

Tjahjono et al. [3] believe that four main features characterize Industry 4.0 among others:

- Vertical networking: The vertical networking of smart production systems is built on computer systems controlled and monitored by computer-based algorithms. It allows the reconfiguration of factories which improves their flexibility and adaptability to customer demand. This facilitates the customization of manufacturing processes which improve the organization of production management autonomy and maintenance management. A network that links resources to products improves the location of materials and parts in any place and at any moment. This monitoring of the process improves equally the troubleshooting during the production process;
- Horizontal integration: the implementation of computer systems controlled and monitored by computer-based algorithms within the smart factory is built upon strategies, models of networks, and business to accomplish the integration of global value chain networks. This improves the levels of flexibility and response time of the company. Moreover, the manufacturer can identify and integrate customer requirements in the production process because of the transparency within the value chain;
- Through-life engineering services: throughout each stage of the product conception, development and manufacturing, innovation, and technical improvements are integrated across the entire value chain. As a result, the large amount of data enable the design of new products and production systems;
- Acceleration of companies' growth through technologies: The implementation of technologies contributes to cost reduction, improved flexibility, customization of products, and rapid manufacturing within companies.

3 BRIEF OVERVIEW OF INTELLIGENT AUTONOMOUS VEHICLES (IAVS) AND SUPPLY CHAIN OPERATIONS

The concept of the Internet of Things (IoT) makes the interconnectivity, the communication, and the interactivity between supply chain entities that play a role in the dynamic management of network operations at a global level possible [7]. This ultimately promotes digital transformation over time [4]. Through technological innovations, Intelligent Autonomous Vehicles (IAVs) are developed to improve business logic and achieve relatively higher technical capability. IAVs can be useful in managing production lines, taking care of warehouse inventories, and supporting logistics services in several economic sectors [5]. Despite the popularity of IAVs, the promotion of digital transformations through their incorporation in the supply chain have considerable technical challenges and capital requirements. Hence, it is necessary to evaluate the operational performance and the sustainability of IAVs using software simulation [8]. This proactive approach will allow supply chain actors to make projections and decide accordingly. Despite the existence of numerous off-the-shelf commercial software, optimum software deployment within a changing manufacturing context is necessary [5].

By 2025, it is expected that the global economy should cater to a population eager for personalised goods and services Ford and Despeisse [9]. In this context, it is necessary to invest manufacturing systems and sustainable methods of production-driven enterprises relying on information and digital technologies [10]. The analysis of enterprise information systems is generally conducted at the designing levels (selection of architecture, integration, interoperability, and network). This analysis enables communication, cooperation, and collaboration among supply chains and network actors through standards and technological innovations [11].

The operational level that describes the integration of manufacturing and logistics (which include storage and transportation) is referred to as "Synchronised Production & Logistics" [12]. It consists of "Synchronising the processing, moving and storing of raw material, the work-in-progress and finished product within one manufacturing unit by high-level information sharing and joint scheduling to achieve a synergic decision, execution, and overall performance improvement". Bechtsis et al. [4] indicate that it is necessary to analyse appropriately the incorporation of IAVs at all levels of an end-to-end supply chain. This would improve the effectiveness of the synchronisation between production and logistics systems. In a typical case, IAVs are developed at the operational level to ensure that the supply chain flows are positively affected. Through an integrated approach, automation can be provided and decisions can be assessed systematically.

It is challenging to select the most suitable IAVs because of the complexity of supply chain operations subjected to functional and budget constraints in addition to specific sustainability. In general, simulation is adopted as a suitable approach to address these issues [13]. This approach doesn't disturb the system and allows the exploration of several conceptual solution alternatives and their impacts [14]. Through the use of a software or hardware object, it is possible to simulate the operation of IAVs and proactively address any potential issues.

4. FOURTH INDUSTRIAL REVOLUTION AND TECHNOLOGIES INVOLVED

Lu [15] conducted research focused on industry 4.0 where he defined the fourth industrial revolution (4IR) is a transformation that encompasses automated, improved, streamlined, and interoperable development that involves procedures, information, and a high level and innovative technology. According to him, the new and high innovative technologies are well-thought-out as the heart of 4IR. According to Bahrin et al.[16], the interconnection of the fourth industrial revolution is enabled by the introduction of communication technologies, software, sensor, and processors. Piccarozzi et al.[17] discussed further on the five major technologies linked to the fourth industrial revolution which has also been discussed in the literature of artificial intelligence and autonomous systems: Big data analytics, Internet of things, 3D printing, cloud computing, and robotic. The five technologies are also mentioned in research conducted by [18], where innovations such as machine learning, artificial intelligence, digital twin, and 5G are evolving. This work is geared towards the application of robotics in supply chains, with a focus on unmanned aerial vehicles (UAV) and autonomous guided vehicles (AGVs) for effective design of product flow at in-bound to out-bound operations in manufacturing settings.

4.1. INTELLIGENT AUTONOMOUS FLEETS FOR EFFECTIVE SUPPLY CHAINS

With the radical transformation going on in all sectors, the use of intelligent autonomous vehicles as delivery agents in in-bound and out-bound supply chains has become necessary. For fast delivery of products, aerial vehicles and ground vehicles will be useful for product distribution. It could be the delivery of raw materials to the manufacturing site or finished goods to customers. According to [20], the use of UAV drones has numerous advantages which include: reduced environmental pollution, early delivery, minimal risk of product damage, reduced road congestion, reduced cost of transportation, and many more.

5. UNMANNED AERIAL VEHICLES

The supply chain has to do with the network of the interaction of products from source to destination. Unmanned aerial vehicle technology has evolved rapidly in recent years as a delivery agent. Depending on the application of the system. The common UAV used in manufacturing settings is the drone. The performance of UAV in terms of efficiency of product delivery is a function of the weight of the object to be lifted from source to destination. Ultrasonic, visual, and thermal sensors support the signal and navigational pattern of UAV. According to research conducted by Association for Unmanned Vehicle Systems International, [19], it was noted that by 2025, drones would be prevalent and useful to support the economy as a delivery agent in the United States of America. According to a drone technology research [21], the new generation of drones popularly called flying mini-robots (FMR) or unmanned aerial vehicles (UAV) are smart and reliable drones. Characteristic of smart drones that makes them different from the traditional vehicular system is that they fast, efficient and capable of navigating to space where a man cannot reach and they possess sensors that can manage operations, monitoring without the necessity of human force, and useful in manufacturing settings, transportation, cargo operations, and logistics [22]. The flying robots or drones can be controlled using a smartphone app or remote-control system, they can navigate to inaccessible zones timely and effortlessly.

This section focuses on the supply chain model for the effective delivery of manufactured products to customers' end. Path planning for easy, timely, and efficient delivery of products using UAV, requires mapping out of routes from the source or location point of drones to the manufacturing centre for onward product delivery to the final destinations. For an effective supply chain of the future, it is important to factor into consideration the online order of products from customers' end, especially when the signal is received from the supply chain manager at the manufacturing site. The UAV can then be activated to lift products from UAV station to outbound manufacturing site or depot and finally to customers. The major objective of this research is to maximize profit for manufacturing companies by designing a path planning model for the optimal supply of products from manufacturing sites to customers end using UAV technology.

5.1. UAV PATH PLANNING MODEL FOR EFFECTIVE DELIVERY OF PRODUCTS

Design of network of the interaction of products using is such that:

1. The station point of the drone or flying robot is known;
2. product availability at the manufacturing site (source) is known;
3. demand requirement at the customers' end is noted.
4. the capacity of the product to be conveyed by the UAV or flying robot from source to destinations is known;
5. product day level is monitored at the source and customers make an order for products at the destination point;
6. the online platform is designed such that customers can make a demand for goods at outbound locations taking into consideration distance from customers to the outbound centres and the time taken to get to that location at a defined speed;

7. In cases where the company have transshipment points or depots, customers make an order for the product at the shortest depots;
8. In cases where products are manufactured daily, production time at manufacturing centres should not exceed waiting time of customers;
9. transshipment model is allowed;
10. the ideal model is such upon assignment of product to the drone, the system departs from the station to the product pickup location, say point A, pick up the product at that point and navigate to the final destination where the request is made at the time (t);
11. upon delivery of the product, the UAV returns to the station, awaiting another delivery.

Model formulation and Notations

The following notations are adopted for the UAV modeling purpose: Assumptions are equally made. The parameters of the model are listed thus:

X = Customers location. The location point of customers can go from 1,2,3 to i.

Y = Outbound manufacturing point or depot (point of product availability). The location route of the company can go from 1,2,3 to j.

Z = UAV location point or station. This is the waiting point of the robot in readiness for the airlifting of products. The station point can go from 1,2,3 to k.

i = index representing a set of customers location point

j = index representing a set of depots or outbound facilities

k = index denoting location set point for UAV.

D_{xy}: the distance between the customers (x) and outbound manufacturing site (y).

D_{yz}: the distance between outbound manufacturing site (y) and customers location (z)

T_y-: In a case where multiple products are required timely, the time taken to produce a unit product at the manufacturing centre y. Ty is zero when the product is available for pickup at the source.

t: waiting time of delivery from the customers' end.

C_i: number of customers waiting at the destination for product pickup.

R: represent the readiness of the UAV to deliver product from station to customer end.

N: represent the number of customers that can be reached during delivery from the manufacturing site.

P: represent the policy of the company in terms of required product at customers' end, in cases where customers make much more demand than the available product, the supply of fraction of product is possible.

M: Number of outbound depots with product availability for supply to the customers' location.

C_{xyz} – Total coverage of the UAV system from the point of location of the drone to the outbound depots and finally to the customers' end. The objective function is therefore expressed thus:

Objective function Z=$max \sum_{i\in I} C_i \cdot N_i - \quad Pi \sum_{z\in Z} X_z$ (1)

Subject to constraints:

Coverage constraint $\sum_{z\in z} c_{xyz} \cdot x_z \geq R_{xy} \quad for\ all\ values\ of\ x\ and\ y$ (2)

Coverage const. with policy $P_i \cdot \sum_{z\in z} c_{xyz} \cdot x_z \geq R_{xy} \quad for\ all\ values\ of\ x\ and\ y$ (3)

Readiness constraint $n = \sum_{y\in y} R_{xy} \qquad for\ all\ value\ of\ x$ (4)

Constraint on reachability $N_i \leq \max(0,\ n_i - M + 1) \quad for\ all\ value\ of\ x$ (5)

Supply constraint $\sum_{j=1}^{n} X_{ik} \leq S_i$ for all i =1,2,3…..m (6)

Demand constraint $\sum_{i=1}^{m} X_{kj} \leq D_j$ for all j = 1, 2 … n (7)

Policy constraint $\sum_{j=1}^{n} X_{ik} - \sum_{i=1}^{m} X_{kj} = 0$ for each intermediate node k (8)

No negativity $X_{ik}, X_{kj} \geq 0$ (9)

$n_i \geq 0 \quad for\ all\ value\ of\ i$ (10)

$N_i \in \{0, 1\} \quad \forall i \in I$ (11)

6. AGV PATH PLANNING MODEL

Model for Interconnected AGV in a Manufacturing System for the Future - Automatic Guided Vehicles (AGVs) have played a vital role in moving materials and products in a manufacturing setting for decades. AGV can be used to load and offload materials at the site, they are equally used for lifting heavy objects within the factory settings. In a standard manufacturing setting where raw materials for production are available at in-bound depots, moving of such materials to the production site is made easy with the help of robots. The same is applicable within the facility, the movement of products for man to machine or machine to machine interaction requires the help of autonomous robots. Also, the movement of finished products to retail depots in readiness for distribution to customers can be done with the use of robots. A single robot cannot operate. There is a need for the interconnection of swarm robots for effective product delivery. Designing a swarm robotics algorithm is important for easy navigation and communication of the community of robots. To have all robots meet at the same location and perform tasks in a manufacturing setting, there is a need to aim for the local neighbourhood. A globally emerging behaviour is expected in search of a solution point.

Model formulation and Notations

L represents the point of location of Robot i.

i, is the index representing robots (i=1,2,3, n)

n is the total number of robots available

k is a constant

Le is the existing position of the robot

L_N is the new position of the robot

(Le-L_N) is the difference between the location of robots

W is the assigned weight.

Modification, finetuning and proper selection of weight are important in assigning robots. Weight W is a function of the distance between the robots. Developing a mathematical model to help in effective robot interaction is important especially getting the robot close to the point of communication and away from the expected point of communication. Therefore, building scalable large robotic complex solutions for the future is possible, a situation where multiple robots can communicate and execute complex tasks with ease (see eq. 12 and 13).

$$Li\,n = Li + k\sum_{i,j\in n}(L_e - L_N) \tag{12}$$

$$Li\,n = Li + k\sum_{i,j\in n} W[D(L_e - L_N)]\,(L_e - L_N) \tag{13}$$

6.1 Model for Autonomous Vehicles - Depots to Customer Location

The model for the AGV defined in this research is focused on available products ready for delivery to customers' locations. The notations and definitions of terms are further stated.

Notations and Terms of Definition

I: Total number of products to be distributed by AV.

N: Total number of locations set aside for AV

J: Number of customers location to be served by AV

K: Number of manufacturing centres (MC)

i Index identifying products to be supplied by AV at the MC with $i = 1,2 \ldots I$

n: Index identifying the location set aside for AV with $n = 1,2 \ldots N$

j: Index identifying customers to serve at various location with $j = 1, 2, 3, \ldots J$

k: Index identifying the MC with $k = 1, 2, \ldots, K$

X_{ijn}: Quantity or amount of product *i* at the MC shipped to the customers end *j* from AV site *n*

X_{ikn}: Quantity or amount of product *i* available at the MC ready to be shipped to customer location *k* from source *n*

X_{ijk}: Quantity or amount of product *i* shipped to customers *j* from MC *k*

Z_k: The capacity of the MC, *k*

A_{in}: Availability of AV i at the source *n* for allocation of product from MC to customers

c_{ijn}: Unit cost of moving item or product (*i*) to customers location *j* from the location of the AV (*n)*

c_{ijk}: Unit cost of moving item or product (*i*) to destination *j* from MC *k*

c_{ijk}: Unit cost of shipping product *i* to MC *k* from the AV station *n*

D_{ij} Demand of item (*i*) at the location point of customers *j*

bj: Fraction of demand that must be met at the customers' location *j*

C: Total cost of product distribution from source to destinations

$$C = \sum_{n=1}^{N}\sum_{k=1}^{K}\sum_{j=1}^{J} c_{jkn} X_{jkn} + \sum_{k=1}^{K}\sum_{j=1}^{J}\sum_{i=1}^{I} c_{ijk} X_{ijk} + \sum_{n=1}^{N}\sum_{j=1}^{J}\sum_{i=1}^{I} c_{ijn} X_{ijn} \tag{14}$$

Subject to:

$$\sum_{i=1}^{I}\sum_{k=1}^{K} X_{nik} \le A_{in} \quad \textit{for all values of I and k} \quad q \tag{15}$$

$$\sum_{k=1}^{K} X_{kji} + \sum_{n=1}^{N} X_{nji} \le D_{ij} \quad \textit{for all values of I,j and k} \tag{16}$$

$$\sum_{n=1}^{N} X_{nji} + \sum_{k=1}^{K} X_{kji} \ge b_j D_{ij} \quad \textit{for all values of I,j and k} \tag{17}$$

$$\sum_{j=1}^{N} X_{ik} \le Z_k \qquad \forall\ k = 1, 2, 3,4,5,\ldots \text{to } k \tag{18}$$

$$X_{ij} \ge 0 \qquad \forall \quad i = 1, 2 \ldots I; \quad j = 1, 2 \ldots J \tag{19}$$

7. DISCUSSION

Supply chain as a global network has been used to deliver products and services from raw materials to end customers. It requires the right information and physical distribution. The traditional approach to the supply chain is quite common nowadays especially in developing and emerging nations. As a result of the fourth industrial revolution, new data architecture and the global network has emerged where people and machines can communicate continuously. This has led to a high standard of safety and has changed society and our daily lives. The use of autonomous systems as a delivery agent has changed the network of the interaction of products at the inbound, in-process, and outbound level. Concepts, production, delivery, and services are digitally guided and share all the process information. The path planning algorithm for effective supply chain management has been successfully developed for UAV and AGV system considering a manufacturing setting. The model for product distribution using UAV and AGV has been described in sections 5 and 6. Section 5 focused on the supply chain model for effective product delivery using flying robots or drones. The mathematical model has been designed for easy, timely, and efficient delivery of products. The major objective is to help maximize profit for manufacturing companies and equally help in material requirement planning and distribution of finished products. Section 6 focused on a model for ground robots in standard manufacturing settings for moving raw materials to factories, work in progress, and distribution of finished products to customers at various locations. The model will equally help organizations in improving the supply chain network using flying or ground robots.

8. CONCLUSION

This research has demonstrated a paradigm shift in supply chain design, processes, and engineering for real-time and dynamic systems. The fourth industrial revolution has forced researchers towards path planning model for effective supply chain design using autonomous systems. Implementing flying robots or UAVs and ground robots or AGVs for product distribution in manufacturing settings will be of great economic benefit since they are programmed to function autonomously, therefore helping operation managers or supply chain experts focus on other business plans, it is affordable, safer, cleaner, more efficient, more transformational. Considering future research direction, we aim to demonstrate the suitability of the model in real life scenario as well as the application of nature-inspired algorithms for dynamic interaction of swarm robots in supply chain networks. This would help in the effective path planning of robots, not only in manufacturing or retail outlets but also in other areas of operations like exploration, surveillance, social rescue, and the healthcare system.

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INVESTIGATION INTO HOW BANKS CAN REALIGN EXISTING EMPLOYEE SKILLS TO DELIVER ON CUSTOMER NEEDS IN THE 4TH INDUSTRIAL AGE

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ABSTRACT

The Fourth Industrial Revolution is introducing disruptive technologies and trends which are changing the way we live and work. The banking industry's adoption of these technologies has created new roles requiring a new set of skills. This study investigated how the existing workforce skillset at a South African Bank can be transformed to address the changing operational landscape requirements. The study followed an exploratory qualitative design in which two data collection methods were used to gather data from employees working in different functions within the bank. Purposive sampling was used to select participants, based on their seniority, experience, exposure, and subject matter expertise. The interviews were structured as per the questionnaire questions to ensure consistent data. This made it possible to compare interviews and questionnaire responses. Thematic analysis was employed to analyse the data. The participants identified several required financial technology skills, and they suggested how the skills gap can be closed. The study found that organisational and national education policy transformation needs to be prioritized. Collaboration between public and private sector stakeholders was also proposed as a response to the organisational resource challenges. The findings were used to propose an organisational skills transition. A few recommendations were also noted for future research areas.

Keywords: Industry 4.0, banking sector, employee skills transition

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1 INTRODUCTION

1.1 Background

The Fourth Industrial Revolution (4IR), a term coined by Klaus Schwab, founder and executive chairman of the World Economic Forum (WEF), is the current and developing environment in which disruptive technologies and trends are changing the way we live and work [1]. These trends include the Internet of Things (IoT), robotics, Virtual Reality (VR), Augmented Reality (AR), Mixed Reality (MR), and Artificial Intelligence (AI) [2]. A wide set of small and medium businesses are expected to thrive through the benefits and opportunities offered by 4IR technologies. On the other hand, the inability to adopt 4IR technologies will have an impinging impact on the bottom line of most of the large organisations in highly innovative sectors [3].

In South Africa, the services sector makes up at least 65 percent of the gross domestic product (GDP) and employs at least 71 percent of the labour market making it the largest labour sector in the country [4]. Sub-sectors include: social services, distribution services, business services, financial services, and transport services. The financial services sector – which is dominated by banks – is the fourth largest sector in the services sector [4]. As a result, changes brought by the 4IR in the work configuration of the financial services will have a big impact on South Africa's employment ability.

1.2 Motivation for Research

The worldwide body of literature on the impact of the 4IR on banking institutions mainly focuses on the benefits of technology application and the potential of disruptive innovations. However, existing traditional banks find themselves in a difficult situation having to transition to a new technological era whilst their current workforce and strategy pose as barriers to the adaptation [5]. There is a critical and urgent need to better understand how the existing banking workforce skillset would need to be transformed in order to support a 4IR business strategy and to better deliver on customer needs.

In 2019, the WEF released a report on the cost-to-benefit analysis of the "training of existing employees" versus the "hiring of new staff" for 4IR roles. The report found that it is most cost-effective for a company to train at most 25% of its workers compared to hiring new workers for the emerging 4IR roles [6]. This analysis did not include other advantages offered by training; such as when a government provides tax rebates to employers that train their employees [6].

The study investigated the strategy for legacy bank organisations to transition into the 4th Industrial revolution technological driven corporation.

1.3 Research Question and Objectives

The research question for this paper was:

> *"How can Bank X realign the skills of its existing employees to deliver on customer needs of the 4th industrial revolution?"*

The study was part of a broader study into the research phenomenon conducted at one of the South African four large banking institutions, referred to from here as "Bank X". Four objectives were investigated; however, this paper focuses on two of these.

The two objectives were to:

- Identify the fourth industrial revolution skills requirements in the banking sector.
- Provide recommendations on how Bank X can close its skill gap in order to deliver on customer needs.

2 LITERATURE REVIEW

Three industrial revolutions are attributed to the foundational makeup of the 4IR hence the effect of the 4IR is better understood in the context of these prior revolutions [7].

The First Industrial Revolution was powered by steam and water for mechanization of factories and railways through the steam engine [8]. The Second Industrial Revolution was powered by electrical power for mass production assembly lines through inventions such as the light bulb amongst others [7]. The Third Industrial Revolution was powered by a combination of information technology and electronics for the automation of production through the computing revolution, robotics, and programmed controllers [7].

Although each industrial revolution is a separate event, together, they are a series of events building upon innovations of the previous revolution resulting in advanced forms of production and optimization of business processes.

2.1 Financial Job Losses

In 2016, Josh Levin of *Autonomous Research* found that most mundane and repetitive tasks will be replaced by Robotic Process Automation (RPA) and AI due to their high degree of susceptibility for automation [9]. Automation of these tasks will allow the workforce to focus on the more complex tasks that are difficult to automate. Figure 2 below shows the estimated job losses per role in the United States of America (USA) by the year 2030 [9].

