SAIIE nexxt

Alternative Realities, Real Alternatives

Proceedings

30 September - 2 October 2019
The Boardwalk Hotel, Port Elizabeth

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PREFACE

The Southern African Institute for Industrial Engineering's (SAIIE) annual conference has become a popular choice for industry, academics and researchers in Industrial Engineering and related disciplines. I am excited and honoured to be the editor again.

This year's editorial process was again administrated by the very capable Stephan Snyman, a PhD student from Stellenbosch University, who acted as track director and technical editor. Thank you for your professional hard work to put the proceedings together and making the editorial process so effortless!

For this conference, prospective speakers were offered the following submission options:

- Presentations submitted for the ***"Industry Presentations"*** or ***"Academic Presentation only"*** track were approved on submission of the abstract only, checking for suitability.
- Submissions for the ***"Academic Papers"*** track were provisionally approved on the basis of an abstract, where-after the authors were invited to submit a full-length academic paper, which was reviewed by a double-blind peer review refereeing process, described below.

193 submissions were received of which 80 peer-reviewed papers made it through the review process, with another 7 non-peer-reviewed submissions, and 4 keynotes.

The review process was managed through an on-line conference system, allowing referees to provide on-line feedback, and to ensure that a record exists for all editorial decisions taken during the process. Papers were allocated at least two reviewers, often teaming up an experienced academic, with a less experienced author, so as to follow a true **peer**-review process and also to serve as a learning experience for the less experienced reviewer, without sacrificing the credibility of the peer review process.

Only papers that passed the peer reviewed 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African Journal for Industrial Engineering. 20 Papers were selected for the special edition, and as a consequence, withdrawn from the Proceedings.

This conference has therefore three outputs:

- The printed ***Conference Programme*** includes an abstract of each Peer Reviewed paper, as well as all the other non-peer-reviewed submissions (Presentations, Tutorials, and Invited Presentations), to enable the delegates to plan which sessions to attend.
- The ***Conference Proceedings*** (this document) is an electronic document distributed to all delegates, and contains full-length papers that were submitted, reviewed and approved for the Peer Reviewed Tracks. Its purpose is to give full access to the complete conference material for many years after the conference is over. The proceedings are also available on-line, on a conference website hosted and archived by Stellenbosch University, to ensure that it remains accessible and indexed by scholarly search engines.
- The **Special Edition of the South African Journal of Industrial Engineering** that will appear in November, honouring the best work submitted to this conference. The Special Edition also contains submissions from other related conferences.

We trust that you will enjoy the 30th Annual SAIIE Conference, and that this publication will serve as a first step for exposing the work of our authors to the world!

Prof Corné Schutte
Editor
September 2019

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Table of Contents

[1] The Reference Number is a unique paper reference that is used throughout the conference to identify the paper. This is also used as a page number prefix in the proceedings, and papers are sorted according to this number in the proceedings.

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UNDERSTANDING THE IMPACT AND APPLICATIONS OF INDUSTRIAL ENGINEERING PRINCIPLES: A SOUTH AFRICA CASE

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ABSTRACT

Industrial engineering is the application of scientific principles in the design, development, improvement, implementation and maintenance of integrated systems of men, materials, machines and money for process optimization. It extracts expert knowledge and skills from physical sciences and mathematics infused with the principles of engineering analysis methods to maximize system utilization. South Africa remains constrained by its low growth potential. Slow private investment growth and weak integration into global value chains prevent the country from reaping the new economic opportunities emerging around the globe, and from catching up with living standards in peer economies. South Africa needs to build on its comparative advantages, that of an industrially skilled economy, to develop new domestic and international markets through higher productivity and innovation. Industrial engineering as a practice is central in improving productivity and cultivating innovation. As a result, the University of South Africa is in an advantageous position due to its reach, reputation and flexibility to disseminate the qualification in Industrial Engineering that will positively impact on the South African economy. However, the enrolment figures in Industrial Engineering are disappointing compared to other engineering disciplines. The research aimed to determine awareness and understanding of Industrial Engineering as a field among students in order to understand the factors that might be responsible for the low enrolment, throughput and graduation rates using quantitative analysis. In addition, the curriculum of the current programme was evaluated to determine its relevance and its adaption to ever-changing material conditions.

Keywords: Industrial engineering, enrolment rates, graduation rates.

1 INTRODUCTION AND BACKGROUND

Perception has a hidden importance in society in general, it is the motive force behind certain decisions including which university students chose at and which course students enrol for, and which career students follow[2]. The Department of Mechanical and Industrial Engineering (DMIE) in the School of Engineering at the University of South Africa (UNISA) take cognisance of such perceptions and postulates that the low enrolment rates could be as a result of the lack of a proper understanding of what an industrial engineer is, amongst academics, industry and the students. This perception was brought to the fore by the different titles with which industrial engineers are referred to. These include quality engineer, manufacturing engineer, project manager, quality control supervisor and systems analyst, amongst many others. Low enrolment rates could also be linked to the perception that could be held by students, that UNISA could not be ideal institution to offer engineering programmes due to its character as a distance learning institution noting further that the discipline requires practical tuition as well. UNISA has traditionally accommodated students who are already working as a result able to apply theory learned at their respective workplaces.

UNISA has over the recent past experienced enrolment of students straight from matric due to affordable tuition UNISA offers, however while other disciplines have experienced a high enrolment rates for instance, mechanical engineering; the opposite (dwindling) enrolment rates were applicable to industrial engineering.

It is with these concerns and speculations that the department approached the Directorate: Institutional Research to assist with conducting a survey aimed at investigating the reasons for the low graduation rates and poor enrolment rates observed in industrial engineering. It is envisaged that the results of the study will clear perceptions of what the discipline is all about and as a result attract quality students which requires the university to be at the forefront of advocacy for the discipline. With quality student enrolment matched by quality tuition the throughput will improve and so will the graduation rates.

The University of South Africa (UNISA) prides itself as an Open Distance and e-Learning (ODeL) institution with a range of cost effective and quality programmes designed to address global needs. However, despite this, the university faces a number of challenges, which if not considered and acted upon, will impact on its effectiveness and sustainability [3]. Amongst these is the need to "rationalise, reengineer and reposition programmes which are no longer financially viable". In other words, UNISA aims to focus its energies and resources on the improvement of quality, service delivery and improved throughputs with a special emphasis on programmes with low-enrolment rates [3][4]. The current difficulties in enrolment rates with regard to industrial engineering requires the university to re-evaluate its feasibility and implement innovative solutions to make the offering sustainable now and in the future.

2 METHODOLOGY

Principally the quantitative approach was adopted as it enables the researcher to focus in a particular area and gather information through various means. In this case study, data was collected through the review of existing literature and triangulated with questionnaires and telephonic discussions. Data was collected by means of a short online survey which had been developed and pre-tested by the Directorate: Institutional Research. The survey comprised a combination of mainly closed ended and some open–ended questions covering students' employment, study choice and knowledge of Industrial Engineering as a field [5].The survey was conducted in January 2016 and delivered to industrial engineering students' myLife email addresses through qualtrics lab software.

This survey was conducted after the research team had sought and obtained the necessary ethical clearance from UNISA. Students' myLife email addresses were provided by the Department: Information and Communication Technology (ICT). Students whose email addresses were requested from ICT were those who had registered for the National Diploma: Industrial Engineering and the Bachelor of Technology: Industrial Engineering during the 2012-2016 academic years.

3 LITERATURE REVIEW

Industrial engineering as a discipline that deals with the design of human effort in all occupations, e.g. agricultural, manufacturing and service, with the aim of optimizing the productivity of work-systems and the occupational comfort, health, safety and income of persons involved [6]. Industrial engineering focuses on business efficiency - or more precisely, on how to design, organise, implement, and operate the basic factors of production and manufacturing (materials, equipment, people, information, and energy) in the most efficient manner possible so as to optimize industrial manufacturing operations, although the skills learned are applicable to other non-manufacturing settings [7]. This makes industrial engineering a multi-disciplinary field of study that equips graduates with the necessary technical background, as well as the economic and people skills vital to making economically justifiable decisions in a business environment [8].

The demand for industrial engineers in South Africa has increased significantly as was illustrated by the listing of Industrial Engineering as a national scarce and critical skill in 2006, and the consequent release of 5 000 quota work permits by the Department of Home Affairs for appropriately qualified foreign nationals. In the national engineering database (August 2007), the total number of professionally registered engineers, technologists and technicians was 5 000, 1 900 and 6 700, respectively. Annually, 2 000 learners register for National Diplomas in engineering but "as a result of poor throughput and their inability to get experiential training, only 500 to 600 graduate [9;10;11].

In March 2005, the total number of registered professional engineers in Industrial Engineering was only 225, representing 1% of the total number of professional engineers in South Africa. The Business Times in March 2007 indicated that "...the shortage of skills – such as industrial engineers, supply chain managers, warehousing and distribution experts, and network analysts – is a crisis that will erode South Africa's competitiveness" [8].

To meet the skills demands in South Africa, an extra 1 000 engineers are required to graduate every year (reference). Though these statistics are not very recent, the general picture has not changed and makes industrial engineers one of the most sought-after human resources due to their skills cutting across various industries [12;8;6].

However, despite this, UNISA has been experiencing low enrolment and graduation rates for this particular programme at both the National Diploma and the Bachelor of Technology levels. The objective of this research is to present key interventions to address this conundrum.

4 FINDINGS

Please note that this is a large study and only certain results are presented.

4.1 Response rate

Table 1 below provides the overall response rate to the survey and the response rate of students who consented to participate.

Table 1: Response rate

	N	%
Population	**1 244**	**100%**
Respondents	**146**	**11.7%**
Consenting	**134**	**10.8%**

The survey was sent to 1 244 students who were identified as enrolled for qualifications in Industrial Engineering as at 21 January 2016 by the Department: Information and Communication Technology. Of these, 146 (11.7%) opened the survey and 134 (10.8%) agreed to participate. It is important to note that this is a poor response rate and measures were taken to improve in another survey. Thus it was decided to present the results as is.

4.2 Demographics

Table 2 provides the race of the population of students enrolled for Industrial Engineering qualifications as well as the respondents' race and the response rate to the survey. The response rate is given as a proportion of the overall population total.

Table 2: Respondents by race

	Population		**Respondents**		**Response rate**
	N	**%**	**N**	**%**	
White/Chinese	242	19.5%	25	19.7%	2.0%
Coloured	43	3.5%	4	3.1%	0.3%
African	897	72.1%	89	70.1%	7.2%
Indian	60	4.8%	9	7.1%	0.7%
Other/Unknown	2	0,2%			0,0%
Total	***1 244***	***100%***	***127***	***100%***	***10.2%***

From Table 2, it is evident that there were 1 244 students enrolled for qualifications in Industrial Engineering at UNISA as at 27 January 2016 (the date the data was extracted by UNISA, ICT). The majority of these students were African - 897 (72,1%), followed by Whites/Chinese at 242 (19,5%), then Indians at 60 (4,8%) and Coloureds at 43 (3,5%) of the population.

A look at the racial distribution of the respondents' points to representative sample being achieved for all race groups, with the exception of Indians whereby the proportion of respondents (7,1%) is higher than that of the population (4,8%). Lastly, in terms of the response rate, the racial distribution mirrors that of the population in that Africans constituted the majority of the respondents, followed by Whites/Chinese, then Indians and Coloureds.

4.3 Gender

With regard to the gender distribution of enrolled Industrial Engineering students, over 70,0% were males relative to approximately 27,0% who were females.

Table 3: Respondents by gender

	Population		Respondents		Response rate
	N	%	N	%	
Female	332	26.7%	40	31.5%	3.2%
Male	912	73.3%	87	68.5%	7.0%
Total	***1 244***	***100%***	***127***	***100%***	***10.2%***

Considering the sample relative to the population, a slight over-representation of females (31,5% vs. 26,7%) and a slight under-representation of males (68,5% vs. 73,3%) are observed. However, despite this over-representation, the distribution of the responses was similar to the population distribution in that males constituted the majority of the respondents.

4.4 Employment status

Table 4: Employment status

	N	%	Valid %
Employed	94	70.1%	74.0%
Unemployed	31	23.1%	24.4%
Self employed	2	1.5%	1.6%
Total	127	94.8%	100.0%
Missing	*7*	*5.2%*	
Overall	134	100.0%	

As presented in Table 4, most of the respondents (74.0%) indicated that they were employed relative to 24.4% who were unemployed and 1.6% who were self-employed. This confirms that UNISA caters mostly for employed students that have to balance studies and work.

4.5 Employment sector

With regard to the sectors within were they are employed, most students selected the manufacturing sector (47.9%) followed by those who selected “other”.

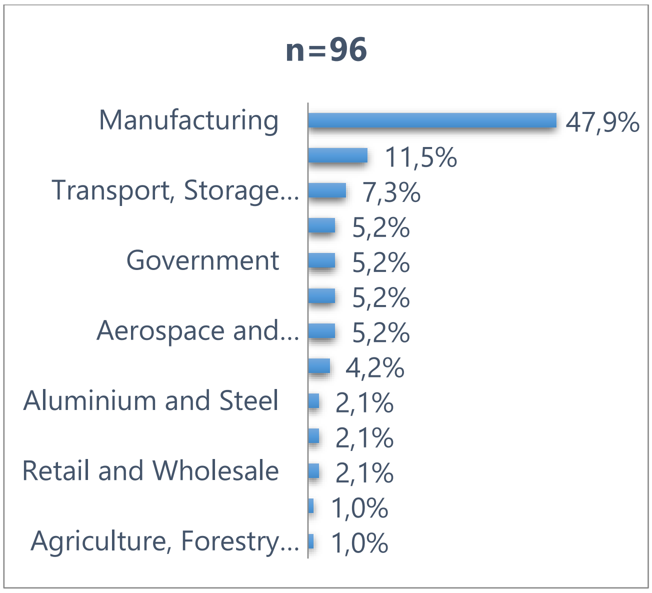


Figure 1: Employment by sector

Figure 1 highlights the following salient points:

- Transport, Storage and Communication accounted for 7.3%. Military, Government, Electricity and Gas as well as Aerospace and Airplanes were at 5.2% respectively.
- The sectors with the lowest proportions of students were Agriculture, Forestry and Fishing as well as the Banking and Finance sector, with 1% each.

Lastly, with regard to the respondents who had indicated "other", the following were the specified sectors: healthcare, import-export, logistics and supply chain management, mining, nuclear industry, petrochemical, sales and telecommunications.

4.6 Current position

Table 5: Current position of students

Vocation	Number
Industrial Engineering Technician	19
Project Manager	9
Operations Manager/Engineer	7
Production Planner	7
Logistics Engineer/Analyst/Manager	6
Customer Service Excellence	5
Supply Chain Management	5
Team Leader	5
Maintenance Engineer	4
Quality Engineer/ Manager	4

Continuous Process Improvement Specialist	3
Information Systems Specialist	3
General Manager	3
Technical Sales Manager	3
Manufacturing Engineer	2
Process Analyst/Engineer	2
Production Supervisor/Manager	2
Safety Officer/Manager	2
Systems Engineer/Consultant	2
Business Process Analyst	1
Entrepreneur	1
Sales and Operations Planner	1
Total	**96**

Table 5 provides the current positions of the 96 students who had indicated that they were employed. Evidently, when analysing at the current positions that the respondents occupy one observes that there is great variety, and the following is observed:

- Most of the students (19) were employed as Industrial Engineering Technicians which is not surprising, followed by Project Managers at 9.
- Production planners and Operations Engineers are tied in third place at 7 respectively.
- In the fourth place are Logistics and Management Engineers with 6 students.
- Supply Chain and Customer Service Excellence and Team Leader are in the fifth place with 5 respondents.
- Quality and Maintenance Engineers are each sitting in sixth place with 4 respondents.
- Information Systems Specialist, Continuous Process Improvement Specialist, Technical Sales Engineer and General Managers were in seventh place with 3 respondents each.
- The second lowest numbers are for Systems Engineers, Safety Officers, Process Analysts, Manufacturing and Production Engineers with 2 respondents each.
- The lowest numbers are observed for Business Analysts, Entrepreneurs as well as Sale and Operational Planner positions with only 1 student each.

4.7 Duration of employment

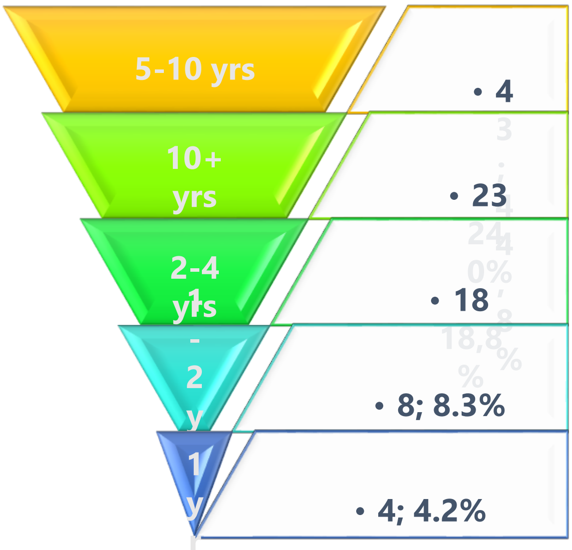


Figure 2: Duration of Employment

With regard to how long the respondents have been employed,

- Most of the respondents (43) (44.8%) of the 96 respondents indicated that they have been working for a period of 5 to 10 years.
- Only 23 (24%) have been working for a period more than 10 years, followed by 18 (18. 8%) that have worked for two to four years.
- Less than ten, i.e. 8 (8.3%) had been working for one to two years and 4 (4.2%) had only been employed for one year.

4.8 Study choice

When asked about whether Industrial Engineering was their first choice, 80 respondents (63.0%) indicated that it was a first choice relative to 47 respondents (37.0%) who indicated that it was not their first choice

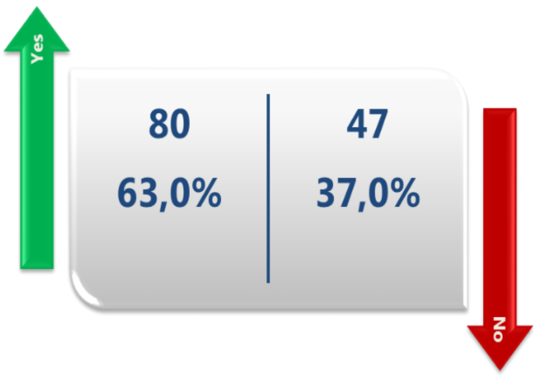
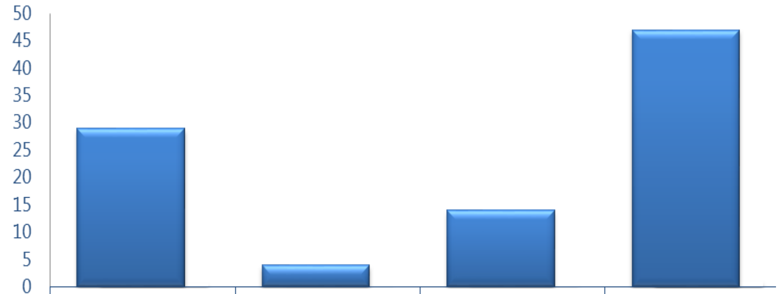


Figure 3: Industrial Engineering as a First Choice

Respondents who had stated that Industrial Engineering was not their first choice of study (47) were then asked why they had not registered for their first choice.



	I did then transferred to IE	I did not qualify for my first choice	Other, please specify	Total
N	29	4	14	47
%	61,7%	8,5%	29,8%	100,0%

Figure 4: The reason for not registering for first choice

The following reasons were provided by the respondents:

- Most of the respondents-29 (61.7%) indicated that they had registered for their first choice but later transferred to Industrial Engineering.
- This was followed by 14 (29.8%) who indicated "other" and lastly four (8.5%) who indicated that they did not qualify for their first choice hence they registered for Industrial Engineering.

Those who had stated "other" provided some of the following reasons (unedited quotes):

- *"Company wouldn't allow me to register for mechanical diploma"*
  "Engineering is more interesting and pilot can be a hobby"
- *"I have a B. Com Honors. Thought it good to get credits for previous engineering & Commerce studies."*
- *"I became interested in the diversity of holding and practicing Industrial Engineering instead continuing with my initial choice."*
- *"Qualified as an Electrical Engineer. When I started working I become more interested in Industrial Engineering"*
- *"too late for electrical engineering"*
- *"Change of career path"*

4.9 Study influence

All 127 respondents with valid responses were then asked to indicate what had influenced their decision to study Industrial Engineering. As this was a multiple response question, 187 responses were received from the 127 respondents, hence the sum of the proportions exceed 100%.

Figure 5: Influence on the choice of field study

The following reasons were provided by the respondents:

- The job prospects that a qualification in Industrial Engineering offered was the most popular response (69.3%) followed by "other" at 22.0%.
- Career guidance at school was the third highest influence at 16.5% followed by the prospects of a better salary at 14.2% and those who were of the opinion that Industrial Engineering was easier than other Engineering disciplines (11.0%).
- Influence by peers and influence by family were the least popular responses at 6,3% and 4.7% respectively.

4.10 Knowledge of Industrial Engineering

In assessing students' knowledge of what Industrial Engineers do, students were asked to rate their agreement with various statements. A total of 11 statements were presented, 7 of which correctly described what Industrial Engineers do with 4 being incorrect. Statements were deliberately mixed in order to test their level of knowledge and understanding of the discipline of Industrial Engineering.

On evaluation of the information the following was revealed:

- The majority of students are aware of the types of work Industrial Engineers do
- Only between 0,9%-13,4% rated the correct statements "False"
- One of the four incorrect statements was correctly rated "False" by 72,4% of the respondents.
- Therefore 8 of the 11 statements were correctly identified.
- There seems to be a notable range in the responses among the students with regard to the incorrect statements, revealing their confusion.
- Between 27.6% and 76.7% rated the incorrect statements as being true.

4.11 Type of work Industrial Engineers do

Students' knowledge of the techniques used by Industrial Engineers was better than their knowledge of the type of work that Industrial Engineers do as evidenced by the high proportions who rated the statements true (90.4%-99.1%). When ranking the techniques rated as true to Industrial Engineering, the results were as follows:

- Project management had the highest rating at 99.1%.
- Tied in second place was Organisational Analysis, Flow Diagramming, Strategic Planning, Statistical Analysis and Information Data Flow at 98.3% respectively. The technique with the lowest proportion was Modelling at 90.4%.

5 CURRICULUM REVIEW

The qualification is responsive to the economy and society as it addresses some of the training needs indicated in the Higher Education & Training Framework for the National Skills Development Strategy (NSDSIII). Also, the qualification adheres to HEQSF in terms of appropriateness, coherence and consistency, articulation pathways and facilitates equity of access in higher education as gleaned from the document which is not publicly viewable at present [13;9;14].

Skilled engineering technicians are required to meet the developmental needs of the country in all service, manufacturing and industrial production fields. Responsiveness to local context takes into account skills development, diversity, equity, redress and increasing access and the extended curriculum. The programme is responsive to international regulatory requirements through the Engineering Council of South Africa (ECSA) and recognized by the Dublin Accord. The Dublin Accord is an agreement for the international recognition of Engineering Technician qualifications.

This qualification is primarily vocational, or industry-oriented, characterised by the knowledge emphasis, general principles and application through technology transfer. The qualification provides students with a sound knowledge base in industrial engineering and the ability to apply their knowledge and skills to a career in industrial engineering, while equipping them to undertake more specialised and intensive learning. Holders of this qualification are usually prepared to enter a specific niche in the labour market. The programme is articulated to the National Qualification Framework (NQF) level 10 so that it provides lifelong professional development as students are required to engage with complexity and changing technology in the engineering environment in UNISA's newly constructed laboratories. The qualification is economically responsive to the economy and society as it addresses some of the training needs indicated in the Higher Education & Training Framework for the National Skills Development Strategy (NSDSIII). Skilled engineering technicians are required to meet the developmental needs of the country in all service, manufacturing and industrial production fields [15; 16;17].

In terms of cultural responsiveness, ELO 6 (engineering learning outcome) in the Form 1 document which concerns the ability of engineers to communicate effectively, both orally and in writing within an engineering context. They should also demonstrate knowledge and understanding of the impact of engineering activity on the society, economy, workplace and physical environment, and address issues by defined procedures. The 27 credit module is included in year one in the section of complementary studies specifically dealing with aspects related to the ability to communicate effectively at all levels both inside and outside the organization and be sensitive to cultural issues when dealing with society which would be done in the laboratory through role plays and through team based learning which involves simulation. The outcome is assessed through both summative and formative assessments.

The diploma in engineering technology is responsive to the knowledge discipline through engagement of students in "systematised forms of enquiry" that considers Luckett's model that is broken into four spheres and alludes to discipline specific knowledge to knowledge application. Academic staff possesses the disciplinary qualification and expertise for the programme and many are engaged with the scholarship for teaching and learning through research engagements. Students are facilitated online in the way knowledge is produced in this discipline and the teaching-learning environment and pedagogy. There is a high degree of practical application of theoretical concepts in laboratories, simulated and real work environments. However, it is unclear as to the extent to which students understand and develop competence in discipline specific knowledge. It is evident that the development of research skills is lacking until third and four year of study in which students are expected to do research projects. It is important that research skills be introduced in the first year of study and act as a scaffolder in all years of study as per Luckett's model [17;18]. Moll's suggestion of "close coupling between the way knowledge is produced" in the discipline and the way students are educated in the discipline would enable new knowledge in the field of engineering [4;19;20;21].

6 RECOMMENDATIONS AND CONCLUSION

The research aimed to determine awareness and understanding of Industrial Engineering as a field among students in order to understand the factors that might be responsible for the low enrolment and graduation rates. The results revealed that students' knowledge of the techniques used by Industrial Engineering was better that their knowledge of the types of work Industrial Engineering are involved in, with the latter revealing some confusion among students. Overall though, knowledge and awareness among respondents was good, although efforts can be strengthened to improve this.

The under-enrolments, suggest that more could be done to increase awareness and knowledge about the field more widely and make this field more attractive. It would therefore benefit the department to address any lack of knowledge through various interventions such as the distribution of paper based information booklets to schools to stimulate an interest in the Industrial Engineering field at school level, career days/open days at Unisa and within schools with a focus on Industrial Engineering and e-brochures circulated to applicants and current students through online sources.

As part of enhancing awareness and knowledge of Industrial Engineering, there should also be a drive to use the variety of job prospects available to Industrial Engineering graduates as an incentive to attract students into this field and to also target females into this male dominated field to ensure greater gender representability. The results do not explain the trend in graduation rates which have been low and this is an area which would require a separate investigation. Interestingly, however, 11,0% of respondents had indicated that their choice of Industrial Engineering as a field of study was influenced by it being "easier" than other engineering disciplines. It could be that students have unrealistic expectations or perceptions about the discipline and this could in turn influence their success. This however, would need to be explored in more detail in future studies [22;23;24].

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THE IMPACT OF CHANGE MANAGEMENT STRATEGIES IN ENHANCING ORGANIZATIONAL PERFORMANCE: THE CASE OF A PUBLIC ORGANIZATION

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ABSTRACT

The study explores the impacts of change management strategies on organisational performance at a National Department in Pretoria. The Department underwent strategic change that was informed by findings from the diagnostic report that highlighted key challenges. Reports on the progress of the strategy indicated leadership instability and ineffective change management that led to the failure of previous change initiatives. The main objective of this study was to identify which change management strategies are in place, what factors affect the strategies and how they impact the organisational performance. The investigation was quantitative in nature using probability as a sampling method and questionnaires as the instrument for data collection. The results were analysed according to responses against duration of service and positions as variables. The results from the survey indicated that factors affecting change management at were the lack of an effective communication plan, lack of leadership influence to drive change, resistance to change, ineffective engagement and consultation with employees, lack of resources, training, and lack of performance management programmes. These factors affected the individual performance and overall organisational performance. Impacts of concern were employee morale created by lack of support from management, lack of consultations that created uncertainty on job security and satisfaction and no value of the change realised.

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1 INTRODUCTION

The Director General of the department suggested during a presentation to staff that leadership instability and ineffective change management are key reasons for failure to implement change. Ineffective change management may be attributed to change management strategies that were previously not in place. The investigation explored the impacts that the change management strategies that are currently in place have on the organisational performance. It would assist the department to identify areas that need urgent attention and potentially lead to achievement of the efficiency desired. The change management process was aimed at turning around (turnaround) the organisation to become more agile, efficient and effective in carrying out its mandate.

2 METHODOLOGY

The quantitative approach was adopted as it enables the researcher to focus in a particular area and gather information through various means. In this case study, data was collected through the review of existing literature and triangulated with informal and telephonic discussions. An exploratory research design was followed in this study. An exploratory research design is undertaken with the objective to explore an area where little is known or to investigate the possibilities of undertaking a particular research study [1]. Questionnaires were sent out to 400 employees using emails. Total responses received were 64 over a four-month period. The questionnaire was conducted on Google Forms Survey.

3 LITERATURE REVIEW

Change is an alteration of a company's strategy, organization or culture as a result of changes in the material conditions that the organization is faced with [2]. Change management is a form of management control through the application of systematic management interventions involving people to achieve a desired future state defined by performance outcomes which are in line with that organisation' strategy [3][4][5] proposes that "change management is the process, tools and techniques to manage the people side of change to achieve the required business outcome".

Passenheim [2] proposes that change management is:

- Correct understanding of the organizations that want or need to be changed
- Correct understanding of the people who are willing or forced to change
- The effectively realization of change
- Understanding the dynamics of change

Change Management is about innovative strategies and ability to adapt with necessary velocity to deal with changing variables and sudden change, it is a systematic process to prepare an organization for and implement ongoing changes that affect the business processes of organization [3]. Every organization needs to be agile, flexible, malleable, and become learning organization to embrace and implement changes and align their resources to critical business strategies if they want to overcome the world of volatility, uncertainty, complexity and ambiguity (VUCA) [6][7].

3.1 Types of change

There are two forms of change, namely, radical change and incremental change. Radical change is a form of change that has an impact on the whole system of an organisation and redefines the basic framework of an organisation including the strategy, structure, people, processes and core values [8]. Incremental change is change that happens all the time in organisations such as, changes in organisation structure, introduction of new technology and significant modifications of personnel practices [9]. Change can be either Reactive or Proactive [[9]. Reactive change is characterized as that change implemented in response to some external event and or serious internal operational and managerial problems. Proactive change is change that occurs when the company is not experiencing any serious problems however, managers anticipate the need for change to put the company in a better position [10][11].

3.2 Drivers of change

Change can be driven by external or internal forces. External forces that can lead to or drive change are political, economic, social, technological, legal and environmental factors. The Political, Environmental, Social, Technological, Economic and Legal (PESTEL) analysis provides a useful external environment scanning framework and a methodology for identifying and analysing factors that can influence the external business environment. Combining SWOT (Strengths, Weaknesses, Opportunities and Threats) analysis with the PESTILE analysis could provide valuable information that can be utilised for strategic decision-making in an organization under study. Drivers of internal change include: new leadership, new strategy, new structures, new business model, organisation growth, redesign of jobs, redesign of business processes, outsourcing, change of location, installation of new technology and systems, changes to employees' terms and conditions, being acquired or merged with another organisation and redundancies [10].

3.3 Managing change

Change most often creates a sense of uncertainty, panic, stress, and anxiety for those impacted by the change, which is often interpreted as resistance by change champions who are far ahead on the change management process due to their involvement from the start and have detailed knowledge of the nature, depth and breadth of the change [12]. It is therefore necessary to meticulously manage the change management process to ensure alignment of thinking, buy-in, create commitment, mitigate resistance, eliminate fear and ultimately ensure compliance[10].

Resistance to change is the biggest hindrance that leaders are faced with when initiating a change process. If not properly handled, resistance to change could literally bring the entire process to a grinding halt [13]. Gupta [5] lists the 8 Kottter's steps required to manage the change process and proposes that these steps are necessary in the 21st Century to bring innovative change. The steps are:

- Establishing a Sense of Urgency
- Creating the Guiding Coalition
- Developing a Vision and Strategy
- Communicating the Change Vision
- Empowering Employees for Broad-based Action
- Generating Short-term Wins
- Consolidating Gains and Producing More Change
- Anchoring New Approaches in the Culture

Thomas [14] argues that resistance to change is a human condition. Every human being and every organization exists in a current reality; an understanding of themselves and the habits ingrained in the organizational culture which shape perspectives of individuals as well as organizations. He postulates that introducing new skills or knowledge into an organization is a difficult task. People fear change because of comfort zones shaped by years of doing things in a certain way. He concludes that management should oversee this integration with sensitivity and ensure buy-in and alignment of thinking to successfully implement the change.

3.4 Impacts on Organizational Performance

[15] argues that in today's fluid and rapidly changing workplace and one planet economy, development of organizational performance is associated with the development individual

performance, skills, knowledge and experience] However, the ability to achieve set goals of becoming competitive and productive is a mountainous task.

[16] proposes that the goal of leadership in any organization is to maximize their operational efficiency and effectiveness now and in the future They argue that the measures of operational performance of organizations are productivity, quality, cost efficiency, timeliness and agility. Change management is therefore geared towards attainment of the organizations goals by involving all stakeholders with a view of obtaining buy-in to ensure single-mindedness, focus and a shared vision.

4 RESULTS AND DISCUSSION

In this section we present the outcome of our study to demonstrate experiences of respondents towards change management.

Question 1: Leadership is influential in implementing the current Change Management Strategy

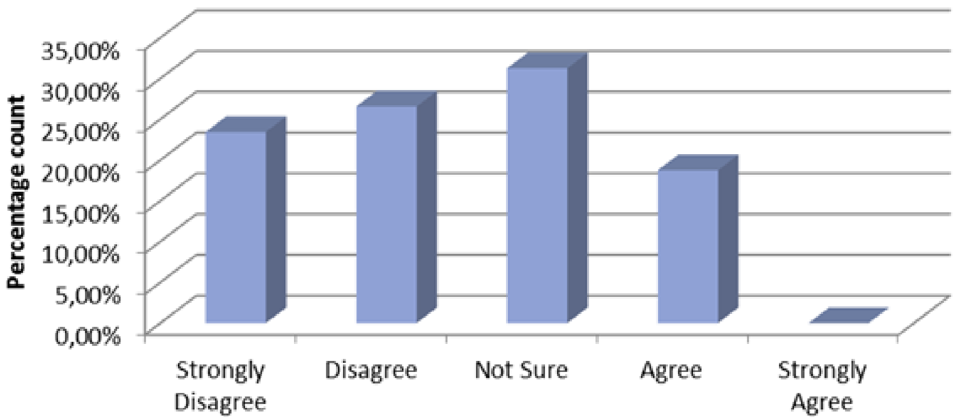

Figure1: Distribution of responses to question 1

The importance of leadership in ensuring the success of a strategy is crucial for any organisation undergoing change. Figure 1 reveals that 19% agree and 50% disagree that the leadership were influential in implementing change management.

Question 2: I understand why there is change

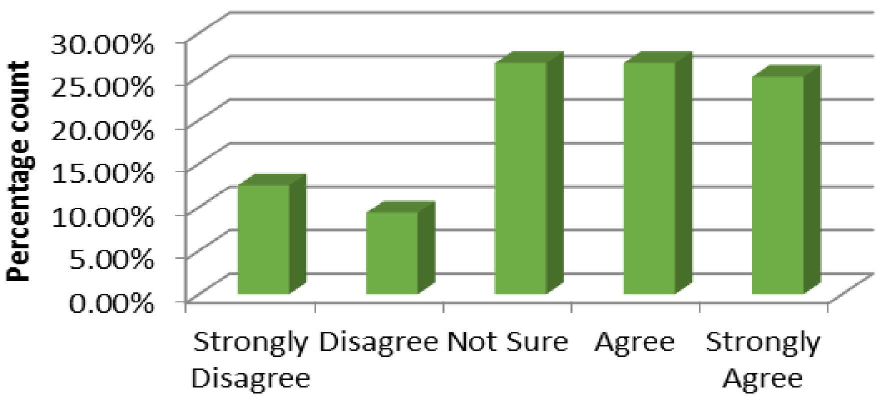

Figure2: Distribution of responses to question 2

The reason for change is understood by 52% of respondents misunderstood by 22% of the sample population (Figure 2). The percentages indicate that the need for change was realised by most respondents.

Question 3: The new Change Management Strategy helps me perform my tasks better

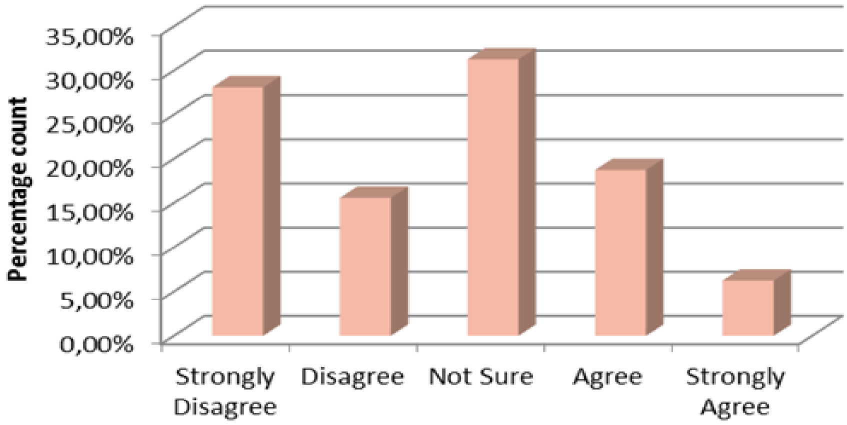

Figure3: Distribution of responses to question 3

The results from the survey indicate that 25% agreed and 44% disagreed that the new change management strategy helps them perform their task better.

Question 4: I have ideas of how changes could have been implemented

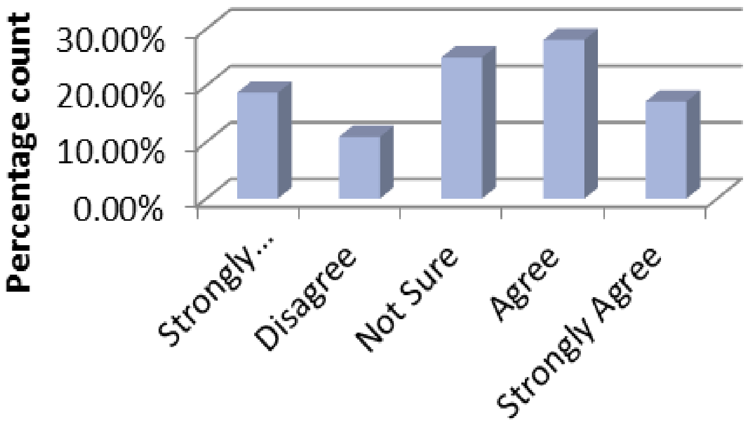

Figure4: Distribution of responses to question 4

A total of 45% agreed they have ideas of how changes could have been implemented and 30% disagreed. The results indicate that not all respondents were given a platform to share their ideas.