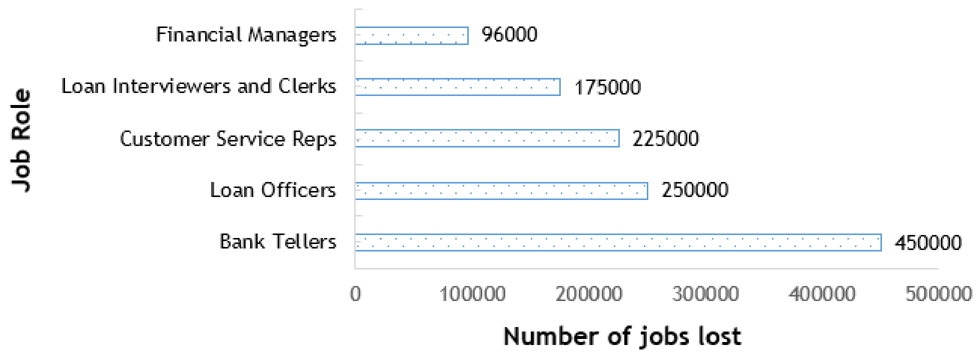

Figure 1: Estimated number of jobs losses due to 4IR financial technology (Fintech) [9]

The four biggest banks in South Africa (Nedbank, Absa, FirstRand Bank Limited, and Standard bank) operate a cumulative of at least 2800 branches across the country [10]. Together, the banks own 81 percent of the South African financial service market share [10]. Due to their market dominance, the banks employ a large workforce. Negative disturbances in the operation of traditional banks may trigger the loss of large profits, consequently resulting in a large number of branch closures and staff retrenchments. A possible reason for these potential disturbances is the uncompetitive reliance on non-digital operations by traditional banks; while smaller, but more nimble, new market entrants are readily using more innovative 4IR technology applications [10]. In 2017, PricewaterhouseCoopers (PwC) estimated that 25% of the big four banks' branches will be closed off by the year 2020 due to digitization and automation of previously face-face and manual tasks [11]. This was expected to improve the bottom line of many banks. This prediction has since been proven true as of the writing of this paper [12].

Table 1 below shows a combination of actual and proposed job cuts for each of the South African major bank, on account of the implementation of some form of 4IR technology [12].

Table 1: Job loss per bank because of Fintech [12]

Local Bank	Job loss because of FinTech
Nedbank	1469 Jobs lost between the year 2018 -2019
Standard Bank	1200 Jobs cut-off proposed for the year 2019
Absa	827 Jobs at potential risk of layoff in the year 2019

Only FirstRand Bank Limited did not report retrenchments or offer similar proposals as a result of 4IR implementation [12]. However, leaders within the finance and technology sector believe this could change forced pressure to cut costs [12].

2.2 Fourth Industrial Revolution Financial Technologies

Four of the most influential technology areas driving the financial technology revolution today are *Chatbot*, *Robotic Process Automation*, *Blockchain,* and *The New Face of Retail Banking (Digital Banking)* [13][14][15][16][17].

2.2.1 Chatbot

A chatbot is a computer program or an artificial intelligence which conducts a conversation via auditory or textual methods [13]. Chatbots can be programmed to respond the same way each time, to respond differently to messages containing certain keywords, and even to use artificial intelligence through machine or deep learning to adapt their responses to fit the situation [13].

For example, a small business lender in Montreal, Thinking Capital, uses a virtual assistant to provide customers with 24/7 assistance through the Facebook Messenger [13].

2.2.2 Robotic process automation (RPA)

RPA is a form of business process automation technology based on the notion of software robot workers. RPA robots are augmented with AI capabilities that help them learn from previous examples and use Natural Language Processing or image recognition capabilities [14]. In 2018, Nedbank installed 259 software robots for process automation with its IT division [14]. Other local banks are also initiating similar innovations that clearly have an impact on the organisation's bottom line [11].

2.2.3 Blockchain

Blockchain is an incorruptible digital ledger of economic transactions that can be programmed to record from financial transactions to virtually anything of value [15].

For the banking industry, blockchain offers benefits such as instant settlements, and reduced fraud via self-sovereign identity amongst others. It is estimated that 20% of the workforce in traditional banks will be disrupted as a result of blockchain financial technology (FinTech's) [16]. The speed and scale of market disruption will mainly depend on the adoption of the new economy by technology users.

2.2.4 The new face of retail banking (Digital Banking)

The new face of retail banking is the technological advancement that has allowed the conduct of banking through mobile (i.e. Virtual Reality, Augmented Reality, Mixed Reality, wearable smartwatches, phones, and personal computers) and digital platforms negating the need for physical infrastructures with fixed location points [17]. An example of this is M-Pesa, a successful collaboration between Vodafone, Kenyan micro-finance institute Faulu, and the Commercial Bank of Kenya which began by facilitating payments and money transfers in Kenya [18].

2.3 Workforce Skill Transition

There are several advantages that are associated with the reskilling and upskilling of workers. These include [6]:

- Reduced cost of hiring new talent
- Government Tax Cuts on employee training [19]
- Retraining of employees reduces the adverse impact on the unemployment rate
- The absorption of employees contributes towards an empathetic brand image
- Reduces risks of labour unrest

3 RESEARCH METHOD

An exploratory qualitative research design was used to conduct the research. This allowed the researchers to hear from and to understand the phenomenon being studied (4IR skills in the banking sector) directly from the involved employees in the organisation. Exploratory studies are helpful when aiming to form hypotheses, in formulating problems; or, as in the case of this study, seeking to clarify concepts [20].

3.1 Research Setting

The study was conducted in a South African Bank. The intellectual property governance of the bank was accounted for in the process of data collection.

3.2 Participants Enrolment

From forty-five invitations sent to potential respondents, thirty positive responses were received and consequently formed the research source of feedback.

3.3 Participants Sampling

Purposive sampling was employed [21]. Field experts, managers, and executive committee members in Bank X were chosen to be respondents of the research questionnaire. The sampling was motivated by the respondents' organisational position, technical knowledge, and experience which provided them with access to Bank X organisational strategy and its current technological state.

3.4 Data Collection Method

As per Figure 3 below, two methods for data gathering were employed. These are structured interviews and questionnaires. Structured interviews ensure consistent and comparable data making it possible to compare interviews and questionnaire responses [22]. Face-to-face, video conference, and telephone call interviews were conducted in live interaction with respondents. Email and online survey questionnaires were administered to respondents whose live interaction could not be secured.

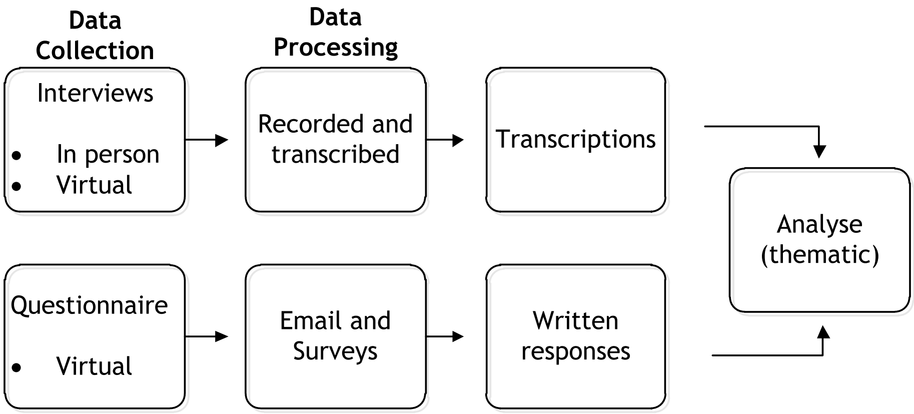

Figure 2: Investigational method approach

Table 2 below shows the majority of respondents classed by organisational position, work experience, and functional area.

Table 2 Majority class of respondents based on sampling criterion

Sample criterion	Majority class	Percentage (%)
Position	Junior and Midlevel	67
Experience range in years	10 - 15	53
Functional Area	Information Technology (IT)	50

3.5 Data Recording

All interview sessions were recorded with the participant's consent. Data collected was digitally recorded by using one of the authors' personal computer. NVivo 12 (Windows) software was used to transcribe recordings [23]. This was time efficient and it increased accuracy in transcription.

3.6 Data Analysis

Thematic analysis was employed to analyse the raw data ultimately generating two levels of themes; one level was the sub-themes, which led to the second level of the main themes). Data from the interview transcriptions as well as the survey and emailed questionnaire (see Figure 3) was coded into shorter phrases. The phrases were then categorised into the generated themes. To remain objective in the process, an inductive coding was employed which assumes that no pre assumptions are made about the question asked. Coding involved the repeated reading of paragraphs then single lines across multiple participant responses to make sense of a theme.

3.7 Investigation Risks and Mitigation

The risk to data collection not completed on time was mitigated by contacting respondents weekly to ensure feedback is received. The risk of poor-quality feedback content was mitigated by selecting respondents based on their seniority, experience, and exposure to the research area under investigation. Sampling was validated against the organisation organogram, as well as individual roles and responsibilities.

- Respondents were provided with the interview questions 3 weeks before the interviews allowing them enough time for preparation.
- Respondents were selected based on their seniority, experience, exposure, and subject matter expertise.
- The findings from the participants were supported by comparing the research findings with literature; thereby increasing the confidence in the findings.
- Ethics clearance guaranteed the anonymity of all respondents to mitigate against uncandid responses from respondents who may fear victimization.

3.8 Data trustworthiness

The trustworthiness of the data (credibility, dependability, transferability, confirmability)

- Credibility was ensured through the gathering of data from different sources using different methods.
- The use of purposive sampling increased the likelihood of study transferability by using respondents who are more related to the subject matter.
- Due to the limited study of this particular topic in South Africa, confirmation of the study was only delved in comparison with global research literature.
- The dependability of this study cannot be extended beyond Bank X as the findings were based on a limited sample within this bank.

4 FEEDBACK AND FINDINGS

Participants were asked to name the skills that the bank must prioritise as critical to transition and be a business leader in the 4IR age. Below are the study’s findings.

4.1 Objective 1: Identifying the fourth industrial revolution skills requirements in the banking sector.

The study found that not all current skills will become redundant. There are some which will continue to grow, while other required skills will be completely new. The required skills were informed by the generated themes from the interview data. Table 3 shows the themes which drive the skills requirement, as well as the set of required skills.

Table 3: Themes driving skills required versus the identified required skills

Themes driving skills requirement	Skills required
Increased collaboration between teams	Programming (Blockchain, Software Engineering, and AI)
Increasing customer demand for digital and mobile banking solution	Data management
Increasing cybercrimes threat	Complex Problem Solving
Increasing volume of customer data	People Management
Increasing market competitiveness	Emotional Intelligence
Shrinking product development time	Coordinating with Others
	Data analysis
	Service Orientation
	Negotiation
	Cognitive Flexibility

To translate the finding of Table 3 into useful information, the authors connected the identified skills with the banking sector roles (as indicated in Table 4). The skills were translated into the different types of roles which would be required. A causal relationship between the diminishing and growing roles was acknowledged. *(To note: The Alphanumeric superscripts represent the relationships between the different type of roles i.e. all the roles with the superscript "a" are related).*

Table 4: Required financial roles (from the required skills)

Impact on roles		
Diminishing roles	**Expanding** roles	**New** roles
Bank Teller	Cybersecurity specialist	Data Scientist[b]
Know Your Customer (KYC) Officer[b]	Quant[b]	Blockchain developer[a]
Call Centre Agents	Software Engineer[a]	Cloud Banking Expert[a]
COBOL Developer[a]	Process engineer	Natural Language Processing (NLP) Expert[a]
Data Entry Clerk	Development product Manager	Agile Coach
Fund Management	Industrial Psychologist	Agile Scrum Master
Loan Interviewer		Storyteller
Financial Accountant[b]		Culture Champions
		Behavioural Psychologist

Participants were asked to provide recommendations to close the current gap for the bank with respect to the transition to a 4IR skills anchored business. Below are the study's findings.

4.2 Objective 2: Provide recommendations on what Bank X must do to close the 4IR skill gap in order to deliver on its customer needs.

Two main themes and corresponding subthemes were generated from the thematic analysis as presented in Table 5 below.

Table 5: Themes and subthemes

Main Theme	Sub Theme
A Policy Change	A1 Banking organisation policy A2 National basic higher education policy
B Method for funding the reskilling	B1 Government B2 Private sector (including banks) B3 Individuals Employees

A. *Policy change*

Education policy in South Africa is governed by the Department of Basic Education and the Department of Higher Education and Training [12]. Before 4IR, the education policy was based on the needs of business in the third industrial revolution particularly post the birth of a democratic state [12]. The respondents of this study recommended a transformation of the current education policy to align with the country's economic growth strategy which in turn will enable the banking sector to benefit from a better-skilled workforce.

Bank X's **organisation policy** governs how the organisation aligns its strategies to support the transition into 4IR. Respondents recommended the fostering of hiring employees based on seniority, as a result, the organisation lacks the ability to grow and to attract young talent. To change these policies, the company is required to self-evaluate and to come to an agreement on what its goals are which facilitate and help advance the transition into a new way of working.

Level 2 of the subthemes were generated in relation to the banking organisation's policy (see A1 in Table 5) are listed in Table 6.

Table 6: Subthemes on organisational policy change

Organisational policy Actions
Draft transformation policy.
Introduce incentivise to motivate workforce skilling.
Update organisational Roles and Job specification.
Consult employees when developing policy.
Prioritise integration of human and robot activities.
Improve labour market dynamism policies.
Prioritise experience-based training.
Change to agile project management.
Prioritise contract and freelance work formats.
Prioritise skills-oriented recruitment.
Break work silos and motivate integrated multi-skilled teams.
Banks foster collaboration with academic institutions.
Offer a range of diversified training options to employees.

B. *Methods to fund the reskilling effort*

The study found that an appropriate funding mechanism requires contributions from stakeholders other than Bank X. These stakeholders are the government, the private sector (including banks), and individual employees. Table 7 shows subthemes developed for each of these stakeholders.

Table 7: Subthemes on funding mechanism per stakeholder

Government	Private sector (including banks)	Individuals Employees
• Collaborate with banks to provide funding. • Tax-based reform.	• Non-profit models (i.e. NGO). • Bank-sponsored internal and external training of employees. • Reinvesting organisational savings in the future workforce.	• Employee contracts. • Income-contingent loans.

5 DISCUSSION

5.1 Objective 1: Identifying the fourth industrial revolution skills requirements in the banking sector.

The study investigated the skills that are critical to support a 4IR-driven Bank X. It was found that a combination of existing and new skills is required to support the transition of Bank X in the era of the 4IR as shown in Table 3. The demand for the roles which are made up of these skills is expected to grow. It was found that activities that are easy to automate (repeatable and mundane) will be the first to be replaced [11]. This finding is significant in that it further strengthens available literature which states that less skill-intensive jobs are disappearing [9].

In Table 3, the themes which drive 4IR roles and the related required skills were presented. These themes are discussed below with both justification and criticism of the findings. The themes from the respondents are in quotation marks, with the authors' discussion following thereafter.

- *"The fourth industrial revolution is the breaker of silos in the workplace through* ***increased collaboration*** *between teams.* A multi-skilled workforce is needed to tackle complex tasks in an age of ever-increasing technology complexity. For example, skills such as project management, business analysis, and software development are being combined to form a single role of the Software Engineer." The Software Engineer would be able to fluently interact with business teams when documenting requirements; yet still technical enough to develop the required software changes.
- *"The* ***increasing customer demand*** *for digital and mobile banking solution compels for an omnichannel digital platform*. This is attributed to customers seeking convenient, self-service, and remote banking solutions." To meet this demand, Bank X must become a one-stop-shop "digital omnichannel" for customers to find all their transaction needs. This will continue to increase the demand for App Developers and IT Solution Architects personnel.
- *"The increasing usage of digital platforms paves the way for an increased* ***threat of cybercrimes****."* To minimize this threat Bank X must invest in Cybersecurity Specialists.
- *"The increasing digital platforms interaction enables the gathering of large* ***customer data*** *that can be used for behaviour-related marketing."* To achieve this, Bank X must hire more Data Scientists and Quant Engineers. Data Scientists and Quants use machine and deep learning algorithms (AI) to develop models that can predict future events by drawing patterns of past events.
- *"The increasing traffic on digital platforms means the platform infrastructure that holds and process this data begins to suffer in handling capacity (i.e. processing speed) and must be regularly upgraded to accommodate data traffic".* ***Upgrading big data platform infrastructures*** *(i.e. Apache Hadoop) is expensive and the alternative is moving to rental platforms.* Cloud computing is a type of infrastructure platform that Bank X can rent to reduce costs." It is cheaper (i.e. no maintenance or upgrade cost) and has become preferential over the last decade with vendors such as Amazon Web Services (AWS) and Microsoft Azure amongst others [24]. Cloud Banking Experts are the skills required to manage cloud-based systems and will be required to achieve this goal.
- *"The* ***increasing market of competitors*** *within the banking industry means banks must compete on price to win customers.* Blockchain enables competitiveness through low transaction fees while providing a secure and transparent way of banking." Bank X will need to employ Blockchain Developers to increase its competitive edge.
- *"The time between the conceptualisation of an innovation until the time that it can be commercialised is shrinking in the 4IR era. This is by part due to the* ***"first to market"*** *competition amongst innovators."* The study found that agile project management is more efficient to deal with changes during a project development cycle compared to "big bang" methods such as waterfall. Minimum Value Products (MVP) are prioritised over big bang products that require long

development time coupled with extremely delayed testing phases. Agile introduces greater transparency of processes and accountability of employees. However, some employees (i.e. poor performing employees or agile method illiterate employees) may not be comfortable with the transformation. The implementation of agile should start from management and can be facilitated by developing internal Agile Coaches and Scrum Masters.

5.2 Objective 2: Provide recommendations on what Bank X must do to close the 4IR skill gap in order to deliver on its customer needs.

Two themes to close the skill gap are discussed in 5.2.1 and 5.2.2. below.

5.2.1 Policy Change

Subthemes for policy change are **organisation** and **national basic and higher education** policy.

5.2.1.1 Organisation policy

In Table 7, themes of ways to transform the organisation for the 4IR are presented. These are discussed below with themes in quotation marks and discussion thereafter.

- *"Employees will only support a program of change if they feel involved and are made **champions of the change**."* There must be a thorough consultation with employees before the formalization of any transformation policy. Only after this can formal documentation of transformation strategy be publicized. South Africa is also a labour-intensive country owing to deeply rooted industries such as mining, agriculture, and farming [25]. This has resulted in other industries such as the banking sector becoming highly guarded with labour unions. For this reason, transformation strategies that seek to enforce change without consultation with employees are likely to result in labour unrest actions.
- *"The **integration of human employees and robots** helps for a gradual transformation hence increasing the likelihood of success."* Robots alone will not answer the needs of customers since they lack empathy skills essential for relationship development. For example, a robot could pick up calls or requests and analyse data while the human employee receives the result and feed it back to the customer. The workforce must be trained to work seamlessly with technology to ensure a good customer experience.
- *"A new economy **"the gig economy"** is emerging.* This economy is made up of employees that do not hold permanent contracts with employers. This new wave of working requires that employers enact policies to protect their intellectual property. The gig economy offers employers the advantage of a reduction in employee benefits cost (i.e. medical aid, pension fund, and life cover, etc.) since gig workers have little to no employee benefits." A disadvantage is that gig workers may be less attached to the company hence making it difficult for the company to make long-term strategies based on current employees.
- *"Due to constant technological change and first to market competition, the bank must operate in an **agile process**.* This does not only refer to IT departments but to all departments within the bank (i.e. Human Resource Management, Business, Project management Office and Process Innovation) to ensure operation synergy." Ultimately, agile results in reducing the project delivery cycle as well as the associated costs, through the early detection of faults.

- *"Training must encompass a **variety of models** to ensure it produces the desired result of mass workforce inclusion.* For example, transfer of experience from senior employees to junior employees must be prioritized to ensure the core business area skills are retained." Bank X must offer a variety of training based on the levels of employees' willingness to learn.
- *"Prioritization of trainees must be based on the **cost to benefit of future returns** based on employee's stay in the company.* This means that employees nearing retirement should not be prioritized over junior employees." For this reason, employees must sign contractual agreements to serve a minimum period after they are trained.
- *"Reskilling requires a **personal commitment** from trainees. Without an **incentive**, there is no motivation for the workforce to acquire new skills.* The threat of losing one's work is a motivation for the workforce to commit to acquiring new skills; however, this is based on negative emotions." The study found that positive motivation such as high wages, promotions, and prioritization of internal staff for new job offers are good motivations for employees toward reskilling and or upskilling. Recruitment policies that prioritize qualifications and skills must also be implemented.

5.2.1.2 National basic and higher education policy

The study found that the standard of the national education is the pillar to ensuring the readiness of organisations for 4IR. Respondents argued that the government must overhaul the current basic and higher education curriculum towards one which emphasises teaching and solving workplace needs. For example, science, technology, engineering, and mathematics (STEM) based education must be used to introduce practical and work-relevant skills to students. In this way, a synergy will be formed between the education system and the skills required in the workplace. Further emphasis must be placed on collaboration between education institutions and workplaces through the sharing of knowledge and resources (i.e. student vacation work, research programs).

5.2.2 Mechanism to Fund Transformation Policies (reskilling)

Three subthemes related to fundraising are discussed below.

5.2.2.1 Government fundraising

The study found that collaboration between the government and banks will be beneficial for both parties. Skilled employees will result in high employment and entrepreneurship levels; thereby raising the tax collection ability of the government. Banks will benefit from the productivity of a skilled workforce.

- *The South African government can use **tax-based compensation** to fund skilling and training.* The government can reduce business tax on businesses that are using business revenue to skill their employees. This initiative is a motivator for banks to train and skill their employees as there is a tax-rebate incentive. For example, in 2018 though with large overall revenue, Amazon paid only a small fraction of tax to the government due to tax rebate resulting from revenue reinvestment to business and employees [26].

- *Banks and governments must provide **income-contingent loans** to employees who enrol in skilling*. This loan is based on the future expectation that the individual being funded will be able to pay back the loan money.

5.2.2.2 Private sector fundraising (including banks)

The study found that private sector organisations can play an important part to fund the skilling of employees. The themes from the respondents are in quotation marks, with the authors' discussion following thereafter.

- *"C**ollaboration** between the private sector (i.e. Bank X) and academic institutions is necessary to provide funding for the skilling of the workforce."* For example this may require Bank X to pay for study fees of a selected employee based on business future skills needs. This mode of funding is efficient in that the academic staff is provided by the academic institution whereas the place of learning can either be in-house or external. The bank also has control of the teaching material offered.
- *"Non-government organisations (NGOs) have a unique ability to raise funds through **donations***. This is based on the public trust they enjoy from their non-association with government status and their non-for-profit long-term goals. NGOs can be used to fund the reskilling and upskilling of the workforce." This type of funding may be in the form of scholarships.

5.2.2.3 Employee fundraising

The study found that employees can play an important part in helping to fund the skilling of employees. The themes from the respondents are in quotation marks, with the authors' discussion following thereafter.

- *"Employees can use work back employment contracts to apply for funding from their employers*. This type of funding mechanism allows the employer to fund the employees' studies provided the employees commit to working for the employer ("work back" the cost) after the completion of their studies or skilling program." This initiative has a high return on the employer's investment as it allows the employee to work during the training period; and it commits the employee to the employer until the set period that has been agreed to has lapsed.
- *"Employees can use their **personal funds** to finance their skilling."* The premise is that the individual has the financial resources to pay for study fees and study resource material. This type of funding mechanism has the advantage that one can simply study towards an area of their interest without having to find approval from the employer or any external financier. It can be argued that individuals who finance their own studies are more committed to their studies due to the shared financial risk hence this is likely to result in a high rate of successful qualification completion.

  Ultimately, the creation of structures for ongoing learning and development within and outside Bank X will ensure a sustainable training programme that will continually feed the organisation with new skills and enable even diversification into new markets.

Long term learning should become a culture for the individual and the organisation. These are traits that draw even aspiring employees to an organisation and retains them within the organisation.

6 CONCLUSION

Based on these findings there are insights and implications for the Bank X transformation strategy. Below are the conclusions:

- The study found that a mixture of new and existing roles will be required to support Bank X in the 4IR. The major roles that will see an upsurge demand include: Blockchain Developer, Natural Language Processing (NLP) Experts, Cloud Banking Expert, Software Engineer, Cybersecurity Specialist, Data Scientist, Culture Champion, Industrial Psychologist, Storytellers, App Developers; Information Technology (IT) Solution Architects; Agile Coach, Agile Scrum Master and Quants. These roles are characterised by people who can design and implement 4IR business solutions. Such people are multi-skilled and eloquent in customer-centric experience, data analytics, management, as well as systems integration solution designs. Information technology and data analysis were found to be the main driving factor in these new roles.

- The national basic and higher education curriculum must be transformed to meet the needs of the workplace. This will necessitate shared accountability from the business institutions, schools, and the government education departments for taking the required actions to do so. Ensuring that the basic and higher education curriculum is informed by the needs of the workplace will produce a skilled workforce. Further development of the curriculum needs to include courses that support the roles listed in the above first conclusion.

- Bank X organisational policy must be changed with clear communication to employees to support the transition into a 4IR.sation.

- The government, private sector, and employees must work together to find a solution to financially support the transformation of employee skills.

Ultimately, adaptation to 4IR will be a fight for the survival of legacy financial organisations. Failure to quickly transform will result in an increasingly declining market share as new entrants to the banking market are technologically advanced to offer innovative and improved customer solutions at less cost.

The responsibility of the employees to upskill themselves is emphasised. Individuals must be invested in their personal development knowing that a skilled individual is empowered to advance their future choices; either as an employee or as an entrepreneur.

The value of the human workforce will never diminish. Technology cannot replace all human engagements; it cannot recreate itself and it cannot replicate the authenticity of human-to-human interaction. The organisation must strive to be an employer of choice for its employees. This means Bank X must prioritise its employees at least the same way it does its customers.

Recommendations for future research

This study was focused only on respondents from Bank X. As a result, the generalisation of its findings is limited to Bank X's position in the market.

- A further study must be conducted with respondents from other banks to increase the external validity of these research findings.
- Future studies must focus on the type of government policies that must be put in place to allow the flourishing of 4IR technology, i.e. government flexible labour laws.

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ASSESSING SOUTH AFRICA'S AFFORDABILITY OF SOLAR POWER

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ABSTRACT

South Africa, just like the rest of the world has become aware of the growing need for an uninterrupted supply of electricity. Due to the lack of clarity on local household affordability for solar power, it has been difficult to anticipate the success of migrating to solar power from the national grid, which is presently powered by coal-generated electricity. A study was conducted to determine whether low- to lower-middle-income households in Gauteng can afford to migrate to solar power. Information was collected using an online survey, distributed via email and social media to residents in urban and township areas. The results revealed that the current monthly electricity payments were less than the cost of the smallest solar panel system. Although the results showed that participants are unwilling to pay more than they currently are (even with the incentive of eliminating power cuts); there was a willingness to financially invest in solar panels if the monthly cost matched their present electricity expenditure.

Keywords: household affordability, solar power, energy alternatives

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1 INTRODUCTION

South Africa is aware of the growing need for an uninterrupted supply of electricity. The reliance on coal and oil has proven to be detrimental because of the growing international environmental pressures which disprove of fossil fuels [1]. This is despite fossil fuels being a source of energy that has continued to drive growth and industrialization in the developed world. Many argue that developing countries deserve an opportunity and relief from carbon taxes. China and India grew economically in the last 40 years due to an increase in the usage of fossil fuels including coal [1]. This seems to motivate why some countries would choose economic growth over efforts to mitigate climate change. Figure 1 shows the relationship observed between the increasing use of fossil fuels and the increase in economic prosperity and life expectancy for China and India.

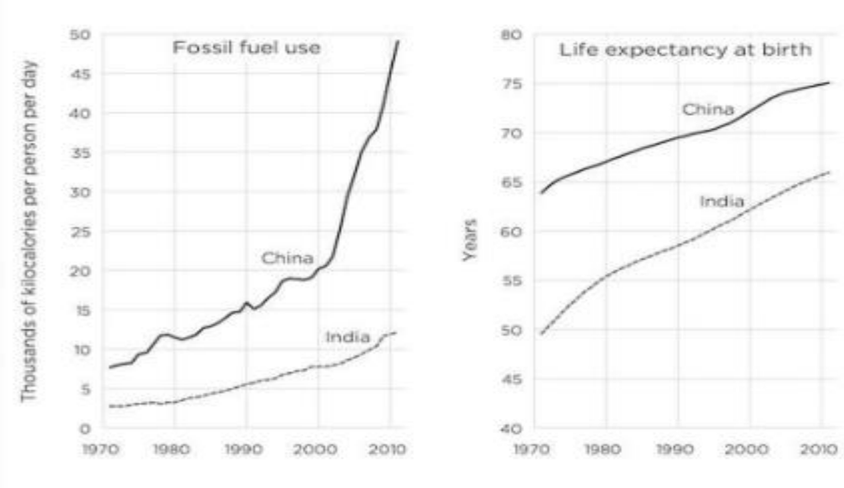

Figure 1: Life expectance and usage of fossil fuels in China and India [2]

The data from Figure 1 opens avenues for other developing countries such as South Africa to find it attractive to use coal to generate electricity. The country is under pressure to implement alternative, cleaner energy and the use of solar energy seems like a viable option. High-income earners have been early adopters towards the use of alternative energy and migrated to solar power or integrated systems (e.g. the use of a mix of solar energy and power from the national electricity grid). However, the financial ability of other end users (e.g. low- to lower middle-income earners in South Africa) is unknown. [2]

1.1 Motivation

The study was aimed at determining the affordability of alternative energy by low- to lower middle-income South African households. It took into consideration the energy and financial profiles of these households. There are several reasons for choosing to focus on these groups of households; of which the main reason is the perceived financial vulnerability of these household groups to migrate to alternative energy sources. Although reports show that high-income earners have begun to migrate towards the use of alternative energy (other than fossil fuels); the adoption of these alternative energy types by low- to lower middle-income households in South Africa is unclear. Furthermore, it appears that the cost of solar power installation may outweigh the disposable income of these two household types.

This investigation was conducted using a survey that was completed by Gauteng households which are based in areas classified as urban (the developed region surrounding a city), township (underdeveloped and racially segregated areas which have been reserved for non-white people since the Apartheid era), or rural (a region with an open swath of land and very few homes or infrastructure) [3]. These households varied from those who paid their own electricity usage; to those that owned the property, they were residing in and were subsidized by the national government to get 50 kW of electricity for free.

The study focused particularly on solar power as a potential energy alternative because Africa hosts great potential for solar power. It is the most readily accessible in terms of technology and CAPEX costs [5]. For this paper, financial preparedness to migrate to solar power will be paralleled to the ability and willingness to take a financial risk; simply because households will be taking a financial risk by investing in solar power. Furthermore, this financial preparedness will extend to the availability of disposable income that can be used to pay for the installation and maintenance of solar power systems [4].

1.2 Problem statement

The "drill-down" [5] method was used to explore the problem. It helps one to break a large and complex problem down into its parts so that one can develop plans to deal with these separated subsets. The tool allowed the researcher to zone in on one specific problem while bearing in mind and showing consideration to all other contributing factors.

Figure 2 shows the contributing factors which were considered in the investigation of the affordability of solar power in South Africa. All the topics outlined have a direct or indirect effect on the implementation of solar power in South Africa and they were identified using the drill-down method. The points highlighted in purple, are the direct effects that will be investigated in the rest of the study. They have a direct impact on how the affordability of users (households) can be determined. The blue sections are contributing factors to solar power adaptation however, they do not directly influence the available disposable income and affordability of users.

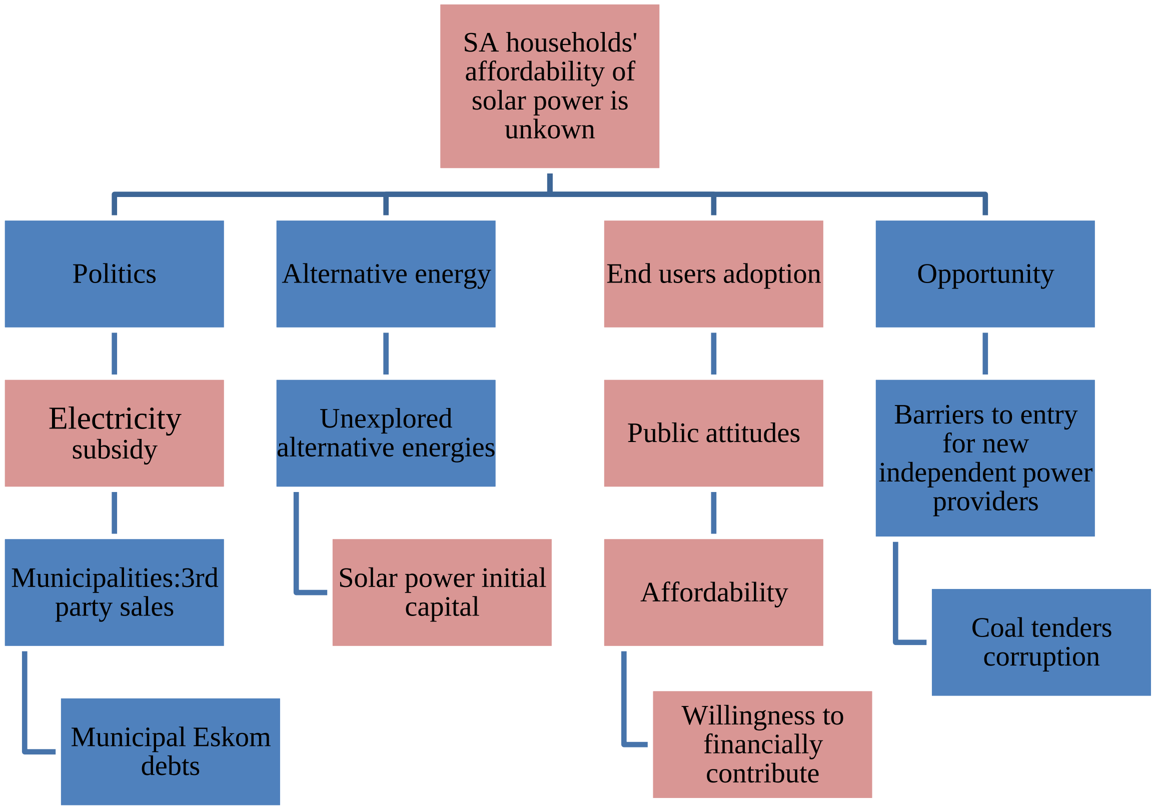

Figure 2: Factors affecting the affordability of electricity for SA households

1.3 Critical research question

How financially prepared are South African households for migrating or integrating to solar power as an alternative energy source?

1.4 Research objectives

The objectives of the research are to:

- Establish the current usage of electricity in low- to lower-middle-income areas *This is because these household groups have been identified as potentially needing financial assistance to install solar panels due to their current monthly available income for electricity compared to payment of solar panels.*
- Compile financial profiles of different households to classify the most suitable candidates for the solar energy program.
- Determine the willingness of the identified groups to migrate to solar power.

2 LITERATURE REVIEW

The research study encompasses different contributing factors to the success of the adaptation of solar power into South Africa's energy mix; however, the project was scoped specifically to look at the financial preparedness of households to partake in this energy shift. This section aims to look at financial preparedness and what constitutes it. It further looks at different configurations of solar power systems and samples of costs associated with them. This was done to assess whether solar power as an alternative energy source is within reach for low- to lower-middle-income households.

2.1 Financial Preparedness

For this paper, financial preparedness to migrate to solar power is defined as *the ability and willingness to take a financial risk*; as households will be taking a financial risk by investing in solar power. *Ability* can be considered as a quantitative assessment of how much an investor can afford to lose relative to their goals. In other words, the ability is about how much wealth one has relative to one's spending needs. [6] In this case it is a comparison of income and how much is available to be spent on electricity needs. *Willingness* is related to one's attitude towards taking a risk. In this case, it would be the user's attitude toward investing in solar power. [7] Lastly, this section will look at income classifications as indicated by a local South African bank.

2.2 Factors affecting financial preparedness [8]

- **The measure of wealth** – This refers to the user's income. The total amount at their disposal and how much of it can be allocated to electricity costs.
- **Time horizon** – This refers to the life stage. The younger the user is, the greater their ability to take a risk and enjoy the benefits thereof.
- **Importance of goals** – This refers to expenses that the user prioritizes. For low-income families, it could be food, clothing, and warmth in contrast to a different expense profile of a wealthier user who perhaps prioritizes more luxurious items such as cars, private education, etc.
- **Ability to withstand portfolio losses** – This refers to the amount of shortfall an investor can tolerate before jeopardizing their goals. It could be the amount of disposable income that would be available to invest in solar power infrastructure without creating shortfall, in other commitments such as food.

2.3 Household income classes

Households are classified by their income. This assists in grouping them and assessing their level of access which is likely to be more or less the same i.e. people earning the same amount of money may have more or less a similar expense profile (when not considering other financial commitments that may differ).

A report by Standard Bank [8] shows that more than 10 million households (10 193 205) in South Africa earn less than R7,167 per month, while a small elite population earns more than R196,668 per month. The wealthiest households only account for 1.2% (R1.48 million – R2.36 million+ per annum), with those who earn more than R2.36 million, account for 0.4% of the household population – or 65,964 households. [9]

Table 1 indicates the classifications of household incomes as indicated by Standard Bank. The banknotes that 62.3% of households fall within the poorest income bracket (low-income households), which is below R86,000 per annum; while middle-income groups (R86,001 – R1.48 million per annum) comprise a combined 26.4% of South African households [9]

Table 1: Income classifications of households [10]

Annual Income	Gross Monthly Income	Classification
R0-R86 000	R0 – R7 167	Low
R86 001-R688 000	R7 168 - R 57 333	Lower middle
R 688 001-R1 481 000	R57 334- 123 417	Upper middle
R1 481 000 +	R 123 418- 196 667	Affluent

2.4 Solar power accessibility for households

Solar energy, like all other renewable energies, is very safe and environmentally friendly [12]. There are no emissions as the source of fuel is the sun, unlike coal-powered stations. Most areas in South Africa average more than 2 500 hours of sunshine per year, and average solar-radiation levels range between 4.5 and 6.5kWh/m2 in one day. [10].

Table 2 is an example of the service offering as given by solar panel providers. There are different options of varying price ranges. Although the 60-month payment plan makes affordability a possibility; when looking at Table 1, it can be noted that some low- to lower-middle-income earners would still not be able to afford even the Starter package option.

Table 2: Solar power on a payment plan [12]

Package	Total Cost [R]	Monthly repayment [R]	Term	Recommendation
Starter Package	23 000	696.08	60 months	For smallholdings
Mini Package	29 000	851.73	60 months	1-2-bedroom homes (lighting, tv, and fridge)
Medium Package	49 500	1383.51	60 months	1-2-bedroom homes (lighting, plugs, fridge, washing machine)
Popular Package	85 000	2304.4	60 months	3-4-bedroom home, light, plugs, tv, fridge, washing machine, microwave, kettle, toaster
Large Package	120 000	3212.32	60 months	5-bedroom home with all the above and air conditioner

2.5 Factors affecting solar grid design in Africa

There are three main types of residential solar electric power systems: grid inter-tied; grid inter-tied with battery backup; and off-grid [13]. Grid inter-tied systems allow the homeowners to get power from either the home electric system or the utility grid. Switching between the residential system and the grid is seamless. A grid inter-tied solar power system is also connected to the traditional utility power grid and adds battery-backup to the system. The addition of a battery backup enables the system to balance production and demand, and it protects against power outages. An off-grid residential system is completely disconnected from the traditional electric power grid. Without a connection to the utility grid, batteries are essential to balance periods of excess production and excess demand. [11]

Low-income and some lower-middle-income homes allocate a relatively high percentage of income to electricity and gas while earning the lowest amount of money [8]. The price of solar panels has significantly decreased over the years; however, it is still out of reach for poor people and some of the lower middle-class households. For low consumption communities, a least-cost option would either be mini-grid and standalone systems, depending on household density and demand. Below a certain threshold however, no grid-based system would be competitive. For this reason, low- to lower-middle-income households might require standalone systems. [12]

Another key cost factor will be the capacity constraints of the local grid, especially if upgrading the local substation is required. A fully constrained grid may mean that new connections are not possible or are only available at significant costs by upgrading infrastructure. In South Africa, there are very long connection backlogs in some parts of KwaZulu-Natal and the Eastern Cape [5]. Statistics show that the national annual connection rate has steadily decreased by more than 250% in 5 years (from 499 000 in 1996/97 to 141 000 in 2011/12 [13]). This can be due to the demand rate, infrastructural constraints, and various other reasons.

3 METHODOLOGY

Table 3 below shows the process followed in creating the foundation of the project from identifying the problem, to determining the gap in knowledge that the study will attempt to fill (answer to the research question). It is followed by a flow chart of the study methodology.

The chosen method of gathering data is a survey which was sent to the target audience. The reasoning behind the choice was that surveys allow for easy comparison of opinions as responses are fixed for all respondents. Participants were also offered anonymity, allowing them to be as honest as they can be. Lastly, the method was affordable financially compared to other primary data collection methods such as focus groups which may have required transportation and catering costs to be considered for participants. The main drawback remains the inability to understand the "why" behind the respondent's choice. Secondary research was acquired using a desktop study as it offered a large library of knowledge and access to books, journals and recent publications.

Table 3: Methodology followed

Method	Expected outcome	Use to the study/ application/ relation to objectives
Primary research: Review themes/ relevant topics to solar power [Literature Review]	1. Quantifying theoretic electricity consumption 2. Area classification (determines panels configuration) 3.Determining aspects of financial preparedness	These were used to inform survey development and see what gaps exist in theoretical knowledge and can be addressed by reaching out to end-users.
Secondary research – Desktop research	Literature study that contains academic material which explores identified topics in detail and looks at what has been commented on regarding the topic	To better understand the technicalities in the identified topics e.g. the varying configurations of solar power systems.
Participants selection criteria: (how were they selected) Households: urban, rural, township areas Distribution: online survey (Data collection)	To compare the preparedness of different households	Determine the answer to objectives 1 (establish current electricity usage of identified groups) and 3 (determining the willingness of end-users)

3.1 Approach used

Primary research is defined as a methodology used by researchers to collect data directly; while secondary research is a method that involves using already existing data. Existing data is summarized and collated to increase the overall effectiveness of research.

A survey was formulated to collect primary data. The survey platform used was free to formulate and distribute via email and social media, if the questions were kept to a maximum total of 10.

3.2 Survey development

To meet the research objectives and address the identified problem, the researcher identified the information that would be required. This was then classified according to primary and secondary research. Doing this assisted the researcher to determine what method of data collection would be suitable. Table 4 is a classification of data that the researcher needed, and it was categorized into primary and secondary data depending on the source and process to obtain it.

Table 4: Classification of required data

Information from primary research	*Information from secondary research*
Actual electricity expenditure	Theoretical electricity expenditure
Proportions of households in rural, urban, and townships in Gauteng.	Municipal debt to Eskom and extent of energy crises
The proportion of people already using alternative energy	Current alternatives provided by the government
Household's willingness to use solar power	The economic viability of using solar power
People's knowledge of alternative energy	Initial capital outlay for solar power implementation.

3.3 Participant selection

The population selected was low-income and lower-middle-income earning households in Gauteng. This specific region was selected due to the researcher's location and ability to easily be in contact with residents of the selected area. The survey was emailed to 200 candidates that fulfil the household type and area criteria because the researcher wanted to diversify the nature of respondents; and also, to be able to compare the results by the identified participant groups (i.e. rural, urban and, township). Authors used convenience sampling and the participants were selected based on their age (older than 18), access to email and whether they have access to electricity bill/prepaid slip. The comparison was also done on the income classification relative to the indicated electricity consumption. The low-income and lower-middle-income participants were identified within the sample as the group of interest as they are most likely to be financially impacted by the roll-out of solar panels. Looking at their income profile and energy expenditure from literature, their ability or inability to financially participate in the transition sparked the interest which motivated the study.

4 RESULTS

The following section outlines the results drawn from the survey data. The outcomes have been summarized with graphs showing quantitative measures of responses. The study was intended to be carried out with a limited number of participants in Gauteng and this sample would then be used to make a conclusion about the Gauteng population. This is a statistical principle known as inferential statistical analysis which infers properties of a population by deriving estimates from a sample. The sample size required to make statistical inference about the Gauteng populations' financial preparedness is calculated below, together with the confidence level (the probability that the value of a parameter falls within a specified range of values).

The sample size from the prospective area was initially calculated to be 299 with a 95% confidence level in the results and conclusions to be drawn from them. The survey response rate however was 81 responses. Of these, 9 entries were discarded, which resulted in a total of 72 responses (acceptable entries) received. This affected the confidence level value, which was recalculated to 83.4%. This is lower than initially expected, but the sample can still provide an acceptable conclusion about the population.

Figures 3 to 8 summarise the results from the survey. They provide insight into what the current needs of households are, what measures they have, or don't have in place to meet those needs, and what they are willing to do to address their energy needs.

Figure 3 shows the geographical spread of the survey participants in the Gauteng province. The survey was electronically distributed. This resulted in a limitation for the results, as it could be expected that access to the internet and smart technology would be limited in the rural areas. This has in some ways skewed the results as expected.