Question 5: I prefer the old way of doing things

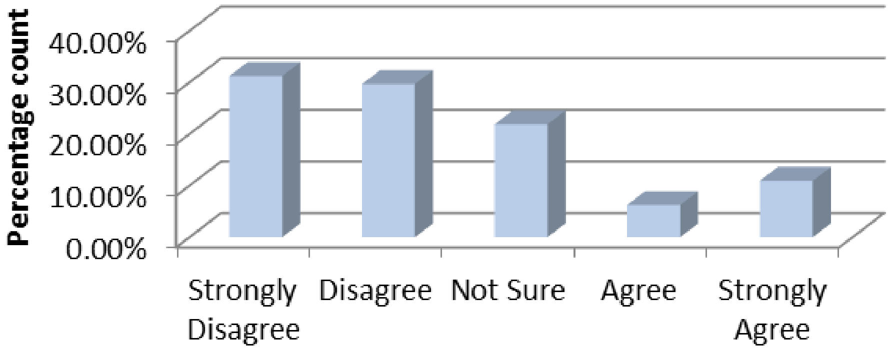

Figure5: Distribution of responses to question 5

In order to further understand whether the strategy was well received or resisted, respondents were asked if they preferred the old way of doing things 61% disagreed and 17% agreed.

Question 6: The new changes have increased my productivity

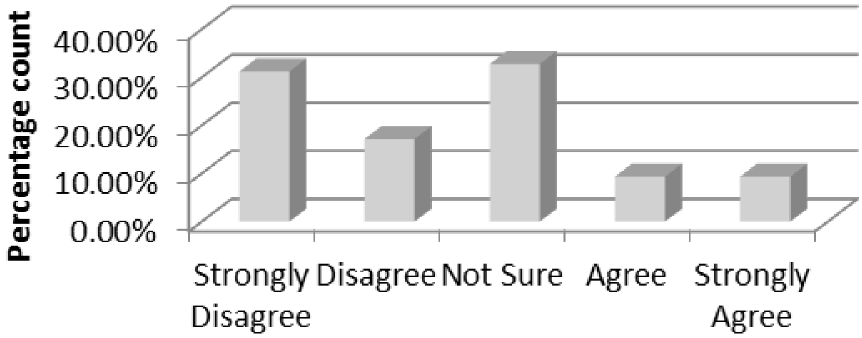

Figure6: Distribution of responses to question 6

The new changes did not increase productivity according to 48% of respondents, 33% were not sure and only 18% benefited from the change. The results show that new changes did not increase the productivity of most respondents.

Question 7: I have been asked about how the new changes affect my work

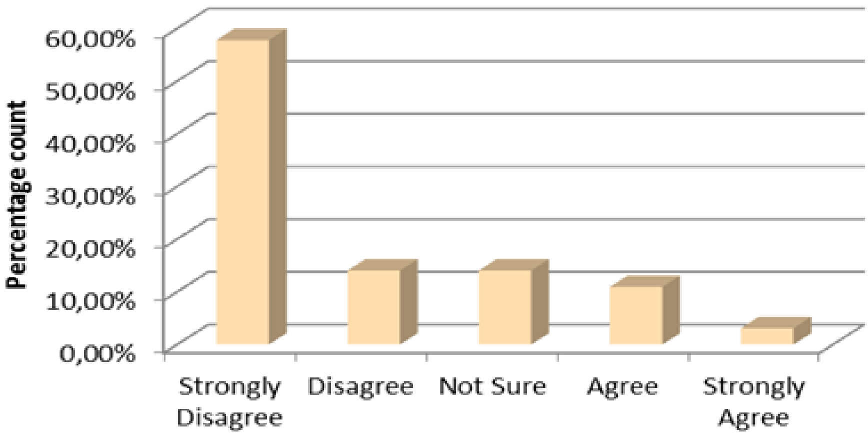

Figure7: Distribution of responses to question 7

The results indicate that 62% of the respondents were not asked how the new changes affect their work and only 14% were asked. This indicated few consultations on a large number of respondents after the change was implemented.

Question 8: I am important for the Change Management Strategy to succeed

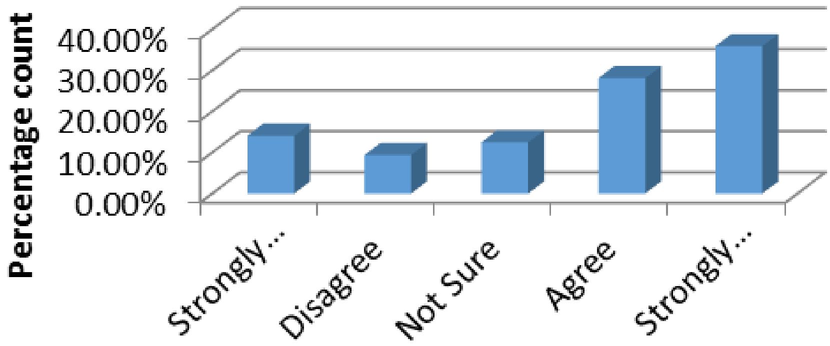

Figure8: Distribution of responses to question 8

The results from the survey indicate that 64% of respondents see themselves as important for the change management to succeed and 23% did not.

Question 9: How we render service still remains the same after the new changes

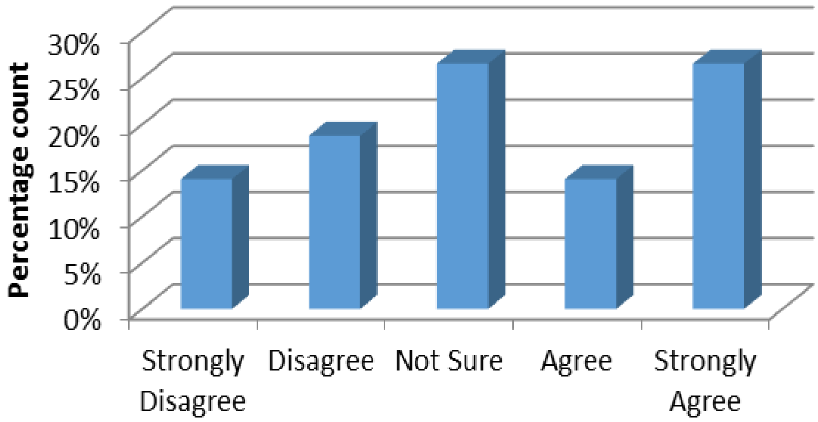

Figure9: Distribution of responses to question 9

The results revealed that 40% of respondents indicated that the way service was rendered remained the same after the new changes, 33% disagreed and 27% were uncertain.

4.1 Descriptive Statistics

Descriptive statistics is the discipline of quantitatively describing the main features of a collection of data [17]. [18] supports this proposition by pointing out that descriptive statistics does not describe data, rather it uses data to describe the world with a goal of understanding and improving comprehension of socially important phenomenon.

4.2 Reliability checks (Cronbach Alpha)

Reliability test were conducted in order to measure internal consistency, how closely related the awareness to the strategy, the impact of the strategy and organizational performance are

(Cronbach Alpha), Alpha was developed by Lee Cronbach in 1951 to provide a measure of the internal consistency of a test or scale; it is expressed as a number between 0 and 1[18]. The Change Management (CM) strategies and organizational consistency were measured and are presented below in Table 1.

Variables Measured	**Cronbach's alpha (0.7+)**
Change Management Strategy and Awareness	0.89
Factors affecting Change Management	0.91
organizational and Individual Performance	0.91

Table 1: Cronbach Alpha score for reliability measures

4.3 Central tendency

Table 2 represents the descriptive statistics for the study in order to measure the central tendency. The table shows how much each variables is scored on average (mean) and how often each respondent was scored (mode).

Statistics	*CM Strategy and Awareness*	*Factors affecting CM*	*Organisational and Individual Performance*
Mean	2.938	2.775	2.658
Standard Error	0.123	0.098	0.101
Median	3.200	2.763	2.647
Mode	4.000	3.684	2.647
Standard Deviation	0.982	0.780	0.806
Sample Variance	0.965	0.609	0.650
Kurtosis	-1.005	-0.508	-0.493
Skewness	-0.177	-0.143	-0.020
Range	3.800	3.526	3.412
Minimum	1.000	1.000	1.000
Maximum	4.800	4.526	4.412
Sum	188.000	177.632	170.118
Count	64	64	64

Table 2: Summary for descriptive statistics results

On average for the mode the results indicated that the responses for CM Strategy and awareness, and factors affecting CM was at 4 meaning that majority of respondent agreed to the statements that they are aware of the strategies and factors affecting the change management strategy at the department.

When measuring the mean across the three variables, respondents were uncertain of the change management strategies and awareness and factors that affect them and how that impacts on the organizational performance.

4.4 Correlation Analysis

Pearson correlation coefficient which measures the degree to which there is a linear association between two interval-scaled variables was done [19]. A positive correlation reflects a tendency for a high value in one variable to be associated with a high value in the second whilst a negative correlation reflects an association between a high value in one variable and a low value in the second variable [20].

	CM Strategy and Awareness	*Factors affecting CM*	*Organizational and Individual Performance*
CM Strategy and Awareness	1		
Factors affecting CM	0.79	1	
organizational and Individual Performance	0.72	0.88	1

Table 3: Correlation between the CM Strategy and Awareness, Factors affecting CM, and organizational and Individual Performance

There is a relationship between CM Strategy and awareness and factors affecting CM strategy (0.79) and between CM Strategy and awareness and organizational and individual performance (0.72), furthermore between factors affecting CM strategy, and organizational and individual performance (0.88).

4.5 Regression Analysis

A regression mode was built with the following as variables:

- Independent variables: CM Strategy and awareness and factors affecting CM strategy,
- Dependent variable: Organizational and individual performance

Regression Statistics	
Multiple R	0.88
R Square	0.77
Adjusted R Square	0.76
Standard Error	0.39
Observations	64

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	31.51602	15.75801	102.07074	0.00000
Residual	61	9.41738	0.15438		
Total	63	40.93339			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*Upper 95.0%*
Intercept	0.13444	0.18341	0.73297	0.46639	-0.23232	0.50120	-0.23232	0.50120
CM Strategy and Awareness	0.06235	0.08196	0.76077	0.44972	-0.10154	0.22624	-0.10154	0.22624
Factors affecting CM	0.84327	0.10318	8.17262	**0.00000**	0.63694	1.04960	0.63694	1.04960

Table 4: The impact of CM Strategy and Awareness, and Factors affecting CM on organizational and Individual Performance

Only one variable, factors affecting CM strategy had a significant impact or influence on organisational and individual performance with P=0.0000 <0.005. Considering other variables such as the CM Strategy and awareness which had an insignificant impact with P value greater than 0.05, it can be concluded further based on correlation that, factors affecting change management require awareness of change management in order to address the performance.

4.6 Interpretation and Discussion

4.6.1 Strategy Awareness

Results from the survey indicated that 67% of respondents were aware of the Turnaround strategy. They worked more than four years and understood the strategy. The percentage decreased with less years worked. Respondents who were at senior positions were more aware and understood the strategy compared to those in administrative positions.

The awareness of change management strategies and drivers of change was recognised only by those in senior positions who worked longer at the department. These were respondents who agreed that they were the agents to drive the implementation of change. This was particularly a concern that majority of the respondents were unaware of how the changes were managed.

This results points to a probable poor interactions or rather a communication gap between respondents at top levels with those occupying administrative functions and those who worked more than four years and those who worked less years.

4.6.2 Type of Change Management strategies

The results from the survey have highlighted certain aspects for understanding the type of change management strategies in place. There were few respondents that were responsible for implementing the change. Only minority that worked for 2-4 years and >4 years and senior positons received consultation regarding how change affected them. As the Turnaround strategy was introduced for improvements in the department, about 51% of the respondents indicated that their tasks were aligned with the Turnaround strategy. Majority (71%) of respondents indicated that they did not prefer the old way of doing things, indicating willingness to embrace change. Most of the respondents indicated that they did not receive sufficient information.

4.6.3 Factors affecting the Change Management Strategy

Leadership Influence

Survey results indicated that a high percentage of respondents employed by NDPW PO, with service period of between 2-4 years and those with service period greater than 4 years clearly understood the need for change, majority of respondents indicated that the leadership was not influential in driving the change. This may impact the success of the Turnaround strategy at NDPW PO.

Resistance to change

Resistance to change is common when change is implemented in organisations, causing anxiety and stress [21]. Survey results indicated that there are some elements that indicate possible resistance to change. A high percentage of the respondents indicated that they had ideas on how the change could have been implemented. The respondents are those who had been in the employ of NDPW between 2 and 4 years and those who had been in the employ for greater than 4 years,

Respondents indicated that they did not receive sufficient information regarding the change. Fifty percent of respondents indicated that they were not given sufficient time to understand the Turnaround strategy. Respondents indicated that they did not have job security after change was implemented (86% with 2-4 years). Those that indicated they have job security, worked for more than four years and constituted 40% in that category.

Respondents (53%) indicated that they did not have support to help them deal with the new changes. 47% percent of respondents indicated that they do not have job satisfaction after the new changes. In all of the categories of years worked, the percentage of those who disagreed were high compared to those that agreed. A total of 59% of respondents indicated that they did not have resources to help them perform their tasks.

Insufficient skills and Communication

The results from the survey indicated that there was leadership and communication skills improvement required to make the strategy successful. Culture

Respondents indicated that they understand the vision and mission of NDPW, they understand why changes are there and they did not prefer the old way of doing things.

4.6.4 Impacts on Organisational Performance

The drivers of change at NDPW were aimed to address challenges such as, leadership instability, lack of support and buy-in and support in governance processes within the organisation, lack of policies, low employee morale, poor planning and management and poor asset management. The results of the survey indicated that a high percentage of respondents hold positions of Above Deputy Director and worked at NDPW PO for more than 4 years were 89%. In total those that hold senior positions and worked more than four years were an average of 91% of the sample population.

The employee morale at the department remains a concern as most of the respondents indicated that they do not have job security, job satisfaction, support from management, new changes did not improve their productivity and few received training to help them cope with changes. Respondents were either not sure (30%) or disagree (34%) that they are coping with the new changes. Areas that need further improvement are, consultation with employees on managing change and providing support in the form of training and resources.

Survey results indicated that a high percentage of respondents did not receive any feedback regarding their performance in all the categories of years worked as well as the position held. Respondents indicated that the feedback regarding the change management was important for their performance. This results indicate lack of performance management systems. Only 13% of respondents indicated that service delivery improved after the new changes.

Forty percent indicated that the way service was rendered remained the same after the new changes. Positive feedback drawn from the survey results includes, respondents are motivated to do their jobs, their tasks are aligned to the Turnaround strategy, they are able to make more informed decisions guided by policies in place, decision making is aligned with the Turnaround Strategy and they are important for the strategy to succeed.

5 RECOMMENDATIONS AND CONCLUSION

In the world that is driven by volatility, uncertainty, complexity and ambiguity (VUCA) the ability to adapt to changing landscapes in the 21st Century is a key requirement for organizations. The phenomenon of change management was discussed, factors that drive change management were presented and lastly the quantitative survey results were presented. It is clear that change management at NDPW PO had major set-backs in terms of successful implementation of the change management process to support the turnaround strategic initiative. The determinants that resulted in poor change management process were poor buy-in and poor alignment to the strategic initiative by all.

Further research should be conducted to understand the system dynamics of the change management process; this could offer insights on what happens to the entire change system when change drivers are manipulated.

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FRONT-LINE SUPERVISOR EFFECTIVENESS ASSESSMENT ON AN ENGINEERING SHOP-FLOOR

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ABSTRACT

This paper entails the creation of a Front-Line Supervisor Effectiveness Assessment Model on an Engineering Shop-Floor. Supervisors were assessed according to assessment criteria to evaluate their performance and effectiveness as Front-line Supervisors. Criteria were determined from literature and documentary research. The paper states how these criteria were determined and why they are relevant. The model consists of 38 assessment criteria by which Front-line Supervisors are assessed at a specific engineering company. Furthermore, the model created is demonstrated and validated by implementing the model. Lastly, various recommendations are made on how to improve the model.

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1 INTRODUCTION

The Front-line Supervisor is the leader of a work team and is directly responsible for relaying management's instructions to the work team [1]. The supervisor's role is to translate the organisational goals and objectives into implementable instructions for his work team [2]. A supervisor is also a mentor to the team since the supervisor understands the organisation and the role that employees need to play within the organisation. This means that the supervisor acts as a guide and provides advice to subordinates. The advice given by supervisors usually includes information about the employee's job at hand and the employee's career as a whole. Furthermore, the supervisor is the connection between top management and the work team; implying that the supervisor informs the work team about new methods, policies and rules implemented by management. The supervisor also needs to communicate the work teams' requests and inquiries to management [2].

This paper deals with the effectiveness of supervisors within an engineering organisation and how to assess them. The assessment created is useful for decision support on supervisor governance, supervisor appraisals, problem-solving with regards to the supervisor's tasks, and the necessary supervisory requirements. The industry partner that was used to implement the effectiveness assessment model was PRASA, the Passenger Rail Agency of South Africa.

PRASA is a state-owned entity with the purpose of providing rail services for commuters in the Metropolitan area of South Africa. However, the Metrorail Infrastructure and Rolling Stock Depot in Salt River, Cape Town, specifically deals with the maintenance and upgrading of rolling stock. This department has various assembling and maintenance divisions for which Front-line Supervisors are responsible.

The paper aims to define a model that acts as an Effectiveness Assessment of Front-line Supervisors on an engineering shop-floor. PRASA has three technical divisions for which Production Managers are responsible. These three divisions, namely: Fleet Maintenance, Reliability Shop and Component Services, consist of subdivisions that are managed by Front-line Supervisors. The subdivisions are as follows: Faults, North Shedding, South Shedding, Lifting Shop, Carriage and Wagon Shop, Coach Repair Shop, Instrumentation and Valve Shop, Armature Repair Shop, and the Rotary Machine Repair Shop.

This study is based on the Effectiveness Assessment of the Front-line Supervisors working in the subdivisions mentioned. Top management has identified the need for Front-line Supervisors in these divisions within the organisation; however, the optimal way in which to assess these supervisors and the determination of whether they are effective, has not yet been reviewed.

The objectives of this study are indicated in Table 1.

Table 1: Study Objectives

1.	Understand the roles of each of the Front-line Supervisors in the Fleet Maintenance, Reliability Shop, and Component Services divisions.
2.	Identify the tasks that each supervisor is responsible for.
3.	Ascertain which tasks are the most important to ensure productivity.
4.	Formulate a Supervisor Effectiveness Assessment model based on the most important tasks identified to assess the Front-line Supervisors.
5.	Assess the Front-line Supervisors using the assessment model created to allow for model validation.
6.	Evaluate the results obtained from the Supervisor Effectiveness Assessments and make recommendations.

2 RESEARCH DESIGN AND METHODOLOGY

Figure 1 is a graphical representation of the research design and methodology followed in this study.

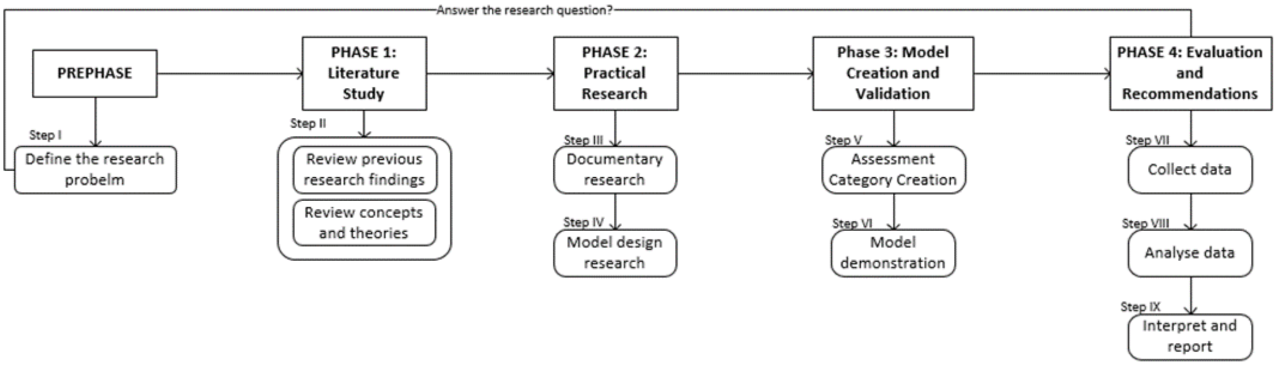

Figure 1: Graphical Representation of Methodology (adapted from [3, p.11])

As indicated by Phase 1 in Figure 1, a literature study was completed to deduce the important criteria and competencies by which a supervisor should adhere to be effective, and to fulfil objective 1 in Table 1. The role of a supervisor was identified, and this includes providing leadership and guidance to employees [7], providing information and feedback to subordinates [8], and providing support [9] [10] [11]. Influences on supervisor effectiveness were investigated which were concluded to be job satisfaction [12], subordinates' use of impression management [13], the self-verification theory [14], supervisor's job experience [15] and performance [16], personality traits of the supervisor [17], and feedback on the supervisor's performance [18]. The supervisor's effect on subordinates was also investigated and this entails how supervisory governance is implemented [19], the connotation of the feedback given to subordinates by supervisors [20], and the subordinate's impressions of their supervisors [17]. In addition, the consequences of an inadequate supervisor were explored, and it was found that they are the following: poor relationships with co-workers, lower performance ratings, conflicts, the tension in the workplace [21], avoiding recognition, instilling fear and cultivating negative environments [22]. Furthermore, previous models such as the Engineering Competency Model [23], Operant Supervisory Taxonomy and Index [24], Operant Supervisory Team Taxonomy and Index [25], and the Supervisor Activity Analysis at Kumba Mine Engineering [26] were studied to allow for a basis on which the Front-line Supervisor Effectiveness Assessment could be created.

The Engineering Competency Model consists of 5 tiers of competencies that a professional should possess within the engineering working environment [23]. To aid the formulation of the Front-line Supervisor Effectiveness Assessment model, tiers 1 and 3 were used. Tier 1 consists of Personal Effectiveness Competencies such as interpersonal skills; integrity; professionalism; initiative; adaptability and flexibility; dependability and reliability; and lifelong learning competencies that the supervisor should display. Tier 3 refers to workplace competencies such as teamwork; planning, prioritising and organising; creative thinking; problem solving, definition and decision making; seeking and developing opportunities; working with tools and technology; scheduling and coordinating; checking, examining and recording; and business fundamentals.

The Operant Supervisory Taxonomy and Index is described as

"operant-based taxonomy and observational instrument of supervisory behaviour" [24, p. 260].

This taxonomy was developed to test the behaviours of supervisors and how these behaviours affect their effectiveness. Previous research was used to generate the categories by which behaviours were grouped. Only those categories that appeared to relate to supervision were chosen. There are seven categories, namely: performance antecedents, performance monitors, performance consequences, own performance, work-related, non-work related, and solitary (the interaction of the supervisor with subordinates). Performance antecedents refer to the supervisor providing instructions to subordinates on how to perform. Performance monitors refer to collecting information on the subordinates' performance, and performance consequences refer to the acknowledgement by the supervisor of the subordinate's performance. These three categories form the basis of the taxonomy [24].

The Operant Supervisory Taxonomy and Index were adapted and expanded to apply it to the supervision of teams, rather than focusing on the supervision of individuals. This adaptation is known as the Operant Supervisory Team Taxonomy and Index. It includes descriptions of the leader's role, the behaviours of the team as a whole as well as interdependent tasks, i.e. tasks that require cooperation from all team members to reach completion. Interdependence coordination is said to be the most important role of a supervisor when overseeing a team. According to this model, the ability of the supervisor to organize and coordinate teams in an effective, efficient manner is a direct indication of the supervisor's effectiveness [25].

The Operation Improvement Management Consulting Company developed the Supervisory Activity Analysis to be implemented at Kumba Mine Engineering. The activity analysis aims to identify the non-core activities performed by the supervisors and the impact it has on the effectiveness of supervisors. The purpose of conducting the study was to highlight the non-value adding activities that should be mitigated to increase the effectiveness of supervisors and increase the value of their roles within the company. From the study, it was noted that supervisors should spend most of their time in Active and Passive Supervision. Active Supervision is known as the direct engagement between supervisor and subordinate on production and safety-related issues. This includes instructions from the supervisor and requests from subordinates. Passive Supervision occurs when the supervisor observes subordinates, inspects and evaluates quality. Passive becomes Active Supervision when the supervisor intervenes [26]. Because time study was not the ideal method to employ in this time-constrained project, the Supervisor Activity Analysis was used as a guideline to determine whether the activities mentioned are included and are the focus of the supervisors' daily tasks.

Phase 2, as shown in Figure 1, consisted of practical research, shown in Step III, which included documentary research such as the job descriptions of Front-line Supervisors at PRASA and model research, shown in step IV, such as determining the advantages and disadvantages of conducting interviews [27] and surveys [28] to collect data. Practical research was completed to further achieve objective 1 in Table 1, as well as achieve objectives 2 and 3. Phase 3 and Phase 4 are discussed in the following sections.

3 RESULTS

The model was created as a resultant of the literature study and documentary research such that the supervisors at PRASA can be assessed with regards to their effectiveness. The formulation of the surveys and interviews is discussed, and the assessment categories and their weightings are justified in this section. Furthermore, validation of the model is established. An example of the model is displayed to demonstrate how the model works and how the effectiveness of supervisors is calculated.

3.1 Assessment Model Creation

This section deals with the formulation of the Front-line Supervisor Effectiveness Assessment Model and refers to Phase 3 of the study, fulfilling Step V as well as achieving objective 4 in Table 1. The way in which the interviews and surveys were constructed is explained and each Assessment Category and its weighting is discussed to give the reader an in-depth understanding of the model that was created. The survey completed by subordinates and managers, and the questionnaire used to interview supervisors are based on the categories, themes and previous models deduced from the literature study, as well as the job descriptions derived from documentary research. The following points highlighted from the literature study and documentary research were used to aid the formulation of the assessment categories and criteria on which the Front-line Supervisor Effectiveness Assessment model is based.

- According to the role of a supervisor, it is deemed the most important for the supervisor to provide support and constructive feedback to subordinates; to ensure the safety of subordinates; to minimise conflict in the working environment and to provide the adequate training and sharing of skills to subordinates.
- The Engineering Competency Model states that a supervisor should possess personal effectiveness and workplace competencies. Personal effectiveness skills refer to the ability of the supervisor to act appropriately in various situations. Workplace competencies in the supervisory context refer to the ability to manage a team and the tasks the team needs to accomplish.
- The Operant Supervisory Taxonomy and Index and the Operant Supervisory Team Taxonomy and Index models state that the supervisor should provide adequate instructions to subordinates on how to perform, they should monitor the performance of subordinates, and they should acknowledge the performance.
- The Supervisor Activity Analysis indicates the activities a supervisor should be involved in daily. Active and Passive Supervision is highlighted as the most important.

The technical skills, initiative, self-management skills, communication and teamwork skills, innovation abilities, leadership skills, project management skills and personnel management skills of the supervisor as well as the quality and quantity of work performed by the supervisor are the matters of interest when conducting the Effectiveness Assessment model. These are referred to as the Assessment Categories and are adapted from the Supervisory Staff Performance Evaluation determined by Oklahoma State University [29]. The Initiative, Leadership Skills and Personnel Management Assessment Categories correspond to and are derived from tier 1 of the Engineering Competency Model, whereas the Technical Skills, Quality of Work, Self-management, Communication and Teamwork, Innovation and Project Management Assessment Categories are derived from tier 3. Discussions of these categories follow.

Technical Skills

Technical skills are essential for the competence and effectiveness of supervisors. It is the most important characteristic trait a supervisor should possess in order to fulfil his duties. A Front-line Supervisor's technical skills consist of being able to perform the supervisory tasks as outlined in their job description and doing so safely such that no harm is encountered by anyone in his department. These tasks include the managing of time schedules and work operations. Technical skills also refer to following the correct procedures and using tools and equipment in the correct capacity.

Quality of Work

Producing exceptional quality of work is what any supervisor should strive for. Quality is a direct indicator of the supervisor’s performance as it indicates the success of the supervisor and his team as they work together to achieve the goals as set out by the supervisor and the Production Manager without extra help. It also indicates whether the supervisor has corrective actions in place to rectify defects or mistakes. Furthermore, it identifies the priorities of the supervisor and whether PRASA’s standards are being adhered to.

Initiative

Initiative is a trait that indicates whether the supervisor is capable of going beyond what is expected of him. This trait is what will separate an exceptional supervisor from one that merely adheres to his job description. A supervisor that is willing to learn new skills and provides effective solutions to arising problems will be more effective.

Self-management

Self-management is a depiction of a supervisor's character as it indicates the time management and punctuality of the supervisor. It is a direct indication of the effectiveness of a supervisor as the supervisor will effectively monitor his subordinates, should he effectively monitor himself. Self-management also stipulates whether the supervisor can be held accountable and be responsible for his actions – these are essential for an effective supervisor. Overall, self-management refers to the ability of the supervisor to display self-control in all situations and handle them without allowing the supervisor's emotions to cause any effect.

Communication and Teamwork

This is vital in each department at PRASA. This is because processes within the departments link together to fulfil the goal of the department. A supervisor's job primarily involves effective communication of instructions to his subordinates such that daily tasks and objectives can be completed and achieved, respectively. Supervisors should also provide guidance and help when subordinates do not understand instructions. It is important that the policies and procedures of PRASA are thoroughly understood by the supervisor and properly relayed to the subordinates. The supervisor has to facilitate teamwork such that the subordinates work together to achieve the departments' goals. Additionally, the supervisor has to facilitate a pleasant working environment such that subordinates are happy, feel respected and can be open about any concerns. Subordinates create the team and without the team, supervisors cannot fulfil their duties.

Innovation

Innovation is important because supervisors have the authority to implement improved ways of completing tasks as long as they adhere to the policies and procedures of PRASA. It is also important that subordinates be allowed to suggest their own innovation ideas and that the supervisor investigate these ideas for implementation. This will make subordinates feel valued and it creates a welcoming working environment. Furthermore, it is essential that supervisors can adapt to changing working environments and relay adaptations to subordinates as improvements are continually being made.

Leadership Skills

It is also important that supervisors have good leadership skills. These skills will ensure that the supervisor has the ability to lead others to achieve the goals of the department in which they work, as well as the goals of PRASA as a whole. A supervisor who exhibits leadership skills will encourage subordinates to grow and expand their knowledge, while continuously improving themselves. This aligns with effectiveness as the subordinates will want to aid the supervisor to achieve departmental goals if they know that the supervisor is willing to help them achieve their personal goals. In addition, supervisors who are good leaders will know how to act appropriately when criticised and perform effectively under pressure.

Project Management

Project management abilities are vital for a supervisor as he is managing a constant project. For example, each train coach that is repaired or each valve that is fixed can be seen as small projects. It is important that repairs take place in a timely manner, with the correct resources and that they are completed to the quality standards of PRASA. This will be done if repairs are managed sufficiently by the supervisor and it can be done should the supervisor provide clear definitions of tasks, provide sufficient time for task completion, and delegate authority when necessary.

Personnel Management

Supervisors should always ensure the well-being of their subordinates as the emotional state of a subordinate can directly affect the work output the subordinate produces. Because of this, a supervisor should promote optimism and enthusiasm in the workplace to ensure a contented working environment. A pleasant working environment is also attributed to the supervisor recognising and rewarding subordinates for their successes. It is important that supervisors provide feedback to their subordinates such that subordinates can be aware of the areas in which they excel and the areas in which they need to improve. A supervisor should also help subordinates to set goals in the areas that need improvement such that growth actually occurs. Finally, it is essential that a supervisor always acts rationally and fairly, and that conflict is resolved in an appropriate manner.

These categories are derived from the literature study and this ultimately produces the results of the project. It also answers the first research question of the study. The job descriptions of the Front-line Supervisors as described by PRASA are also taken into consideration in the development of the Front-line Supervisor Effectiveness Assessment model. The duties completed by the supervisors to ensure safety, quality and the management of resources and products are assessed in the model to evaluate whether supervisors are adhering to their job specifications. A questionnaire is created from the assessment categories and criteria identified such that surveys and interviews can be conducted to allow for the validation of the Front-line Effectiveness Assessment model.

Production Managers, Supervisors and their Subordinates are required to rank the supervisor's performance for each criterion. This is such that a 360-degree feedback method of assessment is employed [18]. Furthermore, it also allows the Production Manager to identify the supervisor's perceived level of competency. The ranking order by which supervisors are to be rated is shown in Table 2.

Table 2: Ranking Order of Supervisor's Performance

1 = Unsatisfactory	Supervisor's performance does not meet the expectations of the job
2 = Needs Improvement	Supervisor's performance sometimes meets the expectations of the job
3 = Meets expectations	Supervisor's performance consistently meets the expectations of the job
4 = Exceeds expectations	Supervisor's performance often exceeds the expectations of the job
5 = Exceptional	Supervisor's performance always exceeds the expectations of the job

It is deemed important to access information from subordinates and managers as the actions of the Front-line Supervisors directly impact them. Subordinates and managers are required to rank the supervisors on a scale of 1 to 5 for various criteria depending on how supervisors perform in each of the criterion, 1 being unsatisfactory and 5 being exceptional. The average of the ratings provided by the manager, supervisor and subordinate is taken to obtain the Average Ranking for the specific criteria. The mean of the Average Ratings is then obtained to determine the Category Rating. This then indicates how the supervisor is performing within the category.

Front-line Supervisors report to the Production Managers in their respective divisions. Because of this, the important factors that Production Managers aim to excel in, should also be the factors in which the Front-line Supervisors strive to achieve. This is because Front-line Supervisors form part of the support team that aid the Production Managers to achieve their goals such that the Maintenance Operation Manager can achieve the overall goal of PRASA.

The assessment criteria by which the supervisors are assessed are weighted according to the Production Manager's Performance Appraisal that was provided by PRASA. This was done to ensure that the effectiveness of the supervisor is attributed to the goals of the Production Manager such that PRASA can reach its objectives as an organisation. The weightings were calculated according to the Business Imperative Performance Indicators. Table 3 indicates the weightings of the assessment categories and the corresponding Key Performance Indicators (KPIs) from which the percentages were derived.

Table 3: Assessment Category Weightings and Corresponding KPIs

Assessment Category	Weighting	Corresponding KPIs
Technical Skills	13%	Safety of Staff - Occupational Health and Safety Management; Ensure sound Labour Relations; Stakeholder Interface – Protection Services and Train Operations
Quality of Work	27%	Train Sets in Service; Fully Configured Train Sets; Operational Safety – Number of Derailments; Mean Time to Repair; Mean Distance between Service Affecting Failures; Conformance Audit
Initiative; Self-Management; Leadership	10%	Corporate Governance: Conformance Audit; Risk Management
Communication and Teamwork; Innovation	10%	Workplace Skills Plan Training; Skills Development (Learning and Growth)
Project Management	20%	Rolling Stock Budget; Management of Overtime Budget; Irregular Expenditure of Fruitless & Wasteful Expenses
Personnel Management	20%	Leave of Staff Managed; Absence of Staff Managed; Overtime
Total	100%	

The KPIs were obtained from the Production Manager Performance Appraisal. The KPIs are grouped according to the assessment category in which they fit. The percentages for the KPIs in each group are summed to determine the Assessment Category weighting. Although the Front-line Supervisor is not directly responsible for some of the KPIs, such as the Rolling Stock Budget, the Project Management duties that are carried out by the Front-line Supervisor assist the Production Manager to draw up and adhere to the Rolling Stock Budget.

3.2 Model Validation

This section concludes Phase 3 in Figure 1 by completing Step VI. It also achieves objective 5 in Table 1. Validation involves implementing the model in the industry. The focus of this project was to create an Effectiveness Assessment model specifically for the Front-line Supervisors at PRASA. For this reason, validation was completed at PRASA. Table 4 indicates an example.

Table 4: Model Example

		Manager	Supervisor	Subordi-nate	Ave.	Category
	Technical Skills					
1	Performs assigned and required duties (e.g. analysis of train delays, quality assurance, etc.)	3	4	3	3	4
2	Follows the correct procedures as outlined by PRASA	4	4	4	4	
3	Uses tools, materials and equipment effectively	4	4	3	4	
4	Works safely and conducts assessments to minimise potential hazards (e.g. breathalyser tests, PPE, etc.)	5	4	4	4	

The category used in the example is Technical Skills. Each assessment criteria, 1 to 4, is rated by the manager, the supervisor and the subordinate. A weighted average rating is then calculated to determine the overall weighting for each assessment criteria. The weighted average is calculated as follows: the manager rating is multiplied by 3, the supervisor rating is multiplied by 2 and the subordinate rating is multiplied by 1. These values are then summed and divided by 6 to obtain the weighted Average Rating values. A weighted average is calculated to eliminate bias whilst still including the 360-degree feedback method of performance assessment.

The manager's rating should weigh the most as the manager's job is to ensure that the supervisor complies to his job description. Subordinates have the lowest weight as they might be biased towards or against the chain of command. Averages are rounded off to identify which order rank is appropriate, according to Table 2. The mean of the averages for criteria 1 to 4 is obtained to determine the Category Rating value. This example yields that the supervisor 'Exceeds Expectations' in the Technical Skills category.

After the weightings are calculated, the supervisor assessed obtained 62% for effectiveness. According to the effectiveness ranking in Table 5, it shows that the supervisor is Very Effective. Although this is a good percentage to obtain, the model allows the assessor to analyse the loss of the other 38%. By doing this, the second research question of the study is answered. The assessor can use the model to identify categories in which the supervisor is performing inadequately. The assessor can then further identify the issues within the categories by inspecting the ratings given for each question. This allows for identification of the problem areas and the need for improvement. Discrepancies between manager, supervisor and subordinate rankings can also be addressed and resolved. To validate the model in the real-life context, the surveys were presented to the employees at PRASA on Wednesday, 12 September 2018. On this day, the Front-line Supervisors were also interviewed to provide feedback on their rankings.

Table 5: Effectiveness Rank Order (adapted from [29])

0 - 20% = Not effective
21 - 40% = Occassionally effective
41 - 60% = Effective
61 - 80% = Very effective
81 - 100% = Extremely effective

4 DISCUSSION

Overall, 60 surveys were distributed to the employees in the Component Services and Fleet Maintenance divisions. Apart from the Faults department, both Production Managers and all Front-Line Supervisors completed surveys to rank the supervisors within the respective departments. Of the 50 subordinates that were asked to rank their supervisors, 39 subordinates completed surveys, 7 of which were marked ineffectual due to mistakes made by the subordinate when completing them. Considering the subordinates who did not want to participate and the subordinates who did not complete the survey correctly, the process resulted in a 70% respondent success rate.

Once the data was consolidated, it was found that all the Front-line Supervisors assessed achieved an effectiveness rating between 61 and 80%, yielding them as Very Effective according to Table 5. The results are shown in Table 6. This fulfils Step IX of the research methodology shown in Figure 1.