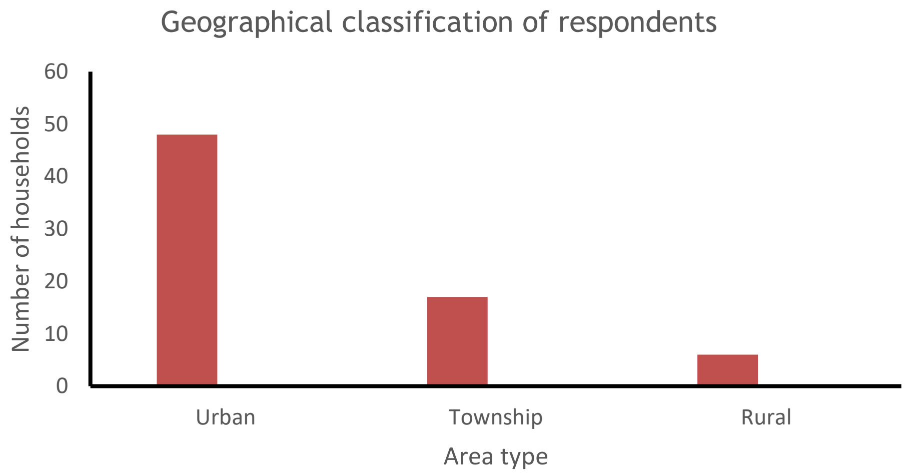

Figure 3: Households in different areas

Figure 4 depicts household expenditure. The graph outlines the range of money spent on electricity in each household. 34% of participants from the chosen sample, spend less than R400 on electricity while the other households spend more than that. This is encouraging financially; however, this is still removed by close to R300 form the minimum (R696) required monthly cost to install the lowest package of solar panels (Table 2). The higher end of this sample may also be because most of the households that were participants in the survey are from urban areas (as indicated by Figure 3) and are more likely to have electronic devices that cause this higher consumption of electricity.

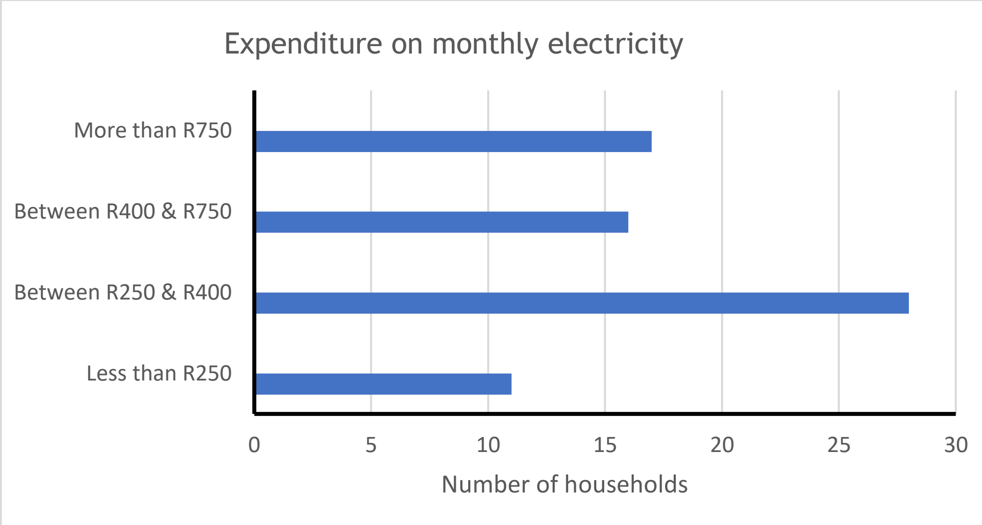

Figure 4:How much households spend on electricity

Looking at the monthly electricity expenditure of this 34% group, and comparing this with the cost of installing solar panels for an 80 square meter home (R23 000) [14]; we note that it would take about (R23 000/R400 =) 58 months (close to 5 years) to pay the installation fee for solar panels. This would not be profitable for the companies doing the installation (this calculation does not consider interest payable over the term); nor is it practical as some households are larger than this proposed unit size.

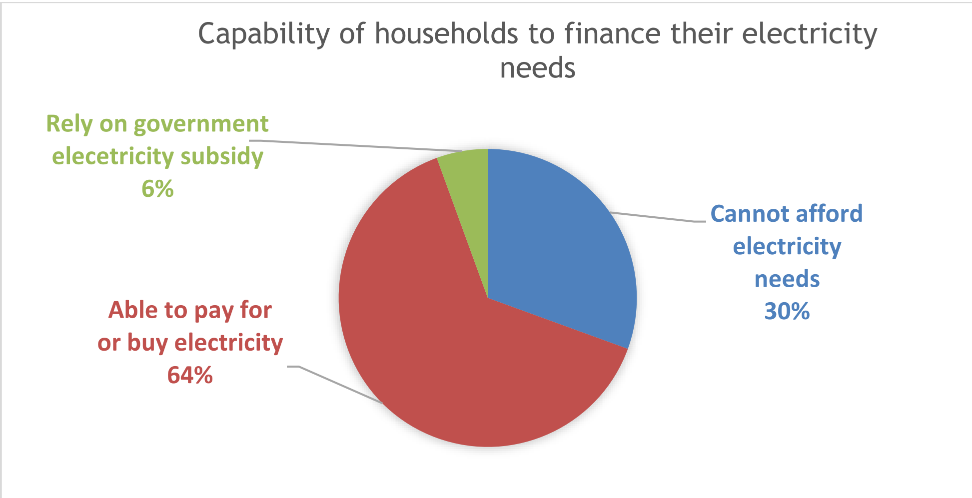

Figure 5: Affordability/ financial capability

Figure 5 shows how many users can afford their current electricity needs. A reasonable 64% of participants can afford their electricity needs, regardless of the range of their expenses (as shown in Figure 4). However, there are 31 % who sometimes cannot afford their electricity needs. The results from Figure 4 are significant when considering that this suggests that even in optimistic conditions where a company could potentially allow a payment plan for solar power installation that stretches over 5 years, there would still be 31 % of people who cannot afford it. This result already indicates that some South African households are not financially prepared to migrate to solar power.

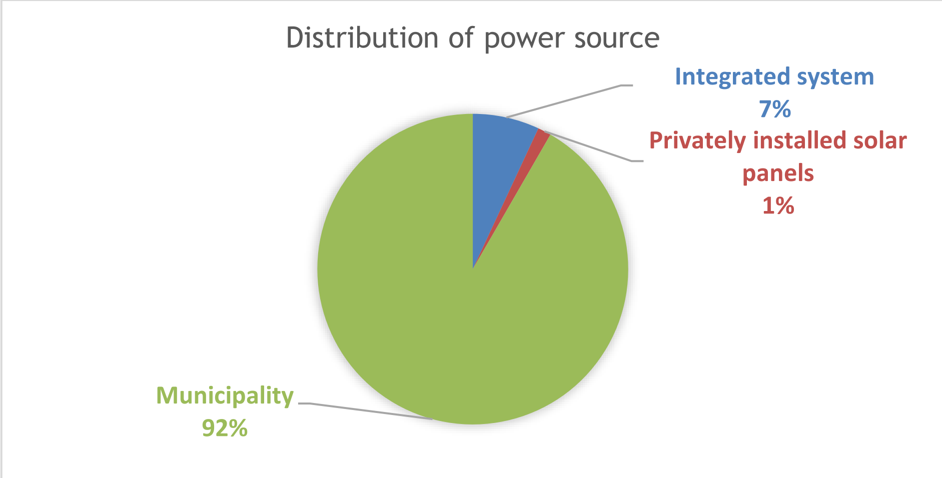

Figure 6: Current systems in place

The indication from the research was that there is a heavy dependence on municipal power, which is sourced from Eskom (coal-generated). A large majority of people (92%) with access to electricity get it from the municipal grid connection, as indicated by Figure 6. There is a hopeful proportion of households that have begun shifting to alternatives for some activities in their households and a select 1.4 % that have solar panels installed. It also, however, then suggests that the cost of solar power is currently ill-fitted for poorer communities who would lack the funds to access it.

Literature reveals that solar power installation becomes slightly cheaper if there are other people nearby already using it. For urban areas, the idea might be feasible as people who afford to live in a neighbourhood may potentially be of similar income brackets. This advantage in urban areas is also the disadvantage in poor communities; simply because in these areas, most households fall somewhat toward the lower end of the income spectrum. Therefore, there are likely to be no neighbours with a solar panel system, so the cost becomes a heavy burden for whoever tries to opt for the installation.

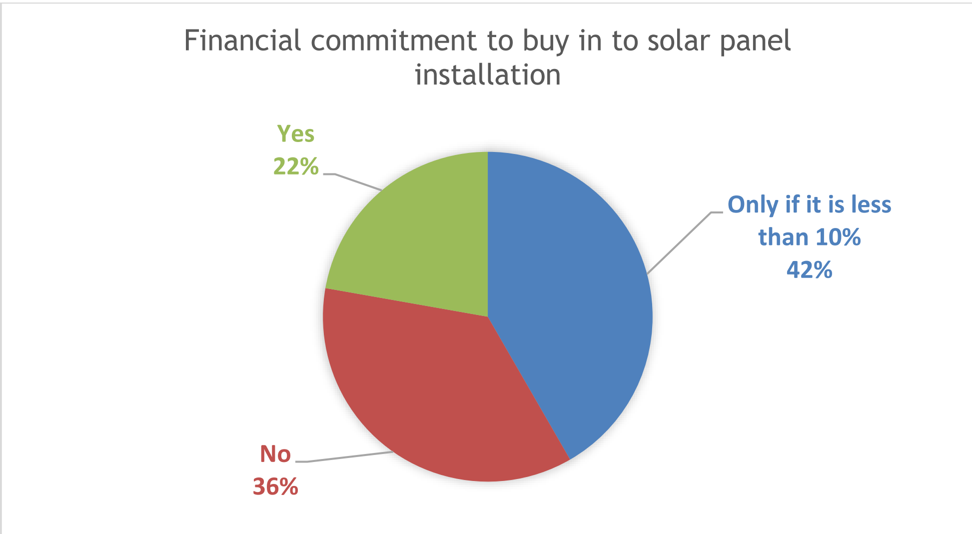

Figure 7: Willingness to financially commit

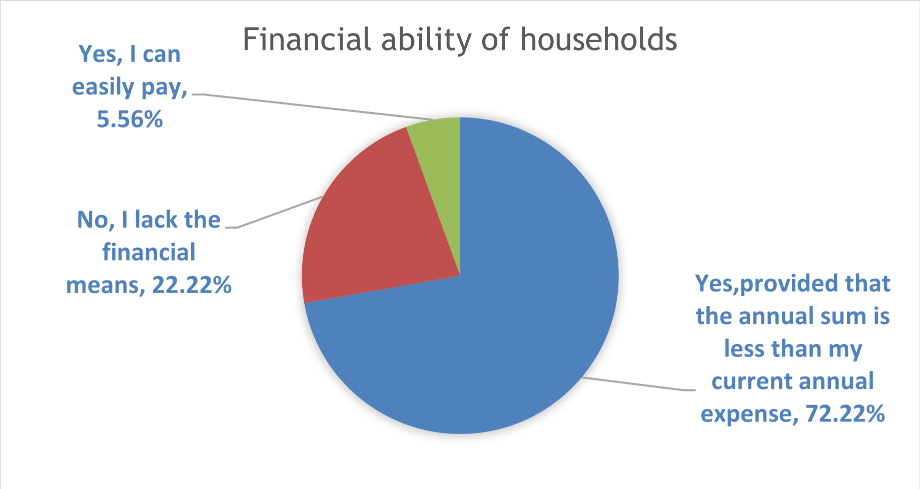

Figure 8: Ability to make the financial commitment

Figures 7 and 8 outline the user's buy-in. There have been service offerings that the government has implemented without the buy-in of the end-users and this has led to complete system failures. An example of this could be of the e-toll system, which was designed and implemented without considering the willingness of its users. The system is failing because road-users have no interest or inclination to pay for the service [13].

The opposite can be said about solar panels. Some people seem to have an interest in having a consistent supply of electricity to their homes even if it costs slightly more per kilowatt. A larger 42 % would be willing to incur the increase only if it is less than 10%. Others (36%) are not interested at all in paying a higher price. So when comparing the cost of having a larger grid for areas with the current price per kilowatt, if the monthly costs would be higher than they already are, 36% of South African households would not be willing to incur that cost (even if it is only for a few years). The lowest cost that users would be expected to pay over 60 months, is R696.08 (Table 2). This amount is a minimum of 74% higher than what the majority is currently paying monthly (R200 – R400). This would not be an option that residents consider, as this is simply above what they are willing to pay (which at most is R440, with a 10% increase).

5 DISCUSSION

5.1 Attitude versus financial participation

The idea drawn from the results with an 83.4% confidence level is that South African households are not financially prepared to migrate to solar power. The results of the survey outline a willingness of people to migrate to a different source of power, however, this willingness has more to do with attitudes than finances. They are only willing to contribute financially within certain limits, specified below 10 % of the current expense, or show no interest to pay more. Figures 7 and 8 are observations of the attitudes of households towards the installation of solar panels. It seems that respondents are keen to gain the benefits of solar power, however not enough to short-change the other financial aspects of their lives.

5.2 Actual expenditure versus theoretical

From Figure 3, it is noticeable that there is a large group of people who spend between R250 and 400 on electricity monthly, however there is much more who spend above R400, this group of people is categorized into two groups (those spending R400 to R750 and those spending 750). Some people in both categories may not be able to afford even the smallest solar panel system (requiring R696.08 per month). These individuals could then install specific systems for certain activities in their households, these could be in the form of solar geysers or solar lighting. It would, in turn, improve (through decreasing) the amount spent on electricity monthly.

5.3 Area profiling

Data is insufficient to make conclusions on rural areas because the respondents were mostly from urban areas and townships, having access to smartphones and the internet. These factors suggest that data is potentially skewed. It may only be assumed that if urban areas and townships (having people who are lower-middle-income earners) are in a certain financial position, rural occupants could potentially be lower than this (assumption based on the economic activities of these areas, which include lack of industrialization and infrastructure).

5.4Objectives analysis

Electricity usage was determined in the form of expenses in response to objective 1. The study found that South African households are indeed not financially prepared to migrate to solar power.

Objectives 2 and 3 were achieved with income profiling in the literature review and demographic location in the survey results. This assisted to contextualize the results and look at the results of extremities. Noting that some of the lower-middle-income earners in urban areas would take 9.2 years to pay off for solar panel installation, it would take much longer for someone earning much less and living in a rural area.

5.5 Comparative study

A World Bank study revealed that solar power is becoming more popular in Kenya and replacing traditional electrification methods such as kerosene. [15] Households with a solar electric system at the moment are not among Kenya's poorest. They are part of the middle-income class. Installation cases have been successful for houses that were previously not electrified as this requires a single installation cost [13]. The challenge in such cases is that the government incurs a double cost when installing solar panels for a house already connected to the grid (removal and installation). An extension of this case study's findings to South Africa suggests that the costs of moving toward solar power would be excessive. Because a large population of the country has already been connected to the grid (at a cost), to spend further on solar panel installations seems to be financially impractical (due to the double cost effect).

6 CONCLUSION AND RECOMMENDATIONS

This study can be used as a basis to explore varying alternative energy resources as it provides a financial framework (derived from the survey questions) that can be used to validate the feasibility of an alternative energy source for households. It established that South African households are not financially prepared to migrate to solar power. The study provided a basis to classify household incomes in urban and township areas and to compile energy profiles for these.

The survey research strategy was deemed suitable because it produced data based on empirical data observations. Secondarily, the breadth of coverage of many people or events means that it is more likely than some other approaches to obtain data based on a representative sample, and can, therefore, be generalizable to a population. This is despite a limitation of the survey distribution strategy.

The explored literature and the study findings; both revealed the lack of preparation to migrate to a different power source (with a focus on solar power). The results of the study showed that low-income and lower-middle-income earning families have low interest in paying an increased fee for their current electricity usage (even if it promises a consistent supply with no power cuts), much less the costs associated with installing solar panels. Objective 2 was achieved and the financial preparedness or lack thereof was established.

Although the study assessed the household's willingness and financial, it lacked formal metrics to determine what costs people would have to incur if the government was offering subsidies for installation. Furthermore, there was no determination of where the funds would come from for the initial capital outlay. This information would have been valuable for the study; however, it was not part of the scope and the researcher strategically did not include it. The aim was to determine household participation to avoid a case of an engineering solution that is designed for people but is not human-centred.

Solar power as an application in industrial and corporate environments should not be an optional question because it is each businesses' responsibility to contribute to combating climate change. There is a consideration of the size of the operation and the associated cost of the migration. It seems to be a question of financial preparedness across the board, from household to boardroom. In thinking about financial implications, society must not forget that it is also a question of conservation and the existence of a friendly living environment for the next decades, and generations to follow.

Low-income earners and some lower-middle-income earners are still at risk of being promised a service that they might not get, simply because the government might not have the funds to continually pay the solar service provider. For future work, further investigation into ways of increasing financial independence in low-income and lower-middle-income homes could be investigated. This is simply because no matter how often the affordability is assessed, at some point, these vulnerable groups will need to pay "some amount" in order to cover the deficit that could potentially be met halfway by a government subsidy.

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IMPROVING SUPPLY CHAIN PERFORMANCE IN THE SOUTH AFRICAN HEALTHCARE SERVICE: A LITERATURE BASED PERSPECTIVE

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ABSTRACT

Supply chain performance management plays an imperative role in keeping healthcare organizations sustainable and competitive by handling the storage and efficient distribution of resources in the value chain. Managing the complexity of healthcare demands and the application of improved technologies requires best practice supply chain models. The South African healthcare industry experiences unsatisfactory capacity limitations where there are extreme deficiencies of beds, equipment, facilities and trained healthcare professionals. This study highlights supply chain management strategies that can enhance efficient healthcare accessibility and delivery in South Africa using literature data. The results show that advanced healthcare delivery approaches such as ambulance divert and predictive analytics stand a good chance of improving supply chain management in the country.

Keywords: Supply chain performance, healthcare, supply chain frameworks, supply chain improvement

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1 INTRODUCTION

Healthcare institutions are indispensable in ensuring timely response to human infirmities and improved quality of life. Owing to increasing challenges in the value chain, healthcare organizations are always searching for opportunities to improve operational planning and lessen costs. The patient care procedures in medical institutions are bolstered by a scope of operational tasks that incorporate stock management and dispersal of supplies. Medical facilities carry a lot of varied items, which portends inalienable difficulties of storing items and distributing them around the healthcare supply chain. A good supply chain management (SCM) system is therefore critical towards achieving and sustaining high standard patient care [1]. The internal supply chain in medical clinics is described by its intricacy, distinctiveness, and operational complexity. For example, there are extremely costly items and medical equipment utilized in operating rooms, challenging stock tracking precisely from the barrage of treatments, and uncertain demand for medical supplies [2]. The deployment of SCM best practices in the medical services sector can both identify physical supplies needs as well as advance patient care [3].

Traditionally, SCM is charged with the responsibility of ensuring the availability of the right item in the desired amount at the required time [4]. Recent investigations show that a huge portion of the expenses connected with supply chains in the healthcare division can be decreased by implementing efficient supply chains [5]. Literature reveals that integrating Lean in the hospital SCM is value adding as it has the potential to reduces supply chain cost, improves instrument utilization, patient safety, and medication distribution systems [6][21]. Despite dynamic market conditions, to date, numerous organizations utilize SCM strategies due to their ability to integrate various stakeholders (suppliers, management, distributors, customers and manufacturers) in the supply chain ensuring that production, procurement, and distribution needs are met at the least possible cost. Yang et al [7] studied the impact of deploying demand-driven supply chain strategies (which includes supply chain intelligence, organizational capabilities, customer knowledge and integration, information sharing, and collaboration) on a just-in-time supply chain systems. The study suggests that customer-driven strategic sourcing improves sourcing efficiency which supports cost reduction as well as JIT supply chain management objectives. [7].

The South African (SA) healthcare industry is poised with unique divisions. The SA medical system has a two-layered medical framework comprising of the public and private segments. The state-owned public medical institutions provide primary and secondary healthcare; while the exorbitant private medical services serve mainly those who can afford the cost. For the start, primary healthcare is carried out on the principles of the District Health System [9]. Concerted efforts have been made towards easing healthcare provision and administration in SA since the end of apartheid, yet the tenacious imbalances and the liability of subdivisions are still obvious [10]. As Maphumulo & Bhengu [8] highlighted, an array of problems have been raised by the public regarding public healthcare institutions…" prolonged waiting time because of the shortage of human resources, adverse events, poor hygiene, and poor infection control measures, increased litigation because of avoidable errors, shortage of resources in medicine and equipment and poor recordkeeping" [8].

More recently, some quantitative and qualitative models have been proposed for the efficient running of the healthcare supply chain. A supply chain performance forecast framework to estimate slacking measurements based on leading metrics to anticipate performance dependent on casual relationships [11] has been advocated. An understanding of past suggestions of researchers on the SCM strategies that can better the healthcare system is key to streamlining healthcare management in SA, in line with the observations of Rodrigues and Carpinetti [11]. This paper attempts to update SCM in healthcare services in SA through a review of recent global SCM literature. In our own opinion, insight from the study can drive SCM in SA healthcare sector towards more efficient health service delivery.

2 RESEARCH METHODOLOGY

The study utilized a quantitative research approach and relied mainly on secondary data abstracted from existing literature. Components and concepts were recognized and explained. In delineating pertinent data needed for the study, the keywords that are associated with the research topic were typed into the search engines of the identified repositories. Specifically, online books, journals, and conference materials were acquired using databases such as Engineering village, Science direct, Google Scholar, Scopus, Emerald, and Pubmed, though not every material accessed and read made the analysis list. The following keywords "Supply Chain Performance", "supply chain performance in healthcare", "healthcare supply chain", "South Africa healthcare supply chain" and "improving supply chain in healthcare" were all used to populate the dataset. A sum of 86 datasets was originally selected from the aforementioned search. This number was subjected to further rounds of sorting and filtering, after which about 65 were considered for analyses and 21 withdrawn completely. The withdrawal was either due to unfitness after careful evaluation against the criteria used, or inability to address the problem adequately.

This category of articles includes monographs, book chapters and other non-peer-reviewed publications such as online materials/periodicals. The reason behind the withdrawal of some peer-reviewed articles published in high impact journals was their inability to address the issues that underlie healthcare supply chain performance or at least healthcare SCM frameworks in the studied area. Hence, those selected in this category was for the sake of providing a general background to the conversations on supply chain performance improvement frameworks. In the end, most of the data that survived the final selection came from Science direct. We did not consider this to be an issue, since all the journals possess high impact standing. The literature was tabularized into categories of sub-themes that stressed the intention, results and area of application of some of the reviewed papers. However, some of the references cited in the introduction and other areas that did not meet the purpose of the thematic categorization were not inserted in the aforementioned table. Recommendations arrived at, were based on the most frequent and tested procedures drawn from a good representative of the data accessed and analysed.

3 LITERATURE REVIEW

The supply chain management (SCM) phrase was initially introduced and later defined and popularised in the nineteenth century by Oliver and Webber [12] and has since been advanced by other researchers [13-14]. The technology has since received good acceptability in almost every industry. Supply Chain Management is used in factories, workshops, engineering establishments, etc, for proper management of inventory. The technology has been extended to containment of the global financial crisis (GFC) cost performances and logistics [15-16] and cost minimization Logistics scheduling [17]. The authors suggest that in hostile extrinsic conditions, low capital expenditure can lead to processes being overvalued. Liu et al [18] maintain that the choices of inventory networks are not always impacted by the loss-averse predispositions. However, the application of manageable inventory chain administration does not automatically enhance expenditure [19-20]. The ideal batch size has a connection with various manufacturing phases and optimal batch size can lessen expenditure [21-22].

The range of resources needed for efficient healthcare discharge have compelled researchers to have key interest in the implementation of SCM in healthcare delivery, while others are signalling the need to find deep-rooted factors that influence healthcare supply chain integration [23]. The SCM system in hospitals, in comprehensive terms, encapsulates regular supply of consumables and tools, the quality, responsiveness and efficiency of both services and maintenance process. The healthcare sector requires to get the essential services and material supplies just when they need it, how they need it, where they need it, and at the best price and quality specification [24]. The Healthcare supply chain can be complex because of numerous features and intricate management demands of patients and other stakeholders of the sector.

4 OVERVIEW OF SUPPLY CHAIN PERFORMANCE MEASUREMENT AND FRAMEWORKS

A performance management framework can keep track of the efficacy of firms' operations techniques [25]. Ample research has been done in areas of capacity development, correlated frameworks, inventory and transportation management [26-28] and regions yearning to pursue strategic supply chain administration. Before 1980, cost accounting frameworks were utilized which depended on quantitative cost-related measurements [29]. Later on, the frameworks were intensified thus the extent concerning the cost related measurements was broadened to incorporate operational efficiency and various roles in the supply chain [30].
A balanced scorecard that deciphers the company's technique in quartet standpoints: economic, client, company procedures, plus instruction along with development was created in the 1990s [31]. Supply chain performance measurement literature is vast, therefore, this presentation ordered information into two categories specifically, financial performance estimation systems and non-financial performance estimation systems. Further we discuss other cost analysis strategies, capacity issues and performance metrics.

4.1 Financial Performance Estimation Systems

These frameworks uses traditional accounting methods for estimating SC performance. The conventional cost accounting frameworks were created under the circumstances where large scale manufacturing was the most appropriate production framework while the reduction of expenses was achieved via scale economies [32]. The two main financial performance estimation systems are economic value added (EVA) and Activity-Based Costing (ABC).

The economic value added (EVA) is a methodology for evaluating the earnings to add up to capital expenditures. It is a computation of an organization's actual income since it completely represents the expenses concerning all sorts of investments, in contrast to accounting wages. Altaf [33] declares that the EVA as a performance estimation almost gauges the actual financial advantage of an organization and is legitimately connected to the investor's worth.

Activity-Based Costing (ABC) utilizes a substantial amount to assignment foundations to calculate the expenses of the tasks that dominate the assets. The ABC frameworks are regarded as highly-priced due to the large numbers of price pools needed, the necessity of uniform evaluations, and the expense of application [34-35]. However, these cost accounting measures have been critisied due to its inability to include other non-financial parameters which are of strategic relevance like operating performance, product quality and customer satisfaction [36].

4.2 Non-financial Performance Estimation Systems

Unlike the financial measures which are short term, historical and profit oriented, the new balanced integrated system which included nonfinancial SCPM is long-term and customer oriented [36]. Based on their measurement criteria, the non-financial SCPM methods are classified into nine. The Function-based Performance Systems (FBMS) which evaluates functions within each SC; Dimension-based Performance Systems (DBMS) which measures pre-determined KPIs throughout the supply chain; Hierarchical-based Performance Systems (HBMS) for assessing all three management levels - Operational, Tactical and Strategic; Interface-based Performance Systems; Perspective-based Performance Systems to assess the six SC perspectives of Logistics, Operations Research, Marketing, System Dynamics, Organization and Strategy; Efficiency-based Performance Systems to assess the SC efficiency; SC Balanced Scorecard (SCBS) Performances measures which cuts across the four supply chain perspectives; and the (SCOR) Performance Model which evaluates the five main SC processes[36]

SCOR Model

The SCOR model (Supply Chain Operations) established by the Supply chain (SC) council is a system for measuring the reliability and proficiency of inventory network. It characterizes a SC by utilizing the combined indexes such as Plan, Source and Make, Deliver and lastly, Return of items. The final estimation is on resources, which cover the potential to effectively make use of assets [37]. Tramarico et al [39] executed a multiple-criteria instruction appraisal for Green supply chain management throughout the quartet superior tasks of the SCOR model. Okongwu et al [40] posed a unified system that is based on the SCOR representative and the customer order decoupling point. Other researchers [38] combined the SCOR model and fuzzy TOPSIS to assess SC while [41] discussed the use of a fuzzy QFD methodology to sustain SCOR KPIs with empirical industrial case research. Akkawuttiwanich & Yenradee [41] developed the practical activities to be administered to reach the set score KPIs. Their findings reveal that the organization may not acquire the aimed KPIs at the end because the association between "What's" and "How's"(technical improvement actions) may have been communicated inaccurately. Research efforts bordering on SC balanced scorecards initiated in 1992 are well documented [30] [42] [43-44].

4.3 Other Cost Analysis Strategies in SCM

In SCM, numerous expenses can affect the presentation as a whole, including the cost of acquisition, manufacturing, standard, transportation, stock, etc. These expenses affect the execution of the supply chain in all industries and have been investigated by researchers. For example, Wong, Chan, and Wadu, [45] presented some understanding on the elements that are significant in improving green acquirement in the construction business and propose a strategic direction for successful endorsement of green attainment [46]. Customer prerequisites in rendering and administration or non-administration company necessities are the variables that were recognized in ecological guidelines. Wong and co-authors inferred that the absence of green acquirement principles as well as constrained green resources have limited its improvement. Shafiei-Kisomi et al [47], presented a combined scientific plan of action dependent on the robust optimization theory to limit the total expenses of the inventory chain by regulating a collection of distributors, shipping quotas and position provision. The model is simple and worked successfully, though may incorporate a huge level of vulnerability in the production network. Petterson and Segerstedt [48], contrast SCC based on definite expense collated to evaluated quality cost. Akhtari et al [49] duplicate representative for two stock frameworks that are order-up-to-level together with fixed order quantity, and Moschuoli et al (2019) [50] fuzzy set model are very good examples of SCC formulations.

4.4 Capacity Issues in SCM

Capacity administration as a performance indicator in SCM plays the role of initiating and alternating capacity degree to execute production plans. Capacity assessment is performed for asset management, matching facility type and degree of equipment utilization for various processes, and determining rough-cut volume. Dominiguez et al [22] examine the vigorous conduct of a controlled system inventory chain with volume limitations in both the assembling and re-assembling lines. The issue of resource availability and establishing the volume required in public healthcare facilities have been discussed [51], as well as automated SC [52].

4.5 Performance Metrics

The performance metrics involve critical analysis of how various industries manage their cost and capacity constraints in the overall SCM. Performance metrics provide distinction for firms and assists in making choices. Furthermore, they analyze the adequacy and proficiency of organization projects. Cost and capacity choices are important performance indicators that can drive an organization to the ground. The cost metric is a bigger measure than all metrics combined because companies and businesses constantly need to assess their performance, resource utilization and the financial state. It can demonstrate the value of a team. Techniques like Return on Investment (ROI) and Earned Value (EV) are widely used in industries. Moreover, the ROI concentrates on assessing the determined advantage of a process while the earned value focuses on giving tactical guidance on how much an organization has made from the money invested in a task. Capacity management empowers organizations to prepare ahead, administer assets proficiently and react to company prerequisites faster. Costs can be minimized when capacity is utilized adequately.

5. CURRENT STATE AND PROSPECTS FOR IMPROVEMENT

Capacity management is a fundamental segment of current healthcare governance as it significantly affects the hospital's financial robustness. It includes the procurement and distribution of high expenditure assets that involve personnel and stock. To improve capacity, South African emergency clinics can evaluate the volume of space accessibility and the patient demand whereby medical facilities can close and open sections as required, based on the patient's capacity. Healthcare organizations are required to have suitable capacity planning to diminish the effect of low bed volumes and personnel capacities which is currently obtainable in the sector. In the SA context, bed usage, and the proportion of beds in emergency clinics are still a challenge [53]. Aligning demand to supply demands can be advantageous for healthcare facilities in S.A and would reduce overpopulation. Patient movement produces irregular inter-correlated demand for Operating rooms.

Emergency department care is under strain due to the high volume of patients in need of care. Unplanned incomers need surgery as well as urgent care. Patient discharges usually occur in the evenings and this generates variations in the demand and supply for beds and healthcare employees. Patients who additionally arrange surgeries for the future also make demand fluctuate. The suggestion is that medical facilities need to implement the ambulance divert system. This is when the ambulances are notified to transport patients to neighbouring medical centres in good time due to the inadequacies in taking the patient to the original destination. This can make for efficient operation management that is not pressured and strenuous to healthcare staff, despite creating a better management scheme for patient's care. High managerial staff turnover and personnel shortages are severely impacting healthcare supply chain efficiency in South African leading to a delayed response to responsibilities [53-54]. Healthcare facilities are best prescribed to retain a collection of caregivers as back up to fill up the gaps for the unscheduled non-attendance. Furthermore, medical care centres have implemented RFID to improve the accessibility of information, comprehend and manage demand. This innovation will generate a database that is bound to recognize the position of the patient, staff member, and machinery [55]. This can steer to a refined capacity and staffing.

In sum, implementing predictive analytics in the South African healthcare industry can assist in meeting the enormous demand for healthcare in the public sector. Predictive analytics is a process of erudition from recorded information to create estimations about unknowns [69]. Information history that can be utilized in predictive analytics is computerized anonymous medical history and related groupings. This framework can be utilized to anticipate patient entry in frequent interims and can permit the medical care personnel to enhance patient movement that will in turn better the supply chain performance of healthcare institutions in the Country.

Table 1 presents the healthcare supply chain literature categorization and the areas considered in the analysis.

Table 1: Literature categorization, outcomes and application

Author(s)	Objective	Outcome	Area of Application	Country and Type of healthcare
Khosravi and Izbirak (2019) [56]	SCM social sustainability estimation Stakeholder theory based framework	sustainability indices for Suppliers, Patients, Patient relatives, Employees, Government & Decision makers	Various wards of a general (Government) hospital	Iranian healthcare located in Tehran
Subramanian et al., (2020) [57]	Quantifying healthcare SC sustainability	Metrics for determining stakeholder collaboration, operations quality and footprints of economic, environmental and social aspects of sustainability	Promotion of improvement in the valuation and health reporting of public health supply chains	Proof-of-concept study for further research on public healthcare SC.
Hussain et al., (2018) [58]	Identification of motivators, barriers, and promoters of social sustainability in healthcare SC	Consideration of all stakeholders in establishing SC social sustainability in healthcare helps in meeting expectations of all involved	Stakeholders made up of suppliers, patients/community, employees, and owners government	United Arab Emirates various departments of 10 hospitals
Reda et al. (2020) [59]	Exploration of Blockchain techniques in healthcare SC.	Implementation of blockchains in the healthcare SC sphere	Status of Blockchain in Challenges and benefits of SCM in health care	Conceptual, can be tested as part of further studies
Rowan and Laffey (2020) [60]	Reducing the Shortage of critical health workers equipment	Measures for safeguarding SC critical equipment	Healthcare personnel and Personal protective equipment	Republic of Ireland; Sterile Services Department of a Regional Hospital
Govindan et al. (2020) [61]	Management of demand in healthcare SC	knowledge and fuzzy inference system based decision support framework for SC	Risk level of community stakeholders	General applicability in healthcare systems

Author(s)	Objective	Outcome	Area of Application	Country and Type of healthcare
		demand management: Supports the potency of the proposed framework		
Kochan et al. (2018) [62]	Applicability of Cloud computing technologies in healthcare SCM	cloud-based information distribution improves healthcare supply chains performance and visibility	Simulated hospital supply chain behaviour. Models generalized to an ideal hospital supply chain setting	No validated empirical data used:
Moons et al. (2019) [1]	Development of SC Performance Indicators in operating rooms	Analytic network process based Decision support Framework for measurement of SC performance in operating rooms	Inventory and internal distribution policies in hospital settings	Not validated on empirical data
Golec and Karadeniz (2020) [63]	competency-based Quantification of SCM in healthcare vis-a-vis operation evaluation	Evolution of a Fuzzy model that measures competency and operation of SCM	Measurement of SCM performance and evaluation of activities of five selected hospitals	Bishkek, Kyrgyzstan Public healthcare system
Khan et al. (2018) [64]	Categorizing dimensions of motivation and its impact on healthcare SC social sustainability	Proposition of a measurement and structural models to evaluate impacts of identified dimensions	social sustainability in healthcare SC	United Arab Emirates: 207 surveys from healthcare units
Skipworth et al. (2020) [65]	Effect outsourcing on healthcare supply chains	Strengthened knowledge base on outsourcing in health care SC	Public-to-private outsourcing Public-to-public outsourcing	Italy: Regional Health Service outsourcing
Imran et al. (2018) [66]	Development of an optimal medicine supply chain model for integrated healthcare systems	Model gave satisfactory results on cost, time and quality of supplied medicine	Model functionality was demonstrated on a hypothetical numerical example	The researchers are affiliated to institutions in South Korea and Pakistan
Dillon et al., (2017) [67]	Inventory management in the blood supply chain model.	Reduction of wastage and overall expenditure in the absence of	Healthcare	Australia

Author(s)	Objective	Outcome	Area of Application	Country and Type of healthcare
		bargaining the administration degree.		
Nasrabadi et al., (2020) [68]	Healthcare facility uncertainties in location and capacity planning	The importance of strong arrangement in keeping up the suitable administrative degree.	Healthcare	Canada
Mapowo et al., (2018) [69]	Incorporating product classification in the Visibility and Analytics Network (VAN)	Product categorization: methods and significance in the SA public health	Public Healthcare pharmaceutical supply chain	South Africa
Scavarda et al., (2019) [70]	Tripod Sustainable Healthcare SCM Frameworks	Theory, Practice and implementable policies	sterilization service department and the stockroom in the supply chain	Rio de Janeiro Brazil: Private healthcare

6 CONCLUSION

This study provides a summary of supply chain performance improvement opportunities from literature-based information. The research is limited in coverage since non-financial performance frameworks from allied industries were not extensively reviewed. The work covered some part on implementing predictive analytics to control demand fluctuations in healthcare, however, there is a knowledge gap on the impact of predictive analytics on supply chain performance in other industries which future research can investigate.

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A PROPOSED FRAMEWORK FOR ASSESSING LEAN READINESS IN SOUTH AFRICAN HEALTHCARE INSTITUTIONS

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ABSTRACT

Recent healthcare literature has upheld lean as a methodology for improving operational efficiency and quality of care. However, the uncertainty of implementing lean successfully is still of concern as implementation failures have been recorded. Insufficient preparedness and lack of readiness assessment among other factors have been highlighted as a reason for failure. This paper develops an instrument for assessing the capabilities, quality management practices, and general preparedness of healthcare institutions for a lean implementation journey. The study identifies, through a comprehensive review of lean healthcare literature and the South African healthcare quality improvement literature to find current best quality management practices, and resource requirements needed to create a healthcare system that is supportive of lean. Application of this framework may provide an opportunity for hospital managers to benchmark with emerging lean success stories within the same operating context for organizational learning.

Keywords – Lean, lean healthcare, lean readiness, lean questionnaire, South Africa.

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1 INTRODUCTION

Healthcare institutions globally are under pressure to stay competitive, improve the quality of patient care, employee wellness and increase stakeholder value. There is also a challenge of emerging infectious diseases, new treatment technologies, and prevalence of medical errors, coupled with under capacity of skilled human resource, shortage of essential equipment, infrastructure and necessary consumables [1-3]. Hence, many are willing to deploy innovations like lean that has the potential to save cost, optimise resource utilization and deliver incremental value creation. Continuous improvement strategies like lean are susceptible to failure due to insufficient preparation – lack of strategic alignment [4,5] poor understanding of 'organizational force field' [6] inadequate managerial intentions and commitment [7] and organizational culture [4,5,8]. Further, the inability to define the potential gain (financial and non-financial) and obtain stakeholder buy-in; poor definition of roles, and lack of strategic direction in the lean journey may result in confusion among employees who fear they may become victims of change, thus resulting to sabotage. People may also experience frustration due to a lack of know-how and resource insufficiencies. Hence, several studies have emphasized the need for organizations to establish their readiness status before a lean implementation journey [4][9][10][11].

The origin of lean can be traced back to over 100 years of the Toyota Production System (TPS) [12]. Lean manufacturing was invented by Ohno Taiichi around the 1950s and deployed by organizations after the world war II, to improve manufacturing productivity – achieving the best quality, shortest lead time and lowest cost, through the waste elimination [13][14]. Lean sometimes referred to as lean thinking, lean production system, lean manufacturing, or lean management was popularized by [15] in their book "The machine that changed the world".

Lean is defined as a management practice focused on improving customer (both internal and external) value by reducing all forms of waste (muda), process variation (mura), and poor working conditions (muri) [16]. Waste is defined by Toyota's Fujio Cho as "Anything other than the minimum amount of equipment, space and worker's time, which are essential to add value to the product" [14]. The common waste experienced in healthcare includes - excessive waiting by patients, duplication of patient records, absence of needed supplies and equipment leading to downtime and idling of staff, unnecessary procedures, unnecessary movement of staff and patients, over-processing like an unnecessary repeat of pathological tests, procedural delays [9][16]

Lean is suitable in a multidimensional knowledge work environment like South African [17] as it fosters teamwork, employee recognition, a common purpose of continuous improvement; and respect for others [18]. However, some authors have cautioned that adopting internationally applied healthcare innovations without meticulous consideration of 'on the ground realities' could be devastating [8][19]. Andersen [20] further recommends that lean implementation, potential outcome, content, and critical success factors, should be explored in the context of the organization's structural, strategic, cultural and technical, environment [20]. Hence, the current South African healthcare system's operational challenges, governance, and contextual issues were also reviewed in the study.

Although lean originated from the manufacturing industry, many healthcare journals show a significant interest in lean as a mechanism for increasing system effectiveness, operational efficiency [21] and safety [1]. Vamsi & Kodali [23] review of twenty years of empirical studies on lean identified a scarcity of empirical studies in lean in undeveloped countries. Additionally, the significance of data triangulation and large sample sizes in lean healthcare research is yet to be explored [23]. They further emphasized the need to develop a systematic, context-based lean application framework to facilitate easy implementation.

Although lean has undergone three decades of application in healthcare, the healthcare domain in South Africa has recorded little empirical contribution. Several recent studies affirm that lean is yet to be fully explored by South African (SA) industries especially the healthcare sector [16][24][25].

SA hospitals and clinics who are initiating lean and benchmarking with implementing countries (with recorded success) must consider current national and system capabilities [19]. Initiating lean without ascertaining the degree of organizational readiness may have both unwarrantable and wasteful consequences.

A readiness assessment enables managers to identify and understand potential implementation gaps some of which are contextual. Bridging these gaps by deploying efforts and resources where necessary underpins the success or failure of sustainable lean systems in healthcare. Developing a framework for assessing the current realities, capabilities and preparedness of SA healthcare institutions is imperative for a successful lean implementation journey.

2 LITERATURE REVIEW

In this section of the paper, we briefly capture the SA context that gave impetus to lean implementation in the healthcare sector; a snapshot on the nexus of lean, potential benefits of lean, lean awareness, lean principles and tools. Further, the quality management practices that are prerequisites for lean implementation in healthcare: operations process planning, co-ordination and control, and quality practices as expected within different stakeholder groups (top management, employee group, patient/customer, and suppliers group) and organizational culture which are needed for lean are presented.

2.1 The South African context

In the new democratic republic of South Africa, compliance to quality standards and commitment to maintaining quality in healthcare is considered a statutory expectation from all concerned [22][32]. Since the post-apartheid, the government has made huge investments towards upgrading the healthcare system [22] [26].

2.1.1 Public healthcare system

The South African health system trajectory is interlinked and driven by her apartheid historical travail [18]. A two-tier healthcare system leading to a wide disparity between public and private healthcare systems, urban and rural facilities [28]. Even in the public sector, healthcare deliverables remain fragmented and unbalanced [27]. The public healthcare system is battling with the problem of long waiting lines, inability to make efficient and safe quality care accessible to patients [27], poor service delivery and shortages of skilled human resources [28].

The funding structure for the Municipality, Provincial and National public healthcare institutions are also different, for example, the provincial government funds the supply of drugs to primary healthcare clinics, while their operational cost is caped and funded by the municipality. In order to remedy the imbalance, the NHI (National Health Insurance) scheme was introduced. The NHI, if successfully implemented will enable all South Africans irrespective of their income level access affordable healthcare through a funding system where all employed citizens and permanent residents are contributors [28-29].

2.1.2 Quality Reforms in South Africa

As Dr. Aaron Motsoaledi (former SA minister of health) stated in the National Core Standards (NCS) *'The importance of providing quality health services is non-negotiable. Better quality of care is fundamental in improving South Africa's current poor health outcomes and in restoring patient and staff confidence in the public and private health care system. If quality is defined as "getting the best possible results within available resources", then these National Core Standards set out how best to achieve this'* [30].

The SA healthcare administrators, over the years, have developed quality standards, an array of policy interventions, training and new quality improvement systems have also been implemented in the public health sector [22][31-32]. These include policies on quality healthcare, the National Core Standards, the SA guidelines on clinical governance and the National Department of Health (NDoH) Primary healthcare supervision manual [31]. Further, various healthcare improvement audits were deployed to improve the quality of healthcare: the quarterly program in-depth reviews for Primary healthcare clinics, clinical program support, monthly supervisory visits, management development training, quality improvement workshops [32]. Despite all these interventions, the healthcare system remained vulnerable experiencing high-level inefficiency, poor quality and loss of public confidence [22] [32]. Hence, the recent introduction of the 'Ideal Clinic' a national quality improvement program designed for infrastructural and operational upgrade of the Primary Health Clinics [33][34].