Evaluating the results for all supervisors, it is noted that most supervisors exceed expectations in the Technical Skills category, most supervisors meet expectations in the Project Management, Self-Management, Quality of work and Initiative categories and all supervisors meet expectations in the Personnel Management category.

Table 6: Consolidation of Survey Results

		Assessment Category									Overall Rank
		Technical Skills	Quality of Work	Initiative	Self-Management	Communication and Team Work	Innovation	Leadership	Project Management	Personnel Management	
Department	South Shedding	4	3	3	3	3	4	3	3	3	66%
	North Shedding	3	3	3	3	3	3	3	3	3	65%
	Instrumentation and Valve Shop	4	4	4	4	4	4	4	4	3	74%
	Armature Repair Shop	4	3	3	3	3	2	3	3	3	62%
	Rotary Machine Repair Shop	4	3	3	3	4	3	4	3	3	68%

5 CONCLUSION AND RECOMMENDATIONS

This section further fulfils Step XI and concludes Phase 4 of the research methodology shown in Figure 1. The Front-line Supervisor Effectiveness Assessment model created produced that overall, none of the supervisors are performing below expectations. However, this may not be a completely true reflection.

It is evident that bias exists based on the results received from the surveys. Apart from the bias, of the 60 surveys that were distributed, 50 were administered to subordinates. Only 39 of these surveys were completed and of the 39, 7 had to be scrapped due to errors. This scrapping accounts for 11.7% of the surveys distributed. Because of this and the bias that exists, it is recommended that if PRASA is to implement the model, participants and employees are to be properly educated on how to complete the surveys and the benefits of being subjective when completing them. These benefits include improving the governance of supervisors and identifying the skills that supervisors lack. Educating employees will not only make them realise the benefits but it will also encourage more employees to complete surveys and become a part of the process to improving supervisor governance and problem-solving.

It is recommended that PRASA does not solely look at the effectiveness percentage a supervisor received when they are proven to be effective. The results of each assessment criteria should be analysed as there is always a need for improvement and should improvements be implemented, it will only better supervisor governance and ultimately the organisation. In addition, criteria in which supervisors are performing inadequately should be highlighted such that training needs and the required improvement of skills are identified.

Furthermore, comparisons can be made between supervisors. These comparisons; however, are not to serve negative purposes but rather to allow the more effective supervisors to help less effective supervisors. From the validation results, the supervisor who achieved 74% can help the supervisor who achieved 62% with the criterion in which the less effective supervisor is receiving lower scores. For example, the Front-line Supervisor in the Instrumentation and Valve Shop attained an Innovation ranking of 4, whereas the Front-line Supervisor in the Armature Repair Shop attained an Innovation ranking of 2. In this case, the supervisor for the Instrumentation and Valve Shop can recommend ways in which the supervisor of the Armature Repair Shop can identify areas for improvement, realise the reason for and become adaptable to changing working environments and identify the importance of generating and being open to new ideas. Additionally, outside factors such as the working environment or task requirements should be investigated if supervisors achieve the same ranking for the same categories.

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THE USE OF ANALYTICAL HIERARCHY PROCESS (AHP) FOR WELDING PROCESS SELECTION DURING RAIL CAR MANUFACTURING

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ABSTRACT

The welding process is a complex manufacturing process, which requires the deployment of multi-criteria decision support system amidst complex and conflicting welding processes, emerging technologies and materials. The Analytical Hierarchy Process (AHP) was employed for the investigation of the most suitable welding process for the assembly of the body shell of the rail car. The process attributes ranked include; crash worthiness, structural integrity, end of life, materials and its cost, welding position and joint orientation, weld quality, thickness of part, rate of material deposition as well as the welding cycle time. The development of the decision support system starts with the development of a conceptual framework that defines the goal, criteria, welding methods as well as their interconnectivity. This was followed by the ranking of sets of alternatives and subsequent comparison by identifying the weights for each criterion while the difference between the alternatives and the ideal solution was determined. The successful completion of this work provided the integration of conceptual and mathematical support system into an organized approach for solving multi criteria decision for the rail car development. This will simplify the decision making process, promote the production effectiveness and enhance overall production cost through the deployment of the best technique.

Keywords: *AHP, Manufacturing, TOPSIS, Welding*

1 INTRODUCTION

The determination of the most appropriate welding technique to be employed for the assembly operation of sub assembly during rail car manufacturing is a critical task, which represents a multi-criteria decision based on the suitability of different types of welding processes as well as their conflicting criteria. The use of manufacturers experience in the selection of welding process without scientific justification based pairwise comparison between the selected process and its alternatives is fast becoming unreliable amidst emerging materials, dynamic production factors and the quest for increased productivity, efficiency and reliability. The combination of the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) and Analytical Hierarchy Process (AHP) offers a knowledge-based multi-criteria decision support system for the determining the optimum manufacturing process amidst complex and conflicting multiple manufacturing methods, emerging technologies and materials [1-2]. While the AHP is suitable for estimating the weights of the criteria and sub criteria, the TOPSIS can sufficiently rank the alternatives [3-5]. The main criteria however lies in the production of quality and reliable structural welds, which are time and cost effective. The combination of welding process parameters as well as the characteristics of the different welding techniques often influences the structural integrity of the welded components as well as the overall welding time and cost. Commonly used welding processes include; Laser Arc Welding (LAW), Resistance Spot Welding (RSW), Metal Inert Gas (MIG) and Friction Stir Welding (FSW).

The aforementioned welding processes have their merits and demerits, which makes them suitable for some specific areas of application during the assembly operations of the railcar. The use of the knowledge based decision support system evaluates the characteristics of each welding processes as well as the total manufacturing cost with a view of determining the most appropriate process. This assist in striking the right balance between weld quality and cost. For instance, Laser Arc Welding (LAW), combines the merits of the laser method with the gas metal arc using low energy input to bring about welding operation that penetrates deeply between the materials, hence, it is a fast cavity-free welding process that produces welded structure integrity and durability. It is also suitable for joining several materials with different thickness and suitable for welding complex geometry. The limitation being the cost of installation and consumables and the fact that the welding operation often requires expensive and time consuming post welding operations [6-7].

The Friction Stir Welding (FSW) is most suitable for joining aluminum particularly for structures with low weight and high strength requirement. The process is cost effective without the need for expensive and time-consuming post welding operations producing welded structures with good appearance and mechanical properties. The limitations lie in the fact that it is slow, creates cavity-welds and difficult to use for non-linear welds and in joining materials of varying thickness [8-9]. The Metal Inert Gas (MIG) is a versatile, fast, clean and efficient welding process but limited to thin materials and inside operations because it is cumbersome coupled with the fact that it requires a shielding gas to protect the purity of the weld [10-11]. The Resistance Spot Welding (RSW), is safe, fast, efficient, cost effective and can be used to join different materials of varying thickness but if the process is not adequately controlled it can bring about the production of welded structure with poor strength and integrity [12-14].

One of the peculiarities of the AHP and TOPSIS is the fact that it establishes a correlating relationship among the performance goal, criteria, sub criteria and alternatives which enhances the ranking of alternatives and decision-making [15-17]. Furthermore, the relationship can be developed into a predictive model for keeping dynamic goals, alternatives and multi or sub criteria within a realistic forecast. Kumar *et al.* [18] employed the TOPSIS technique for the selection of material for optimal design while Javad and Mohammed [19] used the AHP for the selection of a primary crusher. In addition, Singaravel and Selvaraj [20] employed both the TOPSIS and AHP for the optimization of the machining parameters during a turning operation. The research findings from these works indicate that the TOPSIS and AHP is a suitable decision making tool for ranking and selection of the manufacturing process,

process factors, materials etc. The selection of the most appropriate welding process for the rail car assembly using AHP amidst existing and emerging welding processes is a Multi-Criteria Decision (MCD), which has not been sufficiently reported by the existing literature. Hence, this work provides the application of decision support framework in the quest to explore the prospect of Industry 4.0 for meeting increasing design and service requirements in the rail car industries.

2 METHODOLOGY

The welding operation is one of the methods for the assembly of the pre-assembled parts, which makes up the body shell of the rail car in the manufacturer's machine shop. The materials for the assembly of the machine parts as well as the design and finish requirements of the final assembly determines the type of welding process to be employed. The pre-assembled parts of the rail car include the underframe, body side, under side, end and roof amongst others. Notable among materials used are stainless steel, aluminum and carbon steel. Irrespective of the material used for the fabrication, the quest for a cost effective assembly process that will meet the design, finish and service requirements requires a scientific basis for selection rather than the welder's experience alone. For instance, the use of aluminum for the body side panel boast of low weight and energy conservation but requires the process of Metal Inert Gas (MIG) and Friction Stir Welding (FSW) for the production of joint with high structural integrity. The FSW of the aluminum is suitable for the pre-fabrication of the longitudinal side of the rail car body because the welding process operates below the melting point of aluminium hence it can produces welded parts with excellent mechanical properties and permissible distortion. The criteria for selecting the most suitable welding process include; the cost effectiveness of the process, robust design requirement (safety, structural strength and integrity as well as crashworthiness), end of life (dismantling, recycling, reuse to maximize the value of scrap). To ensure the development of welded part with high structural integrity, the welding process also requires a high level of skill and control. The Analytic Hierarchy Process (AHP) was considered suitable or the selection of the most suitable process for the assembly of the body shell of the railcar because it can interactively combine qualitative and quantitative factors to simplify Multi-Criteria Decision and make consistent judgement via pairwise comparison and ranking of the priorities as well as the criteria. The framework for the development of the Multi-Criteria Decision Model (MCDM) is presented in Figure 1.

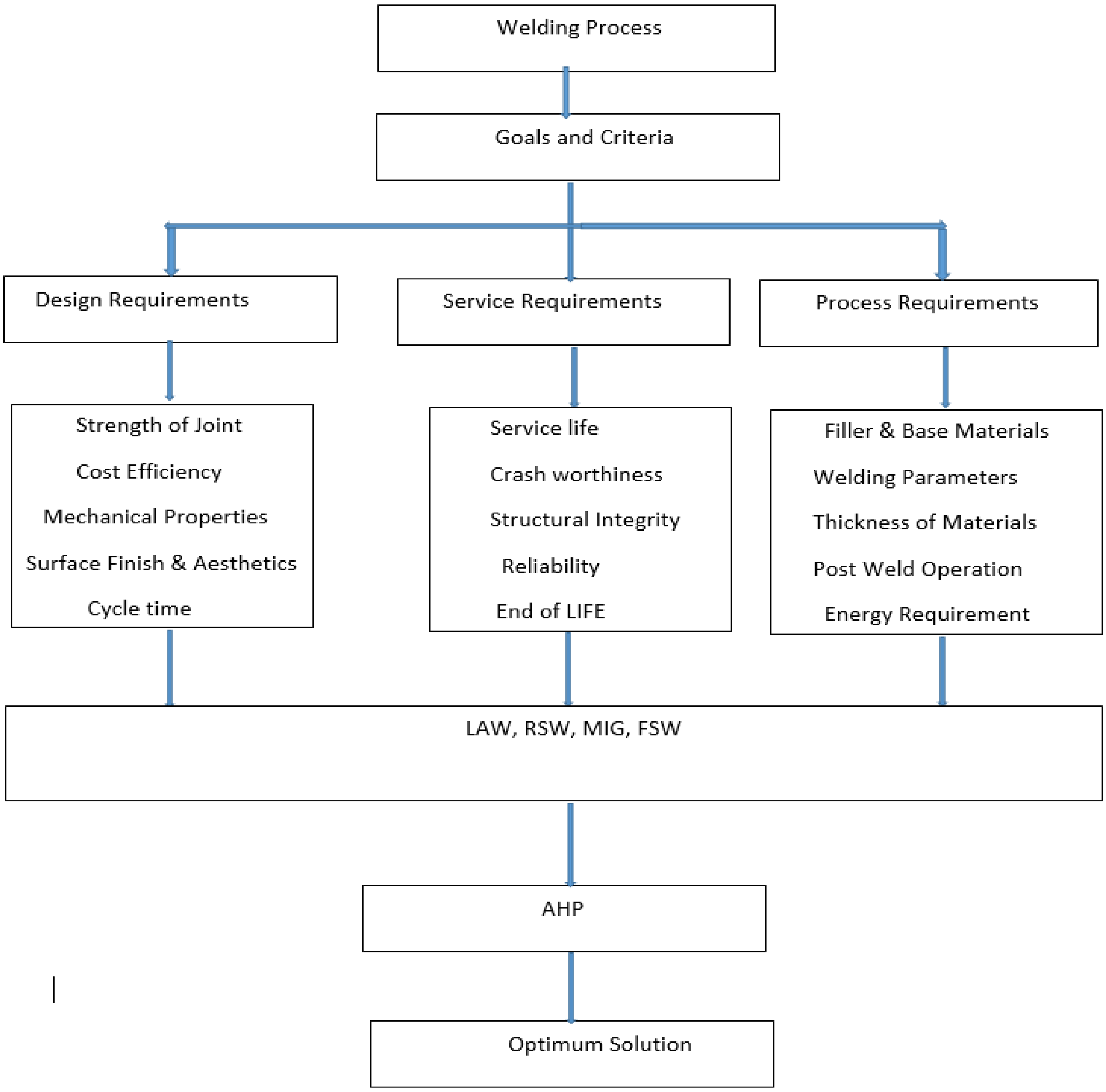

Figure 1: The framework for the development of the Multi-Criteria Decision Model (MCDM)

The Multi-Criteria Decision (MCD) was used for the development of the framework and the two levels AHP. This was followed by the generation of matrix and the pairwise comparisons among the criteria and alternatives based on competing factors. The computation of the values for the Consistency Index (CI), Consistency Ratio (CR) Eigen values and vectors and the Random Consistency Index (CI), assist in the ranking of the priorities as well as the determination of the level of consistency among the criteria and the alternatives. This was followed by the computation of the average and global weights, which forms the basis for the selection of the optimum welding process.

Figure 2 is the two levels of the AHP, which indicates the relationship among the goal, criteria and alternative choices.

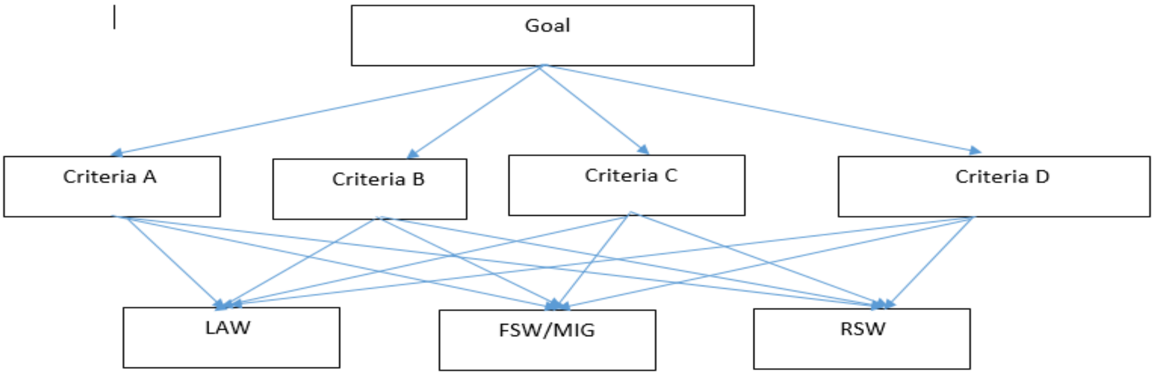

Figure 2: The two levels of the AHP

From Figure 2, the goal represents level zero while criteria 1-4 represent level 1. The different welding processes (LAW, FSW/MIG/RSW) which are the alternatives represent level 2. Level 1 has a 4×4 comparison matrix, which is made up of 3 choices and 4 factors while level 2 has 4 comparison matrix.

The sub-criteria are hidden under the criteria in order to simplify the structure of the hierarchy. The four main criteria in the order of priority and the welding processes considered are as follow;

a. Crash worthiness and structural integrity denoted as Criteria A

b. Surface finish and aesthetics denoted as Criteria B

c. Welding cycle time and operation cost denoted as Criteria C

d. Energy and consumable requirements denoted as Criteria D

e. Laser Arc Welding (LAW) denoted as welding process 1

f. Friction Stir Welding (FSW) and Metal Inert Gas (MIG) denoted as welding process 2

g. Resistance Spot Welding (RSW), denoted as welding process 3

Equation 1 and 2 expresses the Consistency Index (CI) and the Consistency Ratio (CR) respectively.

$$CI = \frac{\lambda_{max} - n}{n-1} \quad (1)$$

$$CR = \frac{CI}{RI} \quad (2)$$

Where;

λ_{max} is the largest Eigen value, n is the number of criteria and RI is the Random Consistency Index.

The matrix for the calculation of the Eigen values and vectors is as follow;

$$Ax = \lambda x \quad (3)$$

$$\begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_n \end{bmatrix} = \begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_n \end{bmatrix}$$

3. RESULTS AND DISCUSSION

Table 1 shows the paired comparison matrix 1 with respect to the goal. The competing criteria are paired based on their relative importance to the overall goal. The more important pair takes higher value of integer and vice versa.

Table 1: The paired comparison matrix 1 with respect to the criteria

Criteria	A	B	C	D	Priority Vector (%)
A	1.00	5.00	7.00	9.00	46.30
B	0.35	1.00	5.00	7.00	30.90
C	0.33	0.35	0.90	2.00	13.50
D	0.22	0.50	0.24	1.00	9.300
Sum	1.90	6.85	15.40	20.00	100

The Eigen values and vectors presented in Table 2 was used in ranking the criteria in the order of their priorities

Table 2: The Eigen values and vectors for the criteria

x_i/λ_i	λ_1	λ_2	λ_3	λ_4
Eigen value λ	5.472	∞	0.1629	0.1629
Eigen vector x				
x_1	0.4030	1	0.9190	-0.9190
x_2	0.3690	0	-0.1585	0.1585
x_3	0.1350	0	0.2802	-0.2802
x_4	0.0930	0	-0.2271	0.2271

The maximum Eigen value λ_{max} is calculated thus;

$$\lambda_{max} = (0.4630)(1.90) + (0.3090)(6.85) + (0.1350)(15.40) + (0.0930)(20) = 6.920$$

The $CI = 0.97,\ RI = 0.99, CR = 9.83\%$

Since $CR = 9.83\%$ is less than 10%, the level of consistency is said to be high.

Table 3: The paired comparison matrix 2 with respect to the welding processes

Welding Process	1	2	3	Priority Vector (%)
1	1.00	1.00	9.00	57.69
2	1.00	0.90	2.00	34.4
3	0.50	0.24	0.10	7.91
Sum	2.50	2.14	11.10	100

Table 4: The Eigen values and vectors for the welding processes

x_i/λ_i	λ_1	λ_2	λ_3
Eigen value λ	3.659	-1.1184	0.3591
Eigen vector x			
x_1	-0.8637	0.9416	0.471
x_2	-0.4608	-0.2774	0.344
x_3	-0.2039	-0.1908	0.07911

The maximum Eigen value λ_{max} is calculated thus;

$\lambda_{max} = (0.5769)(2.50) + (0.344)(2.14) + (0.07911)(11.10) = 3.056$

The $CI = 0.0281,\ RI = 0.31, CR = 8.94\%$

Since $CR = 8.94\%$ is less than 10%, the level of consistency is said to be high.

Table 5: The paired comparison matrix 3 with respect to the welding processes

Welding Process	1	2	3	Priority Vector (%)
1	1.00	0.35	5.00	10.34
2	5.00	1.00	5.00	69.44
3	3.00	0.35	1.00	20.22
Sum	9.00	1.7	11.00	100

Table 6: The Eigen values and vectors for the welding processes

x_i/λ_i	λ_1	λ_2	λ_3
Eigen value λ	5.6387	-2.856	0.2173
Eigen vector x			
x_1	0.1034	0.7746	0.1019
x_2	0.6944	-0.2527	-0.9933
x_3	0.2022	-0.5797	0.0535

The maximum Eigen value λ_{max} is calculated thus;

$\lambda_{max} = (0.1034)(9.0) + (0.6944)(1.70) + (0.2022)(11) = 4.3352$

The $CI = 0.667,\ RI = 0.88, CR = 7.50\%$

Since $CR = 8.94\%$ is less than 10%, the level of consistency is said to be high.

The adjusted weight for Criteria A, B, C, and D are 0.5997, 0.400, 0.304 and 0.407 respectively. Table 7 shows the average and overall weight computed from the adjusted weight of the criteria for the welding processes.

Table 7: The average and overall weight

Welding Process	Weight	Overall weight
1	38.7326	34.015
2	48.732	51.92
3	13.640	14.065

From Figure 3, the welding process 2, Friction Stir Welding (FSW) and Metal Inert Gas (MIG) is considered most suitable process for the assembly operation of the rail car body with the highest values of the followed by the welding process 1 Laser Arc Welding (LAW) and the Resistance Spot Welding (RSW) which has the lowest values of the average and overall weight. The non-suitability of the RSW is connected with its characteristics of producing low strength thus failing to meet the crash worthiness and structural integrity denoted as Criteria A.

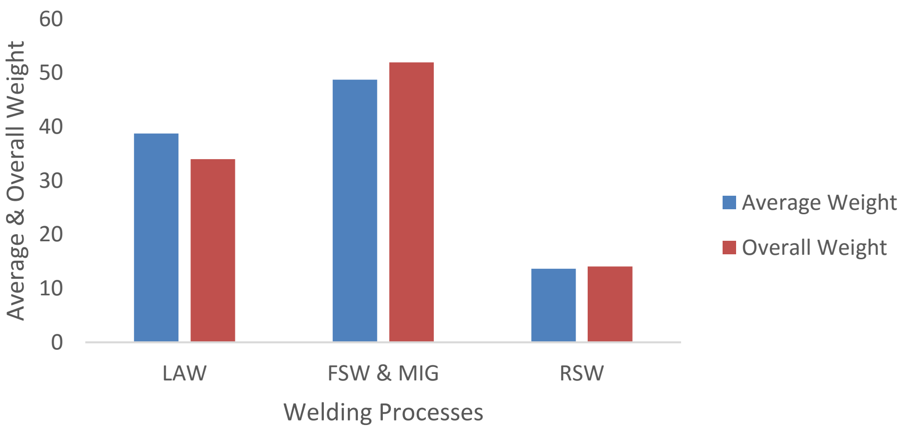

Figure 3: Average and overall weight for the welding processes

3 CONCLUSION

This study presents a scientific based methodology for evaluating and choosing the most suitable welding process for the rail car body shell. Based on the design, service and process requirements, the AHP was employed for structuring the Multi-Criteria Decision problem into hierarchy and ranking of the criteria with respect to the goals and alternatives. The Friction Stir Welding (FSW) and Metal Inert Gas (MIG) welding process was ranked first and considered most suitable for the rail car body shell assembly because of the weld features it presents such as the excellent mechanical properties and good surface finish which is in line with the selection criteria. The work also provides a decision support system as well as a framework for solving Multi-Criteria Decision Problem (MCDP) and sorting out alternatives according to their relative importance to the overall goal during the manufacturing operations of the rail car.

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DEVELOPMENT AND PERFORMANCE EVALUATION OF A HUMIDITY MEASUREMENT BENCH

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ABSTRACT

This work focuses on the measurement of humidity and airflow to ensure a comfortable atmospheric environment for both humans and machineries. The aim is to develop a bench that traps air which is blown out from a duct fan while air flow and the amount of water vapour in the air (humidity) is measured using a hygrometer, anemometer and a manometer. A bench that taps air and would effectively give a result with the accuracy of a precision thermometer for dry and wet bulb temperature calibration was developed. The materials employed for the development include; galvanized steel sheets, which was folded into a rectangular box for the housing of the measuring instruments and square pipes used for the frame and legs of the bench. The accuracy of the thermometer is ±0.05°C and resolution is 0.01°C. The findings of this study were confirmed using a temperature probe and measurement indicator. Test results revealed that effects of different parameters of the psychrometer in the measurement accuracy and stability of relative humidity.

Keywords: *atmospheric, calibration, humidity, water vapour*

1 INTRODUCTION

Humidity is the amount of water vapor present in the air and the amount of water vapour that is needed to achieve saturation increases as the temperature increases [1]. Higher humidity reduces the rate of evaporation of moisture from the skin, thus, reducing the effectiveness of sweating in cooling the human body. The fact that human beings uses evaporation by cooling and perspiration to get rid of waste in the body makes human highly sensitive to variation in humidity. Perspiration evaporates from the skin more slowly under humid conditions than under arid [2-4]. When there is a low rate of heat transfer from the body, which is equivalent to a higher air temperature, the body experiences greater distress of waste heat burden at high humidity than at lower humidity, given equal temperatures [5-6]. The combined effect of the temperature and humidity on the atmosphere's cooling effect on the human body is reflected by two indices namely; the heat index and the humidex [7-8].

In cold climates, the outdoor temperature causes lower capacity for water vapour to flow about. Thus, at high humidity relative to its temperature outdoors, the formation of snow may increase and once that air comes into a building and heats up, its new relative humidity will be very low, making the air very dry, which can cause discomfort and can lead to ill health [9-11]. (Although, dry air is good for those suffering from some lung disorders). The humidity of an environment is often affected by other climate variables such as winds and rainfall. The relative humidity of an air-water mixture is defined as the ratio of the partial pressure of water vapor in the mixture to the equilibrium vapor pressure of water over a flat surface of pure water at a given temperature which is normally expressed as a percentage; a higher percentage means that the air-water mixture is more humid. The accurate measurement of the relative humidity is an important data often used in weather forecasts and reports, as it can be analysed and used for the prediction of the likelihood of precipitation, dew, or fog. In hot summer weather, a rise in relative humidity increases the apparent temperature to humans (and other animals) by hindering the evaporation of perspiration from the skin [12-14].

Humans can be comfortable within a wide range of humidities depending on the temperature from 30% to 70% but ideally between 50% and 60% [15-17]. High humid conditions can cause waste accumulation in the body leading to infections, while very low humidity can also cause respiratory challenges and general bodily discomfort, thus, aggravating other allergies in some individuals. Extremely low (below 20%) relative humidities may also cause eye irritation [18-19]. Humidifier cooling efficiency is dependent on the temperature and humidity of the air introduced [20-21]. The cold-water humidifier on the other hand boast of efficient energy consumption and cost effectiveness. The highly humid environment are located close to the equator, near coastal regions [22-25]. For instance, cities in South and Southeast Asia are among the most humid and they experience very high humidity all year round because of their proximity to water bodies and the equator, hence, they need a reliable_weather forecast system for the prediction of changes in the weather.

Some places also experience extreme humidity during their rainy seasons combined with warmth while some experience high temperatures couple up with bizarre dew point to create high heat index. Some other countries experiences an extremely humid wet season from December to April while some experience extreme humid period in their summer months. During the South-west and Northeast Monsoon seasons (respectively, late May to September and November to March), heavy rains are expected with a relatively high humidity post-rainfall. The variation in humidity from one to season to another often affects the energy budget of some countries. Humidity influences temperatures in two major ways. First, water vapour in the atmosphere contains "latent" energy. During evaporation, the latent heat is removed from surface liquid, thereby, cooling the earth's surface. This is the referred to as the non-radiative cooling effect at the surface and compensates for roughly a substantial amount of the average net radiative warming at the surface. Second, since water vapor is the most abundant of all greenhouse gases, it is a "selective absorber" which absorbs the infrared energy emitted (radiated) upward by the earth's surface but transparent to most solar energy. This is the reason why the humid areas experience very little nocturnal cooling but dry desert regions cool considerably at night. This selective absorption causes the greenhouse effect as it raises the surface temperature substantially above its threshold radiative equilibrium temperature with the sun, hence, and water vapor is the major cause of global warming than any other greenhouse gas. As a greenhouse gas, with the characteristics of condensation and precipitation, it has a much lower scale height and shorter atmospheric lifetime [1]. Some of the various devices used to measure and regulate humidity include the gravimetric hygrometer, chilled mirror hygrometer and electrolytic hygrometer. The developed humidity measurement bench will allow users to explore the various methods available for the measurement of humidity. This is often a difficult concept to understand but is fundamental for the study of air conditioning and evaporative cooling methods (e.g. cooling towers). One of the challenges of the conventional hygrometer is its inability to carry out proper measurement properly above the frost point, but the use of a heated humidity probe can sufficiently address this challenge.

The aim of this work is to develop a laboratory apparatus that can be employed for humidity measurement and measure air flow properly in ducts and re-calibrate other materials of similar use. The work covers the processes of how to improve the humidity and airflow to ensure a comfortable atmospheric environment. This has not been sufficiently highlighted by the existing literature. The work also provides design data for a reliable weather forecast. In addition, the understanding of the variation in humidity and water vapour will help to mitigate the greenhouse effect and to address the issues of climate changes and global warming. Humidity measurements are required for meteorological analysis and forecasting. It also finds application in climate studies, and for many special applications in hydrology, agriculture, aeronautical services and environmental studies, in general.

2 MATERIALS AND METHOD

The experimental setup includes the development of a humidity measurement bench that measures airflow rate in a duct and relative humidity using different types of instrumentation. It has the capacity to carry out comparison of measurement methods for accuracy and ease of use.

2.1 Materials used

The following materials were used for the construction of the humidity measurement bench: steel duct fan, electric fan, orifice plate, manometer, hygrometer, anemometer, galvanized sheets and plates.

2.2 Design parameters for the Bench

The materials used in the fabrication of the bench are made of galvanized steel and square pipes to keep measuring instruments on it. They possesses good tensile strength to hold materials placed on it as well good balance and stability. The design for the measurement bench are shown in Figure 1 -4.

Figure 1: 3D Design of the Measurement Bench

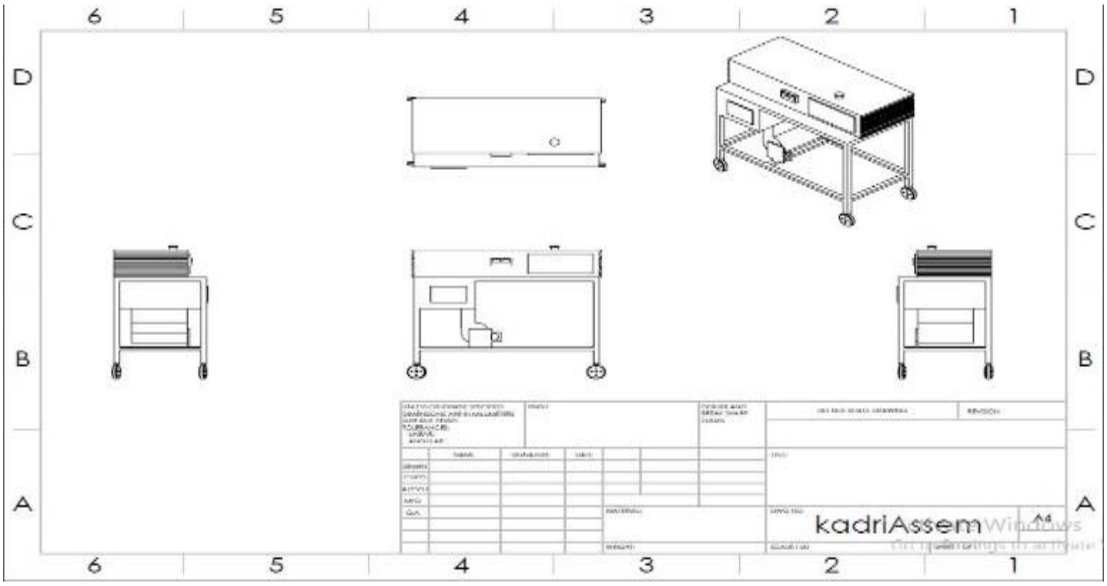

Figure 2: 2D Design of the measurement bench

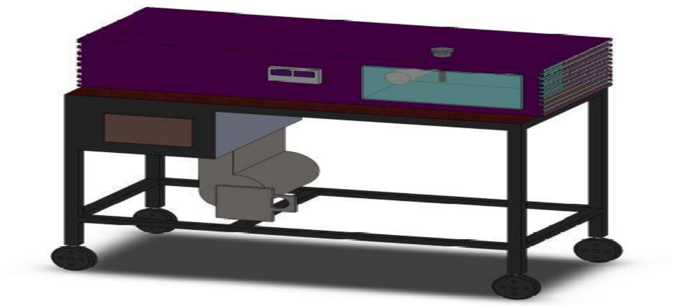

Figure 3: 3D Design of the measurement bench compartment

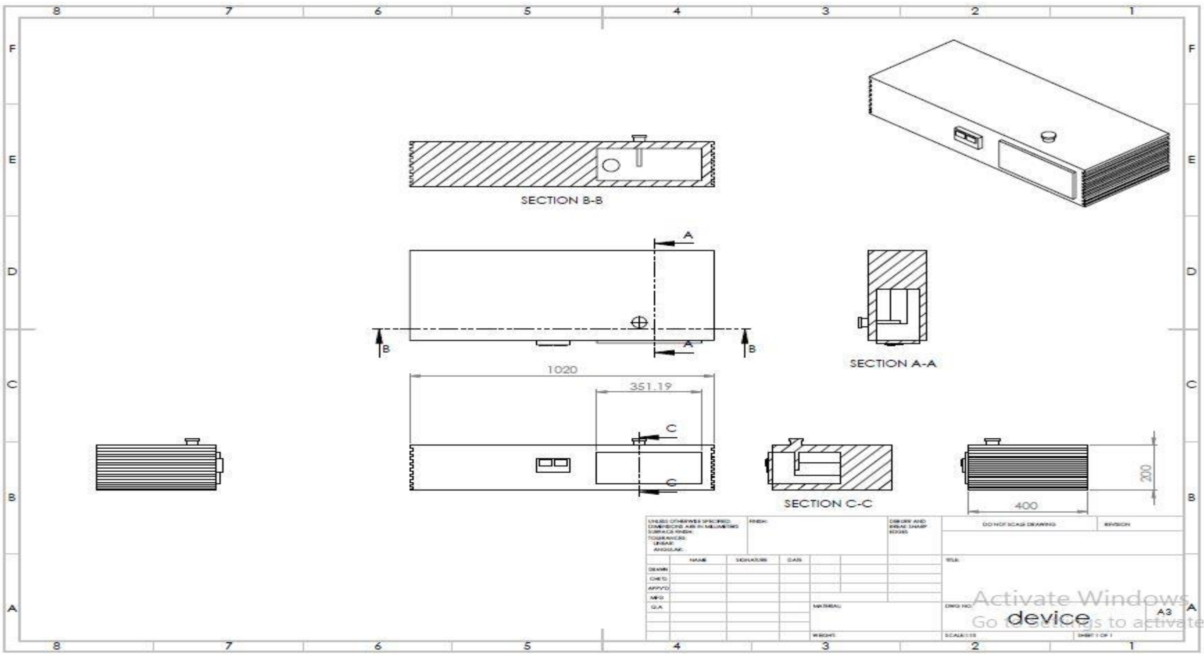

Figure 4: 2D Design of the Measurement Bench Compartment

2.3 Design considerations for the measurement bench

The surface area (A) and the space diagonal (d) is expressed as Equations 1 and 2 respectively.

$$A = 2(WL + HL + HW) \quad (1)$$

$$d = \sqrt{L^2 + W^2 + H^2} \quad (2)$$

Where;

H is the height of the bench (630 mm); L is the length of the Bench (1000 mm); W is the width of the bench (500 mm)

Therefore, the surface area (A) is calculated, thus, according to Equation 1.

$$A = 2(500 \times 1000 + 630 \times 1000 + 630 \times 500)$$

$$A = 2.89 \times 10^6\ mm^2$$

The space Diagonal (d) is calculated from Equation 2 thus,

$$d = \sqrt{1000^2 \text{ x } 500^2 \text{ x } 630^2}$$

$$d = 1283.32\ mm^2$$

The Weight W can be represented as a point load acting at the middle of the bench as illustrated in Figure 5.

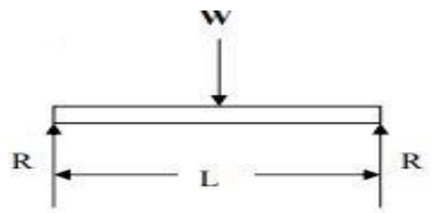

Figure 5: Weight acting at the middle of the bench

The vertical forces (R) are in a balanced position expressed as Equation 3.

$$R = \frac{1}{2}W \quad (3)$$

$$R = \frac{1}{2}(19.62) = 9.81\ N$$

But, the rotational effect of the force is not in a balanced position

If we take the moments about a pivot at the top of the support, the clockwise moment (M) is expressed as Equation 4.

$$M = \frac{1}{2}W \times \frac{1}{2}L = \frac{1}{4}WL \quad (4)$$

$$M = \frac{1}{4} \times 19.62 \times 1000$$

$$M = 4905\ Nmm$$

The clockwise moment is calculated as $4905\ Nmm$ while the anticlockwise moment equals to zero (from external forces).

So to be in a balance position, there must be a counter moment on the bench itself as shown in Figure 6

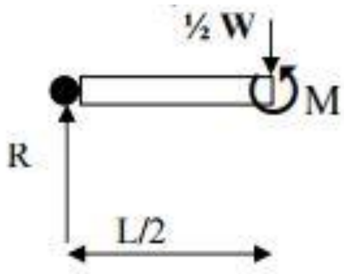

Figure 6: The schematics of the moment in the bench

Equation 5 expresses the bending stress caused by moment (M).

$M = \sigma.Z$ (5)

Where;

σ is the stress (N/mm^2); Z is the geometric property of the bench (mm^3) which is given as Equation 6.

Where;

$Z = \frac{Wd^2}{6}$ (6)

Where;

W is the width of the bench (mm), d is the thickness of the bench (mm).

2.4 Fabrication of the humidity measurement bench

The following processes were taken in the construction of the bench: the galvanized steel sheets were cut using the guillotine machine; A (1000 x 630 mm) square pipe was assembled to make the frame and legs of the bench; another set of sheets were rolled and welded into a rectangular box which was placed on top of the bench; A grinding disc was then used to smoothen the square pipes used for the frame and legs of the bench and sand paper was used to smoothen the surfaces and edges of the bench followed by painting to prevent corrosion. The developed humidity measurement bench is shown in Figure 7.

Figure 7: Construction of the measurement bench

The following processes were taken in the installation of the duct fan: A 8mm diameter pipe was connected to the fan, the fan was placed directly under the bench and the 8mm diameter pipe was passed through a hole carved out under the bench. A sensor was connected to the fan to allow a controller control the speed of the fan. The measuring instrument was placed inside the rectangular box were it takes readings of the humidity being formed as the duct fan passes air to the rectangular box.

3 RESULTS AND DISCUSSION

During the simulating and testing phase of the humidity measurement bench, various results were obtained.