The failure of interventions is not peculiar to South Africa. As Yurtkuran et al [35] highlighted, until recently, healthcare institutions have applied several quality standards to improve the quality of delivery of services, but those standards failed to produce reasonable outcomes hence the recent integration of lean into healthcare operations. The management at the Ekurhuleni Primary Health District has adopted a strategic approach to dealing with quality improvement by introducing training on lean management to clinic managers.

Lean requires a radical transformation in operations, a paradigm shift from the traditional batching and mass production peculiar to manufacturing [36]. Lean management in healthcare demand best practice in medical care, proven quality management practices and techniques that improve service delivery by enhancing operational flow for the purpose of system optimisation (best customer value) through waste avoidance or minimisation [8][25]. When implemented meticulously, lean is a methodology that drives knowledge sharing and increased customer value creation through a continuous search for improvement [17].

2.2 Organizational lean readiness evaluation

Lean readiness evaluation is an analysis to obtain a status quo on the extent of availability of preparatory elements for a lean journey. It is a risk minimization process, done before implementation to secure the certainty of success. Organizational readiness has been defined as "*the ability of the organization to undergo a smooth transformation to respond to the changing needs and expectations of its internal and external environment*" [4]. The organization's change management culture influences its response and adaptation to change [10] [37].

A hospital's lean readiness index is a measure of their competency and capability in terms of the critical success factors identified as necessary for a lean journey. It is an assessment of a hospital's ability to exploit the opportunities provided by lean [38].

2.3 Lean readiness factors

The major readiness factors indicated in letters include, prevalence of quality improvement culture (openness); strong leadership support and participation;

understanding demand, capacity and customer requirement; employee involvement – training, development; Knowledge of lean principles, tools and structured problem solving [10] [25] [38] [39] [40].

Previous studies also identified knowledge of potential befits of lean as an important factor that can influence the willingness and readiness of employees to accept lean as a process improvement philosophy [41] [42]. Lean adoption requires an orientation, change of mindset, and willingness to relearn new systems, most times both at an individual and institutional level. Hence, readiness to accept lean is also a function of the institutional change management efficacy and professional culture which influences the people's resistance to change [4].

Sustainability in the deployment of lean mechanisms depends on the understanding of an organizational operational context. A focus on lean tools and techniques while paying less attention to the readiness of implementers will undermine the sustainability of the lean system [43] [10].

2.4 Major blocks of the Lean readiness framework

The lean readiness evaluation tools deployed in this study is inspired by the works of previous researchers [4] [6] [7] [40-41] [44-47]. Although this study is informed by theoretical constructs contained in the above-mentioned models, the study draws insight from practical applications and interpretation from healthcare in operationalising the constructs. Evidence from operations management literature suggests that the application of lean principles and tools differs between the manufacturing and service sector, hence, [46] [47] [6] were found relevant as they address critical lean readiness factors related to healthcare.There is no 'one fit for all' implementation strategy when it comes to healthcare innovation [18].

2.4.1 Resource availability

According to statistics, only about 18% of the South African population have medical cover [48]. Hence, a high dependency on public-owned healthcare institutions for medical treatment. There is a considerable difference in resource availability between the South African private and public healthcare sectors [49]. For example, the nurse-to-population and doctor- uninsured population ratio in the public sector has been decreasing significantly over the years as most of these professionals are opting to work in the private sector [50]. Evidence from recent South African healthcare literature on constraints of quality improvement show that many public healthcare institutions are less likely to implement quality reforms due to resource constraints [31][33] – workload, staffing crises, poor infrastructure, funding and inefficient distribution of resources amongst levels of care within the public sector [50].

2.4.2 Lean awareness among different institutions

Many studies maintain that the knowledge of lean tools, practices, and benefits paves the way for a deeper understanding of lean and buy-in of both managers and employees [42][40]. Orgnisations need to train on lean tools, principles and requirements; thus they can identify specifics that are adaptable to their operational context so that they able to apply them with proficiency to achieve a sustainable lean transformation. SA hospitals are involved in several quality improvement initiatives, consequently, a high level of lean awareness is expected.

2.4.3 Lean Principles

Application of lean involves five basic principles namely [8] [51]:

I. Define value from the customer (both internal and external) perspective.

II. Map the value stream and eliminate all waste.
III. Develop tight sequential flow of value-creating activities to enable smooth product flow to the customer.
IV. As the flow is introduced, let the customers pull value from the activity flow upstream, shortening the lead time.
V. Start the process again until perfection is reached.

Although the five steps principles were originally proposed for manufacturing, the five principles model has found application in the service sectors including healthcare.

2.4.4 Lean tools usually applied in healthcare

Many lean tools and techniques exist in literature, but the Value Stream Mapping (VSM), 5S, Standardized Processes, Observation Forms, Visual Controls, and root cause analysis are predominantly applied in the healthcare lean systems [16] [39]. Although literature emphasised understanding and application of lean tools and practices, Mutingi et al. [53] suggest that applying the right lean tools at the correct time is necessary to achieve the required success. Effective application comes with knowledge of lean tools, which is informed by appropriate hands-on training.

2.4.5 Quality management practices

Previous research suggests that certain quality management practices and operating environments enable the implementation of lean systems [41]. Also, the absence of such sound practices and environment undermines lean implementation and sustainability. The current study has identified, through a review of healthcare literature, quality practices in healthcare that complement the implementation of lean and practices that are essential for a sustainable lean system. The quality management practices in this study are classified under organizational culture, operations process and planning, coordination and control and quality practices as found within different stakeholder groups (top management, employees, patient/customer group, suppliers) which are needed for lean [9] [7] [30] The National Core Standards domains: operational management, patients right and safety, cooperate governance and leadership, facility and infrastructure. Also included were the items in the SA ideal Clinic model [34] (summer). The SA Ideal Clinic Model demands the provision of adequate staff level, medicine and other supplies, good infrastructure, sound administrative processes, supplier collaboration and use of automated procurement and stocking system, stakeholder support, accurate application of clinical guidelines, protocols, and policies [34]. The essence of quality improvement in healthcare is mainly to enhance quality outcomes especially quality of care for patients. This requires a culture of patient-centered care where service and process redesign is anchored on identifying understanding and prioritizing patient/customer requirements.

2.4.6 Organizational Quality management culture

Many authors emphasized the relevance of conducive organizational culture as a necessity for successful lean healthcare implementation [4] [9] [56]. Further, Bhasin [54] maintain that any innovative strategy including lean, irrespective of its strengths, would not gain acceptance if such innovations does not resonate with the organizational culture. Lean culture emphasizes safe environment for both patients and staff [55], waste elimination and respect for people [56]. Managers who champion lean culture provide mechanisms that enables continuous open conversations about waste, front line staff are encouraged to provide management with information on improvement opportunities found in their line of duty, people feel free to report errors and unsafe working conditions without fear of being victimized. Medical staff are trained on patient safety as all patient treatment processes must be void of any harm or any sources of danger [57] [55]. Taherimashhadi & Ribas [58] developed a lean culture model for assessing national and corporate culture adaptations to close organization cultural weaknesses and have the organizational culture aligned to the lean culture. The model consists of six dimensions four of which were found to be of high relevance – willingness to accept change; employee empowerment, low employee turnover, teamwork, equal treatment for all; performance orientation; and long term success perspective [58].

2.5 Conceptual framework

The LRF presented in Figure 1 was developed from the concepts discussed in the broader study, which has been summarised in sections 2.1 - 2.4 of this paper.

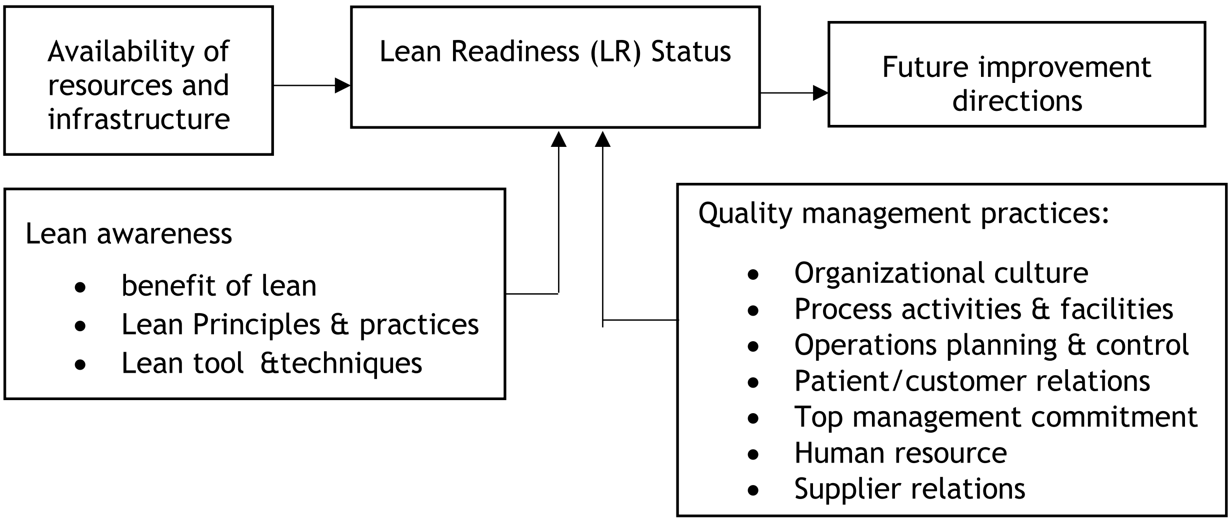

Fig 1: Conceptual framework

3 METHODOLOGY

The lean readiness framework and supporting questionnaire presented in this study were developed through a review of global lean healthcare literature. Further, South African lean and healthcare quality improvement literature was extensively reviewed [27] [30] [31] [33] [34] [49] [59]. Thus, reflecting operating characteristics prevailing in the South African health scenario in the light of current best quality management practices [30][34].

Figure 2 describes the Steps used for the theoretical development of the questionnaire.

1. Identify lean readiness factors from literature and categorise them.
2. Include relevant contextual factors.
3. Decompose each category: operationalise, describe all elements in terms of healthcare operations: Spear & Bowen four dimensions of lean Principles [60] Liker's 14 Principles of lean [45] South African ideal clinic model [34], SA National core standard [30]
4. Questionnaire face validity assessment: round 1 and round 2: Adjust after each round.
5. Testing instrument reliability.

Figure 2: Questionnaire design: Steps used for theoretical development.

The developed questionnaire was reviewed in rounds of panel sessions consisting of lean experts, academics from South African universities who have published on healthcare quality, quality improvement consultants who have pioneered various quality improvement projects in the South African public healthcare system, and focus groups of clinicians from various hospitals. The reviews focused mainly on CSFs for lean implementation in healthcare, lean related quality management practices, technical and contextual issues [25] [34] [38] [39] [41] [45].

The review and discussions enabled the researchers to identify current best quality management practices, capabilities, resource requirements and other contextual factors that are essential to creating a healthcare system that is supportive of lean.

The study seeks to overcome the gaps of the previously developed models as outlined above by asking questions on resource levels, lean waste, placing more emphasis on quality management practices that enable lean, including lean tools and principles and practices, assessment of lean awareness levels in the healthcare sector. The framework further explores hospitals' operations and practices with respect to patients and customer relations; suppliers; top management commitment; employee empowerment and reward systems: training, behavioural and technical skills, use of scientific problem solving; quality improvement culture.

The questionnaire developed has four main sections. Section I deals with participant biographic information, Section II - hospital information, Section III - lean awareness and Section IV - Quality management practices required for lean. As per the questions that test the respondent's perception, the range of choice is a 5point Likert scale to obtain a holistic view on the respondent's level of perception or agreement.

Although an effort was made to separate items/questions a group them under specific construct, a critical standpoint reveal the interwoven and interrelations between the constructs. For example, patient-centered care cuts across employee relations, quality culture, top management disposition of organizational resources to enable employees to acquire the required training, provide infrastructure and other resources needed. One can observe the need for collaboration and the total commitment of all stakeholders to make the lean intervention a success.

The next phase of this study is to administer the instrument to clinicians in three large South African public healthcare institutions, two private hospitals and seventeen primary healthcare clinics from whom permission has already been obtained. This empirical study will test the practical application of the instrument to determine construct validity, reliability and internal consistency. Further, data reduction (by eliminating variables of low significance) using Factor analysis is feasible.

4 CONCLUSION

Lean as a strategic quality management philosophy that has the propensity to drive healthcare transformations. Application of Lean thinking in hospital management offers leaders many possibilities for establishing professional, customer/process-driven health care organizations. Lean is not a quick fix to operational inefficiencies; it requires thorough preparation, steady, continuous, and holistic involvement over a long time. Understanding the complexities provided in this study will provide evidence for informed planning to enable effectiveness in lean initiation and sustainability among clinical communities in South Africa.

Assessment of lean systems is not a once-off event. The process may be iterative and repetitive as contexts changes and new barriers emerge. Healthcare institutions can evaluate their capabilities before a lean journey by using the Lean readiness framework developed in this study. The application of this framework will provide a platform for hospitals operating within a similar context to benchmark with emerging lean success stories.

Further studied to empirically investigate preparedness challenges and the extent of readiness of South African healthcare institutions for lean is recommended.

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6. APPENDIX LEAN READINESS QUESTIONNAIRE:

SECTION I: RESPONDENT BIOGRAPHIC INFORMATION

Gender, Age, Years of experience, Current job position, Current hospital unit employment, highest qualification

SECTION II: HOSPITAL STATUS INFORMATION

Hospital level, teaching status? ISO9000 Certified? Lean status.

Item No.	Please rate the hospital in terms of the following resources:	Very poor	Poor	Average	Good	Excellent
S1	Reliable essential supplies	1	2	3	4	5
S2	Infrastructure	1	2	3	4	5
S3	Efficient back-up electricity supply	1	2	3	4	5
S4	Reliable water supply	1	2	3	4	5
S5	Adequate medical waste disposal	1	2	3	4	5
S6	Staff level	1	2	3	4	5
S7	Internet, communication tools	1	2	3	4	5
S8	Automated patient database	1	2	3	4	5
S9	Doctor to patient ratio	1	2	3	4	5

SECTION III: LEAN AWARENESS

1. According to your understanding, what is Lean management **(Mark all applicable)**

Application of lean tools for improving operations	1
Continuous improvement philosophy	2
Long term “cost-cutting” philosophy	3
A fully integrated management system	4

2. Which of these **lean tools** do you use in this hospital? **(Mark all applicable).**

Observation charts	1	Value Stream Mapping	5
Standardized Processes	2	5S	6
Poka-Yoke	3	None of above	7
Root Cause Analysis	4	Other specify________________________	8

3. Perception on lean implementation benefits: Which of the following benefits could be achieved by this hospital if it adopts Lean management? **(Mark all applicable).**

Increased profit	1	Waste Reduction	5
Decreased inventory	2	Reduced patient waiting time	6
Improved quality of care	3	Increased staff satisfaction	7
Improved productivity	4	Other specify ____________	8

4. Below are some indicators hospitals use to measure performance. On a five-point Likert scale, Please rate this hospital in terms of the following:	Very poor	Poor	Average	Good	Excellent
PI01. Patient waiting time	1	2	3	4	5
PI02. Number of recorded adverse events	1	2	3	4	5
PI03. Number of patient complaints	1	2	3	4	5
PI04. Patient throughput	1	2	3	4	5
PI05. Patient satisfaction	1	2	3	4	5
PI06. Financial management	1	2	3	4	5
PI7. Reduction in cost of inventory/ waste reduction	1	2	3	4	5

SECTION IV: QUALITY MANAGEMENT PRACTICES

Item No.	**1. ORGANIZATIONAL CULTURE:** To what extent do you agree with the following statement regarding the status of quality culture in this hospital? Using a scale of strongly disagree(1) to strongly agree (5)
QC01	In this hospital, we understand that change is usually needed to improve care.
QC02	Organizational culture is open and organic such that employees feel free and valued.
QC03	In this hospital, organizational resistance to change is a challenge.
QC04	The hospital tracks progress made toward attaining hospital-wide quality objectives and communicated such achievements regularly to all clinical staff.
QC05	QI project outcomes are communicated to all personnel.
QC06	If progress made toward attaining hospital-wide quality improvement (QI) objectives is not adequate, corrective action is taken.

	2. **PROCESS ACTIVITIES & FACILITIES** Please indicate the level of implementation in this **hospital using a scale of:** **Never=1, Very Rarely= 2 , Sometime=3, Frequently=4 , Always=5**
PR01	In this hospital each unit has a specific task
PR02	In this hospital related procedures are situated close to each other
PR03	This hospital keeps all workstations clean
PR04	Stores equipment and tools are in appropriate place after use
PR05	This hospital labels and locates each piece of equipment in the right place within the unit
PR06	Uses demand from next internal customer to provide operations at each site
PR07	Hospital infrastructure is maintained
PR08	This hospital has a dedicated manager in each unit
PR09	Displays equipment maintenance checklist
PR10	Manages flow of materials, processes and people well
PR11	Has work instructions and configuration settings for each piece of equipment
PR12	Trains staff on how to use new equipment

	3. OPERATIONS PLANNING, COORDINATION AND CONTROL: Please indicate your perception on the level of implementation of the following in this hospital. Rank the hospital using a scale of: Never=1, Very Rarely= 2 , Sometime=3, Frequently=4 , Always=5
PC01	Organise focus groups of employees for quality improvement (QI)
PC02	Quality circles submits new ideas and solutions to management for action
PC03	Benchmarks are performance against best-performing local hospitals
PC04	Benchmarks are performance against best-performing international hospitals
PC05	Uses evidence-based clinical practice guidelines
PC06	Implements specific disease or condition quality improvement programmes (for example chronic illness registries and planned care for chronic diseases).
PC07	Use Standardises patient care processes and procedures
PC08	Provides standard operating procedure through a mobile application
PC09	Provides patient and operations records online
PC10	Records accurate data
PC11	Synchronises data across departments
PC12	Harmonises work processes across departments and workgroups
PC13	Has zero out-of-date practices
PC14	Uses problem-solving techniques such as fishbone diagrams
PC15	Displays up-to-date charts showing error rates, progress and next job activity

Item No.	**4. PATIENT/CUSTOMER RELATIONS: Please use the following scale 1= Strongly Disagree 2= Disagree 3= Neutral 4= Agree 5= Strongly Agree**
CUR01	In this hospital, there is an awareness of “what is value to the customer/patient”.
CUR02	Patients and families are involved in efforts to improve quality of care.
CUR03	The relationship between employees and patients is characterized by mutual respect.
CUR04	Patients are aware of their treatment life cycle (end to end treatment process pathway)
CUR05	Patients are provided with timely feedback on their health status.
CUR06	The hospital has strategies to improve patient waiting time

Item No.	**5. TOP MANAGEMENT COMMITMENT** Please indicate to what extent you agree with the following management related attributes are evident using a scales of 1= Strongly Disagree 2= Disagree 3= Neutral 4= Agree 5= Strongly Agree
LMG01	In this hospital, leaders “walk-around” to identify problems or issues relating to quality
LMG02	In this hospital leadership support employees in the (QI) journey.
LMG03	Management is first trained on QI before others.
LMG04	Top management is committed to QI
LMG05	Leadership institutionalises dedicated QI positions like quality managers, quality assurance officers.
LMG06	Management adopts a systems approach in QI.
LMG07	The organizational strategic agenda (mission and vision) is aligned with the QI objective.
LMG08	Leadership encourages and coaches staff on QI.
LMG9	Management invests in QI training programs.
LMG10	Management encourages use of external experts/consultants to evaluate quality management processes

Item No.	**6. HUMAN RESOURCES (knowledge, skill, attitudes and behavior, working conditions)** To what extent do you agree with the following employee related attributes? Please use the following scale 1= Strongly Disagree 2= Disagree 3= Neutral 4= Agree 5= Strongly Agree
H01	Employees are encouraged to identify areas of improvement in their jobs.
H02	Staff development needs are identified
H03	This hospital ensures patient safety
H04	This hospital ensures employee safety.
H05	Employees have sound knowledge of both external and internal customer groups
H06	Employees are skilled and knowledgeable enough to contribute to problem solving.
H07	Employees are encouraged to report errors committed or observed to their unit manager.
H08	Workers are encouraged to stop any process if there is a tendency for adverse events.
H9	Admin processes are efficient.
H10	All job positions are occupied by qualified personnel.
H11	Employees have the competency to perform different tasks.
H12	Employees have a clear understanding of their job description and requirement.
H13	Employees regularly undergo quality training to develop competences for problem-solving and waste identification.
H14	Employees are conversant with hospital policies, systems and functional areas.

Item No.	**7. SUPPLIER RELATIONS: Rank the hospital in terms of the following using a scale of: Never=1, Very Rarely= 2 , Sometime=3, Frequently=4 , Always=5**
SU01	A clear mechanism is in place to evaluate our suppliers
SU02	Local suppliers are used where possible to avoid transportation delays.
SU03	Supplies are according to hospital strategic and operation needs.
SU04	Suppliers to this hospital consistently provide goods and service of high quality.
SU05	We have database of approved suppliers and service providers.
SU06	We use mobile phone stocking tool.
SU07	We have efficient supply-chain management.
SU08	Suppliers maintain long term cooperative relationship with the hospital.

INVESTIGATING HOW SYSTEMS THINKING CAN ASSIST WITH THE ADOPTION OF ADDITIVE MANUFACTURING IN SPARE PART PROVISIONING SYSTEMS

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ABSTRACT

Although the adoption of Additive Manufacturing (AM) in various industries is accelerating, the adoption of AM for industrial spare parts provisioning remains slow. AM is indicated as one of the most disruptive innovations of Industry 4.0 (4IR). Innovation is defined as disruptive when it changes the way the current industry operates. This disruption challenges the status-quo and the understanding of the risks and paradigms involved when adopting this innovation. Uncertainty can cause the innovation to be perceived as complex and can prolong the adoption of this technology. A paradigm shift from linear models to integrated, networked non-linear models will be required for adoption of AM produced spare parts and provisioning system evolution.

This paper will attempt to identify how Systems Thinking can assist organisations that would like to adopt AM for spare part provisioning to resolve the above-mentioned reasons and increase the adoption of AM for spare part provisioning.

Keywords: Additive Manufacturing, provisioning system, risk, complexity, Systems Thinking, adoption.

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1 INTRODUCTION

Additive Manufacturing (AM) or 3D printing refers to the process of joining materials to make objects from 3D model data, usually adding layer upon layer, as opposed to subtractive manufacturing methodologies, such as normal milling, grinding and CNC machining [1-3]. AM is gaining more popularity as an emerging manufacturing method in various areas of the economy to produce customized components from jewellery, footwear, toys, architecture, automotive, aerospace, dental and the medical industry [3]. AM is also used for rapid prototyping where a component can be created in the Computer-Aided Design (CAD) software, modelled and then printed to test form and function before the production of the component for industrial use.