3.1 Meteorological requirements

Humidity measurements are required for meteorological analysis and forecasting. It also finds application in climate studies, and for many special applications in hydrology, agriculture, aeronautical services and environmental studies, in general. General requirements for the range, resolution and accuracy of humidity measurements are given in Table 1. In practice, these were not easy to achieve. In particular, the psychrometer in a thermometer shelter without forced ventilation, still in widespread use, had significantly lower performance.

i. Accuracy is the given uncertainty stated as two standard deviations.
ii. At mid-range, relative humidity for well-designed and well-operated instruments are difficult to achieve in practice.
iii. For climatological use, a time-constant of 60 s is required (for 63 per cent of a step change).
iv. For climatological use, an averaging time of 3 min is required.

Table 1: Summary of performance requirements for surface humidity [26]

Requirements	Wet-bulb Temperature	Relative Humidity	Dew-point Temperature
Range	-10 to 35°C	5 to 100%	At least 50 K in the range -60 to 35°C
Target accuracy (uncertainty)	0.1 K high RH 0.2 K mid RH	42% high RH 5% mid RH	0.2 K high RH 0.5 K mid RH
Achievable observing uncertainty	0.2 K	3 to 5%	0.5 K
Reporting code resolution	0.1 K	1%	0.1 K
Sensor time-constant	20 s	40 s	20 s
Output averaging time	60 s	60 s	60 s

Some precautionary measures should taken to protect the humidity sensor from direct solar radiation as well as atmospheric contaminants, rain and wind and avoidance of the creation of a local microclimate within the sensor.

3.2 Environmental influences on the psychrometer

The measurement methods for relative humidity include the direct and indirect measurement methods. The direct measurement methods include the measurement principles of capacitive humidity sensor and resistive humidity sensor while the indirect measurement methods involve other methods of humidity measurement that does not expose the humidity sensitive device to the environment. The psychrometric measurement method is a typical indirect relative humidity measurement method, which measure the temperatures and then convert them into relative humidity (RH) values. The motivation to select two different distances to demonstrate that the effect of the distance between the water level and the wet bulb cannot be ignored. The first experimental set up involves the different distances between the wet bulb probe and the water level, at 20 mm and 70 mm. The variable was the airflow speed, which was changed from 0 m/s (stationary) to 4 m/s at 0.5 m/s intervals. The size of the wet cloth was 60 mm × 120 mm. The test results are shown in Figure 8, for the curves of the set up for 20 mm welt bulb prove and curve for the 70 mm wet probe respectively. The wet bulb temperature probe with a greater distance from the water level shows a lower measured temperature because the larger distance increased the rate of evaporation of the cloth. From left to right, the higher velocity of airflow also increased the evaporation process and decreased the temperature of the wet bulb.

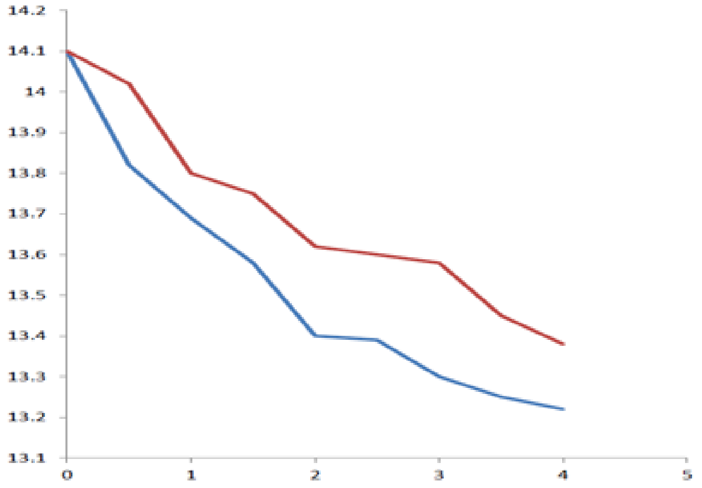

Figure 8: The relation between the airflow speed and wet bulb temperature (cloth size: 60 mm × 120 mm)

The influence of different cloth size to wet bulb temperature was examined in the second experiment. In the experiment, the cloth size was changed to 120 mm × 110 mm and other variables were same as in the first experiment. The experiment result shows, the evaporation process of small cloth size is faster than big cloth size (Figure 9). Again, from left to right, the higher airflow speed increased evaporation process and decreases the temperature of wet bulb.

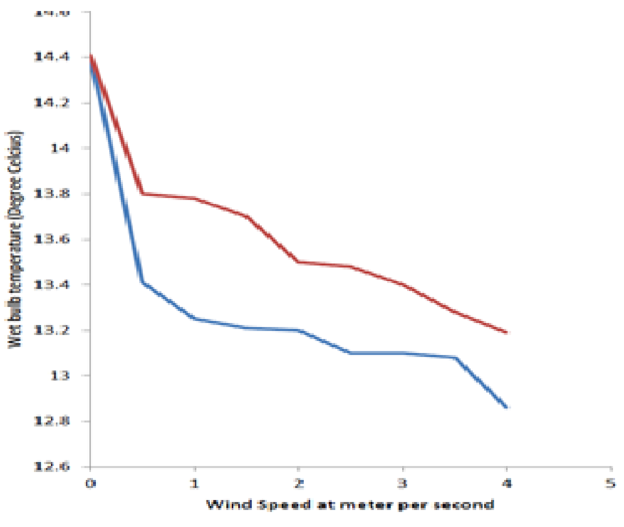

Figure 9: The relation of the airflow speed with wet bulb temperature (Cloth Size: 120 mm x 110 mm)

The influence of environmental factors are shown in Figure 8 and 9, which include the airflow speed distance between wet bulb and water level, and wet bulb cloth size on the psychrometer. A larger distance between the wet bulb and water level increased the evaporating process and decreased the wet bulb temperature. The higher airflow speed increased the evaporating process and decreased the wet bulb temperature. Lastly, comparing the curves in Figure 8 and Figure 9, the different cloth sizes also caused the wet bulb temperature to change. It was observed that the temperature of wet bulb to decrease faster with the small cloth as opposed to the big cloth. The results obtained was similar to the results obtained by Zhang et al. [26] during the performance evaluation of the relative humidity measurement methods developed. Based on the above results, the sensitivity of wet bulb temperature to the variation of various environmental factors was estimated. At a constant airflow speed of 2 m/s, different cloth sizes caused 0.2˚C uncertainty in the wet bulb temperature. The different distances between wet bulb temperature probe to water level added 0.3˚C uncertainty, and if the air flow speed changed from 2 m/s to 0.5 m/s then the uncertainties would increase approximately by 0.3˚C. The total change was approximately 0.8˚C of the measured wet bulb temperature value.

3.3 Discussion of results

There are several key factors were chosen to improve measurement accuracy. These factors includes the distance between the dry and wet bulb probes, wet cloth size, the distance between the wet bulb and water, the distance from blow fan to dry bulb and wet bulb probe, the air direction from fan to wet bulb probe and the air flow speed. The accuracy of resistance temperature detectors, and signal conversion. A dry well and precision thermometer were used for dry bulb and wet bulb temperature calibration. The accuracy of the thermometer is ±0.05˚C and resolution is 0.01˚C. The humidity and temperature probe and measurement indicator were used as a confirmation instrument. Table 2 shows the calibration results of humidity and temperature for the probe.

Table 2: Calibration Results of the Humidity and Temperature

Humidity/Temperature	Measured Value 1 Unit	Measured Value 2 Unit	Measured Value 3 Unit
Reference relative humidity	+33.1% RH	+54.0% RH	+74.7% RH
Reference temperature	+22.06 °C	+22.05 °C	+22.05 °C
Observed relative humidity	+33.7% RH	+54.5% RH	+74.9% RH
Observed temperature	+22.06 °C	+22.04 °C	+22.05 °C
Relative humidity difference Permissible relative humidity difference	+0.6% RH ±1.0% RH	+0.5% RH ±1.0% RH	+0.2% RH ±1.0% RH

3.4 Measurement accuracy of the improved psychrometer

The improved psychrometer and the relative humidity measurement instrument (comprising of the humidity and temperature probe with measurement indicator) were tested. The test results of the improved psychrometer and the humidity measurement instrument are shown in Figure 10.

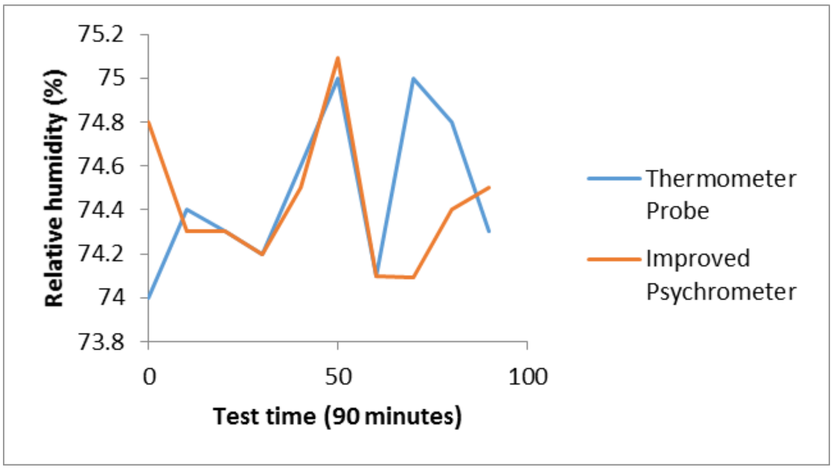

Figure 10: Comparison of measurement accuracy between the improved psychrometer and relative humidity instrument

The measurement error is specifically the difference between the improved psychrometer measurement value and the measurement value of humidity measurement instrument. The measurement value obtained for the improved psychrometer was observed to be in close agreement to the measurement value of the humidity measurement instrument. The deviation between the two instruments was less than ±0.5% RH. According to the certified accuracy of the humidity measurement instrument, the measurement accuracy of the improved psychrometer was ±0.6% RH.

3.5 The influence of temperature in the measurement accuracy of relative humidity

It was also observed that temperature directly influences relative humidity measurement accuracy and stability. The effect of the varying factors in the relative humidity measurement can be evaluated using Table 3. The coupling relationship of temperature and relative humidity close to the values of 13˚C and 73% RH are given in Table 3. Table 3 shows the coupling relationship of temperature and relative humidity.

Table 3: The Coupling Relation of Temperature and Relative Humidity at the Proximity of 13 ˚C and 73% RH.

Humidity/Temp.	Observations								
	1	2	3	4	5	6	7	8	9
Temperature (˚C)	11	11.5	12	12.5	13	13.5	14	14.5	15
Relative humidity (% RH)	83.3	80.6	78	75.4	73	70.7	68.4	66.2	64.1

Based on Table 3, the temperature change of ±1˚C will lead to the relative humidity change at least 4% RH.

4 CONCLUSION

The work describes the development and testing of a humidity measurement bench using a duct fan and several measuring instruments like the hygrometer, manometer and anemometer that measures airflow rate in a duct and relative humidity using different types of instrumentation and also have the capacity to carry out comparison of measurement methods for accuracy and ease of use.

The work also shows the limitation of the use of the psychrometer which may be fragile in harsh conditions and repeatability can be dependent on user interpretation of temperature measurements. Test results revealed that effects of different parameters of the psychrometer such as the distance between the water level and the wet bulb on the measurement, accuracy and stability of relative humidity. The work finds application in meteorological analysis and forecasting, climate studies, and for many special applications such as in hydrology, agriculture, aeronautical services and environmental studies.

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BUILDING BLOCKS FOR CONTINUOUS IMPROVEMENT: RESULTS OF THE ENERGY MANAGEMENT PILOT PROJECT IN SOUTH AFRICAN FOUNDRIES

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ABSTRACT

The manufacturing Industry is one of the cornerstones of hope for a brighter future in Africa, and is pivotal in ending poverty through the creation of decent work [1]. The challenge of globalisation, rising input costs, a changing world with new technologies, the fourth industrial revolution, as well as a lack of skills, make this dream difficult to attain [2, 3]. Business often looks to changes in government policies or legislation to reduce input costs or to protect markets; or, alternatively, how to secure funding to invest in new technologies, as a quick-win solution to improve competitiveness. In times of economic distress, business often overlooks the power of continuous improvement to become globally competitive. The South African foundry industry is a classic example of a mainly SME industry in distress, supported by various government programmes to improve competiveness [2]. The Innovation Hub funded a pilot energy management project to assist foundries to reduce energy costs. The purpose of this paper is to evaluate this pilot project through the lens of continuous improvement. It firstly gives an overview of the South African foundry industry and the challenges related to energy costs and then reviews Deming's contribution to the understanding of continuous improvement and learning. Finally, we discuss the pilot project according to the PDSA cycle and highlight how we used elements of Industry 4.0 to complement the PDSA cycle.

Keywords

Continuous Improvement, PDSA, Energy Management in Foundries, Pilot Project, Learning, Feedback Systems, Industry 4.0, Collaboration

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*Corresponding author

1 INTRODUCTION

> *"The aim of leadership should be to improve the performance of man and machine, to improve quality, to increase output, and simultaneously to bring pride of workmanship to people. Put in a negative way, the aim of leadership is not merely to find and record failures of men, but to remove the causes of failure: to help people to do a better job with less effort."* W. Edward Deming. [4, p. 268]

Continuous improvement is synonymous with W. Edward Deming (1900-1993). In the words of a friend and close associate, Prof Neave: "Deming's life's work was all about providing guidance for how to improve, to make things better, and to stop doing things which cause harm and make things worse" [5].

"T*he man who discovered quality* " [6], is often credited as the management philosopher and consultant who was instrumental in the economic recovery of post war Japan as well as for the rise of quality as a strategic approach in the 20th century [7].

In the early 1950's Deming worked closely with the Japanese government and industry leaders to find a way forward after World War II. To help them out of their crisis, he not only taught them statistics, but his teachings focused in great detail on the theory of a system of cooperation, to assist them to integrate their uncoordinated efforts into a system of production [5]. He was a kind man who treated the Japanese with warmth and respect. The founders of Toyota have drawn particular inspiration from Deming's work. The fact that their culture, which is the cornerstone of the Toyota Production System (TPS), is built on the two pillars of continuous improvement and respect for people, is a beautiful tribute to their appreciation of Deming's teachings and contribution [8]. The lean production methodology evolved from TPS and has been adopted worldwide as a production methodology. The golden thread of respect and continuous improvement is embedded in one of the core principles of leanness, namely the striving for perfection.

In the late seventies the American manufacturing industry was in serious trouble and could not keep pace with Japan. In 1980, Deming featured in an NBC television programme called "If Japan Can, Why Can't We?" At this late stage of his life Deming found renewed inspiration and his teaching greatly broadened and deepened to help people gain knowledge of transformation to a new style of management [5].

> "*As the world grows even more complex and often more cruel, and as technology increasingly provides opportunities to do greater good but, if misused, can also do greater harm, do we not increasingly need the help of the Deming philosophy—its values, its principles, its logic, its practical guidance?" Prof Henry R. Neave* [5]

In a time when Africa is in deep need of transformation, would it not perhaps be fitting to revisit and explore this transformation expert's profound contribution to promoting continuous improvement; to draw inspiration and compare our continuous improvement efforts with the building blocks he recommends? Maybe, if we listen carefully, we can learn how to create a better future for Africa.

2 FOUNDRY INDUSTRY BACKGROUND

Globally foundries can be seen as the backbone of the manufacturing industry and are key contributors to the development of both the economy and civilisation [9]. According to statistics provided by the South African Institute of Foundrymen (SAIF), South Africa has 170 foundries ranging from small, medium and micro enterprises (SMME) jobbing foundries to large mass production foundries, with 66% of the foundries located in the Gauteng area. South African foundries are struggling to be internationally competitive, and local production volumes have decreased since the early 2000's by more than 25 % [10].The local foundry industry has a similar SME profile to the global industry, with 80 % of companies employing fewer than 250 people [9].

The South African government recognises the importance of foundries and has identified metal fabrication, capital & rail transport equipment as one of the key sectors to drive economic growth in the Industrial Policy Action Plan (IPAP) (2018/2019 - 2020/2021). The DTI initiated the National Foundry Technology Network (NFTN) as an action programme in the metals sector aimed at revitalising the foundry industry through skills and enterprise development [2].

At a recent industry workshop in May 2019, Dr Andrew de Vries, general manager of the Smart Industries Unit of The Innovation Hub, a wholly owned subsidiary of the Gauteng Growth and Development Agency, announced that one of the focus areas of the Smart Industries Unit will be on Foundry 4.0 with the aim of supporting the industry through incremental innovation and skills transfer that will enhance connectivity, productivity and efficiency within foundries. The support for foundries will be largely through the organisation's open innovation exchange programme known as OpenIX.

The Technology Implementation Agency (TIA) is managing the technology station programme on behalf of the Department of Science and Technology. Both the Process Energy and Environmental Technology Station (PEETS) and the Metal Casting Technology Station (MCTS), are based at the University of Johannesburg and support the foundry industry through various interventions and skills development programmes

The metal casting industry is a resource-intense industry, and one of the most energy-intensive manufacturing sectors. A survey conducted by the National Foundry Technology Network in conjunction with the BRICS Foundry Association, shows that energy costs contribute 16 % of the total manufacturing cost in South African foundries. This is higher than the other BRICS countries, whose energy costs vary between 8.5 % and 15 % of the total manufacturing cost (Figure 1) [3].

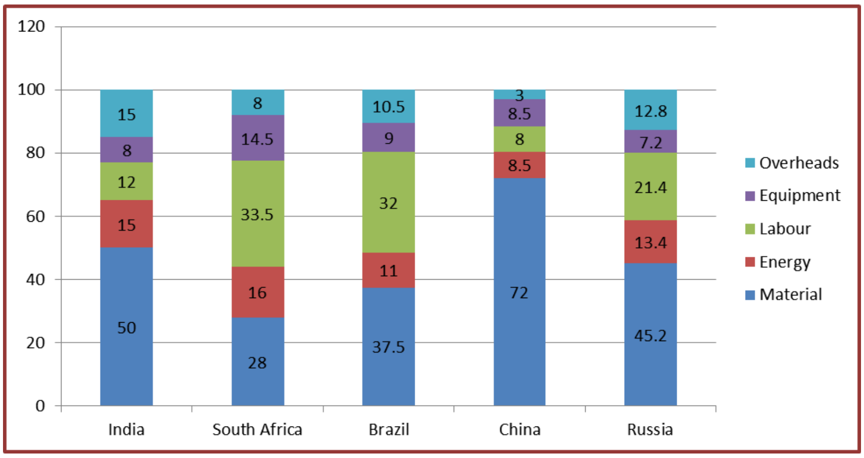


Figure 1 : Combined production cost structure of BRICS Iron Foundries [3]

Since 2008, South African foundries have not only been subjected to drastically increased energy prices, but have also experienced additional pressures due to power supply constraints and stricter environmental law restrictions. Management often believes that focusing on the installation of energy efficient equipment, or pressurising government to reduce electricity tariffs are the only means to reduce the energy cost, leaving foundries "paralysed" to address the issue of energy cost reduction.

3 PDSA CYCLE

When performing research on continuous improvement, one will inevitably come across the concept of the Plan-Do-Check-Act cycle (PDCA). The PDSA or PDCA cycle is a methodology which consists of a logical sequence of four repetitive steps for continuous improvement and learning, namely: Plan, Do, Study (Check) and Act, and is also known as the Deming Cycle [11].

But, according to Ron Moen who interacted with Deming directly during the 1983 – 1993 period, and who has written an excellent article on the foundation and history of the PDSA cycle [12], Deming himself had a major concern referring to the PDSA cycle as the PDCA cycle or the Deming cycle. In the paragraphs below, we will briefly summarise the history of the PDSA and PDCA cycles and, explain the differences as described in the article by Moen [12].

The origin of these cycles are a simple straight-line sketch, representing the mass production process (specification, production, inspection), by Dr. Walter Shewhart (Figure 2) [12]. He went on to modify the initial straight-line representation to a circle (cycle). Shewhart explained the change as "these three steps must go in a circle instead of in a straight line. It may be helpful to think of the three steps in the mass production process as steps in the scientific method. In this sense, specification, production and inspection correspond to making a hypothesis, carrying out an experiment and testing the hypothesis. The three steps constitute a dynamic scientific process of acquiring knowledge". [Figure 2] [12].

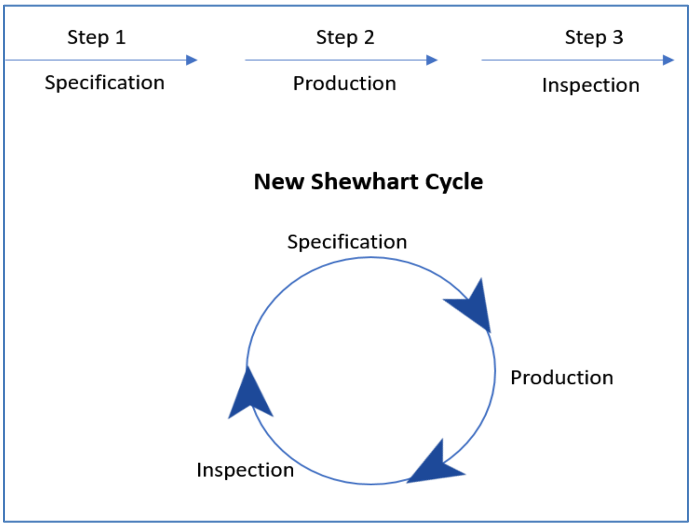


Figure 2: Shewhart Cycle [12]

In 1939 Deming edited Shewhart's book and modified the Shewhart cycle. In 1950, he presented the modified version at a Japanese Union of Scientists and Engineers (JUSE) seminar on statistical quality control for managers and engineers. He added a fourth step: Step 4 - redesign through marketing research. Deming stressed the importance of constant interaction among design, production, sales and research, and that the four steps should be rotated constantly, with quality of product and service as the aim [12].

In 1951, the Japanese modified and generalised the cycle presented by Deming at the JUSE seminar, into the Plan-Do-Check-Act (PDCA) cycle, which they named the "Deming Wheel" (or Deming Circle). The Japanese PDCA version was further refined and, together with the seven basic tools (check sheet, histograms, Pareto chart, fishbone diagram, graphs, scatter diagrams and stratification) and the QC story format, became the foundation for improvement (kaizen) in Japan and are still used today.

In 1986 Deming reintroduced the Shewhart cycle, which he emphasised came directly from his 1950 version, not from the modified Japanese version. Figure 3 illustrates the procedure to follow for improvement.

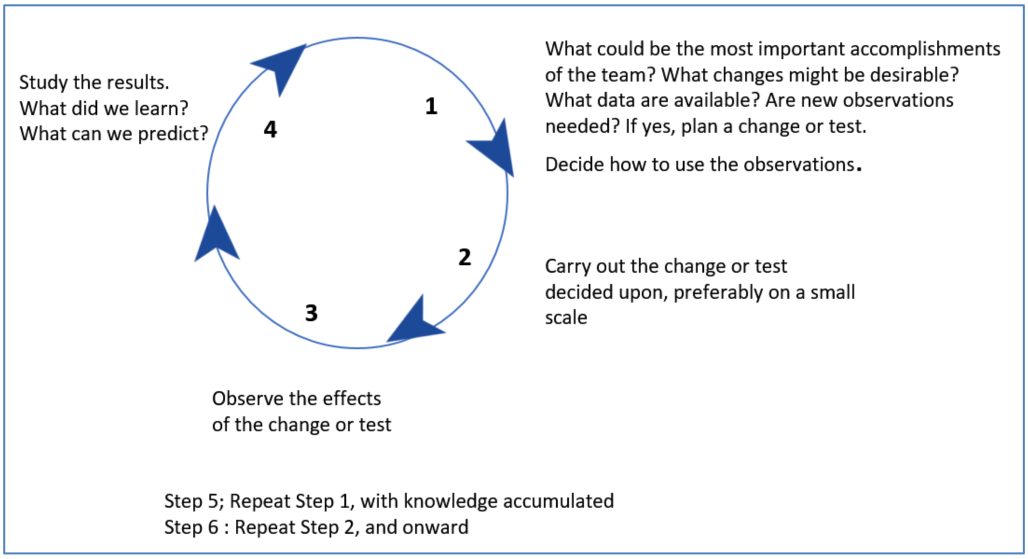


Figure 3 : Shewhart Cycle: Deming, 1986 [12]

As described on the website of the Deming Institute [13], Deming strongly supported his PDSA Cycle, not the PDCA Cycle, with the emphasis on Study (S) as the third step, not Check (C). Deming expressed his concern that the word 'Check' focuses more on the result of the implementation, namely success or failure, followed by corrective actions to the Plan in the case of a failure. Whereas the 'Study' phase, as described in his model, focuses on predicting the results of an improvement effort, studying the actual results, and comparing them in order to possibly revise the theory. He also emphasised that the need to develop new knowledge, from learning, is always guided by a theory.

In 1991, Moen, Nolan and Provost added these additional details to the Planning and Study steps of the Shewhart cycle. [14] They modified the planning step to include that an associated theory is required as well as a prediction of the result. The study step was amended to include that the observed data should to be compared to the prediction to form a basis for learning. It is not enough to determine that a change resulted in improvement during a particular test [12]. As you build your knowledge, you will need to be able to predict whether a change will result in improvement under the different conditions you will face in the future. Langley, Nolan and Nolan [16] added three basic questions to supplement the PDSA cycle in their Model for Improvement. Both the detailed cycle and the model with all the additions are given in Figure 4 [14].

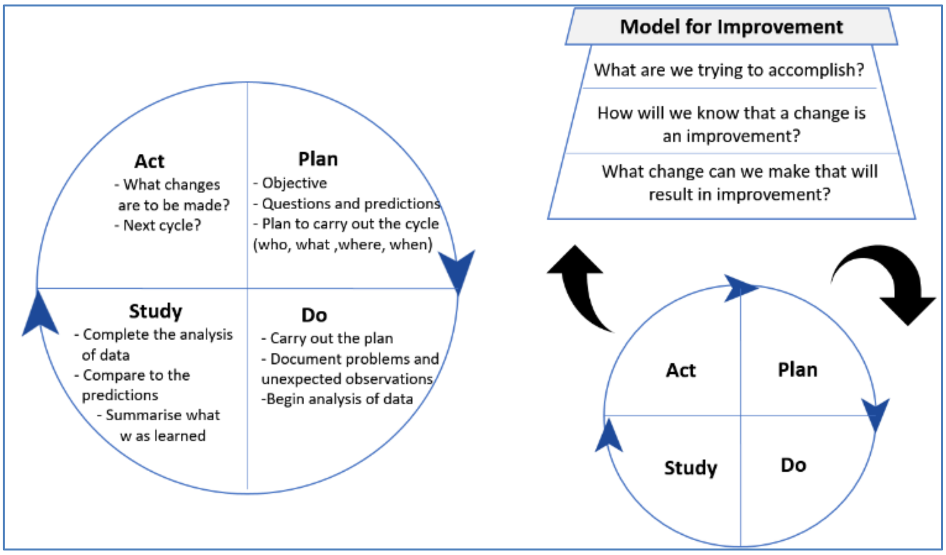


Figure 4: PDSA Cycle and Model for Improvement, 1991, 1994 [14]

The cycle was rightfully renamed Shewhart's Cycle for Learning and Improvement - the PDSA Cycle. Shewhart already recognised the correlation between improvement and learning from the earliest stages. It is in essence a flow diagram describing the 'how' of learning, and of improvement of a product or of a process, with the critical aspect the prediction and the implicit theory upon which the prediction is based.

Unfortunately, the successful implementation of a continuous improvement culture in a manufacturing environment is more complex than just following the PDSA cycle to the letter. In the next section, we will explore how Deming suggests we create an environment where the PDSA model can flourish, changing stagnation into one of continuous improvement and organisational learning.

4 PILOT PROJECT DISCUSSION

This pilot project was an intervention programme specifically developed to assist foundries to reduce energy costs and to introduce Industry 4.0 concepts. In other words, to complement the process, rather than just be a research project. In the light of Deming's approach to continuous improvement, as discussed in Section 3, we will evaluate this project according to the PDSA cycle.

4.1 PDSA Cycle

4.1.1 Plan

In the never-ending search for achieving greater competitiveness as well as the discourse surrounding the Fourth Industrial Revolution, South African foundries cannot afford to find themselves left behind. The Innovation Hub in collaboration with Concepts 4.0, an SME knowledge-based company, and PEETS piloted an Energy Management project in three Gauteng-based, ferrous foundries with the following objectives:

- Reducing the energy costs in foundries, with a project target of 10 % identified saving opportunities
- Introducing elements of Industry 4.0 onto the foundry shop floor, such as real-time data recording, visualisation, analysis of data, cloud-based data, online support and communication
- Capacity building in the understanding of the elements of Energy Management, how operational practices influence energy cost, as well as an introduction to the elements of Industry 4.0
- Integrating the energy management activities into the existing company's operational systems and processes to support and sustain the improvements in the long term

To achieve the objectives, the action plan included the following:

- Analysis of data
- Develop and implement a cloud-based dashboard system, utilising Industry 4.0 elements
- Combine formal training sessions with interactions on the shop floor to create a basic understanding of energy management concepts and exploring the influence of operational practices

Three Gauteng-based ferrous foundries were selected to participate. The diversity of the participating foundries, from mass production to jobbing foundries as well as the different technologies employed, provided a further learning opportunity for the group.

4.1.2 Do

4.1.2.1 Analysis of Data

After the initial learning workshops where the basics of electricity tariff structures and the impact of operational practices on energy costs were unpacked, the team followed a systematic approach to perform an analysis of the electricity tariff structure and the historical energy costs. We differentiated between maximum demand and network access charges, which are both related to the maximum kVA, and consumption charges related to kWh consumed. We further distinguished between savings related to load shifting to cheaper periods in line with the time of use (TOU) tariff and a reduction in consumption (kWh) due to improved energy efficiency.

We established the energy consumption of each major piece of equipment. PEETS assisted with the recording of data from the compressors and subcontractors were used to measure the high voltage equipment, such as the furnaces. We performed linear regression to establish the correlation between energy consumption and output.

4.1.2.2 Cloud-based System

Part of the project scope was to develop and implement a cloud-based dashboard system, to not only demonstrate some Industry 4.0 elements, but also to provide a feedback and collaboration tool and promote transparency.

We utilised free online tools such as Google Drive and Zapier to build a cloud-based system which integrates electricity data from the council's real time recording with production data. The user interface is a Google sites website, easily maintained by the internal staff. The data is displayed in different formats to assist with understanding the different cost elements, and the interactive screens assist with drilling down into detail or zooming out to see long-term trends. The system also includes a library where company information can be uploaded and shared. The system is accessible from computers as well as mobile devices and is shared with all key personnel.

Initially the IT departments were sceptical as to the capability of the data capturers to work on a cloud-based system, but we spent time teaching them the basic digital skills, as well as the importance of data accuracy, and how to do some fault finding. With the help of the IT, financial and technical teams, the system was successfully implemented and is now used in daily production and management meetings as a learning tool, driving decision making and building business intelligence.

Initially management saw this system as a control tool, but in essence this is a learning tool promoting organisational learning. Companies should install control systems such as maximum demand controllers to physically set the limits of the maximum demand. It is, however, very important to continuously study the trends and understand your system in order to identify improvement opportunities. This system is supporting the 'Study' action in the PDSA cycle, and was instrumental in driving the awareness and broadening the company knowledge to include different perspectives - the view through a maintenance, financial or production lens.

4.1.2.3 Learning

A core theme of this project was learning and breaking the silos. We designed the programme to include participants from different companies and departments, as well as organisational levels and demographics, enabling us to broaden our knowledge base and incorporate their different perspectives into the learning experience.

During this project we focused on building the following skills:

- Understanding electricity tariff structures and how operational practices influence the cost of electricity
- Data analysis from collected data, presenting data, reading and interpreting graphs
- Continuous improvement
- Digital skills
- Teamwork and problem solving

Two candidates per pilot plant, one representing melting (production) and the other finance were selected to participate in the formal training sessions. During the capacity building at the foundries we followed different approaches for each foundry to fit in with their current working conditions. Informal training, brainstorming, discussions and learn-while-we-work sessions with management, maintenance and production were arranged to explain the basics of the electricity cost structure, reading and interpreting graphs, as well as how operational practices influence energy cost. In cases where the participants were familiar with basic digital skills, focus were given to system development, data analysis and regression.

Management of all the participating foundries agreed to share the details of the electricity bill per cost element with the workforce and assisted greatly in being more transparent and drive the learning process.

We believe the inclusion of a diverse group as project participants, was key to the success of the project.

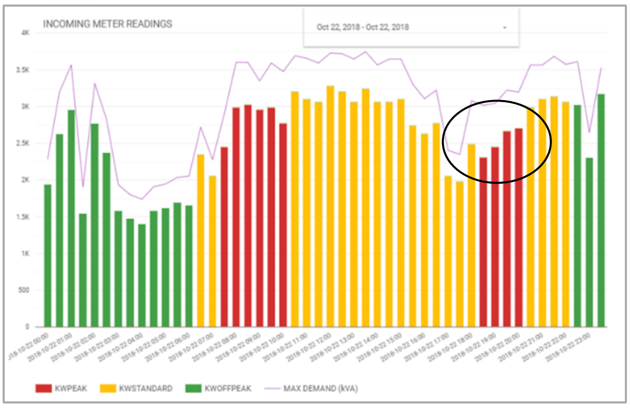
4.1.3 Study

Broadly, this paper is part of the 'Study' action of the overall project. In this section we will specifically focus on how we experienced the 'Study' element at the foundries during the implementation of the project.

During the literature review of the history of Deming's PDSA cycle, we re-discovered what we call the 'S-factor'. From our experience of the reality on a factory shop floor, we agree with Deming. 'Check' represents a go-no-go action, an instant decision which does not necessarily allow time for reflection or activate deeper level thinking. In this project, we saw the benefit of using the cloud-based system as an instrument to promote the 'Study' action, as described in Section 3, assisting foundries to move away from what we call emotional decision making to data-driven decision making and building a collective company knowledge base. Below we will discuss a few examples of our study experience during the project and highlight the improvement opportunities identified.

Afternoon Peaks

After the initial analysis we identified a case where one foundry was melting during the afternoon peak periods. In discussion with management they disagreed and assured us that the staff was aware of the peak periods and only started melting after 22h00. Only after we presented the data graphically (Figure 5), did they realise that this was not the case. After our training sessions and sharing the information with the workforce, the profile of the afternoon energy consumption improved drastically, as can be seen in Figure 6.



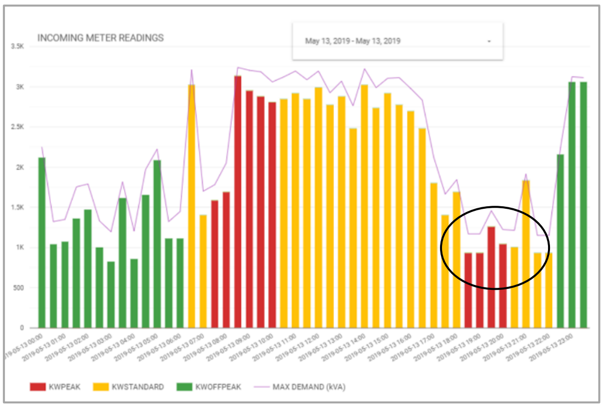


Figure 6: Energy Consumption Graph 22 October 2018

Figure 5: Energy Consumption Graph 13 May 2019

KVA related charges (maximum demand and network access charges) have increased drastically since 2008, and constitute between 30 % and 34.35 % of the total electricity costs in the participating foundries (Table 1).

Table 1: Breakdown of Energy Costs per Charge Type

Foundry	Consumption Charges	Max Demand Charges	Network Access Charges
Foundry A	68.87%	19.15%	11.98%
Foundry B	70.09%	17.01%	12.90%
Foundry C	65.65%	34.35%	

In our attempt to understand maximum demand, we prepared a table, indicating the maximum demand (kVA) reached per half hour interval for a three-day period from 06:30 and 21:00, and highlighted the values in excess of 7500kVA in grey (Table 2). The maximum demand for this period was 8616 kVA, reached at 11:00 on the 5/2/2019. Maximum demand in periods just before or after the highest demands, is significantly lower and, with careful planning and improved communication, the load could be shifted to reduce the maximum demand.

Table 2 : Maximum Demand Analysis: 2019/02/04 - 2019/02/06

TIME	TOU TARIFF	2019-02-04	2019-02-05	2019-02-06
6:30:00 AM	Standard	4305	6566	6480
7:00:00 AM	Standard	2580	3019	7191
7:30:00 AM	On Peak	3200	4757	8000
8:00:00 AM	On Peak	4659	5297	5874
8:30:00 AM	On Peak	4874	6155	6155
9:00:00 AM	On Peak	6659	7241	6848
9:30:00 AM	On Peak	4010	5248	6788
10:00:00 AM	On Peak	4446	4457	5364
10:30:00 AM	Standard	5248	5724	5901
11:00:00 AM	Standard	3578	8196	7586
11:30:00 AM	Standard	7367	7018	7025
12:00:00 PM	Standard	7018	5697	7707
12:30:00 PM	Standard	3906	4010	5598
1:00:00 PM	Standard	3906	4874	6012
1:30:00 PM	Standard	6597	5883	5589

TIME	TOU TARIFF	2019-02-04	2019-02-05	2019-02-06
2:00:00 PM	Standard	6180	6480	5874
2:30:00 PM	Standard	5278	7746	6659
3:00:00 PM	Standard	4048	4615	5874
3:30:00 PM	Standard	5874	2950	5468
4:00:00 PM	Standard	5170	4457	3535
4:30:00 PM	Standard	6336	3263	2560
5:00:00 PM	Standard	6566	5160	6213
5:30:00 PM	Standard	2950	8400	3200
6:00:00 PM	Standard	1723	5874	7464
6:30:00 PM	On Peak	2263	5160	6803
7:00:00 PM	On Peak	3649	5874	6213
7:30:00 PM	On Peak	3461	4582	8196
8:00:00 PM	On Peak	6012	4885	5952
8:30:00 PM	Standard	5883	3649	3649
9:00:00 PM	Standard	7297	3732	6012
TOTAL PERIOD		**7367**	**8616**	**8196**

Linear Regression

We performed regression analysis to derive the correlation between the tons melted and consumption (kWh). The graph below shows a correlation with a correlation coefficient of 95.2 % (Figure 7). The slope of the regression line is 1270 and related to the amount of energy required to melt one ton of metal in this specific foundry. The intercept is 493 092 and indicates the fixed portion of energy consumed for the period (in this case a month), which is not directly related to the melting of metal.