The use of AM technology is growing at an exponential growth rate year on year as indicated by figure 1.

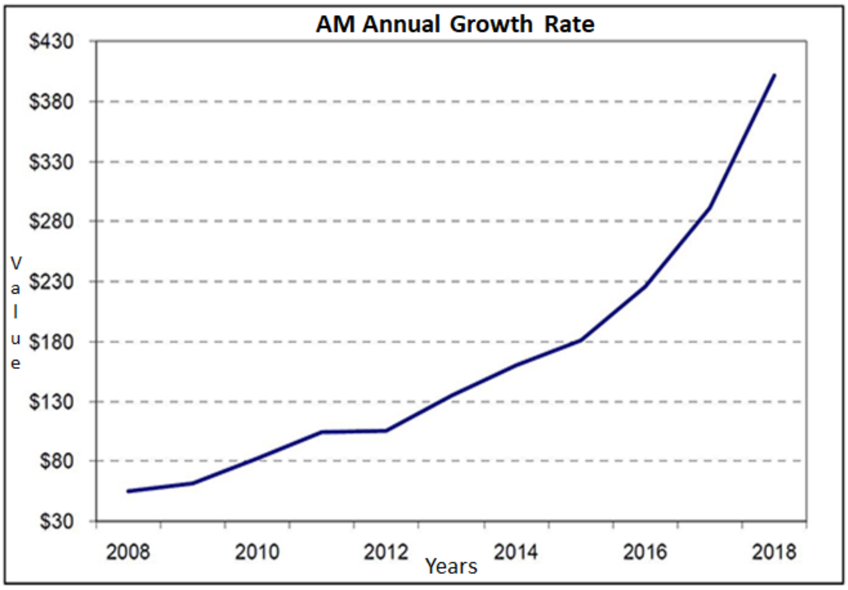

Figure 1: Annual AM growth rate - [4]

As the technology matures and moves away from rapid prototyping towards the production of spare parts [5], so does the requirement to understand and manage the uncertainty initiated by this disruptive technology [6]. Den Boer [7] contemplates that AM will not only disrupt the manufacturing and Supply Chain processes but will also fundamentally transform these activities. AM presents significant potential to enable organisations to apply new, creative, non-linear thinking to create components that can improve the reliability and process efficiency of the operations [8].

According to Olesen [9], successful organisations distinguish themselves by their willingness and ability to acquire technology and to take technology risks. AM is described as one of the most disruptive innovations of the Fourth Industrial Revolution (4IR) [10,11]. A technology is described as disruptive when it replaces current operating practices and industry norms with radical new ways [12]. This will require a paradigm shift from traditional design for manufacturing (DfM) and Supply Chain principles to new design for AM (DfAM) and network-integrated provisioning systems [13].

With DfM, and with the current spare parts manufacturing processes, complexity is expensive. One of the requirements for operating in the new business eco-system is the ability to manage complexity. When spare parts are produced with DfM, the material is removed from a block of material, layer by layer until the final component is created. This process leads to significant waste and there is little room for complexity. AM shifts the paradigm from a reductionist approach to a systemic approach. AM is a system where complexity can be accommodated, and components are built layer by layer from the bottom [14]. Figure 2 indicates the design principles for traditional manufacturing (DfM) and AM (DfAM).

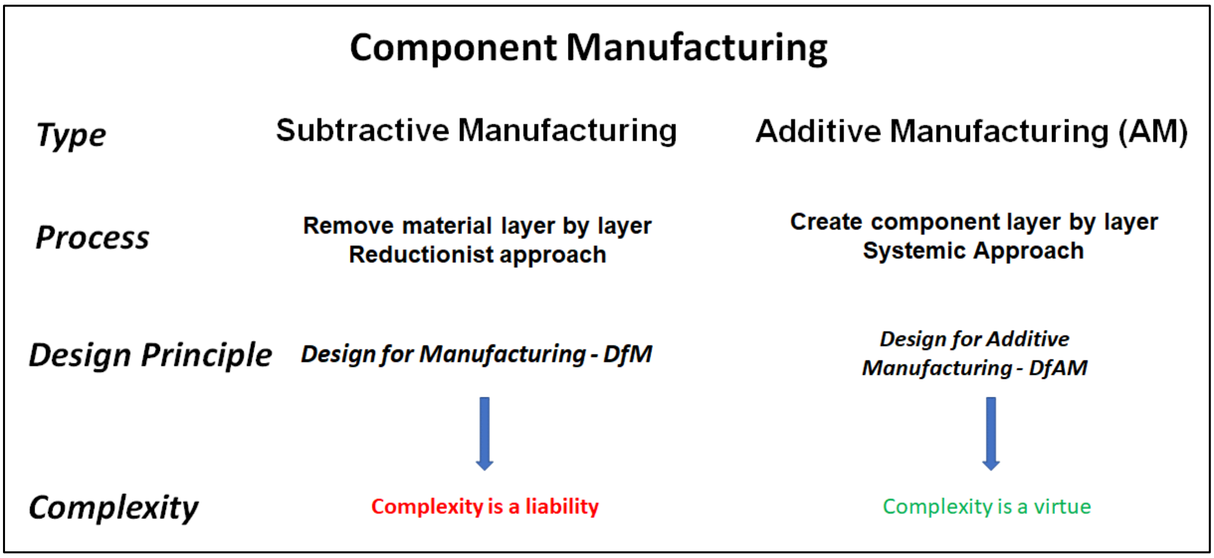

Figure 2: Difference between Traditional Manufacturing and Additive Manufacturing - Author

In order to adopt AM in spare part provisioning, a paradigm shift will be required from DfM to DfAM. This will require a disruptive change in how business risks are managed, from the traditional linear paradigm to a dynamic, non-linear, systemic network paradigm and understanding how to manage the perceived complexity created by adopting AM. Christensen [15] states that disruptive innovations are seen to be complex because their value and applications are uncertain. However, Roos [13] indicates that the strategic implications of AM across industries are significant, yet poorly understood and this attributes to the slow adoption of AM in spare part provisioning.

AM can also require a change in business model [16,17]. The process of adopting a new business model must be an agile and dynamic process. Successful companies repeatedly reinvent themselves by creating new business models that leverage these changes in disruptive technology. To translate strategies into action companies will need new tools, new talent and a new mindset [13].

When adopting a technology that will disrupt the status quo, there will all ways be resistance to change [18]. Possible reasons for the resistance to change can be contributed to some entrenched paradigms that slows down the adoption of the technology. Thomas-Seal [19] and Mellor [20] indicated that the barriers to the progression of AM for the wider adoption of AM for industrial spare parts requires attention. The focus of researchers to date was either based on broad level adoption or been highly focused on material and energy consumption. According to Douglas [21], AM is to an extent following the S-curve model of diffusion, although for wider adoption, AM will need to deviate from the current rate of adoption. In order to deviate for the current rate of adoption, organisations will have to transition from a linear paradigm to a non-linear paradigm [22].

The purpose of this paper is to investigate some of the entrenched paradigms that can contribute to the slow adoption of AM in spare part provisioning. Once these paradigms have been established, it will be investigated if Systems Thinking can be applied as a possible solution to change these paradigms that will enable the accelerated adoption of AM in spare part provisioning.

2 PURPOSE AND METHODOLOGY

2.1 Purpose of research

The research questions that will be investigated in this paper are:

Q1: What are some of the key paradigms that can contribute to the slow adoption of AM in the spare part provisioning systems?

Q2: What role can Systems Thinking play to change these paradigms in order to enhance the adoption of AM in spare part provisioning?

Figure 3 provides a layout of the research. In order to answer question 1, a Literature review, Abductive reasoning and personal experience have been used to determine the key paradigms contributing to the slow adoption of AM in spare part provision (Section 3).

Question 2 will be answered by investigating the role that Systems Thinking can play to assist in improving the adoption rate of AM in spare part provisioning. (Section 4).

The paper ends with a discussion on the findings summarizing the research outcomes and suggestions for future research will be provided.

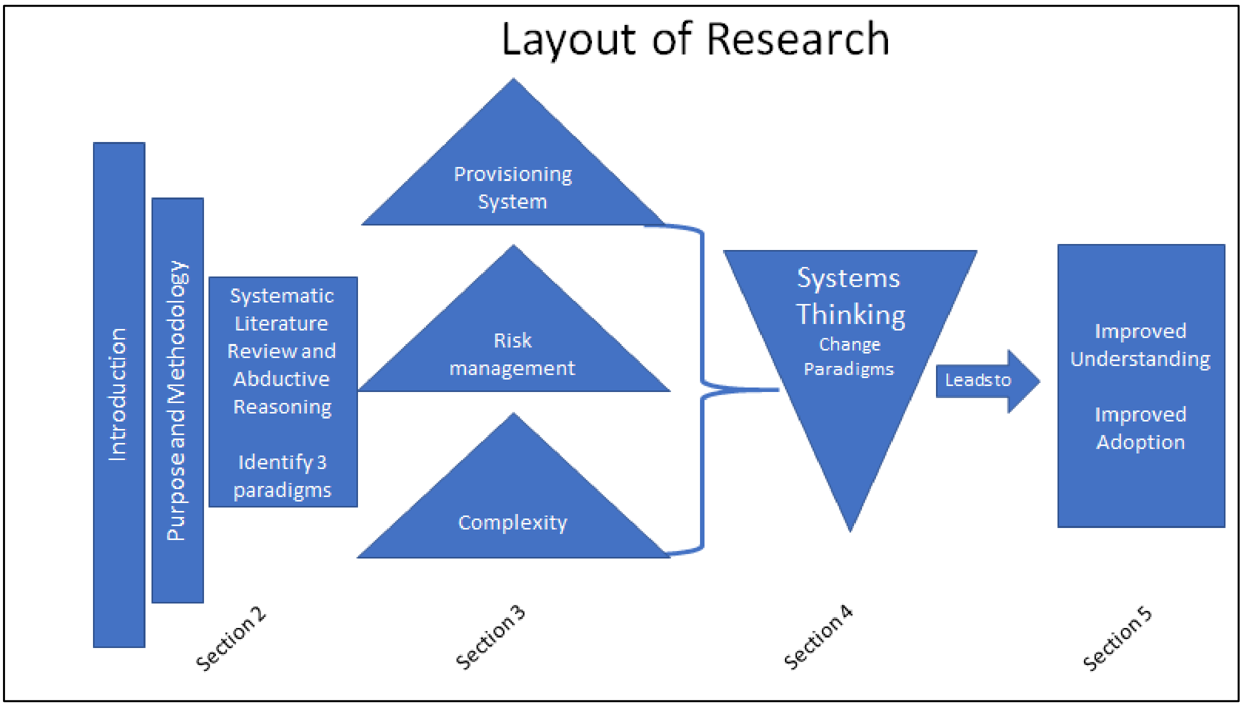

Figure3: Layout of Research

2.2 Methodology

2.2.1 Data Gathering

A Systematic literature review was conducted. Table 1 is the review protocol for the study:

Table 1: Review protocol for SLR

Purpose of the study	**To investigate how Systems Thinking can assist with the adoption of Additive Manufacturing in spare part provisioning**
Inclusion criteria:	Literature indicating Additive manufacturing and Systems Thinking in their title, abstracts or keywords. Literature on Additive manufacturing and risk Literature on Additive manufacturing and complexity Literature on Additive manufacturing and Supply Chain Literature on the business impact of Additive Manufacturing
Exclusion criteria:	Non-English literature Technical and material evaluations of Additive Manufacturing
Search databases	Searches were conducted for 5 databases EbscoHost, Emerald Insight, Science Direct, Web of Science and Scopus
Keywords	All the selected databases were searched using the following key words: "Additive manufacturing" AND "Supply Chain" "Additive manufacturing" AND "Supply Chain" AND "Evolution" "Additive manufacturing" AND "Risk" "Additive manufacturing" AND "Systems Thinking"
Quality assessment criteria	All duplicate literature was excluded Recovered literature will be checked for relevance (besides inclusion and exclusion criteria)

The bulk of the material focused on the operational performance of AM. There was an increase in the number of researchers requesting a more holistic approach to understand the impact of AM on business [11,20,23-24]

2.2.2 Data Analysis

Abductive reasoning and personal experience were applied to the literature in order to define three paradigms that can have an impact on the adoption of AM for spare part provisioning.

O'Reilly [25] indicates that Abductive reasoning is used when synthesizing complex information to generate insight and in reasoning toward creative new solutions for current problems. Creativity has always been closely associated with engineers. Due to the disruptive nature of AM, it will be required from organisations to change their paradigms and create an understanding of the systemic interrelationship that exist between different activities and processes in the business.

2.2.3 Artefact Development

The concept of Systems Thinking was investigated as a possible solution to assist with the creation of an integrated understanding and the relationship of the defined concepts from the literature study that plays a role in the slow adoption of AM in spare part provisioning. Systems Thinking can be defined as: Systems Thinking synthesizes systems theory and interactive design, providing an operational methodology for defining problems and designing solutions in an environment increasingly characterized by complexity [26].

3 FINDINGS: LITERATURE REVIEW AND ABDUCTIVE REASONING

3.1 Paradigms contributing to the slow adoption of AM in spare part provisioning

Three paradigms that were identified according to the literature review and abductive reasoning that can contribute to the slow adoption of AM in spare part provisioning is summarized in Figure 4 and will be discussed individually in the sections to follow.

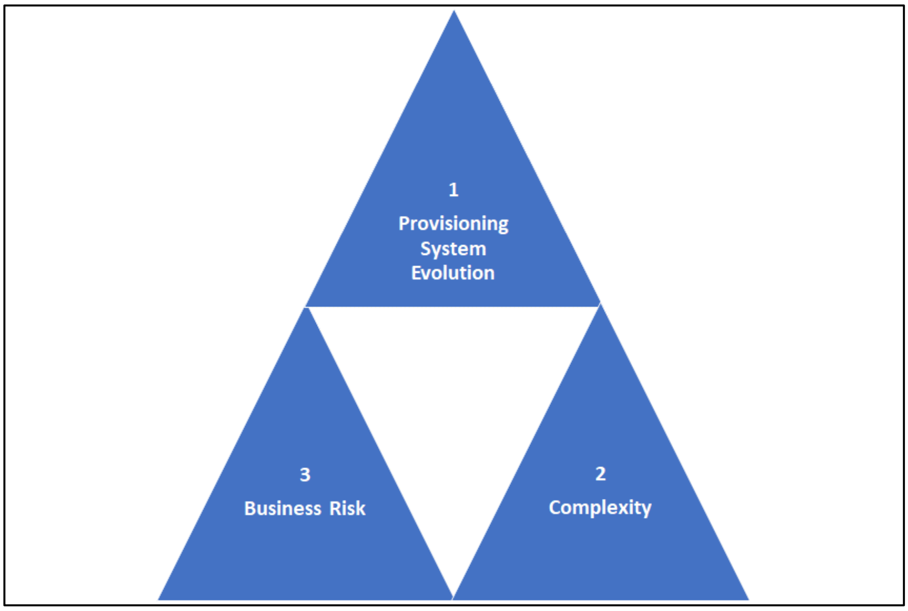

Figure 4: Paradigms contributing to the slow adoption of AM - Author

3.1.1 Provisioning system evolution

Apart from the exponential growth of AM, the adoption and provisioning systems for the use of AM for spare parts is not developing at the same rate [27]. With the advent of the 4th Industrial Revolution (4IR), provisioning systems must evolve from a linear perspective where the sum of the parts makes up the whole, to a holistic systemic view where the interrelationship in the system needs to be managed and understood [23,28]

One of the risks that remains inherent in the current Supply Chain, is that it re-enforces traditional linear thinking. Gattorna [29] states that the term Supply Chain Management was never a good term because it emphasizes the supply side of the enterprise. The chain descriptor implies, participants are dealing with linear chains or strings of enterprises, when in fact the provisioning systems are involved in multi-dimensional, integrated networks or eco-systems. 4IR necessitates that organisations move away from static, linear provisioning systems to dynamic eco-networked non-linear systems [30].

Disruptive technologies change the attributes required to manage the business and the nature of the provisioning systems which is sometimes ignored by companies [15,18]. The business is not operating in a linear supply chain any more but will become part of the global network or eco-systems [31]. Harmse(a) [32] in their study on the evolution of business models from supply chain to demand networks contemplates that the focus in the provisioning system has to transcend from a supply culture to a demand culture understanding the dynamic requirements of the integrated networks or eco-systems.

Moore [33] defines the eco system as:

> *"an economic community created from interaction between individuals or groups, with the emphasis on the networks between the actors within the ecosystem and the dynamic interaction between these networks."*

Choi [34] indicate that eco-systems are complex adaptive systems that can function in a dynamic business environment.

Figure 5 is a summary from Mellor [20] of the model that they propose for adoption of AM. This model indicates the integrated nature of the different activities when embarking on the adoption of AM for spare part provisioning. Although Supply Chain is part of the model, it still presents a linear view with the emphasis on the supply side of the business.

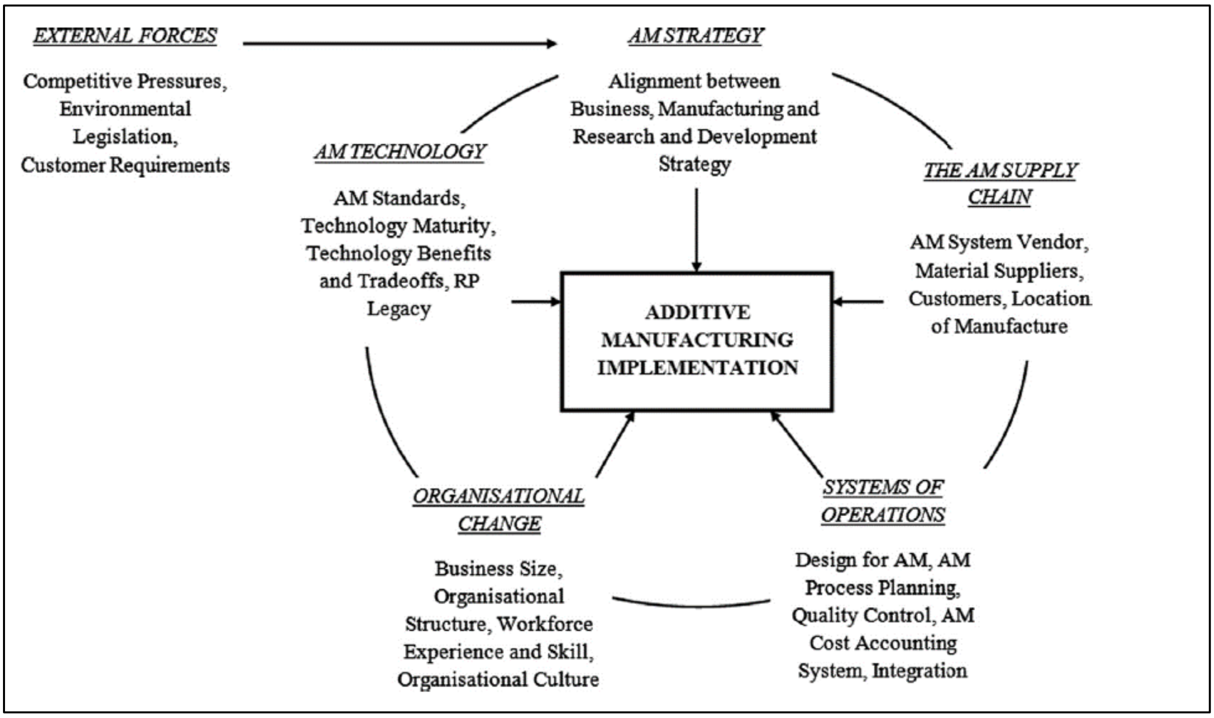

Figure 5: Model for AM adoption – [20]

McCarthy [35] contemplated that a new Supply Chain evolution is needed to adapt to the requirements of 4IR. There should be a transition from Supply Chain to Supply Networks to incorporate the multitude of different actors in the operating environment. Harmse (a) [32] indicated that due to the disruptive nature of AM, it will also require a disruptive view of Supply Chain that will focus on the integration into the eco-system.

Harmse (a) [32] compiled a model for the Supply Chain evolution from Supply Chain to Agile Demand Networks. This model can be seen in figure 6.

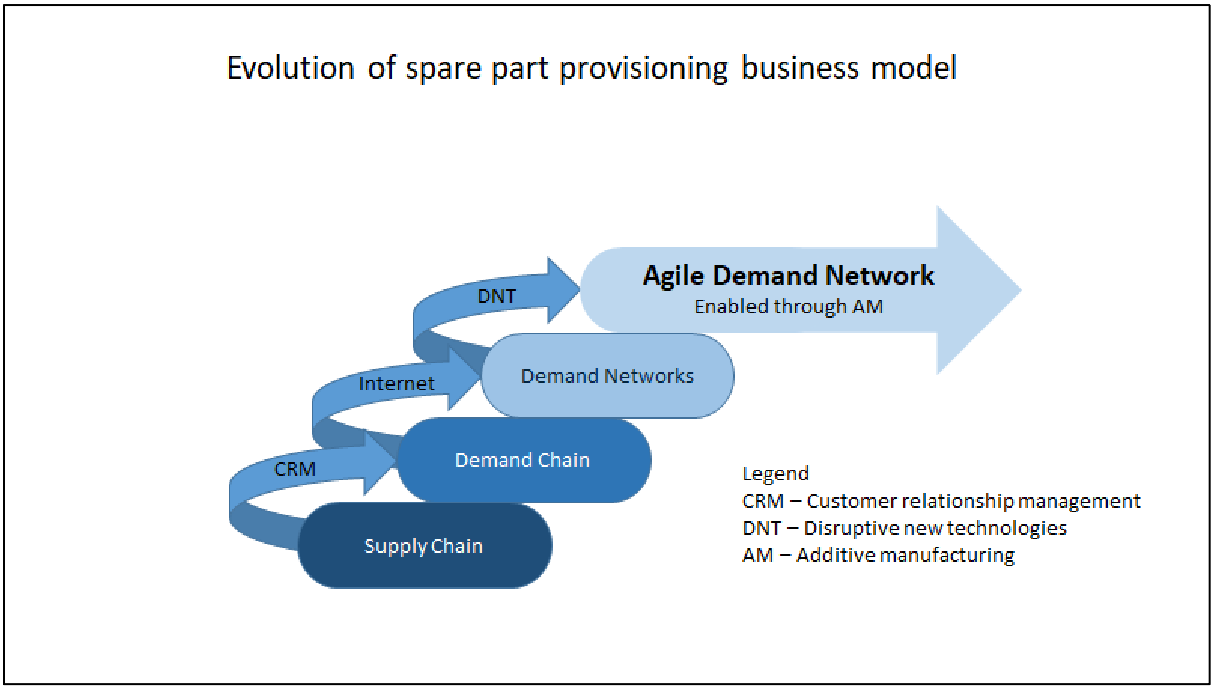

Figure 6: Provisioning system evolution model - [32]

The evolution from Supply Chain to the Demand Chain has been initiated by the implementation of Customer Relationship Management (CRM) software and a focus on the demand side of the business. The next evolution was initiated by the advent of the global internet. The internet allowed many different networks to be connected and created more real time visibility. 4IR, introduced new disruptive technologies and the requirement for agility became sturdier. With the proliferation of these technologies, where AM is the most disruptive, an improved systemic understanding of the provisioning system and how to function in turbulent, agile and complex, non-linear business networks will be required to fulfil the dynamic demand [32].