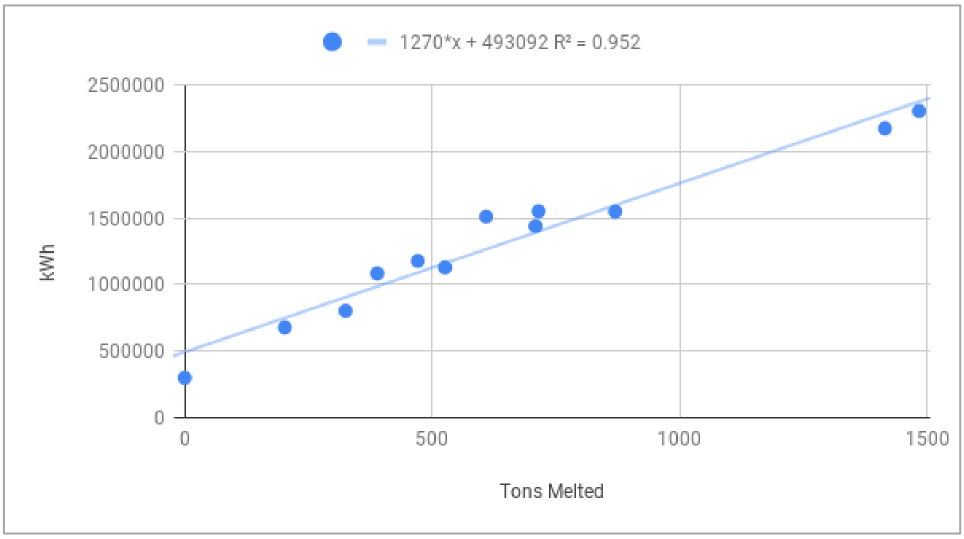


Figure 7: Linear Regression: 2017 Tons Melted vs Electricity Consumption

This equation can be used to establish the base line and to determine if there is an improvement in consumption. Unfortunately, the project duration was too short to fully explore utilising linear regression as a prediction tool, but should be explored in the future and used by foundries to predict and evaluate continuous improvement.

4.1.4 Act

Savings opportunities to the value of R9.85 million, based on the 2018/19 tariffs, were identified, resulting in a 16.24 % potential saving on an annual electricity expenditure of R60.5 million. We only included savings that were realistic to implement with no major investment, and agreed to by the team. Table 3 summarises the savings per category.

Table 3 : Summary of Potential Savings

Focus Area	Foundry A	Foundry B	Foundry C
Max Demand Savings	30.63%	19.02%	31.67%
Consumption Savings - TOU	7.92%	5.16%	3.53%
Consumption Savings - Reduction	5.00%	5.00%	5.00%
Total Savings Identified	**18.39%**	**13.14%**	**18.11%**
Average Saving Identified			16.28%

The typical cost structure of a South African foundry, as described in the BRICS Iron Foundry Survey Report [3], is summarised in Table 4 in the 'Before Savings' column, indicating that electricity cost is 16 % of the total cost. Effectively, a 16.28 % electricity reduction, reduces the electricity cost component from 16% to 13.39 %, resulting in an overall potential saving of 2.61 %, as shown in the 'After Savings' column of Table 4.

Table 4: Impact of energy savings on total cost

Cost Element	Before Savings	After Savings
Material	28.00%	28.00%
Labour	33.50%	33.50%
Electricity	16.00%	13.39%
Other	22.50%	22.50%
Total Cost	**100.00%**	**97.39%**
Potential Overall Cost Saving		**2.61%**

It is often stated that South African foundries are 20 % - 30 % less competitive on pricing than other BRICS foundries. If a single intervention can identify opportunities to reduce the overall cost by 2.61 %, it should encourage foundries to explore how a continuous improvement culture could help to reduce the gap significantly.

At a company level, the management of all the participating foundries committed to implement the identified opportunities and incorporate the lessons learnt during the project into their operations, specifically how to embrace the 'Study' element amidst the pressures of running production and to promote collaboration and sharing of knowledge between departments and different organisational levels. The introduction of additional Industry 4.0 elements should be further explored to not only enhance production control but also collaboration and learning. Specific attention should be given to developing data analytics to include predictions.

At a project level, a few recommendations to take into consideration for future energy management intervention projects are:

- An initial combined orientation workshop with top management of all participating foundries as well as participants, to stress the scope of the project and get the buy-in of the top management in the initial stage, and not halfway through the project.
- The cloud-based system should be set up prior to the initial training sessions. This will enable learning, and change the approach from checking the results to studying, from the onset of the project, giving more time to entrench this practice.
- Additional training on data analysis is required, specifically how linear regression could be used as a tool to track continuous improvement.
- Although this programme highlighted some aspects of building a continuous improvement culture, an in-depth programme should be developed to equip leaders on how to build a culture of continuous improvement and respect to enable true transformation. Later work by Deming, such as his system of profound knowledge, should be explored to develop leaders for a better future, and unlock potential blocked by cultural and systemic issues.

5 CONCLUSION

This paper illustrated how we utilised the PDSA methodology not only to evaluate the pilot project, but also to obtain insight into energy management in local foundries.

In this particular project it was possible to identify at least 16.24 % in energy cost savings, equivalent to an overall cost reduction of 2.61%, by applying the basic PDSA principles, involvement of people and using a cloud-based feedback system.

South African foundries should be innovative during this difficult economic time and include the building blocks of continuous improvement into their company's DNA, to ensure competitiveness and growth.

The current study was limited to three ferrous foundries in the Gauteng area that could be considered proxies for the local ferrous foundry industry. However, in future, such intervention projects should be extended to other foundries and the project scope should be broadened to include addressing how to transform company cultures to embrace continuous improvement and respect.

6 ACKNOWLEDGEMENT

This contribution is the result of the energy management pilot project implementation. We would like to thank the Innovation Hub (project funders), and PEETS (project partners) and all the employees of the participating foundries for working with Concepts 4.0 to realise this project and for your valuable contribution to the learning experience, it is much appreciated.

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A GENERAL APPROACH TO DEVELOP AND ASSESS MODELS ESTIMATING COAL ENERGY CONTENT

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ABSTRACT

The energy content of coal is an important indicator for energy efficiency in industrial mining facilities. Energy content is quantified from the gross calorific value (GCV) but the measuring process can be time-consuming and expensive. More accessible variables are thus commonly used throughout literature as an alternative to model coal GCVs. Manifold such models already exist in literature, however, these models have major variations and use different modelling approaches. This makes the models' results difficult to accurately and objectively compare.

This paper considers the existing GCV models and ultimately presents an approach to develop new GCV models. This new approach includes fundamentals from industry "best practices" and allows for major variations such as type and conditions of coal. The presented approach therefore enables the objective comparison of model characteristics and subsequent results through visualisation techniques.

New models developed using the presented approach delivered errors below 2.63%. This improved accuracy allows industrial mining facilities to accurately quantify the energy content of coal and ultimately improve mining efficiencies. The new and existing models could also be compared visually, and the new approach proved an overall improvement of the modelling process.

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1 BACKGROUND

Global energy demand is predominately satisfied with fossil fuels such as fuel-oil, natural gas and coal [1]. Among the fossil fuels, coal is the most abundant energy resource generating between 29% and 38% of the world's energy supply [2-4]. Understanding coal as an energy source is therefore vital for analysis within the energy landscape.

Coal is primarily used as a solid fuel to produce electricity and heat through combustion [1]. The electricity industry, along with several other industries such as the ferrochrome, iron and steel, and petrochemical facilities, use coal as their primary energy source [3]. It is therefore expected that coal usage would receive a high priority within the respective industry's energy management strategies.

Energy management thus forms a fundamental part of any energy-intensive industry [4]. In order to determine and improve their energy management, industries need to accurately know the energy content of their coal [5] Further, knowledge of the accurate energy content is also important for energy reporting purposes and other tax incentives, such as Section 12L* of the Income Tax Act or for Carbon Tax purposes [6]. It is therefore, crucial to accurately quantify the energy content of the coal used for industrial applications.

It is a common practice within the coal industry to assess the quality of coals and to express it using gross calorific values (GCV) and proximate analyses. The proximate analysis includes the weight percentage of ash (A), moisture (M), fixed carbon (FC) and volatile matter (VM) present in the coal. These variables are usually measured in industry thus making them widely available and easily accessible. However, measuring the GCV of coal is a complex, expensive and time-consuming process and these values have therefore not always been readily available [8-10]. For this reason, several mathematical models have been developed using the proximate analysis to calculate the GCV values theoretically [11-26]. There is however significant variation between these models. Major variations include the specific combination of proximate and ultimate analyses, the type of coal (bituminous, lignite, coke, etc.) used for these analyses, and also the approach followed to develop the model. These variations increase the uncertainty related to the reported energy content of coal [11, 15, 16, 19].

The need therefore exists to devise a general approach that can be used to develop alternative GCV models for variable datasets while enabling the use of the different properties that are quantifiable through specific analyses. The aim of this study is thus to present an approach to develop new alternative GCV models that will take into consideration the major variations not included in the existing models.

2 EXISITNG APPROACHES TO ENERGY MODEL DEVELOPMENT

Various models have been developed in the past for predicting the GCV of coal. These models consist of different combinations of the four variables of a proximate analysis namely ash, volatile matter, moisture and fixed carbon.

In 2008, Majumder et al. [18] evaluated seven different existing coal models with the aim of improving on these models. Each of these models they investigated were developed in a unique manner [30]. Certain key characteristics are commonly included when developing new models and it is important to understand what these common characteristics are and the relevance

* The 12L Tax incentive, according to Income Tax Act, 1962 (Act No. 58 of 1962) provides an allowance for businesses to implement energy efficiency savings. The savings allow for tax deduction of 95c/kwh saved on energy consumption.

of each. Once these characteristics are understood best practice procedures can be used to include them in future models [31].

Statistical procedures use historical data to correlate energy consumption as target with most influential variables as inputs. These procedures rely on the quality and quantity of historical data in developing statistical models [17,20]. A number of these approaches are available in literature [11-13, 36 & 39].

Such procedures are encapsulated in an approach previously developed for predictive modelling in the energy field [28]. The approach is based on five focus areas [33]. First, to define the purpose of the model being developed. Second, the focus is placed on the collection and preparation of the data to ensure that the information is free of errors that could influence the model [6]. This ensures that the models developed in the third focus area are fundamentally built on high quality data [33]. This results in a process that ultimately presents a model that is statistically correct and performs accurately when implemented on real data during the fourth step [34]. Confirming that the model is feasible for use and allows for continuous improvement constitutes the final step.

This approach presents a base for the development of new models for GCVs. To test the approach, the various GCV models found in literature were evaluated to see if the same main steps were followed. Table 1 shows the main focus areas of Xu's approach [28], and indicates whether or not the GCV models followed these steps.

Table 1: Evaluating literature models with Xu's best practise approach [28]

Referencing GCV model	**Focus area 1**	**Focus area 2**	**Focus area 3**	**Focus area 4**	**Focus area 5**
Relative question asked?	Are motives given on the objectives and desired outcomes?	Data obtained in an orderly manner?	Develop a model with reasonable accuracy?	Were models validated against a set criterion?	Were models continuousl y updated with latest data?
Literature model 1: *Majumder et al. (2008)* [18]	X	X	X	X	
Literature model 2: *Patel et al. (2007)* [21]	X	X	X	X	
Literature model 3: *Gulec & Gulbandilar (2018)* [22]	X	X	X	X	X
Literature model 4: *Parikh et al. (2005)* [23]	X	X	X	X	
Literature model 5: *Behnamfard & Alaei.(2016)* [12]	X	X	X	X	
Literature model 6: *Nhuchen & Afzal (2008)* [24]	X	X	X	X	
Literature model 7: *Verma et al. (2010)* [15]	X	X	X	X	
Literature model 8:	X	X	X	X	

Mesroghli et al. (2009) [25]					
Literature model 9: *Huang et al. (2008)* [19]	X	X	X	X	
Literature model 10: *Akkaya et al. (2009)* [20]	X	X	X	X	X
Literature model 11: *Mason & Gandi (1994)* [26]	X	X	X	X	X
Literature model 12: *Kock & Franzidis (1973)* [16]	X	X	X	X	

A first glance of Table 1 shows that all of the models followed the same approach. The only difference is observed with regards to the last focus area. The last focus area in Xu's approach [28] is specifically included for simulations and models that use real time data, such as within the actuarial science industry [28]. Since the GCV models are developed and tested on a set of existing data, this focus area is easily neglected.

For the development of a proper GCV model that would be able to include all variable aspects this step, however, is important to ensure that the model is continuous and constantly applicable.

These are the various different methods used apply each of these focus areas. The application of these focus areas on GCV models will therefore be discussed in more detail.

3 DEVELOPMENT OF A NEW APPROACH FOR ENERGY MODELS

The abovementioned thus identified that the existing approaches for modelling GCV models include five main areas when building a model. The five focus areas are; (1) Define the purpose of the model, (2) data preparation, (3) development of the models, (4) validation, and the subsequent (5) model comparison. The five focus areas will be used to present a general best practice approach to develop and compare coal GCV models. The diagram in Figure 1 shows the chronology of the five focus areas of the approach.

Each of the five focus areas are assess using the steps taken by the existing GCV models.

Figure 1: Five focus areas for GCV modelling of coal

Each of the five focus areas are assessed in the Sections below using the steps taken by the existing GCV models.

3.1 Define purpose

The first focus area in his diagram is to define the purpose of the model. This is the basic background step where one decides why a model is required and what the model should achieve. For GCV models, this step is similar for all of the models, since the aim is to use a set of input variables to predict the GCV of a type of coal [18].

3.2 Data preparation

The second focus area of the methodology is the data preparation. This is done in four sub-steps, namely; gather data, inspect data, clean data and split data.

Gather Data

Firstly, data is gathered from different sources and evaluated for missing data or substantial errors. The required datasets are most commonly obtained from either the coal mines themselves or from the industrial processes that utilise the coal [36]. The utilising industries can also analyse the coal samples at different conditions [15]. This can be as-received (original coal sample), air-dried (coal sample taken after it has been air dried), dry-base (total moisture has been completely removed) or dry-ash-free (total moisture and ash have been removed) [11 & 12]. It is thus important to ensure that the various coal data used in the prospective models were sampled on the same basis.

Inspect Data

The quality of the dataset is important since it will have a direct impact on the quality and results of the developed models. In this sub-step the data quality is thus checked for completeness by investigating the dataset for abnormalities and ensuring a representative sample size. Common abnormalities include samples containing missing, incorrect or irregular data. It is possible that a significant number of samples are removed during the evaluation. However, in order to ensure that the dataset remains representative, the number of samples used should be above a minimum required sample size. To assess the sample size, Green's method is used due to its wide applicability and simplicity [37]. The formula used to determine the sample size (n) is thus given in Equation 1.

$$n = 50 + 8p \quad (1)$$

Where n denotes the minimum required sample size and p the number of variables associated with each sample. In this study four proximate variables are considered, corresponding to a minimum sample size (n) with four variables considered (p=4) of 82.

However, a complete dataset on its own does not prove high quality. The quality of the data is also dependent on the metering and analysis equipment [18]. In order to assure a high data quality, it is recommended that the calibration of the bomb calorimeter, used to obtain the gross calorific value (GCV) of the samples, is verified. Data obtained from a calibrated calorimeter will be perceived as high quality due to external assurance that the information is accurate [28].

Clean Data

Potential outliers are also identified using the *is-outlier* function within MATLAB [18]. Data points larger than two standard deviations from the mean are flagged and should be evaluated on whether or not it need to be removed. Outcomes from the evaluation will be based on logic and specific knowledge on the samples.

Split Data

Once a clean dataset is obtained, the dataset is split into data used for modelling and validation purposes, respectively. It is however necessary to randomise the data first. The purpose of this randomisation is to ensure that both the validation and modelling datasets include a representative and fair distribution of data.

Figure 2 illustrates a total dataset, where the figures distinguish between samples from different sources using different shapes. After randomising the samples, the recommended 30/40/30 split method is used to split the samples into modelling and validation data [29].

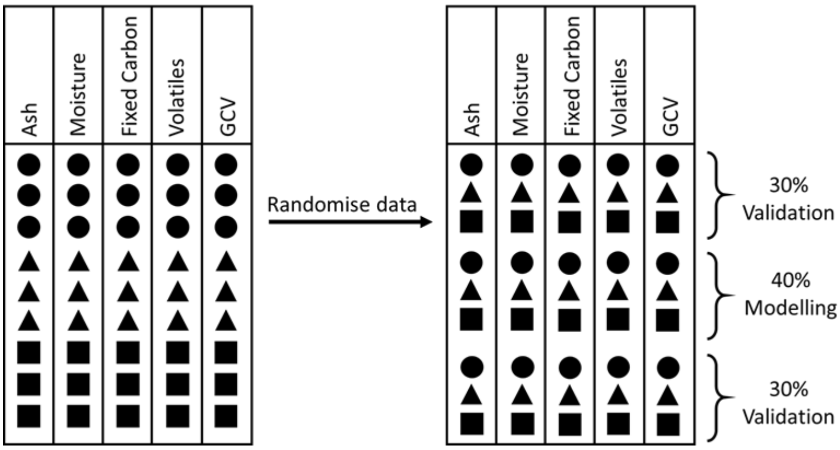

Figure 2: Data split into modelling and validation sets

The 40% modelling data will be used to develop the model in the next focus area. The two groups of 30% validation data will be used to validate the model twice in the third focus area. The average of the two validations will then be calculated and used to validate the final model. Splitting the data thus presents three different but comparable datasets as the last step for the data preparation focus area. These datasets can then be used to develop and validate GCV models.

3.3 Model development

In the third focus area the high-quality dataset from focus area one is used to develop GCV models. This is done in four sub-steps, namely; model type selection, identify modelling variables, develop model and test model.

Model Type Selection

The first step to building a new model is to decide what type of model to build. The most prevalent options for the modelling of coal GCV is Regression modelling and Artificial Neural Networks (ANNs). These methods have both been discussed in detail by various literature sources [16, 19, 28 & 33] and it was found that both the regression model and the ANN gives similar results. Regression models are however generally more understandable and user friendly [11, 12 & 25].

Identify Variables

It is recommended that the relationship between the GCV and the individual proximate variables on a new set of data be evaluated and confirmed. For the instances where a clear linear relationship is observed, a linear regression model can be devised [18]. For nonlinear relationships either nonlinear regression models or an ANN will suffice.

Develop Model

After determining the model type and variables to be used, the model can be built. This is done by using the 40% modelling data as prepared in the data preparation section. In this study the LINEST function in Excel™ was used to build the linear regression models. The LINEST function gives the constants for each variable (x_1 to x_4) as well as the intercept. These are then used to express the developed model in the form of Equation 2.

$$GCV = x_1(Ash) + x_2(IM) + x_3(FC) + x_4(VM) + C \quad (2)$$

Where GCV is the gross calorific value in MJ/kg, the variable x_i is a constant associated with each of the four proximate variables (ash, moisture and volatile matter presented by A, IM, FC and VM, respectively.) and C is the residual error which is a constant value throughout.

Model Testing

It is important to evaluate the constants of the model to see if the model is as expected. If all the constants are zero, it means that the GCV will be completely dependent on the residual error value (C) irrespective of what the proximate variables are. It is therefore important to do a quick 'sanity check' after the model is developed but before full scale validation occurs.

The developed regression model is thus evaluated against a set criterion presented below. This is done to ensure that the model is representable of the dataset [31]. For this evaluation, the modelling data is used to test the model. The correlation coefficient (R^2), the root mean square error (RMSE) and the mean absolute error (MAE) are evaluated in order to give information on the credibility of the developed model.

The validation parameters and the criteria that they should be measured against are given below:

1. R^2 / CC - Close to 1
2. MAE (modelling) - Small value
3. MAE (validation) - Small value

If the models comply to these criteria, it can be validated and used. However, if the model does not adhere to the criteria in this sub step it is advised to develop a different model that does adhere to said criteria [27], [34].

3.4 Model validation

In this focus area the developed model is validated. This ensures that the model reproduces authentic behaviour with enough fidelity to satisfy the analysis objective. The model is first validated by calculating the MAE between the experimented and the predicted GCVs. The model is then further validated by using the relationship between the experimented and predicted GCVs, known as the comparison coefficient (CC). The relationship evaluation is performed using the two 30% validation datasets from the data preparation focus area. This focus area ultimately ensures that the model represents a reasonable representation of the experimented GCVs.

Mean absolute error

The MAE is the absolute average errors calculated between the experimental GCVs (from the analyses) and the predicted GCVs. Figure 3 shows an x-y axis along with the relationship between the experimental GCV and the predicted GCV. The closer the black dots are located to the blue line, the more accurate the model. The difference between the black dot and the blue line thus indicates the error value associated with that prediction.

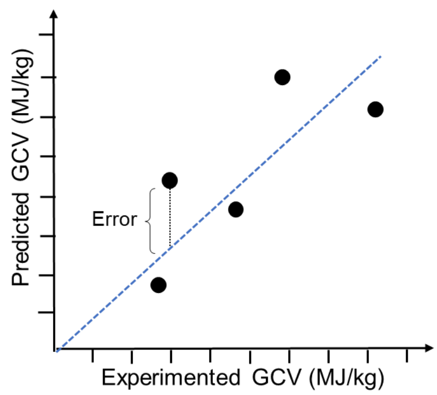

Figure 3: MAE of the developed model on validation data

The MAE for the model is calculated by determining the mean absolute value of all these errors between the dots and the blue line.

Comparison coefficient (CC)

In addition to the MAE parameter, the model is validated by comparing the experimental and predicted GCVs. This is done by calculating the CC on the relationship which will further evaluate the accuracy of the prediction.

The GCVs of the two sets of 30% validation datasets are calculated using the developed model and illustrated in Figure 4. The dots illustrate the desired outcome ($CC = 1$). The two striped lines in Figure 4(a) indicates the outcome when each of the validation sets as used in the developed model to predict the outcome. Figure 4(b) illustrates the average CC value between the two validations.

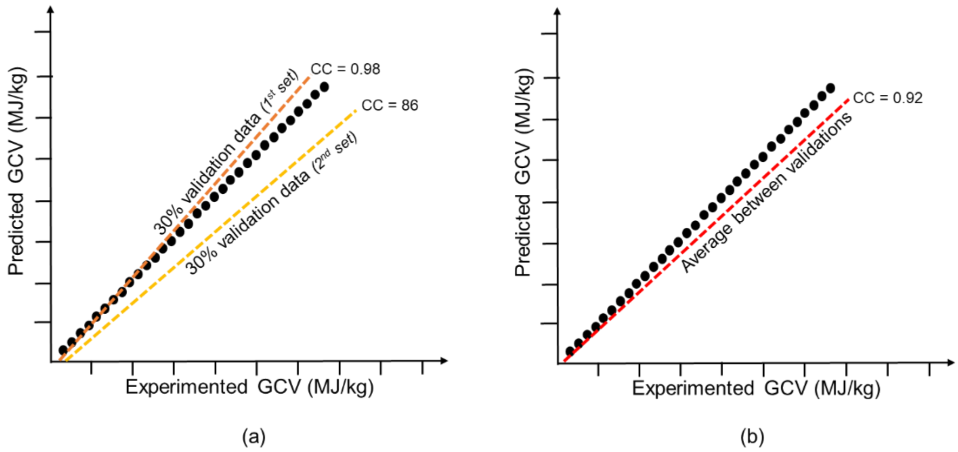

Figure 4: Experimented vs predicted GCVs

The average CC in Figure 4(b) along with the MAE in Figure 3 gives a judgment on the validity of the model. The validation parameters and the criteria that they should be measured against are given below: [20, 36].

1. MAE - Small value
2. CC - As close to 1 as possible

3.5 Model comparison

The last focus area in the model development approach is the visualisation and objective comparison of the GCV models. This is done to objectively compare various models with each other in order to ultimately choose a preferred one. This focus area consists of three sub-steps, namely; boundaries and limits, visualisation technique and objective comparison.

Boundaries and Limits

Limits of the illustrated parameters are respectively set and used as guidelines within the visualisations to assist in identifying the most suitable model. This is done to compare the statistical relevance of the different models using a visual representation. These limits will thus enable users to easily identify the accuracy and representativeness for each model.

One or more statistical parameter(s) can be used during the evaluation. These parameters include, but are not limited, to the R^2, F-value, SSE, sample size and minimum and maximum boundaries of a variable. Within this study the R^2 and MAE parameters will be used to evaluate the performance of the model on its original dataset. Results from the developed model will also be compared to results published in literature [12, 15-19, 21-31]

Visualisation Technique

A scatterplot is used to show the relationship between the two parameters. Figure 5 illustrates a scatterplot axis with the set limits and example results. The ideal relationship point is any point where the two parameters satisfy the respective criteria as illustrated with the shaded area. An undesired relationship would therefore be any point with a high MAE and a low R^2.

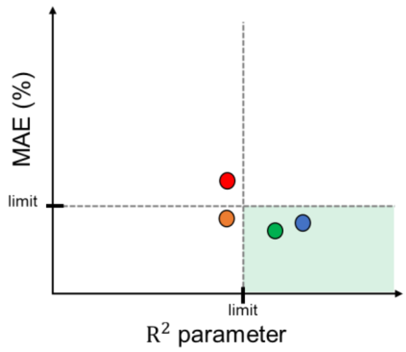

Figure 5: Scatterplot with the limits and the models

Objective Comparison

This visualisation technique enables the user to easily and objectively identify which models shows better relationships, thus highlighting the models that are more or less preferable with regards to specific criteria. The preferred models can then be utilised to estimate the coal energy content.

3.6 Summary of new general approach to develop energy models

Figure 6 presents a summary of the best practice general approach that was devised for the development of GCV models. Using this approach, a high-quality dataset is delivered from the data preparation focus area and can be used for model development. The developed models are then validated and further compared to existing models from literature. Visual comparison also presents an objective manner in which to decide on the best model.

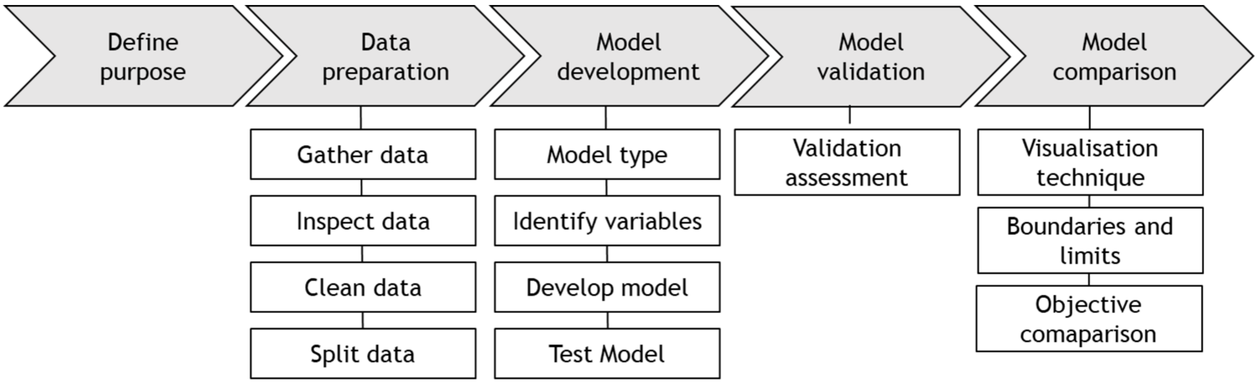

Figure 6: Devised approach for GCV modelling of coal

4 APPLICATION AND VERIFICATION

4.1 Define purpose

The aim of the GCV model to use a variable set of inputs to predict the GCV of a type of specific or random type of coal. A GCV model will, thus, be developed considering various coal types and analyses to ensure that the final model will accurately predict the energy content of that coal.

4.2 Dataset preparation

The developed approach was applied on data from an industrial facility in South Africa. The gathered data were inspected to ensure that the dataset is representable and of good quality. The sampling and analysis procedures followed to obtain the proximate variables also follow the ASTM standards [5-9, 14], thus promoting consistent results from reliable data obtained through verified methods. The data quality was further inspected for completeness by investigating the dataset for any abnormalities (missing or incorrect data).

Two samples of data were observed to have missing information. These data samples had the proximate variables available, but not the corresponding GCV. These two data samples were therefore removed from the dataset.

Data obtained from the respective sources were further evaluated for incorrect data. Each of the proximate variables were plotted against the corresponding GCV, as can be seen in Figure 7 for the ash and moisture.

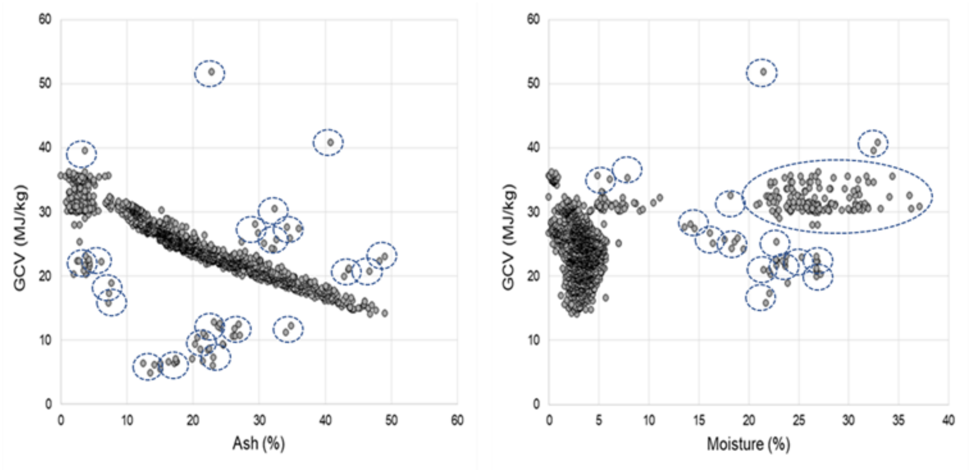

Figure 7: Proximate analysis versus GCV relationship

From Figure 7 it is observed that there are two distinct groups of data. Investigation into this phenomenon showed that some samples included total moisture (TM), and not only inherent moisture (IM). A possible reason for this is that the second source's samples were analysed on an *as-received* basis and incorrectly labelled as being analysed on an *air-dried* basis. Samples containing TM (as indicated with the dotted line) were removed from the dataset, since the IM provides a better representation of the coal [38 & 39].

A total of 795 samples were removed from the original 2850 samples due either to abnormalities or to being an outlier. The sample size was therefore tested, and it was found that the dataset containing 2098 samples complied with Green's minimal sample size of 84. Resulting in a high-quality and representable dataset, allowing new models to be developed.

4.3 Model development

In the previous section, proximate variables were plotted against the corresponding GCV values. A linear relationship was noted in these plots and therefore justified the use of multiple linear regression to develop a model. Multiple linear regression will capture the linear relationship while still ensuring that the effect of each respective variable influences the model accordingly [40].

A model was thus developed based on the dataset compiled within the previous section. The developed model is given by Equation 3.

$$GCV = 21.5 - 0.743(\mathrm{A}) - 0.365(\mathrm{IM}) + 0.512(\mathrm{FC}) + 0.743(\mathrm{VM}) \qquad (3)$$

The developed model produced a high R^2 value of 0.994, as well as acceptable RMSE (0.47%) and MAE (0.86%) values. The high correlation and relatively small errors indicated that the model passed the minimum criteria for the 'sanity check'. Further validation is however required in order to ensure that the model produces results that are trustworthy and realistic.

4.4 Model validation

The model developed in the previous section needed to be validated. Validation was performed to assess whether the predicted GCVs were reasonable with respect to the experimented GCVs.

The two sets of 30% validation data were used to calculate two MAE parameters and two CC parameters (one for each validation set). The average between the two parameters were then used as the reporting answer.

The MAE between the experimented and the predicted GCVs were calculated as 2.63%. Indicating that the predicted GCVs were relatively similar to their respective experimental counterpart. The relationship between the experimented and predicted GCVs were plotted and the CC was determined as 0.942. These parameters thus indicated that the model was likely to provide trustworthy and reliable GCVs. Figure 8 shows this relationship.

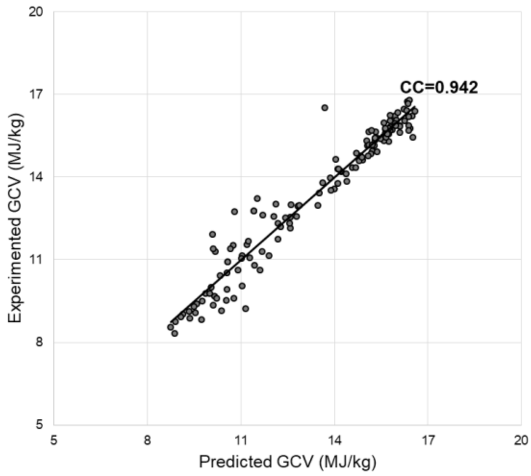

Figure 8: Validation of the developed model

4.5 Objective comparison

The objective of this section of the study is to compare the developed models' performance to those from literature [11-23]. Visualising the comparison will assist in selecting the most suitable model for a given dataset. Comparisons were thus made between the newly developed model and existing literature models by evaluating the R^2 and the MAE of the models on their a) modelling data and b) validation data.

The reported parameters (R^2 and MAE) from the literature models are used [11-23]. Several of the models only reported the model's R^2, on the modelling data. Only the models that reported on both parameters were used for the comparison.

The developed model was then objectively compared with the literature models through visualisation of the parameters. These parameters were visually presented on a scatterplot with the R^2 and the respective MAE's chosen as the limiting parameters. The limits for these parameters were identified as the average values obtained from all the literature models. These parameters and their respective limits are listed below:

- R^2 / CC - 0.90
- MAE (modelling) - 1.5%
- MAE (validation) - 3.0%

Figure 9 shows the respective R^2 and MAE (modelling) results of each model. The shaded box represents the area which will satisfy both the identified limits of the R^2 and MAE (modelling) parameters. Figure 9 also indicates the optimal performance of these models, as it represents the data used to develop the model.

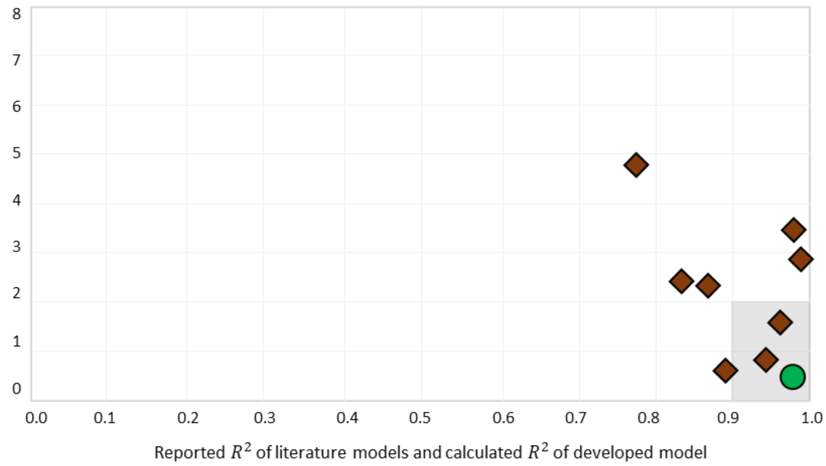

Figure 9: Visualisation comparison on modelling data

From Figure 9 the developed model (dot) performed similarly to the literature models (diamonds) which validates the developed models.

From Figure 9 it is expected that the use of the models within the shaded box will give a MAE of less than 1% when used on a new dataset

4.6 Discussion of application

Using the devised approach several observations could be made with the development of the new GCV model. The new approach delivered a new alternative GCV model which is comparable to the existing GCV models. This new approach used fundamentals from industry “best practices” and includes major variations such as type and conditions of coal.

The developed model allows the industrial facility to accurately know the energy content of their coal. Further, the devised approach also allows the facility to adapt to changes in coal quality and/or suppliers. This has assisted them with energy reporting and environmental impact assessments for Carbon Tax purposes and for tax incentives, such as Section 12L of the Income Tax Act.

It was also initially noted that the data samples contained abnormalities that would have greatly influenced the subsequent model. By removing these samples after a detailed evaluation, the data quality was greatly improved. However, this also allowed for the identification of flaws in the facility’s data management system which could be reported to the relevant stakeholders. This was seen as an additional benefit by stakeholders.

5 CONCLUSION

Multiple literature models exist that can predict the GCVs of coal based on its proximate and ultimate variables. However, these models have problems with consistency and applicability [11-23]. The need to objectively compare the performance of the literature models on a new dataset were therefore highlighted. A need therefore existed for a general approach that can be used to develop GCV models and to ultimately compare the performance of the various models on a new dataset.

This study therefore devised an approach to develop models that can predict the GCVs of coal based on its proximate variables. The approach consisted of five focus areas: *define purpose*, *data preparation*, *model development*, *model validation* and *comparison of results*. Each of these focus areas also consists of various sub-steps applicable specifically to GCV modelling.

The approach was applied on coal data from a South African industrial facility. A qualitative dataset was compiled and used to develop a multiple linear regression model, dependent on the four proximate variables. A validation dataset was then used to validate each of the developed models.

The results from this study showed that the devised approach could be applied effectively in order to develop GCV models and enable the objective comparison thereof. These models were developed in a consistent and accurate manner, thus presenting a structured method to estimate the energy content of coal in an alternative manner.

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ADAPTING ACCOUNTING BEST PRACTISES FOR USE IN ENERGY-RELATED REPORTING

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ABSTRACT

Corporate energy- and environmental reporting requirements are constantly evolving in a drive to clearly represent the realities associated with industrial activities. This change creates a dynamically changing landscape full of uncertainties. Financial accounting and reporting experienced similar challenges which eventually led to the development of universally accepted concepts and conventions (principles). This allowed for the effective review and reporting of financial results to a wider stakeholder audience.

This paper presents a strategy that can be used to adapt accounting best practices for application in the engineering- and energy reporting field. The strategy follows an iterative approach to develop a parallel between the two disciplines. This parallel is further applied to a pool of 83 energy-related research publications. The results from this critical analysis highlight the need for integration between multiple disciplines and provides a relation between well-established financial principles as an alternative solution to real engineering challenges.

An application of this concept is to evaluate a specific energy-related question with a financial implication. When considering the carbon tax exposure of industries in South Africa, a possible improvement of approximately 6% (R2.5 billion) can be recognised with the application of the accounting principles in the energy/environmental environment.

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1 INTRODUCTION AND BACKGROUND

In the past decade, corporate energy- and environmental reporting have become increasingly important, resulting in the adaptation of numerous legislative responsibilities of several businesses [1][2]. One of these responsibilities includes the increased need for transparency in corporations towards the consumer [3]-[6] and the increase in transparency of contractors to corporations [7]. Transparency in businesses is considered a very important aspect as it supports informed, efficient and capital allocated decisions [8]. One way of being transparent is through corporate reporting.

This section will highlight new challenges associated with energy-related reporting, as driven primarily by the global need to reduce greenhouse gas (GHG) emissions, as part of the Paris agreement on climate change [9]. An insight on lessons learned from the financial reporting structure will be provided. These insights will be used to propose a solution to the associated uncertainties in new energy-related reporting structures.

1.1 New challenges for energy-related reporting

Figure 1 highlights several new reporting requirements relevant to energy- and emission related factors. Some of these include the regulations relating to the Section 12L energy efficiency tax incentive [10], the Task Force for Climate-related Financial Disclosures' guidelines (TCFD) [8], the draft regulations on energy management plans [11], the national integrated energy plan [12], mandatory Greenhouse Gas (GHG) reporting regulations [13] and the Carbon Tax Act which commenced in June 2019 [14].

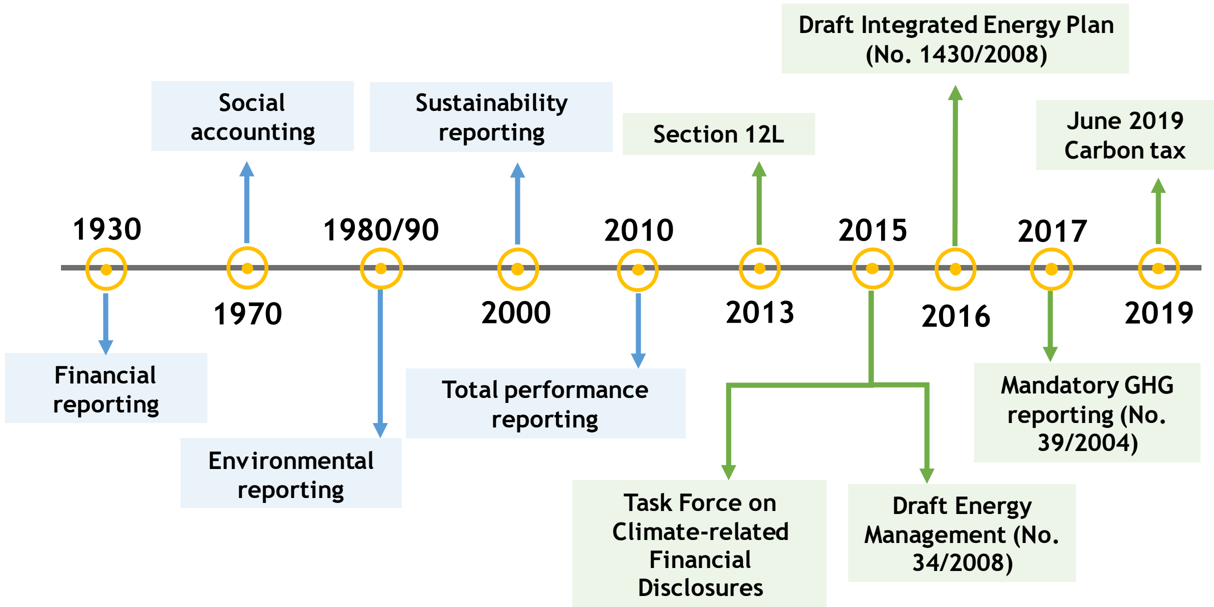

Figure 1: Timeline of corporate reporting in South Africa

Companies are under pressure to continually introspect and disclose their exposure to climate change by means of new reporting requirements. This has led to four main uncertainties regarding energy-related reporting in South Africa (SA), which will be discussed in the following sub-sections (Section 1.1.1 to 1.1.5). Relevant challenges relating to GHG and carbon tax reporting is provided as examples of the uncertainties faced by industry.

1.1.1 New reporting requirements

New reporting requirements are inevitably related to the new developments in energy-related reporting structures. This ultimately leads to numerous associated uncertainties. Within the South African energy industry, many new developments have been realised which focuses on developments and key issues regarding the energy industry [15].

From media statements and interviews, it is highlighted that the newer types of reporting which are related to topics such as carbon tax, environmental impact, and energy management, are still in the developing stages and therefore have numerous associated uncertainties [16]–[20]. It is expected that several reporting uncertainties will only come to light during the actual implementation of the new requirements.

1.1.2 Reporting non-financial data

Mandatory non-financial reporting requirements in SA currently only include GHG emissions, although it is believed to expand to all energy-related fields since this environment is constantly evolving. New energy-related reporting requirements have recently been implemented in the United Kingdom (UK) on the 1st of April 2019 [21].

This includes a Streamlined Energy and Carbon Reporting (SECR) structure. This structure requires the reporting of the company's annual carbon emissions, energy consumption, and a description of all implemented energy efficiency measures [21]. Rapid developments in the current environment of non-financial data reporting causes a concern for developing countries such as SA. A few problems were highlighted in a recent air pollution monitoring report from Eskom, emphasising an array of additional concerns and uncertainties [20][22]. These problems include:

- Incomplete datasets used for reporting,
- No access to clear and comprehensive data,
- The air pollution monitoring reports are not standardised,
- Monthly reports were missing or are incomplete, and
- Some monthly reports simply replicated all the graphs from previous months.

When looking at financial data used for reporting, great care and detail is provided to ensure the data is of high quality [23]. The reporting of non-financial datasets however does not comply with the same standards [22]. It is therefore considered not as advanced in ensuring the reliability of data. Mass and Energy balance (MEBs) are widely used in the energy and engineering environment for exploration, improvements and sustainability projects which assists with the decision making process [24].

MEBs are also highlighted as an effective tool to evaluate data and to mitigate/mange the associated uncertainties. The approach however currently lacks the necessary features for assurance and requires improvement to increase its reliability and therefore the associated uncertainty.

1.1.3 Trace the impact of actions to total performance

Total performance reporting is an important factor in any industry's reporting structure. This typically includes a wider range of information (financial, social, environmental, business and sustainability) concerning the overall performance of the organisation [25]. The performance of any organisation is influenced by several strategies, for example, energy efficiency (EE) initiatives and carbon tax exposure, which both have financial implications towards the organisation.

The quantification of these implications is therefore important to ensure accuracy and reliability when tracing the impact of these actions to the organisations' total performance. Furthermore, the implementation of initiatives and projects needs to be measured and reported to ensure mitigation actions are delivering on their original intent. It is however expected that the effects of such mitigation projects must be noticeable on a reporting basis therefore increasing the assurance and transparency of total performance reporting.

1.1.4 *Multidisciplinary requirements*

Reporting based on energy-related performance, together with financial impact disclosures and tax-directives, implies the requirement of a multi-disciplinary approach. For example, the technical quantification of GHG emissions for carbon tax is governed mainly by published guidelines and is not generally included into daily business operations [13][26]. It is widely acknowledged that the quantification process may require an expert with an engineering or environmental sciences background since finance professionals do not have the necessary knowledge on the CO_2 policy [26][27].

In addition to the technical quantification of GHG emissions, companies also need to ensure that reporting is done in-line with associated tax rules. SARS published draft rules for the administration of the carbon tax as an environmental levy [28]. This process necessitates a tax professional with knowledge of the Customs and Excises Act under which such environmental levies are governed.

Although the quantification and administration of carbon tax can be cumbersome (as noted in the discussions above), a key challenge also lies in the actual mitigation of GHG emissions. On this topic, a professional with knowledge regarding mitigation options such as ISO 50001-based energy management and project implementation, is required [27].

It is also important to convert the observations made from non-financial data to monetary terms, to show the possible financial impact. This need is highlighted by TCFD which requires a link between financial disclosure and climate impact observations [8]. These arguments clearly highlight the need for the integration between multiple disciplines to effectively report on energy-related directives.

1.1.5 *Summary of reporting challenges*

The problems discussed in the preceding sub-sections highlight the uncertainties associated with energy-related reporting structures. A summary list of these four reporting challenges is provided:

- *Numerous new developments in energy and environmental reporting,*
- *Reporting relies more on mass, energy and emission (non-financial) data,*
- *Increasing pressure to accurately trace the impact to total performance reporting, and*
- *Multiple disciplines are involved within the reporting structures.*

This paper proposes research on more established corporate reporting types, such as financial reporting, as a possible option to decrease the above-mentioned uncertainties in the newer types of reporting structures. This research is required to investigate the lessons learned from previous reporting failures and to understand the structures which are in place to prevent these failures, or associated problems, from occurring. In the next section, the lessons learned from financial reporting are discussed, to provide insight into well-established reporting principles.

1.2 Lessons learned from failures in financial reporting

The main objective of financial reporting is to provide high-quality information regarding economic entities, which is primarily financial in nature and used for decision making [29]. It is thus important to provide high quality information to ensure capital providers and stakeholders have reliable and accurate information. Since its inception, financial reporting has become well-established, with significant changes to improve its credibility and consistency.

In the early 21st century, a large increase in accounting failures occurred which pointed to weaknesses in financial reporting quality [23]. Financial reporting is also still the subject of criticism regarding the relevance of annual financial statements for investor decision making [30]. To prevent further financial failures and ensure high quality financial reporting, the American Institute of Certified Public Accountants (AICPA) and the Financial Accounting Standards Board (FASB) established structures which accountants must follow [31].

These structures will be termed accounting principles throughout this paper and are based on the basic foundation of the Generally Accepted Accounting Principles (GAAP) and the International Financial Reporting Standards (IFRS).

Structures in place to prevent failures

The accounting principles consist of 13 well-established standards, which includes 9 concepts and 4 conventions [32]–[35]. These form the foundation for preparing and maintaining accounting records [36]. The accounting principles are:

- Business entity concept,
- Money measurement concept,
- Going concern concept,
- Accounting period concept,
- Accounting cost concept,
- Duality aspect concept,
- Realisation concept,
- Accrual concept,
- Matching concept,
- Materiality convention,
- Full disclosure convention,
- Consistency convention, and
- Conservatism convention.

The aim of these principles is to eliminate differences in accounting practices, provide uniformity, prevent stakeholders from making ill-informed decisions, increase the independency of the accounting firm and, finally, to create a universally shared language [23]. It is essential that all individuals within an organisation, not just accountants, use these principles to ensure accurate financial statements [37].

1.3 Proposed solution to energy-related uncertainties

From the previous two sections, it was highlighted that energy-related reporting is still in the developmental stages, while financial reporting has a clear set of structures (accounting principles) to ensure high quality in reporting and presenting. To ensure energy-related reporting doesn't undergo the same type of failures as financial reporting, it is proposed that the accounting principles be used in the engineering field to decrease any related uncertainties. From this background and introduction section, the following critical research question is put forth:

Can well-established accounting principles be used within the energy/engineering environment?

This paper's focus is on researching and describing the well-established accounting principles within the context of energy-related reporting. This is done by applying a critical analysis to a wide range of literature-based sources (Section 2). The findings from this analysis are then applied to a case study to test how accounting principles can be used to improve existing energy-related reporting (Section 3), before a conclusion is made (Section 4).

2 METHODOLOGY

The methodology entails a five-step strategy. These steps are (1) Research, (2) Investigate, (3) Create, (4) Conduct and (5) Test. This method is based on a qualitative research method, namely conceptual analysis, which is generally used to analyse texts and solve issues in a systematic manner [38]. The key objective of this strategy is to conduct a critical analysis in order to test the research question formed in Section 1. An overview of the strategy is presented in Figure 2.

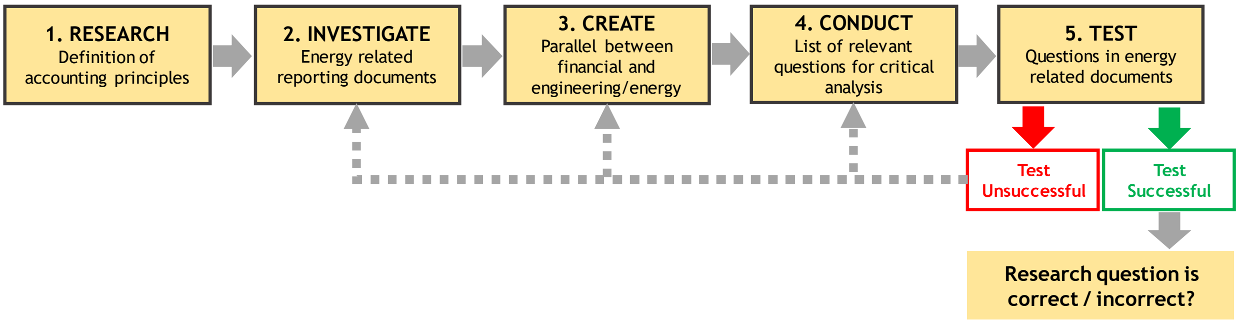

Figure 2: Critical analysis strategy (adapted from [38])

The strategy starts with the research of the accounting principles (Step 1) and the investigation of literature for energy-related reporting documents (Step 2). The third step is to create a parallel between the financial and energy environment. This is to ensure the accounting principles can be understood in an energy context. Step 4 of the strategy is to conduct related questions from the background provided in the first three steps, to test whether the accounting principles are addressed or evaluated in the relevant literature (Step 5). The outcome of Step 5 (literature based critical analysis) will either show if the research question is correct or incorrect. Each step of the strategy will be discussed in more detail in the following sections. The results of each step will also be presented and discussed.

2.1 Step 1: Research

The first step of the strategy is to do a full research study on all the mentioned accounting principles (as noted in Section 1.2). This entails researching the meaning and context of each principle to be used in the following steps of the strategy. The list of accounting principles that will be used in this study are provided in Table 1.

Table 1: Definitions of accounting principles

Principle	Accounting definition
Business entity	The business enterprise and its owners are two separate independent entities. Business and personal transactions of its owner are separate. [32]-[35]
Money measurement & Accounting cost	All business transactions must be in terms of money, that is in the currency of a country. All assets should furthermore be recorded in the accounting books at their purchase price. [32]-[35]
Going concern & Conservatism	A business firm will continue to carry on its activities for an indefinite period of time. Simply stated, it means that every business entity has continuity of life. Furthermore, revenues should be included, and losses anticipated, only when they are realised in the form of cash or other assets. [32]-[35]

Principle	Accounting definition
Accounting period	All the transactions are recorded in the books of accounts on the assumption that profits on these transactions are to be ascertained for a specified period. A balance sheet and profit and loss account should be prepared at regular intervals. [32]–[35]
Duality aspect	This concept assumes that every transaction has a dual effect, *i.e.* it affects two accounts in their respective opposite sides (debit and credit). Therefore, the transaction should be recorded at two places. [32]–[35]
Realisation, Accrual & Matching	Revenue and expenses from any business transaction should be included in the accounting records only when it is realised (when legal title passes between buyer and seller). Expenses should be recorded in the same period as the revenues they are related to. [32]–[35]
Materiality & Full disclosure	If certain information or material is important to an investor or lender using the financial statements, that information should be disclosed within the statement or in the notes to the statement. [32]–[35]
Consistency	Transactions of a similar nature should always be recorded in the same way. This is to ensure that the Profit and Loss Accounts and Balance sheets can be meaningfully compared each year. [32]–[35]

A clear understanding of the accounting principles is necessary for the critical analysis. Table 1 and the indicated references will help with the interpretation of the principles. In this step, the relevant accounting principles, which will be used to investigate existing applications from literature-based sources, were identified and described.

2.2 Step 2: Investigate

The second step is very similar to the first step in the sense that both are research steps. In this step, the energy-related documents that should be used in the critical analysis need to be retrieved and investigated to determine the relevance. If documents are not relevant, these documents should be removed or replaced. Techniques that were used in finding relevant material include, searching electronic databases, using a reference from a previously obtained useful reference and manually searching journals to ensure articles not detected in the electronic search are not overlooked [39].

This study focuses on the review of existing studies and therefore requires an extensive list of references for the investigation. According to Behrouz Ahmadi-Nedshan [40], a comprehensive research study usually includes between 60 and 120 references to ensure all the relevant approaches are covered and no specific field is overlooked.

To guarantee a comprehensive critical analysis, 83 energy-related documents were obtained for the investigation (investigation of the research question). These 83 references were found through the search of various keywords such as, “mass balances”, “energy balances”, “industry”, “energy reporting”, “GHG emission” and “energy accounting”. A breakdown of the literature sources is presented as a pie chart in Figure 3. The applicable references for this critical analysis study can be found in the reference list [41]-[123].

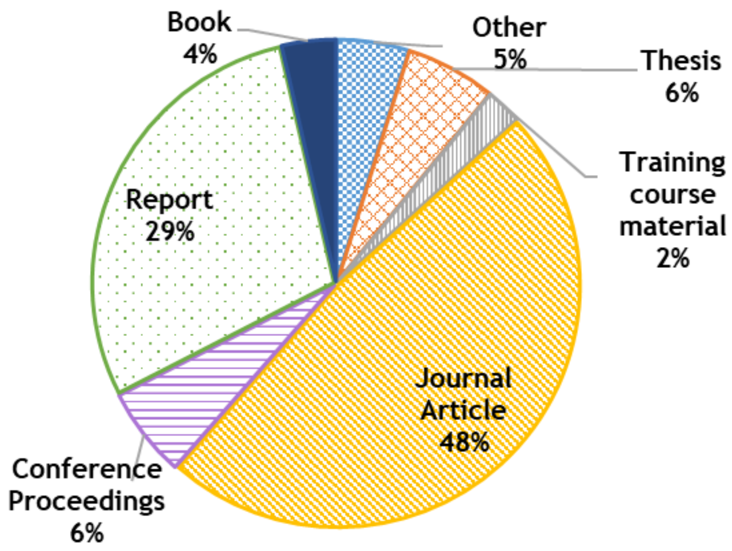

Figure 3: Breakdown of literature sources

The distribution of references in Figure 3 indicates that roughly 92% of the documents obtained for the investigation, are considered reliable sources. These documents include journal articles, published reports, conference papers, theses or dissertations and books. Other sources, such as training course materials, were also included as they were found to be relevant to the topic of this study. The composition of the documents used in the critical analysis is presented in Figure 4.

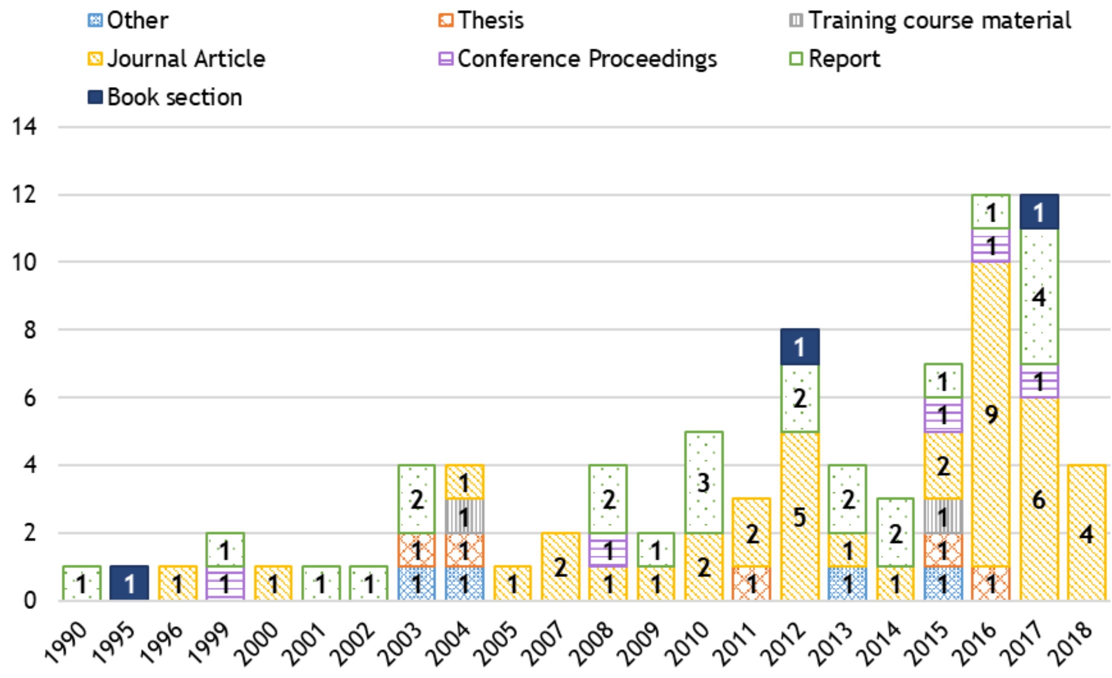

Figure 4: Timeline and type of documents included in the study

Almost 70% of the documents were published after 2010, which relates well with the establishment of the newer energy and emission types of reporting structures. This again highlights the increase in development and deployment of these structures. The timeline in Figure 4 also indicates that the documents used in the critical analysis presents an accurate view of the current field where the majority of the documents were published in 2016 and

2017. The pool of references identified and described in this step will be used to test the parallel between accounting principles and the energy reporting environment.

2.3 Step 3: Create

The third step of the strategy is to create a parallel between the financial field and the energy/engineering field. Since multiple disciplines are integrated in this study, there is a need to establish a logical development to apply the identified accounting principles in the energy/engineering environment.

A parallel was created by choosing the accounting principles and expanding on them (*i.e.* define the principles in Step 1), in order to understand the full meaning of the principle in the financial environment. The principles were then evaluated to understand if any connection can be made or if the action of the principle could be compared to a situation in the energy field. The created parallel for each accounting principle is presented in Table 2.

Table 2: Parallel of accounting principles in energy environment

Principle	**Parallel in energy environment**
Business entity	Business entity relates to **measurement boundaries**. Energy efficiency should be determined for each individual measurement boundary. Energy should be accounted and balanced for each applicable entity. [13][124][125]
Money measurement & Accounting cost	All calculations should be in the relevant unit of measurement *i.e.* Energy in kWh, mass in tonnes etc. [14][124][126] Accurate **conversion** between different units and forms of energy is important to illustrate and disclose. [13][14][124][126]
Going concern & Conservatism	This relates to the Plan-Do-Check-Cycle in SANS 50001: 2011 [127]. Energy context should be continually investigated, not just before and after a specific event. This will ensure **uncertainty** is managed and can be mitigated. [125][128][129][130]
Accounting period	Balances should be done over a relevant **time period**. All the relevant balances should be done for the corresponding time period. Identify measurement and reporting periods for the assessment of energy. [14][124][125]
Duality aspect	For every input value there should be an output value. Use **double entry method** when balancing energy/mass. [131][132]
Realisation, Accrual & Matching	Distinguish between difference in actual measurements and predictive/estimated data. Actual measurements will have a specific transaction **time and date stamp.**[13]
Materiality & Full disclosure	Data is not always available. Sometimes estimations and **assumptions** are necessary. **Disclose** ALL assumptions in full. [14][124][126][128][131]
Consistency	Ensure calculation methods used are consistent from one FY/year to another – follow a consistent **standard/approach or guideline.** [13][133]

Table 2 provided a parallel of the accounting principles in the energy environment to be used in the critical analysis' relevant questions.

2.4 Step 4: Conduct

After the parallel was created for the principles in Step 3, a list of relevant questions should be compiled to be used in the final step for the critical analysis. This is considered an important step in the strategy as the questions should be relevant to the research question as it will be used to determine the outcome. In order to test the research question, the questions should be structured in such a way to test whether the accounting principles are addressed or applied in the energy environment (energy-related documents).

From the parallel created in an energy context, relevant questions were generated. Table 3 presents the accounting principles along with the generated questions that were asked in the critical analysis. Each question, relevant to the accounting principles, is supplied with an appropriate letter that will be used in the following step for an easier presentation and discussion.

Table 3: List of questions generated from Step 3

Principle		**Question**
(A)	Business entity	*Is there any mention of integration of different boundaries?*
(B)	Money measurement & Accounting cost	*Is there a discussion on conversion?*
(C)	Going concern & Conservatism	*Is energy data and uncertainty assessed on a regular basis?*
(D)	Accounting period	*Is the energy assessment aligned with the financial assessment periods/year?*
(E)	Duality aspect	*Is there mention of a double entry method to balance energy/mass?*
(F)	Realisation, Accrual & Matching	*Is the data linked to a specific transaction (date and place)?*
(G)	Materiality	*Is it indicated whether it is measured or estimated?*
(H)	Full disclosure	*Are assumptions fully disclosed?*
(I)	Consistency	*Follows a guideline/approach/framework?*

From Section 2.2, eight (8) accounting principle groups were created while nine (9) questions are presented in Table 3. To ensure the critical analysis is thorough, it was decided that there would be separate questions for Materiality (G) and Full disclosure (H), although they were paired into one idea in Step 1.

2.5 Step 5: Test and repeat

The last step of the strategy is to finally evaluate the questions developed in the previous step. The questions are evaluated against the energy-related documents investigated in the second step of the strategy. This should be done by preparing a comprehensive critical analysis of all the relevant energy-related documents.

As indicated in Figure 2, if the test is unsuccessful, meaning: if the questions could not be answered or if the documents are not relevant, the strategy should be reiterated, and Steps 2 to 4 should be repeated. If the test is successful and useful results can be obtained from the critical analysis, it should be decided whether the research question is correct or incorrect according to the obtained results.

A summary of the critical analysis results is presented in Figure 5. In the figure the questions (A – I) from Step 4 are presented on the y-axis while all the literature references (1 – 83), [41]-[123], are presented on the x-axis. A green dot is indicated if the answer to the question is yes, meaning that the accounting principles were addressed or assessed in the energy-related sources.

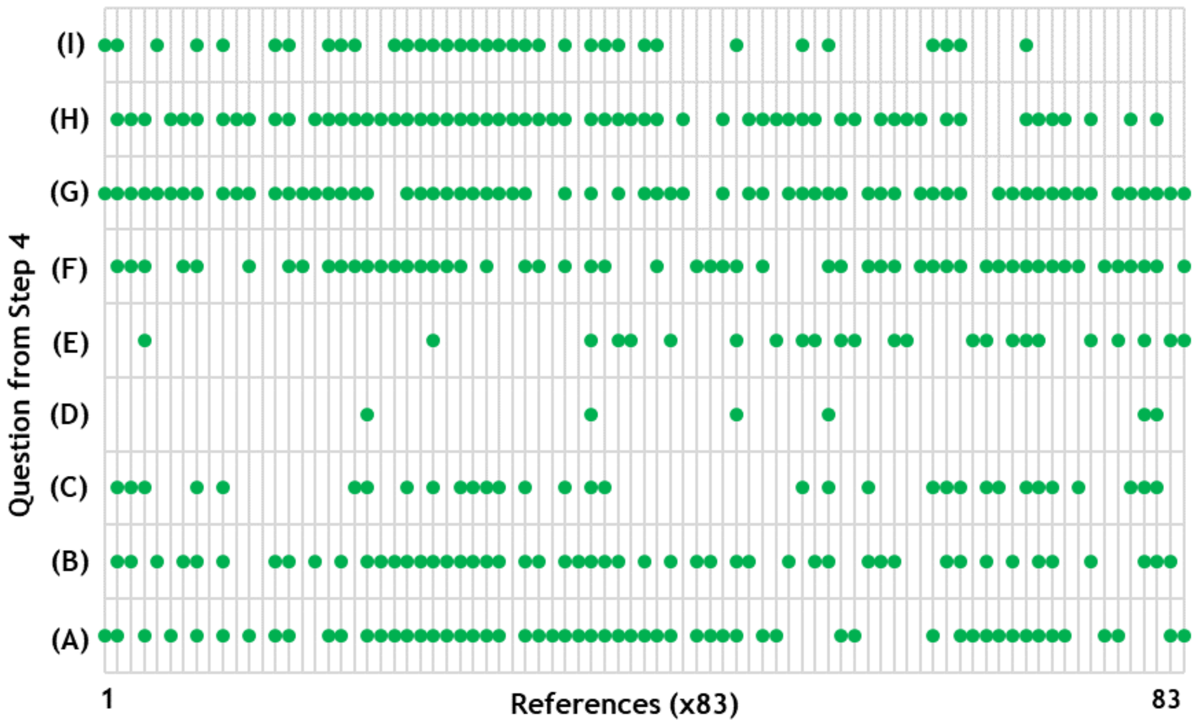

Figure 5: Critical literature review

Discussion and results from critical analysis:

From Figure 5, it is determined that accounting principles (A), (B), (F), (G) and (H) are well discussed throughout the documents. These five principles were discussed or addressed in 50% or more of the energy-related documents. The study also showed that these five principles are typically applied and associated with specific problem investigations and not the actual improvement or sustainability thereof. This indicates that the applications (specifically MEB) in the energy-related documents are widely used, and that the practice thereof is not difficult.

Whether the application of the proposed solutions is correctly applied, is however considered unreliable and inconsistent. The remaining four principles (C), (D), (E) and (I) are on average discussed in less than 30% of the energy-related documents, which indicates that the actual quality, reliability and assurance of the data and applications are not generally associated as challenges. This is a problem since it makes it difficult to correctly evaluate the overall effect of a specific event and specifically trace the effect back to a specific performance report.

Overall there is, however, no energy-related document that clearly links the accounting principles to engineering applications. This indicates a significant gap in the energy-related reporting environment and, additionally, numerous inconsistencies between how the selected principles are applied and addressed. This critical analysis therefore indicates that the research question stated in Section 1 is confirmed and that there exists a need to link well-established accounting principles to energy-related reporting structures.

In order to test whether existing energy applications can be improved, and whether the literature-based research question is applicable to industries, a practical application on MEB will be evaluated in the following section.

3 RESULTS OF PRACTICAL APPLICATION ON MEB

In this paper, it is suggested that energy-related reporting can be improved when considering well-established accounting principles. The energy/engineering environment consists of complex systems with a wide range of applications that can benefit from adhering to accounting principles. For this paper, an existing MEB application will be evaluated to test whether the application can be improved by adhering to the listed accounting principles. The limitations which prevent the MEB application's further usage are identified, and the possible solutions linked to the accounting analogies are discussed.

3.1 Existing MEB application

MEB are widely utilised to quantify and manage resources by accounting for the exact path, quantity and flow of multiple materials. A typical presentation of MEBs is by using a Sankey diagram [134]. A Sankey diagram is used to indicate the complexity and integration of a facility, where the width of the line connection is shown proportionally to the flow quantity. The diagram furthermore illustrates the energy primarily supplied to the facility, which energy sources are used in production- and utility processes respectively, and finally the energy required for utility conversion (electricity generation, *etc.*).

For this case study, an existing MEB application will be evaluated on an energy intensive facility. The complex energy reticulation of this facility is presented in the Sankey diagram in Figure 6.

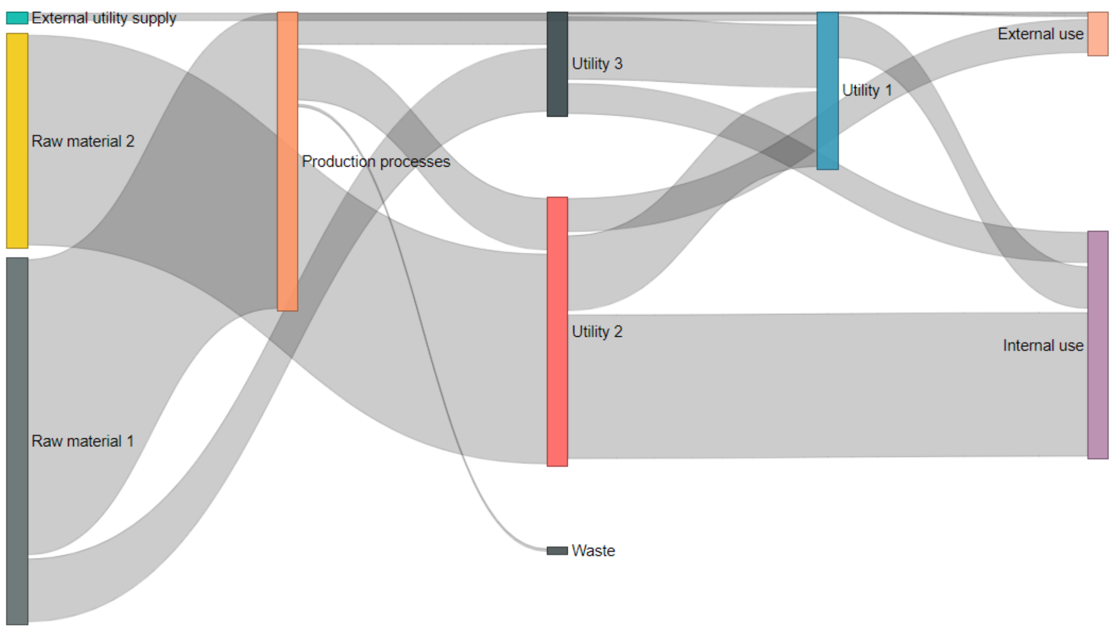

Figure 6: Sankey diagram of facility used in practical application [134]

MEBs were developed based on the processes in Figure 6 and should be used as the foundational work for EE investigations. This will ensure that the impact of these EE calculations is correctly evaluated, since a specific event or occurrence can be easily assessed. Two types of balances were conducted for this study, namely unit balances and distribution balances. Both of these are based on the first law of thermodynamics [107][135].

Unit balances include the assessment of energy/mass streams over a specific unit, where all the energy/mass in and all the energy/mass out should be accounted for. The distribution balances include the conservation of mass/energy in the distribution of individual streams. These concepts are illustrated in Figure 7 in energy terms.

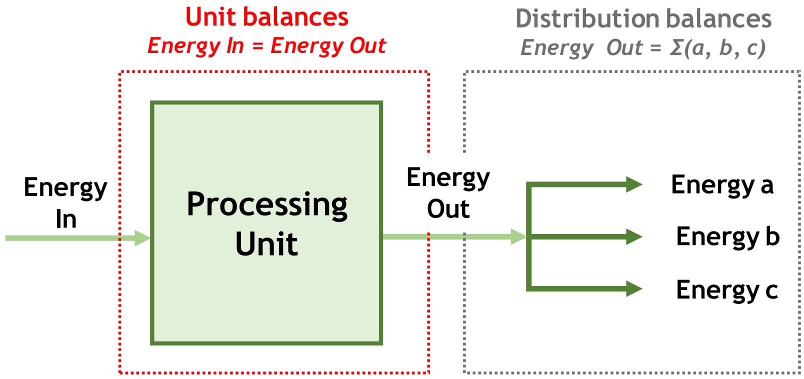

Figure 7: Types of balances (adapted from [107][135])

As previously mentioned, MEBs were conducted over the system presented in Figure 6 using the different balances illustrated and discussed in Figure 7. A summary of all the balances over the facility in Figure 6 is provided in Table 4. Table 4 also presents the amount of balances for each type (unit or distribution), as well as the total degrees of freedom (DoF) made for each type of balance (number of assumptions made in each balance). It should be noted that all balances are in energy units where applicable.

Table 4: Balance summary of practical application

Distribution balances				Unit balances			
Total no. balances	No. DoF	Balance closures		Total no. balances	No. DoF	Balance closures	
		Min	Max			Min	Max
29	55	0.00%	37.25%	8	19	1.00%	5.45%

From the summary table (Table 4), it is shown that a total of nearly 40 balances were conducted over the facility with overall 74 assumptions. The table further presents the balance closure or error range which extends from 0.00% to a maximum of 37.25%. This error shows how well the balances could be closed based on raw meter data from the facility. The balance errors can be decreased through a data reconciliation process. During this process, industry professionals allocate the error either towards losses or a dedicated stream to ensure the overall balance error equates to zero.

From this review it can be concluded that MEBs are mostly limited in the engineering- and energy fields due to their complexity and associated uncertainty. A need therefore exists to expand MEB applications to assist with multidisciplinary interactions since MEBs are currently complex with little traceability. They can also be inconsistently evaluated and reported, and data quality is occasionally not a priority. This shows a clear need for accounting principles to be applied, to address the challenges and extend the MEB application to other fields or disciplines.

3.2 Changes required to extend MEB application to other fields

In the critical analysis (Section 2.5) it was shown that energy-related documents do not comply with accounting principles. In the background (Section 1) it was noted that it would be beneficial to industries if MEBs follow the accounting principles. Table 5 provides a summary discussing the conformity of MEB to the accounting principles. In the table, the MEBs conducted in Section 3.1 and their compliance with all the accounting principles and exactly in what manner, is discussed.

Table 5: Conformity summary of MEB for industry application

Accounting principle	Conformity summary
Business entity	The foundational balances (Table 4) were compiled for all possible measurement boundaries in the facility. The balances can therefore be used to **isolate the different business entities** depending on each case study's required objective.
Money measurement & Accounting costs	The unit of measure and relevant conversion factors of each of the developed balances were specified. This information can be used to report in **comparable and relevant units of measure** depending on each case study's required objective.
Going concern & Conservatism	The balancing errors and DoF assumptions were specified for each of the developed balances which captures the total uncertainty associated with the balances. This quantification allows for **continuous management of uncertainty and conservatism** depending on each case study's required objective.
Accounting period	The mass and energy balances were compiled for four consecutive years of operation. This allows both **long-term or short-term investigations** depending on the application's required objective.
Duality aspect	All balances are reconciled and closed to **allocate all mass and energy used within the facility** to the relevant business entities. This ensures that all streams are accounted for.
Realisation, Accrual & Matching	All mass and energy streams in the balances were linked to a **specified time, date and place**. This allows relevant investigations for the specified time, date and place of each case study's objective.
Materiality & Full disclosure	All assumptions and balance closure errors were quantified and listed. These disclosures provide a basis to **evaluate the materiality or significance of the assumptions and accuracy margins.**
Consistency	A consistent standard/convention was followed to conduct the balances. The foundational balances allow for a **consistent methodology to compile and evaluate mass and energy balances** in terms of the accounting principles.

3.3 Observations and result discussion

The observations from literature and the selected case study show that MEBs are generally only used in, and mostly limited to, the engineering- and energy fields. Inherent complexity and uncertainty make them less applicable to other fields, however, MEBs are utilised widely to quantify and manage resources. Hence, MEB methods can provide valuable insights to business' operational performance, which will inevitably also affect the financial indicators.

The critical analysis of literature indicated that applications in the engineering- and energy fields can be aligned and improved with certain well-established accounting principles from the financial field. This notion was confirmed by evaluating an existing MEB application in the selected case study.

The case study evaluation showed that although MEB methods were conducted, they were rarely used outside of the operational domain. However, the application of MEB can be extended by considering the well-established accounting principles. If the MEB application can be adjusted to comply with accounting principles, the following objectives may be achieved to address reporting uncertainties:

- Improving the approach followed for overall mass and energy balance,
- Correctly evaluating the impact of a specific event or occurrence,
- Increasing the accuracy of total performance reporting, and
- Increasing communication quality within multiple disciplines.

This foundational work can be used to evaluate specific questions that relate to the use of mass and energy, which also has a financial implication. Relevant examples of this are:

- Carbon tax exposure, risks and opportunities,
- Tax incentive opportunities,
- Investment performance evaluation,
- Or other business performance metrics.

This paper was mainly prepared to test a research question with relevant literature. It recognised the potential improvement of energy-related reporting by considering well-established accounting principles. This entails the combination of multiple fields (*e.g.* engineering and financial) in order to address real uncertainties. To illustrate the potential impact of this a study, the uncertainty of the South African industry carbon tax exposure was used. When considering this, a possible improvement of approximately 6% can be recognised with the application of this strategy. This results in a R2.5 billion monetary value (@ R120 per tonne CO_2e emissions) [27].