3.1.2 Complexity

Organisations are facing unprecedented levels of change and the ability to adapt to and manage the change should be well understood [36]. As the world becomes more interconnected as part of the participation in the eco-system, so does the need to understand and manage complexity [37].

Gartner [38] indicates that AM is still perceived to be a single technology whereas AM consists of a whole manufacturing paradigm and a wide range of different processes and techniques that integrate across boundaries and networks adding to the complexity of the global eco-system.

Rogers [39] published the Innovation diffusion theory (IDT), an influential work which helps to explain the adoption of innovation. The IDT indicates that an innovation's adoption rate is influenced by five specific innovation attributes. Table 2 is a summary of these attributes.

Table 2: Innovation adoption Attributes - [39]

Innovation Attributes	Definition
Relative advantage	Perceived superiority of an innovation to existing practices
Compatibility	Perceived consistency of an innovation with existing values, past experiences and needs of potential adaptors
Complexity	Perceived difficulty to understand and use the innovation
Trialability	Perceived degree to which the innovation can be experimented with
Observability	Perceived degree to which results of an innovation are visible to others

The IDT indicates that a high degree of relative advantage, compatibility, trialability and observability of an innovation is positively associated with its adoption, whereas complexity is negatively related to an innovation's rate of adoption. Rogers [39] further indicated that the idea about a disruptive innovation can cause some uncertainty by possible adopters and that some degree of risk is involved in the adoption that exacerbates the uncertainty and fear of complexity.

Gartner [38] indicated in their study on the construction of a theoretical framework to explain the disruptive potential of Additive Manufacturing that the complexity of AM technologies has been underestimated. According to Oettmeier [40], this can be attributed to the insecurity about the how, where and why to deploy additive technologies.

Burnes [36] contemplates that organisations are like complex systems in nature, they are dynamic, non-linear systems and that their actions can be unpredictable as part of the integrated network environment.

Table 3 indicates the difference between complicated (traditional linear) systems and complex (eco-based systemic, non-linear) systems. This summary is derived from Sammut-Bonnici [41] and author own inputs.

Table 3: Difference between complicated and complex systems - [37, Author]

Complicated (Traditional systems)	Complex/Complexity (AM Eco system)
Complexity is a burden	Complexity is a challenge
Attention to detail	Investigate behaviour of whole system
Rich in detail	Rich in structure
Getting task done	Action in one-part affect other
Problems are broken down into small parts	Activities shift and adapt according to situation on hand
Experts solve parts	Agile, multi-disciplinary teams create solution
Management hierarchy	Evolves and adapt with internal systems and external environment

Complicated (Traditional systems)	Complex/Complexity (AM Eco system)
Rules established – linear processes	Operations framework
Organisations viewed as complicated and static	Organisations viewed as complex set of self-organizing components
Mass production and division of labour	Economic and organisational phenomena are like those observed in science and nature
Attributes: Diminishing returns, rules based regulated environment, stagnation, linear dynamics	Attributes: Increasing returns, self-organizing system, continuous adaptation, sensitivity to initial conditions, non-linear dynamics
Component design Methodology: Design for manufacturing (DfM)	Component design methodology: Design for Additive Manufacturing (DfAM)

Table 3 indicates that an organisation must move from complicated, linear systems to complex, non-linear systems. There needs to be a clear understanding of how to manage the complexity introduced by adopting AM as part of the spare part provisioning systems.

3.1.3 *Business risk*

Roos [13] and Christensen [15] contemplates that disruptive, innovative technologies that replaces current industry platforms, can have a significant impact on the structure of the industry. It is therefore important to understand the systemic nature of the structural changes and the risks associated with such a disruptive, innovative change. Disruptive technologies also require new structures and capabilities of the organisations where they are implemented [15]. The philosophy of management towards new technologies will also influence their decision to adopt disruptive technologies [42,43]. Managers needs to understand the systemic impact that these new technologies introduce in the business and the risks associated with them.

Matinaro [43] contemplates that the diffusion of a new technology is linked to the propensity of the organisation to adopt innovation and change. According to their study, the key to the adoption of new innovation in an organisation, is much more linked to the attributes of the organisation and their propensity for risk and not so much to the new innovation. Table 4 is a summary of the list Matinaro [43] prepared of the business attributes required for adoption of an innovation.

Table 4: The innovation process characteristics and explanations – [43]

Innovation Process characteristics	Explanation
Braking industry traditions	Willingness to change traditional approaches
Communication	Increased communication between organisations and its employees including clients and subcontractors
Co-operations	Increased co-operation between organisations from company level to projects and from projects to other projects. Increased cooperation in top and middle management and with stakeholders
Leadership skills	As general, identifying innovators, and strengthen innovators, positive messengers, skills and competencies, with clients, with design etc. Leading the people.

Innovation Process characteristics	Explanation
Knowledge management	Sharing the knowledge throughout organisation and project boundaries, the spread of know-how.
Organisational learning	Support of all functions of learning. In project-based industry learning must happen in a project itself and across inter-organisational boundaries.
Organisational culture	Positive and supporting. Positive towards innovations and changes
Management acceptance	Open mindset, resource allocation, investment in technology, supporting innovations, leadership
Top down – bottom up approaches	Emphasises organisational learning and breaking the barriers that project based industry have.
Vertically integrated organisations	Increased ability to spread needed information to organisations, learning aspect, decrease internal barriers.
Human resource management	Need of changes compared to traditional approaches, emphasis leadership kind of features on management, work circulation, creating an open atmosphere, social skills of management and project management, willingness to change, changing career paths.
Stakeholder integration	All stakeholders should take part in developing industry, better cooperation, common ways of doing designs
Standardization	Common and accurate standardization to integrate stakeholders and making models more usable, accurate designs.

Thomas-Seal [19], Oberg [16] focus on risks relating to the implementation of disruptive new technologies like AM. The authors focused on risks that are related to the production of the components i.e. the operational risks. Harmse (b) [24] contemplates that one of the most important business risks is the adaptation of AM by the leadership of the organisation. AM is not only a disruptive innovation but is also a disruptive strategic intervention impacting a multitude of processes and structures inside and outside the organisation. Leadership is also identified in table 4 as an important component for the adoption of an innovation.

Schniederjans [44] indicate in their study on the adoption of AM that there is limited focus on the impact of the required change in leadership of the organisation as a risk for the adoption of AM in spare part provisioning and successful functioning in the eco-system. In Christensen [15] the author reasons why great companies fail. The conclusion is that they don't fail because there are changes in the market that they don't understand, but because the leadership in the companies did not understand the specific requirements of disruptive technologies. This denial of the business impact of disruptive technologies where AM is implied as the most disruptive is one of the most significant risks of any company.

Some of the other business risks that will be impacted when adopting AM is a required change in the culture and the structure of the organization when adopting AM for spare part provisioning [43] (b) [24]. Due to the disruptive nature of AM, it will require significantly different skills than what has been prevalent in most traditional organisations [15].

Oettmeier [40] indicates in their study on AM technology adoption that it is important to focus not only on the intra- but also on the inter-organisational factors. Gartner [38], Oetmeier [40] and Matinaro [43] emphasise that there are external factors outside of the organisation that plays an important role in the successful adoption of an innovative new technology, in this case, AM that requires careful attention. These external factors and the systematic interaction of these factors as risks to the organisation must be well defined and understood.

Oberg [16] contemplates that companies don't have a clear understanding of how to manage the risks involved in venturing into AM. One of the key risks that traditional organizations are faced with, is the risk of changing from linear processes to non-linear, network-based processes with constantly changing competitors [43].

In a study by Oettmeier [40], they concluded that the adoption of a new technology, in this case AM, will be emphasized by three groups of variables or risks in table 5:

Table 5: Variables for the adoption of Innovative new technology - [40]

	Adoption Variable
1	Technology related factors – relative advantage and ease of use – complexity.
2	Firm related factors – how adaptable is the company to embrace change.
3	Market structure related factors (Eco system) – external pressure and perceived outside support.

To reduce the risk of slow adoption of AM in spare part provisioning, the variables in table 5 needs to be well understood and managed.

Organisations are still trapped in a mindset where risks can be avoided by removing the complicated activities from the processes and therefore create a stable, manageable and linear environment where they can control the behaviour [33].

White [45] summarized in a study on risk management, that most of the current models are based on a reductionist approach see fig. 7.

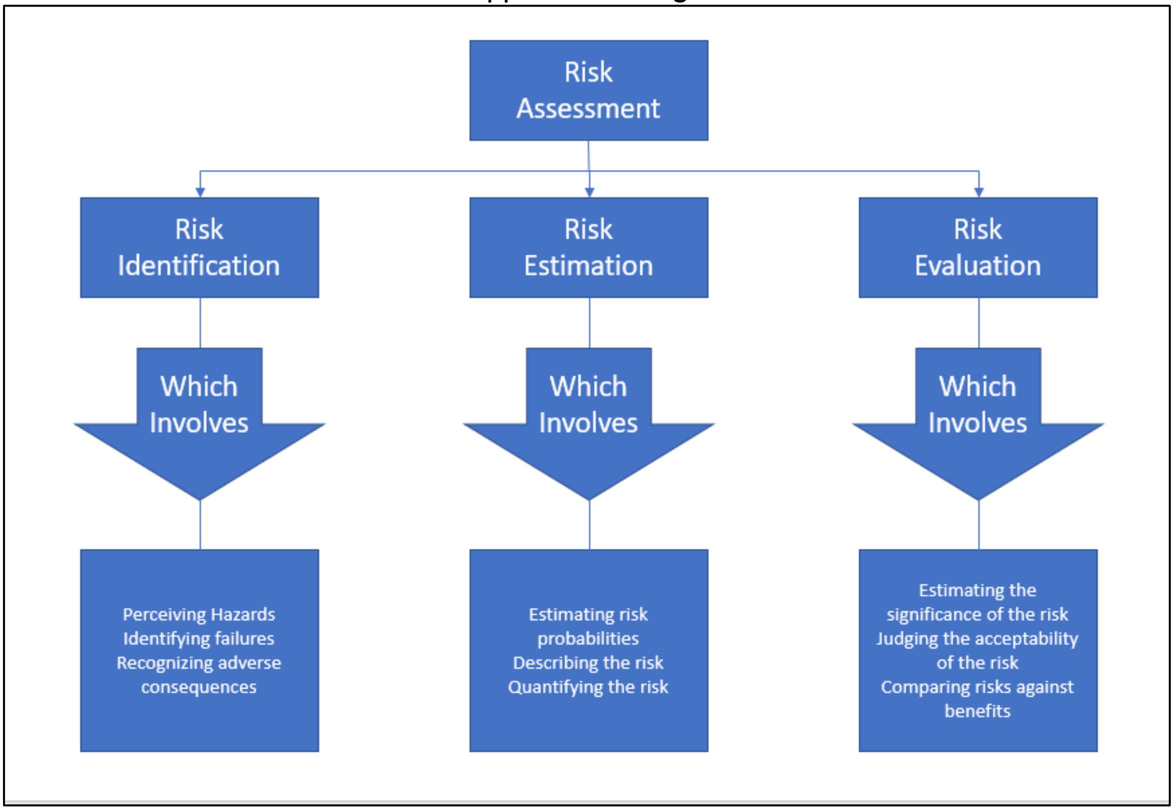

Figure7: The process of risk management - [45]

This way of managing risks is to identify the risks, breaking it down into its smallest components and then use experts to identify the criticality of the components. The risk factors are then multiplied, and a hierarchy of risks is established that is seen as the total risk exposure. This linear approach fails to recognise the interrelationship of the components of the whole system and that the identified risks can be affected by components surrounding the identified risk as part of the global eco-system [22,46].

Table 6 is a summary of the key differences between the linear approach and the holistic approach of risk management derived from [45].

Table 6: Difference between Reductionist and Systemic approach to risk management - [45]

	Reductionist Thinking - Linear	**Holistic Thinking - Systemic**
Method	Systemic	Systemic
Issue tackled by	Reducing problem into smaller and smaller parts	Investigating the problem's environment
Approach characterized by	A downward movement	An upward movement
Simplifies by	Breaking down problems into simplest parts	Taking multiple partial views

When adopting AM, the organisation will have to transition from the traditional reductionist thinking and business management to a holistic and systemic culture. In the next section, an understanding of Systems Thinking will be investigated as a possible solution to assist with the adoption of AM and the required change in thinking from reductionist, linear thinking to non-linear, systemic thinking.

4 THE ROLE OF SYSTEMS THINKING TO IMPROVE AM ADOPTION

In section 3, three paradigms that can contribute to the slow adoption of AM in spare part provision have been discussed. In section 4 the role of Systems Thinking will be discussed as a possible solution of how to manage these elements and to create a culture that will allow organisations to improve the adoption of AM for spare part provisioning as indicated in figure 8.

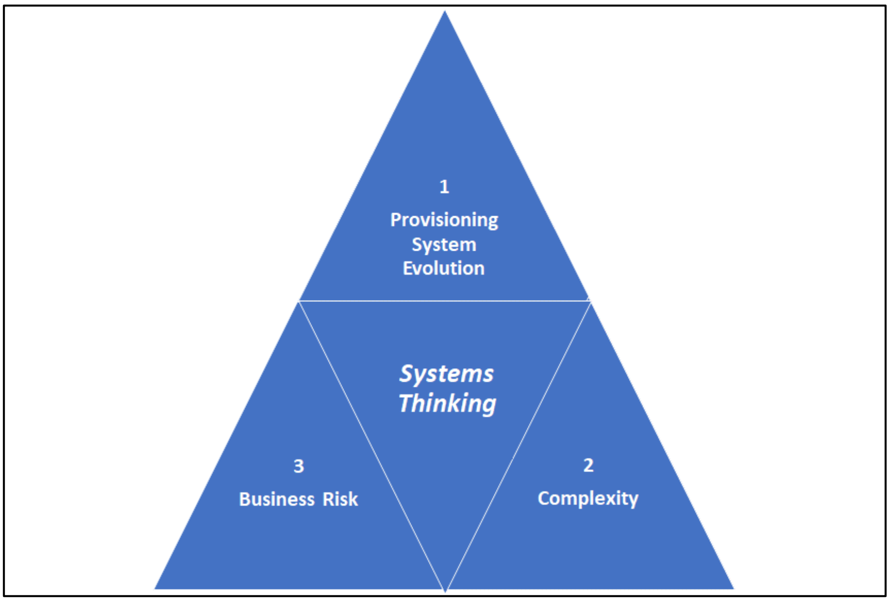

Figure 8: The role of Systems Thinking in the adoption of AM - Author

Behl [47] defines Systems Thinking as the ability to think holistically about a system, rather than only considering the parts individually. Senge [48] defines Systems Thinking as a discipline for seeing wholes and as a framework for seeing interrelationships rather than things, for seeing patterns of change rather for seeing snapshots. Systems thinking can be defined according to [49] as:

> *"a set of synergistic analytical skills used to improve the capability of identifying and understanding systems, predicting their behaviours, and devising modifications to them in order to produce desired effects. These skills work together as a system".*

A sub section of Systems Theory is Complexity Theory. Sammut-Bonnici [41] indicates that Complexity Theory provides an understanding of how systems, grow, adapt and evolve. Complexity Theory explains how the relationship between the members give rise to collective behaviour and how to understand and utilize complexity for adopting disruptive innovation [37].

The principles of Systems Thinking and Complexity Theory enables the user to create an understanding of the systemic nature of the system and how to manage the perceived complexities. Behl [47] specify that companies are faced with increased complexity due to the nature of the integrated networked business environment and dependencies. Critical to systems theory is firstly the recognition that because of dependencies, the properties of components cannot behave independently but must obey certain rules and secondly, it is their

relationship that provides for emergence and can create complexity. In order to successfully managing this transition and understanding how to embrace complexity, it is imperative that

there is a comprehensive understanding of Systems Thinking and Complexity Theory and the inter-relationship of all the components in the eco-system [37].

Provisioning systems requires an evolution from Supply Chain to an Agile Demand Network as can be seen in figure V. This evolution will allow practitioners to focus on the dynamic interaction and the agility required for success in the global networks or eco-system. This evolution will transcend the Supply Chain from a linear system to a non-linear system where it is important to understand the interrelationship and cross-functional effect of the different components of the network. Systems Thinking will assist with this to create an understanding of the total system in a non-linear complex network.

Complexity can be daunting especially if a myriad of activities requires different understanding away from the stable status quo. AM is a system that moves spare part provisioning from a complicated, linear environment to a complex, non-linear environment. Understanding complexity, allows companies that adopt AM not only to fulfil the immediate requirement but to use complexity to improve the efficiency of the total system. An understanding of Systems Thinking and Complexity Theory will assist in understanding and managing the complexity in the global network or eco-system. Complexity creates new risks and alters activities that were not seen as risks to become risks due to the new requirements in the global eco-system.

Risks are identified and broken down into small manageable components. This is a reductionist approach the same as traditional manufacturing where the material is removed until the final component is created. AM is a process where components are manufactured layer by layer from the bottom up and an integrated view of the risks is required for an optimized solution. An understanding of the principles of Systems Thinking will contribute to understand the risks and to define the interrelationship between the different risks. Figure 7 indicates how Systems Thinking can influence each of the three elements identified as possible contributors in the adoption process of AM in spare part provisioning.

5 CONCLUSIONS AND FUTURE RESEARCH

The adoption of AM as part of the spare part provisioning system, will not only disrupt the business or the eco-system but also requires fundamental new ways of operating and managing business risks and complexity and new paradigms are needed. Normal business processes can become business risks if the systemic relationship between the different processes are not well defined and understood. Participation in the global eco-system, will introduce complexity in the organisation that will require innovative and creative solutions. Both risk management and the provisioning system needs to transcend from a linear system with a functional view to a non-linear system with a systemic view. The role of Systems Thinking is to assist organisations to create an understanding of the true value that AM can deliver by eliminating the fear for complexity and to see risk as an opportunity.

To complete this process, future research can focus on a maturity model with which organisations can plot their current position on the provisioning system evolution against the key business risks. This maturity model could then assist organisations to understand the systemic relationship between the key business risks and what is required to manage these risks for the adoption of AM as part of spare part provisioning. The maturity model could serve as an evolutionary road map that will allow organisations to remove the perceived complexity on their journey to adopt AM for spare part provisioning.

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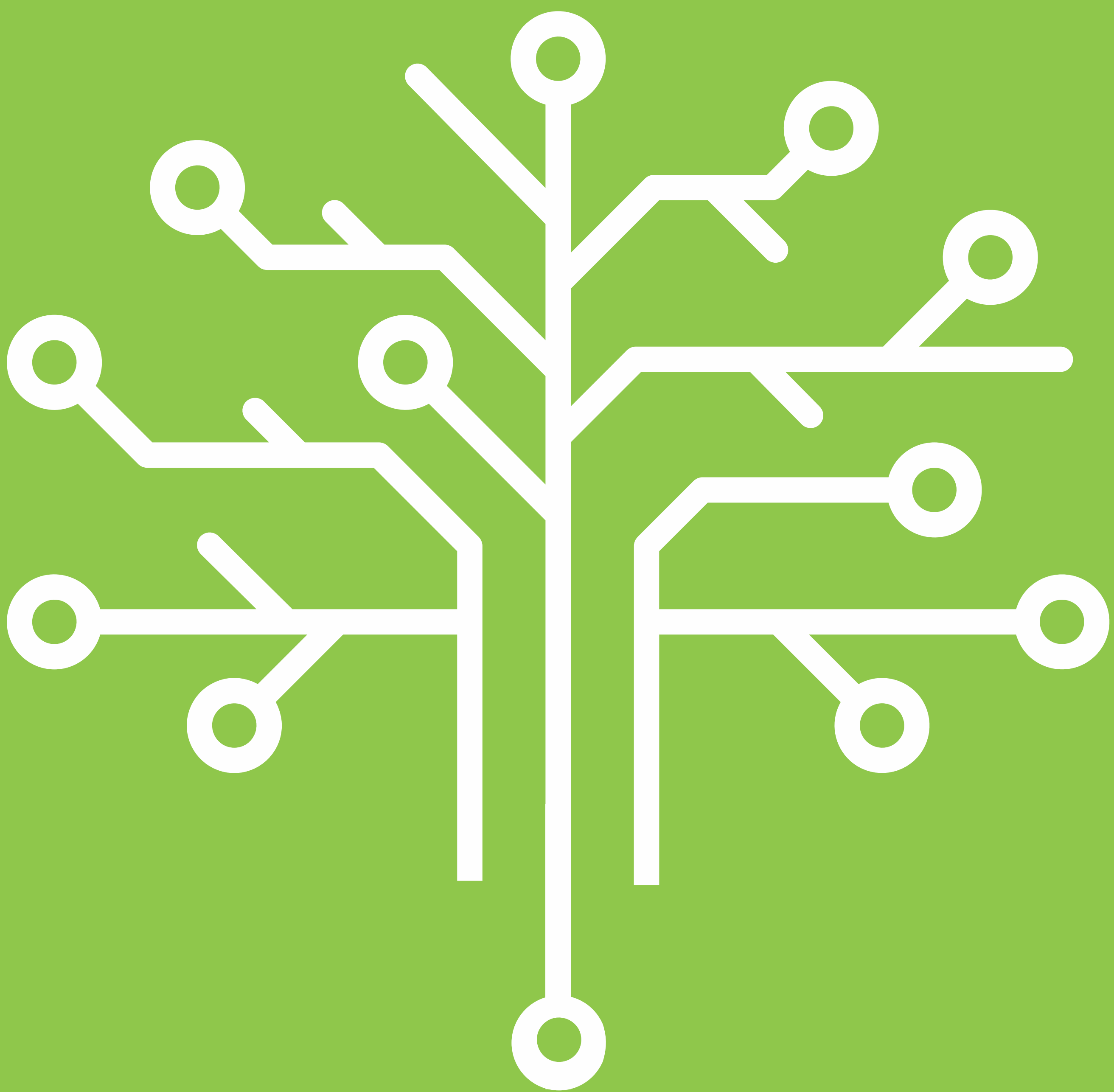

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