Future work on this topic entails the actual application of accounting principles in the engineering field. This requires the development of a framework to support the transparency and traceability of results through multidisciplinary analogies. Lastly, the foundational work discussed and presented in Section 3 needs to be applied to evaluate specific financial-related questions which are dependent on operational (*i.e.* non-financial) observations. This is required to support communication between corporations and their stakeholders.

4 CONCLUSION

This paper highlighted the uncertainties associated with new energy-related reporting requirements. From literature it was found that there is a need to apply well-established accounting principles in the financial environment to energy- and engineering. This study provided substance to this need through a structured and critical review of 83 relevant documents from available literature. The results were further evaluated with a practical application to demonstrate how energy-related reporting should be approached to ensure all the check boxes in the financial environment can also be ticked.

The practical application presented a summary of the groundwork that is needed for energy-related reporting. It also showed that all the financial principles can be addressed in the application, and exactly in what manner. Overall, this study provided a researched argument for the extended application of accounting practices to energy and engineering related reporting. This study therefore provided a basis to decrease the uncertainty in energy-related reporting by:

- Improving the approach followed for overall mass and energy balance,
- Correctly evaluating the impact of a specific event or occurrence,
- Increasing the accuracy of total performance reporting, and
- Increasing communication quality within multiple disciplines.

By decreasing the uncertainties, it can be ensured that energy-related reporting is of a high quality and has the same qualitative characteristics (relevance, faithful representation, understandability, comparability, verifiability and timeliness) as intended in the financial environment. A potential improvement of 6% (R2.5 billion) on the energy industry can be realised with the application of the accounting principles on the energy/environmental environment.

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BALANCING LEADERSHIP STYLES BASED ON PROJECT TYPE AND LIFE CYCLE PHASES: A MODEL

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ABSTRACT

With the current trend towards empowered teams, hierarchical company structures are increasingly being replaced by team-based ones. As a result, a shift in the classic understanding of leadership is needed and research on leadership in project management is increasing. Two major concepts have developed in recent years: shared and vertical leadership styles. This paper reports on the development of a new Model of leadership styles that considers the effect of project types and the project life cycle phases on leadership style (vertical versus shared leadership), and how an appropriate balance between the two styles influences the likelihood of project management success. A web-based questionnaire yielded 313 complete responses and the data was analysed using hypothesis testing. Based on this empirical work and relevant literature, a novel Model is proposed. The Model explains how project types and life cycle phases influence the appropriateness of different leadership styles, and it guides the practitioner to selecting appropriate leadership styles for specific situations. Recommendations for furthering the model are discussed.

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1 INTRODUCTION

Scholars and practitioners have realised that leadership is a major success factor in projects and, as a result, leadership is progressively gaining interest in project management research [1]. In 2000 only 26 research papers used the terms 'leadership' and 'project management' in their titles, while in 2015 the use of these terms grew to 271 [1]. Hierarchical organisational structures are increasingly being replaced by team-based ones, which also emphasises the importance of leadership [2]. The emergent practice of empowered teams, as well as the levelling of organisational structures necessitates the need for a shift in the classic understanding of leadership [3]. Two major streams have developed: shared leadership and vertical leadership [1], [4]–[6]. Both leadership styles take place in projects, resulting in the need to study the balance between them, including how an appropriate balance between the styles may lead to project success [7].

This paper reports on a study, carried out amongst South African project practitioners, to investigate the influence that specific project types and phases have on the leadership style (vertical and shared leadership), and how an appropriate balance between the two leadership styles may influence the likelihood of project management success. The study builds on current literature, which includes empirical studies done in various countries to investigate the project-related aspects that have an impact on the choice of leadership style and the effect of style on project management success. Although many researchers have studied project leadership, little has been published on the appropriate balance in leadership style, and how project type and phase may influence this balance. Moreover, South African studies relating to this topic are very limited.

We have therefore undertaken a research project with the aim of determining whether:

- Project types influence the balance in leadership style;
- Project phases influence the balance in leadership style;
- An appropriate balance of project leadership styles influences project management success.

We conducted a web-based questionnaire in which several questions asked respondents to indicate on a sliding scale how the project type and project life cycle phase influences the appropriate balance between vertical and shared leadership. A total of 313 project practitioners completed the questionnaire. Statistical analysis allowed us to determine how the different project types (pace, complexity, novelty and technology) as well as different project life cycle phases (pre-execution, execution and post-execution) influence the appropriate balance of leadership styles (vertical and shared leadership).

The following eight hypotheses are tested in this paper:

H1: The higher-paced a project, the more the appropriate balance is towards vertical leadership.
H2: The more complex a project, the more the appropriate balance is towards shared leadership.
H3: The higher the novelty of a project, the more the balance is towards shared leadership.
H4: The higher the level of technology involved in a project, the more the balance is towards shared leadership.
H5: During the pre-execution phase, the leadership style tends towards shared leadership.
H6: During the execution phase, which includes much of the monitoring and controlling aspects, the leadership style tends towards vertical leadership.
H7: During the post-execution phase, the leadership style tends towards shared leadership.
H8: The more the appropriate balance between vertical and shared leadership, the higher the perceived likelihood of project management success.

The next section will provide a literature review and explain how the above hypotheses were derived from literature.

2 LITERATURE REVIEW

2.1 Leadership

Leadership definitions have abounded during the past decade [10]. Rost [11] found more than 200 different definitions for leadership in material written from 1900 to 1990. Each person usually know what leadership is, until asked to define it [12]. The word 'leadership' also has different connotations to different people [13].

2.1.1 Vertical Leadership

Leadership is often referred to as 'vertical' when an organisational hierarchy is in place. In such a hierarchy, a formally appointed leader functions as the main source of instruction, oversight and control for those reporting to him/her [14], [15]. Ordinarily these leaders influence projects in a downward, 'one-to-may-style' [14], [15]. This leadership model has been most prominent for many years [16].

2.1.2 Shared Leadership

Pearce and Wassenaar [17] are of the opinion that that the different leadership definitions and styles are "simply the proverbial old wine in new skins." They [17] state that shared leadership incorporates all the definitions and styles and define 'shared leadership' as a meta-theory of leadership, meaning all leadership is a form of shared leadership. Sometimes leadership is shared completely, while at other times it is not shared at all.

In shared leadership there is a "cooperative state of mutual influence", in which the leadership role emerges from individual team members [15],[18]. Shared leadership is an informal process that incorporates collaborative decision-making, shared accountability for outcomes, the sharing of information and interdependency [19]–[21]. A project manager is likely to be confronted with stages or situations in the project where he/she does not have the required skills and knowledge to lead the team effectively [22]. One team member who, chosen by the team because he/she is the most capable person to lead the team in a particular situation, will then take over the leadership role for the period that his/her particular skills are needed [18], [23]. This temporary leader subsequently steps down as leader to allow others to take up the leadership role; this shift may occur many times during a project [24].

2.2 Project Types

Shenhar's [25]–[28] 'diamond of innovation' model (see figure 1) was used for the study. This model suggests a framework for analysing a project's specific setting and for selecting the appropriate project management style. The model has four dimensions: pace, complexity, novelty and technology, and each has a different impact on project management [28]. Each dimension is subdivided into four different project types, ranging from low to high on the scale pertaining to the dimension.

Based on, and supported by previous studies, we postulated the following in the study:

- Vertical leadership is more appropriate for 'Blitz' projects or projects dealing with emergencies [2], [25], [28]–[32].
- Shared leadership is predominantly beneficial for teams involved in complex, knowledge-based, self-motivated and inter-reliant tasks [33]–[36].
- Teams working on highly novel projects participate more in shared leadership [2], [37]–[39].
- Shared leadership is utilised by teams involved in high technology projects, as interdependence is required between the highly specialised team members [22], [30], [40].

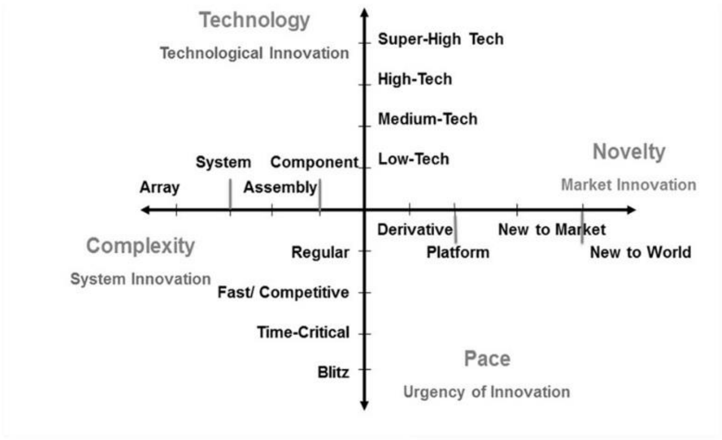

Figure 1: The diamond of innovation - for adapting a project to context [25]

The above statements lead to the first four hypotheses:

H1: The higher-paced a project, the more the appropriate balance is towards vertical leadership.
H2: The more complex a project, the more the appropriate balance is towards shared leadership.
H3: The higher the novelty of a project, the more the balance is towards shared leadership.
H4: The higher the level of technology involved in a project, the more the balance is towards shared leadership.

2.3 Project Life Cycle Phases

The PMI [41] classifies four generic project life-cycle phases, which may be successive, iterative, or overlapping. The phases are:

- Starting the project;
- Organising and preparing;
- Carrying out the work;
- Ending the project.

Archibald, Di Filippo and Di Pilippo [42] propose that 'Post-project business value assessment' be considered as the final project life-cycle phase. This phase is also stated in other papers and is incorporated in the PRINCE2™ methodology [43], [44]. In the light of this, although it is not listed in the *PMBOK® Guide* (PMI, 2017), this phase was included in the study as the final project life-cycle phase [45].

For the purposes of this study, the following three phases, as illustrated in Table 1 were considered:

- Pre-execution;
- Execution;
- Post-execution.

Based on, and supported by previous studies, we postulate the following in the study:

- Shared leadership is predominantly practised during the pre-execution phase [46], [47].
- During the execution phase, which includes much of the monitoring and controlling aspects, the leadership style tends to be more vertical [47], [48].

- Shared leadership is beneficial for the post-execution phase [49]–[52].

Table 1: Phases in the study [46]

Phases used in this study	Pre-execution		Execution	Post-execution	
***PMBOK® Guide* phases and PRINCE2™ stage**	Starting the project	Organising and preparing	Carrying out the work	Ending the project	Post-project assessment

The above statements lead to Hypotheses 5 to 7:

H5: During the pre-execution phase, the leadership style tends towards shared leadership.
H6: During the execution phase, which includes much of the monitoring and controlling aspects, the leadership style tends towards vertical leadership.
H7: During the post-execution phase, the leadership style tends towards shared leadership.

2.4 Balanced Leadership

Shared leadership is not a substitute for vertical leadership and organisations should not be forced to choose between the one or the other; the two styles complement each other [53]. There is a continuum between vertical and shared leadership and there should be an appropriate balance where the leadership style is tailored, based on the specific circumstances and needs of the project [54].

2.5 Project Management Success

Despite the fact that there has been an increase in studies on project management success factors in recent years, many projects are still failing [10], [24], [31], [55]–[58]. Success furthermore does not have the same meaning for everyone [56] as people judge the success of projects differently, depending on their personal objectives [59], [60]. The 'iron triangle' (i.e. budget, time and quality) is often used to assess the success of a project [32], [41]. However, several authors are of the opinion that it is an oversimplification [55], [61]–[64]. In this study, success was self-defined by the respondents.

The final Hypothesis is:

H8: The more the appropriate balance between vertical and shared leadership, the higher the perceived likelihood of project management success.

2.6 The Model

Figure 2 illustrates the model that was used in this study, based on the eight hypotheses that were derived from literature as discussed above.

3 RESEARCH METHODOLOGY

A structured questionnaire with close-ended questions was employed to conduct a quantitative study with the objective of confirming theoretical relationships. A pilot study was conducted with a reference group of six people prior to the survey. The pilot study improved the questionnaire in terms of clarity, correctness and construct validity.

Purposive sampling was used as it is a recognised method in social sciences research, and is a valuable instrument when used correctly [65]. The self-administered questionnaire was distributed as a web-based questionnaire using Qualtrics XM Platform™. The target group consisted of individuals working in project environments, such as project/programme/portfolio managers, project team members, project sponsors and project stakeholders. A total of 46 members of the PMI South Africa Chapter also participated in the survey. The target group was selected because they have comprehensive knowledge of projects and that they are working in key positions in the projects. A total of 313 complete responses were received.

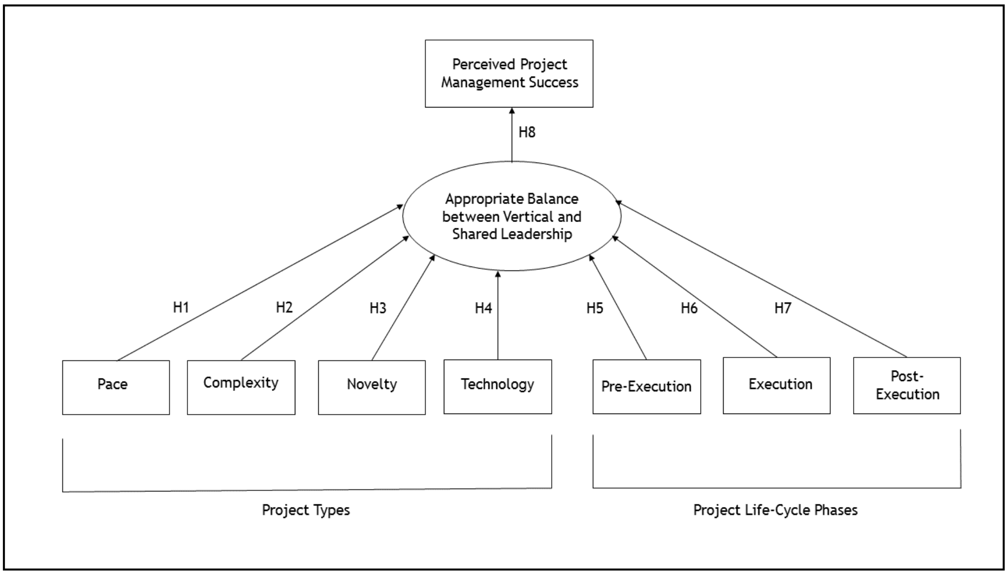

Figure 2: The Model

A one-sample chi-square (χ^2) test was used to test Hypotheses 1 to 8. For hypotheses 1 to 4 as well as Hypothesis 8, this test was done to assess if a significant difference exists between the number of respondents who indicated the hypothesised direction (e.g. the continuum between vertical and shared leadership) as opposed to those who indicated contrasting views. Thus, this test was based on counts. An additional one-sample t-test was done for hypotheses 5 to 7: this test was performed to investigate whether the average score (between 0 and 100 with 0 being vertical leadership and 100 shared leadership) was above or below 50 as hypothesised. Thus, this test was based on means. Table 2 provides the resulting p-values. Statistical hypothesis testing was done at a 5% level of significance.

4 RESULTS AND ANALYSIS

4.1 Demographic Data

The bulk of the respondents indicated that their principal industry was engineering (12%), consulting (11%), information technology (11%), construction (9%) and mining (8%). A total of 51% of the respondents were project managers, and 58% of respondents specified that they worked in projects with a monetary value of R1 million to R100 million. This information indicates that most of the respondents did not work in mega-projects.

Figure 3 illustrates the project types that respondents were involved in.

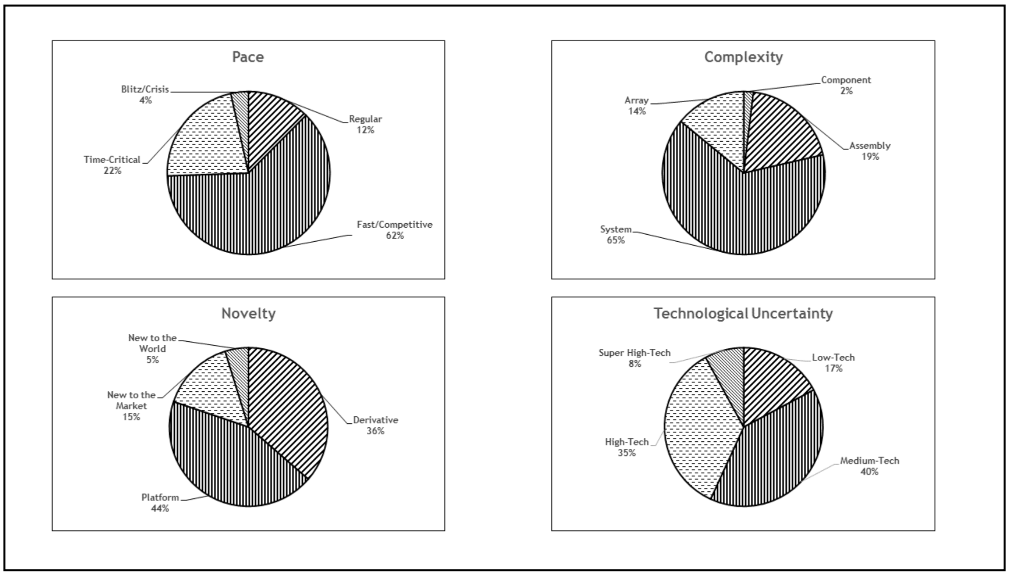

Figure 3: Project types that respondents worked in

4.2 Hypothesis Testing

Table 2 provides a summary of the hypotheses, their p-values, and their validity.

Hypotheses 1, 2, 4, 7 and 8 were supported while the validity of Hypotheses 3, 5 and 6 could not be established.

Table 2: Hypothesis Testing for H1 to H8

	Hypothesis	p-value	Null Hypothesis	Validity of Hypothesis
Project Type	H1: Pace	p<0.001**	Rejected	Supported
	H2: Complexity	p<0.001**	Rejected	Supported
	H3: Novelty	p=0.194	Cannot be rejected	Could not be established
	H4: Technology	p=0.001**	Rejected	Supported
Project Life Cycle Phase	H5: Pre-execution	Counts: p=0.865 Means: p=0.185	Cannot be rejected	Could not be established
	H6: Execution	Counts: p=0.283 Means: p=0.079	Cannot be rejected	Could not be established
	H7: Post-execution	Counts: p= 0.001** Means: p<0.001**	Rejected	Supported
	H8: Balanced Leadership	p<0.001**	Rejected	Supported

*Significant at a 5% level of significance

**Highly significant at a 1% level of significance

4.3 Reliability and Internal Consistency

Cronbach's alpha was used to test the reliability and internal consistency of the questionnaire. It was assumed that the questions in the questionnaire measured the same underlying construct.

The alpha-values for H1 to H7 were low ($0.5 \leq \alpha < 0.6$), which imply a poor internal consistency – each respondent did not answer the questions consistently. This indicates that the respondents were uncertain of the influence of each project type and life cycle phase on the appropriate balance of leadership style. The alpha value for H8 was 0.85, which shows a high internal consistency – the questions were answered consistently. This indicates that there was certainty between respondents that the correct balance of leadership will lead to project success.

4.4 Cross-tabulation

Cross-tabulations were used to compare H1 to H7 with the following demographic data derived from the questionnaire:

- The respondent's typical role in a project;
- Respondents' years' experience in project management;
- Monetary value of projects that the respondents were involved in;
- Principal industry of the respondent.

The chi-square test was used to do the comparisons. H_0 was rejected for only one of the cross tables. H_0 for H3 (novelty) was compared with years' experience, which resulted in $p=0.017$ and could thus be rejected. This indicates that years' experience had an effect on the influence that novelty projects have on the direction of the leadership balance. All the other H_0 values could not be rejected which indicate that the role in the project, years' experience, monetary value and principal industry did not have an effect on the influence that project types and phases have on the balance of leadership style.

5 DISCUSSION

This study investigates the influence of four project types (pace, complexity, novelty and technology), and the effect of the different life cycle phases on leadership style (vertical and/or shared leadership), and moreover the influence that the appropriate balance of project leadership styles has on perceived project management success. Eight hypotheses were tested: H1, H2, H4 H7 and H8 were supported while H3, H5 and H6 were rejected. Cross-tabulations with demographic data yielded no noteworthy findings, except for 'years' experience' that had an effect on H3 (novelty).

Even though H1, H2, H4, and H7 were supported based on the chi-square test results, the low alpha-values pointed out that there is no significant difference between the questions asked for each hypothesis in the questionnaire. This implies that there was a measure of confusion amongst respondents regarding the 'exact' direction of leadership style (vertical and/or shared leadership) on the continuum.

No uncertainty existed amongst respondents regarding the definition of 'balance', as it was provided, and respondents' understanding of the concept was tested in a qualifying question in the questionnaire. Respondents were however unsure of the ideal point of this balance on the continuum between vertical and shared leadership for different kinds of projects and life cycle phases. The uncertainty pertaining to pace (P1), complexity (H2) and level of technology (H4) could be explained by the fact that the majority of the respondents were not exposed to high-paced, highly complex or high-technology projects (see Figure 3). They probably did not possess the necessary understanding and experience, which influenced their answers, and in the end the data.

A possible explanation of the rejection of H3 (novelty), is that South Africa in general has not had many highly novel projects in the past two decades and that 80% of all respondents indicated that they work in the less novel projects. We found that respondents with more years' experience tended to agree that high-novel projects lead to a more shared leadership approach, which makes sense if it is considered that an individual with many years' experience could have been exposed to highly novel projects earlier in his/her career when more novel projects were executed in South Africa. It can thus be deducted that the respondents simply did not have adequate exposure to highly novel projects to answer the questions.

The respondents' uncertainty of the influence of project life cycle phases on the appropriate balance of leadership style may result from South Africa's current lack of skilled people. Many skilled and semi-skilled people have left South Africa in recent years, resulting in a workforce of less-qualified people in positions previously occupied by more suitable candidates in terms of qualifications and experience [66]. Due to this lack of expertise, technical and operational skills are predominantly situated in the private sector while the relatively large government sector has to subcontract many of their projects. The situation then arises where the people who were involved in the pre-execution phase (i.e. preparation of the tender document), those who carried out the work, and those who participated in the post-execution phase, might be in separate teams. It is often required from those involved in the project execution phase to work with the client team to get their buy-in on the project and to clarify the scope of the tender. In such cases, some shared leadership is required for project execution. The hypotheses were derived from international studies and leadership styles in South Africa could differ from those hypothesised in the study. In contrast with South Africa, many international companies employ people that are more skilled and probably practise concurrent engineering, resulting in team members being more involved in a project from start to finish.

6 CONCLUSION

In the study, the target group all agreed that an appropriate balance in leadership styles (vertical and shared leadership) would increase the likelihood of project management success. This is in line with studies done in other countries. However, most respondents were uncertain of the influence of different project types (pace, complexity, novelty and complexity) as well as different project life cycle phases (pre-execution, execution and post-execution) on the 'exact' position on the continuum between vertical and shared leadership (i.e. the appropriate balance of leadership style). Possible reasons and explanations for this occurrence are provided above.

Figure 4 provides the final Leadership Style Model.

Another possible reason for the outcomes of the study could be the so-called 'cultural trap' [67]. This phenomenon occurs when western project management approaches are not recognised by team members in developing countries (like South Africa). Reasons for this include different ethnic and social traditions and beliefs, and patriarchal, male-dominated cultures.

It should also be noted that South Africa is a developing country with a great cultural diversity, while the majority of the literature that led to the formulation of the hypotheses originates from studies done in developed countries. Further work should be done to get to an ultimate, empirically supported model.

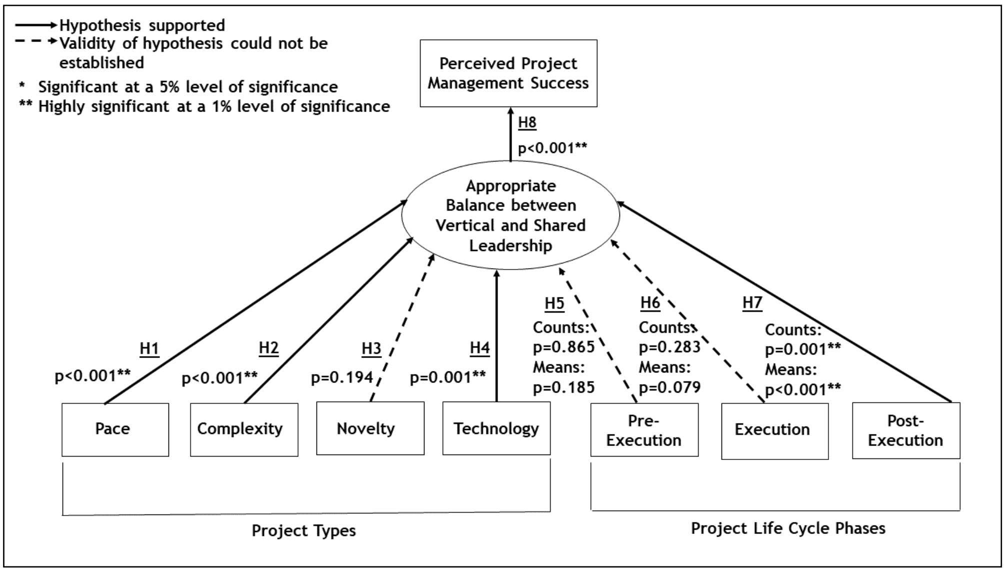

Figure 4: The Leadership Style Model

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INVESTIGATING THE ROOT CAUSES OF LONG LEAD TIMES IN THE AUTOMOTIVE AFTERSALES INDUSTRY BY MEANS OF THE LEAN PHILOSOPHY: A SOUTH AFRICAN CASE STUDY

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ABSTRACT

The aftersales service industry has the potential to produce 80% of an organisation’s profit, although most only generate 20%. Similarly, the organization, used as a case study, struggles to achieve their operational performance indicators (OPIs) and the consequent profit margins. The aim of the study was therefore to investigate the root causes and develop corresponding preventative actions.

The research followed a DMADV (Define-measure-analyse-design-verify) approach, uniquely designed by integrating specific methods: Gemba walks defined the scope of the problem and aim; The root causes determined by a 20-Key audit and five-why analyses were reported in a thematic map; Potential solutions were developed utilising Kernel theories, and verified via the Delphi technique.

This study points out the many challenges, such as low employee moral and high staff turnover rates, when implementing a German adaptation of a Japanese philosophy (Lean) in the South African service industry, emphasizing the misunderstanding of lean principles. Furthermore, it highlighted the implications of a cross-cultural adaptations of lean, within organizational cultures.

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1 INTRODUCTION

The aftersales service department of a company has the potential to produce 80 percent of a company's profit and improve Operational Performance Indicators (OPIs), although most only generate 20 percent [1]. In 2018, the South African automotive industry was under strains due to fiscal uncertainties. Ergo, automotive dealerships around the country have begun to attentively focus on the improvement and optimisation of their after sales service departments [2].

Conversely, it has been discovered that the after sales department of an automotive dealership, used as case study, is currently experiencing a decline of the department's OPIs (productivity, efficiency and effectiveness). This poses a potential loss of income for the organisation.

The organisation, used as a case study, is part of an international German automotive company. This German company adapted the lean approach (with its Japanese foundation) and are implementing it in their different organisations, worldwide. However, this could lead to complications within the organisational cultures of these different companies.

The lean methodology often provides organisations with a continuous improvement approach needed to combat organisational inefficiancies (amongst other things) [3]. However, although there are many Lean Production System (LPS) techniques that may be utilised in the after sales services, there is no all-inclusive route available for every and any company [1]. This lends to the idea that companies will require tailored lean procedures, ergo building a lean culture specific to the organisations' systems and goals.

2 RESEARCH AIM

The aim of this research was to investigate the root causes of the organisation's poor OPIs: productivity, efficiency and effectiveness, by means of the lean continuous improvement approach.

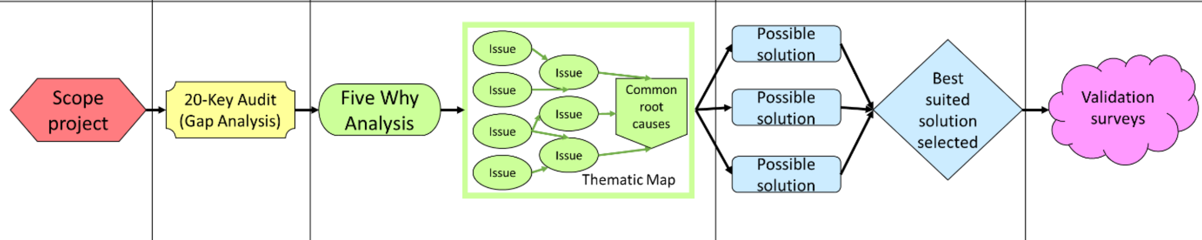
The next section explains the research design that was followed, while section 4 provides the findings of each phase of the research. The study is concluded in section 5, with further research recommendations stated in section 6.

3 RESEARCH DESIGN

The research spanned across multiple departments of the after-sales service centre, with a complex problem and unknown root causes Therefore, the research design incorporated many problem-solving methods, in order to narrow down the problem and its causes that needed to be addressed. These methods were integrated using a DMADV (Define, Measure, Analyse, Design, Verify) approach [4], which is an adaption of the DMAIC (Define, Measure, Analyse, Improve, Control) approach. The DMADV method is ideally used for improvements, adjustments or the creation of new concepts, which made it well suited for this improvement focused study [4].

The research design (Figure 1) illustrates the different methods and finding during the various phases of the research. The detail of each segments in the diagram is discussed in the corresponding section (illustrated with section "§" numbers)

Referring to Figure 1, the research initiated by scoping the study and measuring the current state. The problem diverged into multiple issues during the five-why analysis, but converged again into common root causes, during the thematic analysis. Subsequently, diverging once again into multiple solutions, which later converged to the best suited solutions for verification. The resulting research design is explained in the sections to follow. The results of each phase of the research is presented in Section 4.



	Define	Measure	Analyse	Design	Verify
Diagram					
Method	§3.1- Conduct **Gemba walks** and **literature studies**.	§3.2- Conduct a **20-Key audit**.	§3.3- Conduct a **five-why analysis** on each of the 20 keys, thereafter conducting a **thematic analysis** on the outcomes of the five-why analysis.	§3.4- Utilising **Kernel theories** to design multiple possible solutions to address the root causes.	§3.5- Conducting surveys (via the **Delphi method**) to verify employee agreement with the solutions.
Findings	§4.1- Overall scope of the **problem and aim** are define.	§4.2- A **radar diagram** that indicates the audit's outcomes.	§4.3 – A **five-why summary** of the results, followed by a **thematic map** illustrating the convergence to common root causes. A table comparing the root causes to their corresponding **violated lean principles**.	§4.4- The **proposed solutions** to address the root causes.	§4.5- **Verified solutions**.

Figure 1:Research design

3.1 Define Phase - Gemba walks and literature study

For the define phase, the overall scope of the problem and aim were defined. This was achieved through Gemba walks, where walking the shopfloor allowed for the observations of process executions and activities [5].

Literature studies on lean were also conducted in order to compare the current state of the organisation to literature [6] [7] [8] [3]. It was found that lean is the philosophy of focusing on eliminating waste, ergo only including the value adding activities to a process [2] [8] [6]. These wastes are identified as transportation, inventory, motion, waiting, over-production, over processing, defects and underutilised intellect [7] [6]. The lean philosophy was selected for this research, as the organisation (used as a case study) utilised lean approaches and concepts in daily operations. This South African dealership is part of an international German automotive company, who has also adapted the lean philosophy from Japan. The results of this phase are captured in section 4.1.

3.2 Measure Phase – 20 key audit

This phase of the study composed of collecting (measuring) information on the current state of the organisation. The 20 Keys strategy was engineered by Iwao Kobayashi, as a system to improve an organisation in 20 different operational zones [9]. In his book 20 Keys to Workplace Improvement, Kobayashi [10] defined his approach as a Practical Program of Revolutions in Factories (PRORF), a five-point (five level) evaluation system [10]. Furthermore, the 20 Keys approach allows one to conduct a gap analysis in an organisation, in order to discover which areas (of each of the 20 keys) needs the most attention. For this study, Kobayashi's book was utilised in developing a 20-key audit sheet, allowing for the placing of the organisation on one of the five levels for each of the 20 keys. Information for the 20-keys audit was gathered by interviewing several employees and via observations during further Gemba walks. The results from the audit, a radar diagram is presented in Section 4.2. This proved to be useful in narrowing the scope of the problem's causes.

3.3 Analyse Phase - 5-Why analysis

The analyse phase investigated (and converged) the root causes of the issues highlighted during the 20-key audit in the measure phase. A five-why analysis was conducted on each one of the 20 keys. Whilst conducting the analysis, trends in the root causes started to emerge. When working with data that converges (or diverges), it is recommended that a thematic map be utilised for analysis [11] [12] [13] [14]. and visual representation of patterns in data, [15] [13], while not overlooking the smaller data points in the grand scheme of things [14].

The data obtained during the five-why analysis converged to six root causes as indicate by the thematic map, explained in Section 4.3. The thematic map also illustrates the links between the data gathered from the five-why analysis.

3.4 Design Phase - Kernel theories

The design phase proposed different solutions to the root causes outlined in the thematic map. All proposed solutions were based on various Kernel theories, which are described as nuggets (kernels) of knowledge and theories from nature or science, that allows for the justification of a process design [16] [17]. By utilising Kernel theories, the design of a solution is based on previous evidence discovered within academia.

The alternative solutions that were proposed in this stage, were evaluated based on the following criteria (using a 5-point Likert scale for each criterion) (table 1):

- Cost to the company,
- Implementation time,
- Complexity of solution,
- Resistance expected from management, and
- Resistance expected from workshop employees.

Table 1: Likert scale used to score alternative solutions

Extremely High	High	Average	Low	Extremely Low
(1)	(2)	(3)	(4)	(5)

This allowed for the selection of the possible best-suited solution to address each root cause. These solutions are discussed, in terms of implementation details, in section 4.4.

3.5 Verify Phase – Delphi method

The verify phase made use of surveys via the Delphi method. The Delphi method is defined as gathering input from relevant people on a specific topic [18]. Due to the structure of the Delphi method, it allows for multiple rounds of surveys, each based on the outcome of its predecessor [19]. The rounds of surveys may only stop once consensus is reached on each research question. This may be declared if the average rate on a question is greater than 75% (e.g. 3.75 on a 5-point Likert scale) [18]. On average, consensus is reached after three rounds [18] [20] [21]. The surveys allowed for the testing of the suggested solutions, as well as testing the suggested implementation time frames, detailed in section 4.5.

4 FINDINGS

4.1 Define phase - Problem and aim

From the Gemba walks and literature studies, it was revealed that the problem causing the decline of organisational OPI's was long lead times. Thus, the aim of the study was to investigate the root causes of the organisation's poor OPIs, by means of the lean continuous improvement approach, as provided in section 2.

4.2 Measure Phase - Radar Diagram

The results from the 20-key audit are illustrated as a radar diagram (figure 2). The findings indicate that the organisation did not score more than three (out of five) for any of the 20 operational zones. This is indicative of the fact that there is room for much improvement within the organisation. Upon conducting the 20 key audit, it was also apparent that the service centre lacked synergy. The lack of synergy was observed during the interviews (on the Gemba walk), when employees were confused on the roles and responsibilities for different operational zones and/or were unaware of their existence.

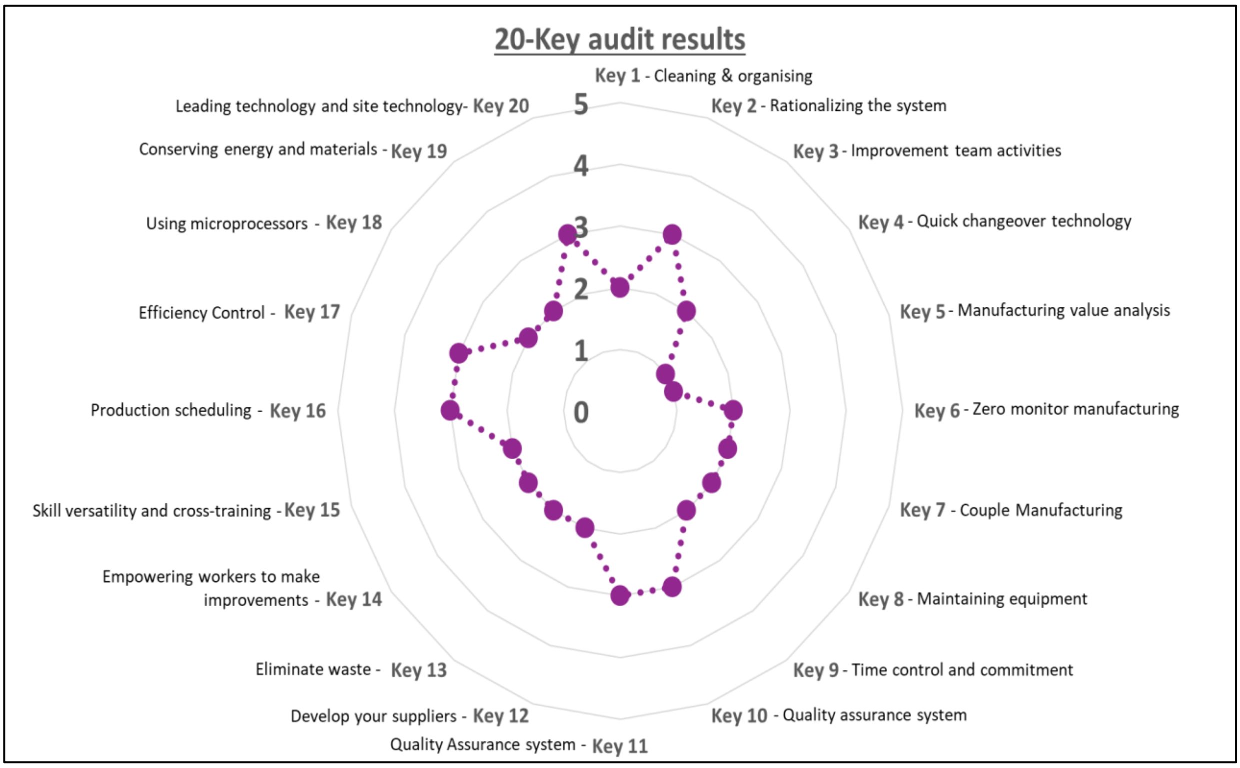


Figure 2: Radar diagram of the results from the 20 key audit

4.3 Analyse Phase – Thematic Map

A five-why analysis was done to find the causes for the low score of each of the 20 keys. The five-why summary is shown in Fig 3. This matrix grid was created by allocating the 20 key numbers to the rows and allocating A to E levels for each of the five whys across the columns. During analysis of the data suspected trends emerged, which were colour-coded.

The outcome of the five-why analysis was further investigated by means of a thematic analysis in order to discover the root causes of each of the 20 keys. The thematic map is illustrated in Fig 4.

The matric grid created by the 1-20 numbers and A-E levels, were used to illustrate the correlation between the five-why summary and the thematic map. Ergo, section A1 in the five-why summary (Figure 3) is labelled block A1 in the thematic map (Figure 4). Each of the suspected trends were confirmed as a root cause theme and therefore allocated the same colour as in the five-why summary.

The thematic map illustrates the convergence to the six common root causes of the low score of each of the 20 keys: (1) late job distribution to employees, (2) low employee morale and norms, (3) high staff turnover rate, (4) low employee skill level, (5) insufficient/absent tools and equipment, and (6) lack of demarcated areas; of which "high staff turnover rate" and "low employee morals and norms" were found to be the root causes for most of the issues (evident by the number of arrows ending at it).

The organisational culture could have had an influence on the employee moral and norms (root cause nr 2), as well as creating the work atmosphere, which could in turn influence staff turnover rates (root cause nr 3) [22]:

"Organisational culture is manifested in the typical characteristics of the organisation. It therefore refers to a set of basic assumptions that worked so well in the past that they are accepted as valid assumptions within the organisation... (which manifests itself in attitudes and behaviour)".

Hence, an ineffective organisational culture may have contributed to the situation in the case study organisation, as it dictates how things are done within an organisation (regardless if it is wrong or right) [22].

Suspected Trends	
Staff turnover	
Not enough equipment	
Job distribution in mornings	
Employee skill level	
Lack of demarcated areas	
Employee Moral and norms	

Level	A	B	C	D	E

Key	Problem Statement	Why 1	Why 2	Why 3	Why 4	Why 5
1	Work surfaces are disorganised	Technicians are comfortable with work surfaces	They have to wait for some tools and equipment	There is not enough tools and equipment	Technicians must have their own tool boxes and share some equipment	
2	Specific objectives are not displayed with graphs	It was not seen as a need. They have data boards declaring hours.	Its is believed to be a waste of time	Workers may not look at it	There is new staff and it may take time to view visuals with understanding	There are different levels of knowledge and skills in workers.
3	There are no improvement teams	Technicians are already very busy and won't have time for it	It is seen as extra work	They feel that they won't be paid for it, thus they are resistant		
4	There is WIP piled up on work surfaces	Workers leave WIP closest to the car it belongs to	They are unsure where to leave it	There are no demarcated areas to place WIP		
5	It take more than 10 min to changeover jobs	Each job is different	There are different things wrong with each vehicle, and it needs time to get the parts for the job	The part store is situated away from the bays	It is the design of the building.	
6	Waste removal (for all types of waste) has not begun	It is difficult	Staff find it hard to grasp the current waste removals	There is new staff often (high staff turnover rate)		
7	The organisation still sees a need for monitoring	Workers some times need supervision	There is a lack of certain skills, so it is taught through supervision	Some workers were previously disadvantaged and there are new workers often		
8	There are only some forms of Kanbans	Workers are unsure of what they need for the next job	Workers only receive job cards in the morning	This is how the current system functions		
9	Maintenance and inspection of equipment has not formed part of their daily routines	Workers will not have enough time to do so	There is a delay in starting up in the mornings	Due to Job allocations being done in the mornings and low employee moral		
10	There is a delay to start up in the morning on jobs	There is time needed to prepare for the day	The moral of workers is low and there is a leadership issue	Jobs are distributed in the mornings	It is the current system of doing things	
11	There are no measures in place to conduct self quality checks	It is seen as a waste of time	People are not going to be honest, this it is a risk to check ones own work			
12	There are no value adding study groups across the departments with the suppliers	All suggestions and observations are done via managers	There is a lack of time for workers to be apart of study groups			
13	There are no waste improvement sessions	The service centre is still trying to master the current wastes	Workers feel like it is extra work	They are struggling to cope with the current work load	There is new staff often	People leave for better opportunities
14	There are no employee improvement teams	There is no time for extra activities	Workers are struggling to cope with the current work load	Employee moral is low	The staff turnover is high, thus there is new staff often. There are also some issues with leadership	They leave for better opportunities else where
15	Employees are not able to execute everyone's tasks on a basic level	Some workers are better trained for specific jobs	Their past experiences and abilities are different	Some employees come from previously disadvantaged backgrounds		
16	Service and efficiency goals are not met	There is overbooking and a lack of employee motivation	There is a lack of planning and high staff turnover rate	They are booking cars and not hours, ergo there is a lack of work scope. Also, staff find better opportunities else where		
17	Daily efficiency is not displayed in control charts	It takes too much time to develop these charts	There is a lack of skill to draw and interpret these charts	Workers still need to go for training to develop excel and analytical skills		
18	The service centre is not as automated as it could be	The service centre is not allowed to bring in new technology	They are apart of an international company, which requires standardisation throughout the world			
19	There is a struggle to actively reduce costs via conservation	Most of the equipment stays on throughout the day	It has become operator and workshop floor norms	It has not been formally addressed		
20	The company struggles to successfully incorporate new technologies	Workers take time to adjust	Due to the different levels of experience	Workers come from different backgrounds, as well as a high staff turnover		

Figure 3: Five-why summary

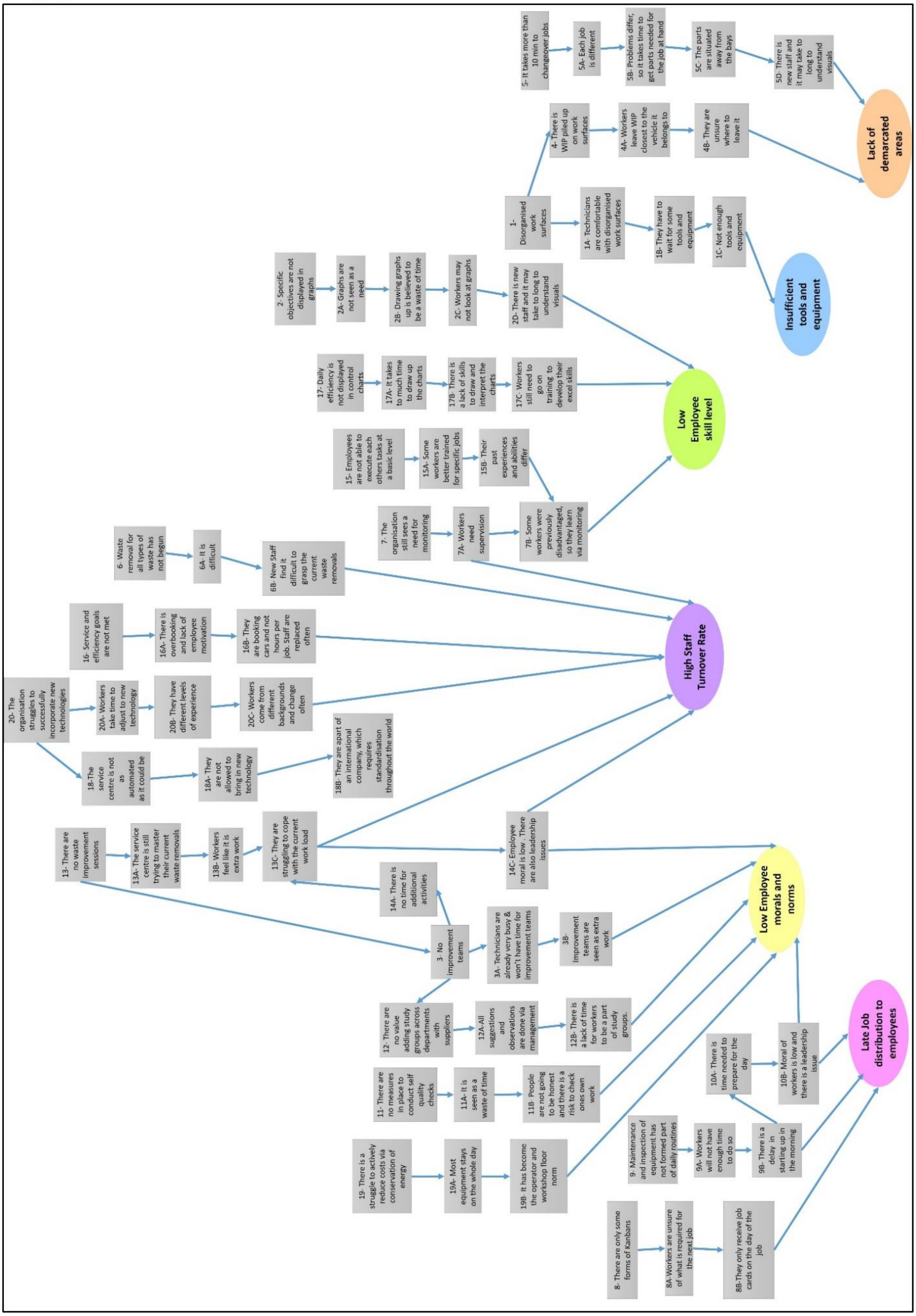


Figure 3: Thematic Map of root causes

The thematic analysis contradicted the case study organisation's opinion that they have implemented or adopted lean principles, while the results indicated that there was a mismatch of multiple principles [7]. The root causes and the violated lean management principles [7] are provided in table 2: The left column states the root cause and the he right column , states which of the 14 management principles of the Toyota way [7] was violated, indicated with a "P" and the principle number.

Table 2: Identified root causes and contrasting lean aspects

#	Identified Root Cause	Violated Lean Principle
1	Late job distribution to employees -The organisation takes extra time to start up operations in the morning, because jobs are only distributed to the employees in the morning. As a result, there is a delay in acquiring the parts and tools required to complete the job for that day.	1.1. **P4** - *Level out the workload (heijunka)*- Planning 1.2. **P6** - *Standardised tasks are the foundation for continuous improvement and employee empowerment* - Standardised tasks
2	Low employee morale and norms - Worker morale is low; this was recognised by management. Management has identified leadership issues. Many shop floor employees expressed their feeling of not being heard within the organisation, as there are not enough opportunities to express their suggestions. This lends to the waste in the form of unused employee creativity.	2.1. **P10** - *Develop exceptional people & teams who follow your company's philosophy* - Respect for people 2.2. **P2** - *Create continuous process flow to bring problems to the surface* - Eliminate waste (Unutilised employee creativity)
3	High staff turnover rate - The high staff turnover rate refers to the fact that workers are often resigning. Like with many organisations, some workers leave to pursue better opportunities at other companies.	3.1. **P1** - *Base your management decisions on a long-term philosophy* - Long life employment 3.2. **P10** - *Develop exceptional people & teams who follow your company's philosophy* - Employee development
4	Low employee skill level - Some employees come from disadvantaged backgrounds. In addition to this, not all employees are at the same skill level. These factors culminate to impacts the work experiences and skill levels of the various employees.	4.1. **P10** - *Develop exceptional people & teams who follow your company's philosophy* - Employee development 4.2. **P9** - *Grow leaders who thoroughly understand the work, live the philosophy, and teach others* - Grow leaders
5	Insufficient/absent tools and equipment - Technicians and shopfloor employees are required to bring their own toolboxes. Specialised equipment and tools are supplied at the specialised tools room. Due to this, employees frequently must share tools, which causes delays in jobs.	5.1. **P6** - *Standardised tasks are the foundation for continuous improvement and employee empowerment* - Standardised tasks
6	Lack of demarcated areas - Employees leave parts and tools used on vehicles next to the vehicles, as there are no demarcated areas for work-in-progress and tools. This causes multiple wastes in terms of motion, as workers walk around the parts and tools on the floor, as well as having too move them often	6.1. **P6** - *Standardised tasks are the foundation for continuous improvement and employee empowerment* - Standardised tasks 6.2. **P7** - *Use visual control so no problems are hidden* - Visual management

4.4 Design Phase - Improvement

During the improvement phase of the study, Kernel theories were used to develop suitable solutions, to address the root causes. These Kernel theories were aligned with the violated lean principle in table 2, striving towards achieving a true lean transformation. The root causes, applicable Kernel theories, solutions and implementation details are depicted in Table 3.

Table 3: Table of explanations of solutions

Root Cause	Kernel Theory	Solution	Implementation details
1 - Late Job distribution to employees	Optimisation tool for planning	Weekly job schedule	Employees skill levels must be evaluated to ensure that they are able to complete jobs allocated to them. In order to allocate jobs fairly, a justified method of allocating jobs must be identified. Weekly meetings must be set up to allocate jobs to employees for the up and coming week.
2 - Low employee moral	Improvement via team activities (Key 3 of 20 Keys)	More team building activities.	Group activities must be identified and scheduled. Thereafter, all employees must be invited to the events
3 - High staff turnover rate	Toyota's approach to Maslow's need hierarchy	Small improvement teams	Small improvement teams will aid in utilising employee creativity and involvement within the organisation. As it will require developing teams of 5 people from different departments, determining the roles within the teams and identifying improvement projects.
4 - Low employee skill level	Growing leaders who thoroughly understand the work, live the philosophy and teach it to others	Mentorship program	Employee skill levels must be reviewed to determine where they need to improve. This will allow for allocation of mentors based on the skill level of employees. A list of tasks to train on must be drafted and employees must be tested on their ability to complete the tasks.
5 - Insufficient (absent) tools and equipment	Standardise work (Using standard times)	Schedule for tools and equipment	A schedule will aid in providing structure to the method of sharing tools and equipment. A tool schedule must be created. Time studies must be conducted to determine the standard times for using tools. Lastly employees must be trained on how to use the tool schedule and it should be displayed on the workshop floor.
6 - Lack of demarcated areas	Use visual control so no problems are hidden	Standardised workstation layouts	A Kaizen event must be hosted to implement 5S in work cells. Hereafter, employees must be trained on how to set up their work cells based on the outcome of the 5s kaizen event. Lastly, all work cells must be inspected on a monthly basis.

4.5 Verify Phase – Testing Solutions

The Delphi method was used to verify the proposed solutions that were designed in the previous phase, by developing a survey to investigate employee's agreement with the proposed solutions.

Since each solution was developed from a Kernel theory, these Kernel theories were utilised to develop a hypothesis-based outcome for each solution which was in turn utilised to design a corresponding survey statement. Hypothesis-based outcomes allowed the researcher to assume what the outcome of the solution would be (based on literature) in order to test the participants agreement. The statements were compiled in a survey with a 5-point Likert Scale (Table 4) to evaluate their agreement with each of the statement. All statements were written in basic English (ensuring all jargon was explained).

Table 4: Likert scale used in the survey

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
(1)	(2)	(3)	(4)	(5)

Table 5 provides a summary of the root causes, proposed solutions, Kernel theories, hypothesis-based outcomes and survey statements).

Table 5: Table of summary for developing the survey

No.	Problem (Root causes)	Solution to address the problem	Kernel theory	Hypothesis-based outcome	Survey Statements
1	Late job distribution to employees	Develop a weekly job schedule	Optimisation tool for planning	A weekly job schedule will enable workers to coordinate jobs and prepare for jobs before the time.	1. A weekly jobs schedule will help workers to prepare for their up and coming jobs.
					2. A list of skills needed to complete each job can be compiled in 2 months.
2	Low employee morale and norms	Implement more team building activities	20 keys to workplace improvement - key 3 (Improvement via team activities)	Team building activities will improve employee relationships. This will lead to employees feeling valued by the organisation, which will improve the morale of employees.	3. Team activities will help workers build better relationships with each other.
					4. Team activities will show employees that the company values them.
					5. A suggestion box can be installed in 2 weeks, so employees can suggest team activities they would like to do.
3	High staff turnover rate	Create small improvement teams	Lean's approach to Maslow's Need Hierarchy	Small improvement teams will allow employees to feel valued and a part of the organisation, because it gives them a platform to provide their input. This will lead to employees wanting to stay at the organisation.	6. Small improvement teams (group projects to improve the work environment) will lead to employees feeling valued by the company.
					7. Small improvement teams will lead to employees feeling part of the company.
					8. A small improvement team can focus on one project in a month.

4	Low employee skill levels	Develop a mentorship Program	Principle 9 of the Toyota Way (Growing leaders who thoroughly understand the work, live the philosophy and teach it to others)	A mentorship program will allow more experienced workers to train other workers, via a practical transfer of knowledge. Lower skilled employees will be able to enhance their skill set, while developing leadership in higher skilled employees	9. A mentorship program will allow employees to gain new skills from other experienced employees. 10. It will take one month to evaluate the skills that employees have and need.
5	Insufficient (absent) tools and equipment	Create a schedule for tools and equipment	The lean tool of standard work (using standard times)	A tool and equipment schedule will allow increase access to tools and equipment. This schedule will further reduce waste in the form of waiting	11. A schedule for tools and equipment will allow workers to use and share tools with each other, so that workers do not wait a long time for tools. 12. It will take 2 months to measure the time employees spend using a tool/equipment for a job task. (Time measurements will be done for all tools and equipment).
6	Lack of demarcated areas	Create standardised workstation layouts	Principle 7 of the Toyota Way (Use visual control so no problems are hidden)	Standardised workstations will be more organised. This will reduce waste in terms of motion, waiting and defects, as employees will not have to look for parts/tools.	13. Having the same layouts in all the workstations will organise them and reduce waste (motion, waiting and defects). 14. It will take 2 weeks to hold a 5S kaizen event (A team-based activity to organise the workstations, which allows employees to have a say).

After the employees participated in the survey, their responses were tabulated and analysed using control charts. Consensus was defined as the average for each statement being above 3.75, which is a 75% agreement (on a 5-point Likert scale) [18]. The results are shown in table 6, including their position in the company, years at the organisation and age.

Responses to statements 1-3 and 6-14 of the survey, all displayed an average greater than 3.75 after the first round, declaring consensus and responses within the control limits (Table 6). However, responses to statements 4 and 5 provided challenges, as the response of participant 7 was out of the lower control limit (indicated in red in table 6). Upon investigation, it was revealed that the participant was a 52-year-old individual, placing him in the “aging and high seniority workforce” category [23]. It was also found that he had only been working at the organisation for 3 months. It can be deduced that the combination of being new to the organisation and older than most employees, caused him to view the organisation differently, since his view on feeling valued by the organisation was not yet established. This renders the data point removable with a valid cause, and the average re-calculated for statement 4 and 5. The last row of table 6 portrays that consensus on all statements were reached, as all averages are greater than 3.75.

Table 6 : Data from survey responses

#	Position	Position details	Years of service	Age	Response to statements													
					1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Management	Service Manager	0.33	28	4	3	4	4	3	4	4	3	4	2	4	3	4	4
2	Management	Workshop manager	0.25	34	1	2	5	5	5	5	5	5	5	4	1	2	4	1
3	Management	Dealership principle	2.00	38	3	4	5	4	5	4	5	4	3	5	5	5	5	2
4	Technician	N/A	3.00	28	5	3	5	5	5	5	5	5	5	5	5	4	5	5
5	Technician	N/A	0.58	31	4	3	5	5	4	4	4	3	5	5	5	4	4	4
6	Technician	N/A	1.00	33	4	4	4	4	4	4	4	4	4	3	4	4	4	4
7	Technician	N/A	0.25	52	5	2	5	2	2	4	5	5	5	5	2	5	4	5
8	Technician	N/A	0.08	32	4	5	4	4	4	4	4	4	5	5	3	3	4	4
9	Technician	N/A	0.50	31	2	3	5	5	5	4	4	4	3	3	4	5	4	4
10	Apprentice	N/A	1.00	26	5	2	5	5	5	5	4	4	5	5	5	4	5	5
11	Apprentice	N/A	0.25	21	4	4	5	5	5	4	4	4	5	4	4	2	5	3
12	Apprentice	N/A	0.17	24	5	5	5	5	5	5	5	5	5	2	5	5	5	5
13	Apprentice	N/A	1.00	36	3	4	5	5	5	5	5	5	5	5	3	4	3	4
14	Apprentice	N/A	0.17	26	5	5	4	4	5	5	5	5	5	5	5	4	5	5
15	Apprentice	N/A	0.50	28	5	3	5	5	5	5	5	4	3	4	5	4	5	2
16	Other	Parts Clerk	3.00	33	5	5	5	4	4	5	4	3	5	4	4	5	5	4
17	Other	Parks Clerk	1.00	45	4	5	5	5	5	5	5	4	5	5	5	5	5	5
18	Other	Contractor	2.00	35	4	5	4	5	5	4	5	5	5	2	2	2	4	5
19	Other	Windscreen Contractor	2.00	41	4	4	4	4	4	4	4	4	4	4	4	4	4	4
20	Other	Customer Relations	1.50	26	4	4	5	5	5	5	5	5	4	4	3	3	5	5
Initial Averages					4.00	3.75	4.70	4.50	4.50	4.50	4.55	4.25	4.50	4.05	3.90	3.85	4.45	4.00
Final Averages					4.00	3.75	4.70	4.63	4.63	4.50	4.55	4.25	4.50	4.05	3.90	3.85	4.45	4.00

This study reached consensus amongst participants after the first round of questions, ergo there was no need for additional rounds of the Delphi method. Since consensus amongst participants were reached, the solution can be considered verified.

5 CONCLUSIONS

In this study the organisation, used as case study, was experiencing a decline of the department's OPIs, which posed a potential loss of income for the organisation. Therefore, the aim of this research was to investigate the root causes of the organisation's poor OPIs by means of the lean continuous improvement approach.

The study was conducted by means of the DMADV approach, combining different problem-solving techniques in a novel approach. The root causes determined by a 20-Key audit and five-why analyses were reported in a thematic map. Potential solutions were developed utilising Kernel theories, after which they were verified via the Delphi technique.

This study indicated, the mismatch of multiple of the 14 lean management principles which is a common problem during lean implementations world-wide [24] [25] [26]. Hoogvelt and Yuasa [24] express that "The experience with Japanese or 'lean' production systems when transplanted to the West has often been below expectations", this was attributed to the misunderstandings in different social, economic and organisational cultures [24].

Furthermore, this research has also revealed the importance of organisational culture, ergo the people (employees) of an organisation have the power to make the organisation succeed or fail. The case study highlighted the issues with trying to implement the same organisational management strategies world-wide, throughout different organisations of the same "parent-company", causing lean and organisational cultural mismatches. From literature, it was made apparent that lean is rooted deeply in the Japanese culture [24]. Japan's history and folklores depict a lean culture of doing nothing without meaning, thus ensuring that all members in a party understand the implications of decisions made. This ideology has transcended into the business world of Japan, making it the pioneers in lean. This could explain why there is a mismatch of lean in other countries' organisations.

The study also found that when dealing with organisational culture, there is no universal solution, instead continuous improvement approaches must be adapted to the current culture. When lean techniques are used verbatim, it may cause misunderstandings between the organisational culture and lean principles. The aforementioned cross-cultural adaptations of lean, highlights the importance of an effective organisational culture for successful lean implementation. Management should therefore be aware of the difference in cultures when adapting lean cross-culturally.

In summary, this study has developed a novel approach to discovering, analysing and addressing the mismatch of lean principles within an organisation and thereby emphasises the influence that organisational culture has on lean implementation.

6 FUTURE RESEARCH

The focused of this study was on identifying the root causes and solutions for improving the organisations OPI's. However, an implementation plan was not developed for the proposed solutions. It is therefore recommended that future research focus on such an implementation plan.

This research focused on a single organisation of an international automotive company. This international body's parent-company is a German based automotive company, which has taken lean tools from Japan and adapted it to the German culture. This set of adapted tools is utilised in strategies of the international organisation across the world. It is suggested that further research be conducted on the adaption and integration lean tool strategies to the South Africa culture.

During this study, it was proven that there is a misunderstanding of lean principles and it is recommended that future research be done on addressing this problem.

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REDUCING PARCEL PROCESSING TIMES BY MEANS OF THE LEAN METHODOLOGY

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ABSTRACT

The parcel industry holds potential in improving customer service levels and is tasked with reacting to increasing e-commerce platforms nationwide. The aim of this study is therefore to improve the processing times of a local courier department using a lean approach and consequently improving their customer service delivery levels.

The DMADV methodology was followed, utilising Therblig classifiers, value stream mapping, root cause analysis, a Pareto chart, an Ishikawa diagram and a V-model. The investigation revealed that the long processing times were owed to high levels of transcribing, leading to the implementation of an electronic barcode system. The electronic system was successful in reducing the 12 Therblig classifiers by 33% on average.

However, the overall lead times were not reduced significantly, thus emphasising the challenges associated with implementing new technology without the parallel human skills development, which is pivotal for ensuring the success of any improvement initiative.

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1 INTRODUCTION

The parcel industry has become strained with meeting the operational needs dictated by the growing e-commerce consumer market in South Africa [1]. Courier companies make use of in-house distributions centres in an attempt to accommodate the increasing speed, volume, and variety of products across this complex supply chain [2].

This study focused on a courier department housed within a private organisation, which executes a number of courier activities in aid of said organisation. One of the primary activities relates to integrated order-fulfilment processes between external courier companies and end-customers.

In contrast to a tone of underlying simplicity in the process, the department experiences several operational challenges resulting in long processing times. The high variety of parcels are received with no supply chain visibility. Storage bins are defined according to customer surnames, resulting in poor space utilisation due to volumes exceeding dedicated storage areas. Manual transcription processes monitor parcels received from external courier companies, those collected by and delivered to customers across the private organisation. This inaccurate data capturing technique, adapted by the department, is time-consuming for employees registering parcels and customers verifying collections or deliveries with their personal information.

An SMS client is used to communicate with customers via single SMS prompts. This system ensures customers are informed when their parcel may be collected at the service centre. Insufficient information from external courier companies introduces new complexities surrounding customer information and intended delivery addresses. The parcel processing method and communication with customers impacts parcel cycle times, varying between 5 to 15 days with reported storages for up to 18 months. The timespan between customer notification and collection was outside of the research scope. This study recognized the inability to account for customer message response times according to their availability and convenience, all of which influence the time before collections are executed.

The handwritten parcel information is archived in files, as their primary account for customer verifications and traceability in instances where returns are pursued with external courier companies. The current process inefficiencies have hampered customer satisfaction, which has led to poor service delivery levels experienced within the department.

The lean philosophy has derived many improvement initiatives across manufacturing and service sectors, between operational, strategic and managerial levels [3]. Lean comprises of principles which identify inefficiencies (waste) in order to improve customer value [4], [5]. Lean principles have been introduced in many industries within the service sector, which includes supply chain management & healthcare centres [6], [7]. Examples of lean practises adopted within distribution centres (similar to the research case study), are also witnessed in modern literature [8].

2 RESEARCH AIM

This study aims to apply lean principles in order to reduce the long parcel processing times and improve customer service delivery levels.

Section 3 explains the research methodology (Define-Measure-Analyse-Design-Verify) that was used, while Section 4 provides the findings and discussions of each of these research phases (Table 1). The paper is concluded in Section 5.

3 RESEARCH METHODOLOGY

An adaption of the DMAIC (Define, Measure, Analyse, Improve, Control) process, denoted DMADV (Define, Measure, Analyse, Design, Verify) was followed throughout the study [9]. The DMADV approach is used in developing new products or services [10], or the remodelling thereof [11]. This research methodology is summarised in Table 1 and explained in the sections to follow.

Table 1: Research Methodology [12]

Phase	Method	Purpose
1.Define	1.Introduce current system and define the problem (§4.1)	Clarity and agreement on the problem is required, before improvements can commence.
2.Measure	1.Facilitate 5S Kaizen event (§4.2.1)	Impart lean principles, obtain buy-in from employees and introduce standard housekeeping practises.
	2.Conduct a time motion study (§4.2.2**Error! Reference source not found.**)	Measure current processing time
	3.Create current state Therblig-embedded Value Stream Map (TVSM) [13] (§4.2.3)	Waste identification process
3.Analyse	1.Weight limit verification using the NIOSH equation (§4.3.1)	Ergonomic considerations for heavy lifting of loads
	2.Generate a Pareto chart of parcel Therbligs (§4.3.2)	Identify 20% of the Therblig classifiers contributing to 80% of the long processing times
	3.Create Ishikawa diagram (§4.3.3)	Root cause analysis
4.Design	1.Design proposed artefacts (§4.4)	Problem solving process
	2.Weighted criteria evaluation of solutions (§4.4)	Evaluate each proposed solution as a screening process
	3.Apply V-model decomposition on the highest ranked solution (§4.4)	Detail design of preferred solution
5.Verify	1.Apply V-model integration on the solution designed (§4.5)	V-model unit and integration testing using checklists
	2.Conduct time motion study on improved state (§4.5.14.5.1)	Quantify Parcel Therblig reductions
	3.Construct Future state TVSM (§4.5.24.5.2)	Measure processing time reductions
	4.Survey all employees (§4.5.3)	V-model acceptance test method

3.1 Define

The first phase was used to define the process and the problem. The courier department (used as the case study) completes several processes integrated between external courier companies and e-commerce customers for the private organisation. The core functions executed include customer collections and deliveries within the organisation. The overview of the processes (within the scope of this research) is explained in Section 4.1 and illustrated in Figure 2. As explained in Section 1, the problem within the courier department is defined as long parcel processing times hampering service delivery levels.

3.2 Measure

The measure phase comprised of a 5S Kaizen event and time motion studies followed by the Therblig-embedded value stream mapping of the current state.

3.2.1 Kaizen event

A 5S kaizen event was used to introduce lean and impart its principles onto employees within the department. The team building event promoted standardised and sustainable housekeeping practices.

3.2.2 Time-motion studies

The measurements of Therblig classifiers were incorporated into a current state value stream map. Therbligs, established by Frank Gilbreth, originate from principles which were derived from motion studies and motion economies [14]. The hetero-palindrome (Therblig) developed from its founder's surname (Gilbreth), details micro movements associated to specific tasks [15]. The 17 elements are categorised by effective and non-effective Therblig clusters. In this study, Therblig classifiers were created for the parcel processes [13]. In order to capture the Therblig classifiers, time-motion studies were undertaken using video analytic software.

In order to substantiate the sample size used in the study, the central limit theorem was considered. The central limit theorem states that the sampling distribution of $\bar{x}$ can be approximated provided a sample size is sufficiently large. According to Devore et al [16], a sample size $n \geq 30$ is a suggested guideline for invoking the central limit theorem. In this study, the central limit theorem will be invoked and a sample size of 30 parcels will be measured. Moreover, assuming that the average processing times measured from the sample are representative of the population, namely the average process times for all parcels within the courier department.

These times were analysed and portrayed using a normal quantile plot, commonly referred to as a Normal Quantile-Quantile (Q-Q) plot. A Normal Q-Q plot depicts the linear relationship between the normal quantiles and the z quantiles. If the sample is representative of a normal distribution (μ, σ), the points will lie close to the 45-degree reference line, with the slope σ [16]. Hence, Normal Q-Q plots were generated using R, as statistical evidence for the sample size normality according to the central limit theorem. The findings are discussed in Section 4.2.2.

3.2.3 Current state Therblig-embedded Value Stream Mapping

The method of Therblig-embedded Value Stream Mapping (TVSM) followed an approach proposed by Zhang, et al. [13], deployed in a lean energy machining process in order to accurately determine energy wastes. Similar to this machining process, the parcel processes of the current study are predominantly repetitive and could therefore be accurately studied according to their motion elements. Through the Therblig elements, this method will also provide additional information relating to the current processes. Thus, the use of this method promotes simultaneous micro movement and value stream evaluation. These classifiers also featured in a Pareto chart as a subset of the root cause analysis explained in Section 3.3.

The Parcel Therblig classifiers created during this study have been categorised in Table 2. Each classifier is listed in the first column, while the second column (resource) defines interactions with respective resources (parcel, file and computer). The intersection of each row and column formulates the desired Therblig classifier.

Table 2: Parcel Therbligs

Therblig classifier	Resource			Description
	Parcel (P)	File (F)	Computer (C)	
Reach (R)	RP	RF	RC	Reaching for a parcel, file or input device
Move (M)	Generic			An operator moving to any workstation
Grasp (G)	GP	GF	GC	Grasping for a parcel, file or input device
Position (P)	PP	PF	PC	Positioning any item for an operation
Release (RL)	RLP	RLF	RLC	Releasing any item
Examine (E)	EP	EF	EC	Inspecting any item
Do (D)	-	DW	DT	Writing in files or typing on a computer
Pre-position (PP)	PPP	PPF	-	Positioning for the correct orientation
Search (S)	SP	SF	SC	Searching on/for any item
Select (SE)	SEP	SEF	SEC	Selecting an item from a group
Plan (PL)	PLP	PLF	-	Deciding on the parcel/file location
Unavoidable Delay (UD)	Non-item specified			Delay inherit to process or task

The results of the time-motion study and Therblig-embedded Value Stream Map are presented in Section 4.2.2 and Section 4.2.3.

3.3 Analyse

The analyse phase investigated primary causes for the long processing times experienced by the department. A sequence of a NIOSH equation (weight limit verification) and Pareto chart analysis were summated into a cause and effect diagram (available in Section 4.3.3).

3.3.1 NIOSH equation

The NIOSH equation was used to stipulate recommended weight limits with regards to material handling [17]. This ergonomically focused equation was used to balance human well-being and operational needs with regards to the heavy lifting of loads [18]. The NIOSH equation is formulated as follows:

$$RWL = LC * HM * VM * DM * AM * FM * CM \quad (1)$$

The variables for the NIOSH equation have been summarised in **Table 3**.

Table 3: NIOSH Equation Variables

Abbreviation	Meaning	Theoretical value
RWL	Recommended Weight Limit	Solution obtained
LC	Load Constant	23kg
HM	Horizontal Multiplier (distance between hands and the midpoint between ankles H)	$\frac{25}{H}$; $25cm \leq H \leq 63cm$
VM	Vertical Multiplier (hand height between start and end of task executions)	$1 - (0.003 * \lvert V - 75 \rvert); 0 \leq V \leq 175$
DM	Distance Multiplier (horizontal distance travelled)	$0.82 + \left(\frac{4.5}{D}\right)$; $D = \lvert V_{end} - V_{start} \rvert$
AM	Asymmetry Multiplier (twist motion denoted by the angle of asymmetry A)	$1 - (0.0032 * A)$; $0° \leq A \leq 135°$
FM	Frequency Multiplier (lift frequency per minute F)	Table value
CM	Coupling Multiplier (coupling rating between hand and load)	Table value

3.3.2 Pareto Chart

The Therblig classifiers (Table 2) were used to generate a Pareto chart, by combining all Parcel Therblig classifiers in descending order, accompanied by a cumulative line graph. According to Pareto's Law [19], 20% of primary causes often contribute to 80% of the problem encountered. When solving an inefficiency, it is suggested that efforts are fixated on addressing these causes in an attempt to resolve 80% of the problem [20]. This deduction can be made with the aid of a Pareto chart (Figure 5).

3.3.3 Ishikawa diagram

An Ishikawa (cause-and effect) diagram illustrates primary and secondary causes attributed to a specific problem [21]. This diagram will be used to categorise the causes identified by the NIOSH equation and Pareto chart. The results are provided in Section 4.3.3.

3.4 Design

Four conceptual artefacts were postulated, all of which were tapered towards addressing the primary causes identified during the analyse phase. The selection criteria for evaluating these artefacts were focused on the financial feasibility, data accuracy, programming ease, support and maintenance of each design. The artefacts proposed were (1) a modified table entry sheet, (2) an electronic barcode and a macro-enabled spreadsheet, (3) an RFID database system and (4) a barcode scanning and mi-fare card reading system. After evaluating these concepts against the weighted criteria, the fourth design obtained the highest rating and was thus selected as the preferred solution (explained in Section 4.4). In order to design the preferred solution, the decomposition stages on the left-hand side of a V-model were applied (Figure 1).

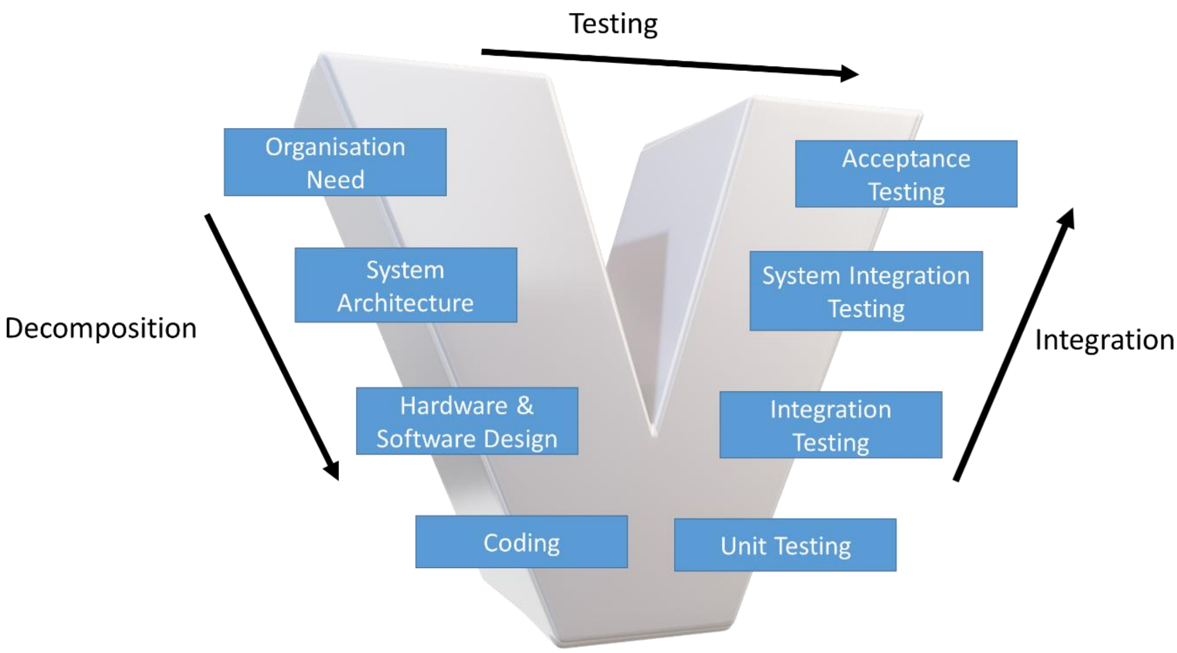

Figure 1: V-model

3.5 Verify

A pilot study implementation and training commenced after the preferred solution was fully developed. Each level of decomposition was verified using the parallel stage of integration (right-hand side of Figure 1). For the unit and integration phases, checklists were used for testing the coding, hardware and systems design decomposition stages.

3.5.1 Time-motion studies

Time motion studies measured a new sample of parcels that were processed using the electronic system.

3.5.2 Future state Therblig-embedded Value Stream Map

A future state TVSM evaluated the performance of the electronic system implemented as a pilot study.

3.5.3 Survey

In order to verify the acceptance test stage, a survey sampled all employees within the department. A Likert scale was used to motivate the level by which job satisfaction and job requirements were addressed by the electronic system. The results from the verification phase are presented in Section 4.5.

4 FINDINGS AND DISCUSSIONS

The DMADV method followed in this study, was explained in Section 3. The results of each phase of the research are provided in Sections 4.1 - 4.5.

4.1 Define

As explained in Section 2, the problem was defined as long parcel processing times impeding customer service delivery levels. An overview of the processes considered in the study have been mapped using Business Process Model Notation (BPMN 2.0) [22], as depicted in Figure 2**Error! Reference source not found.**.

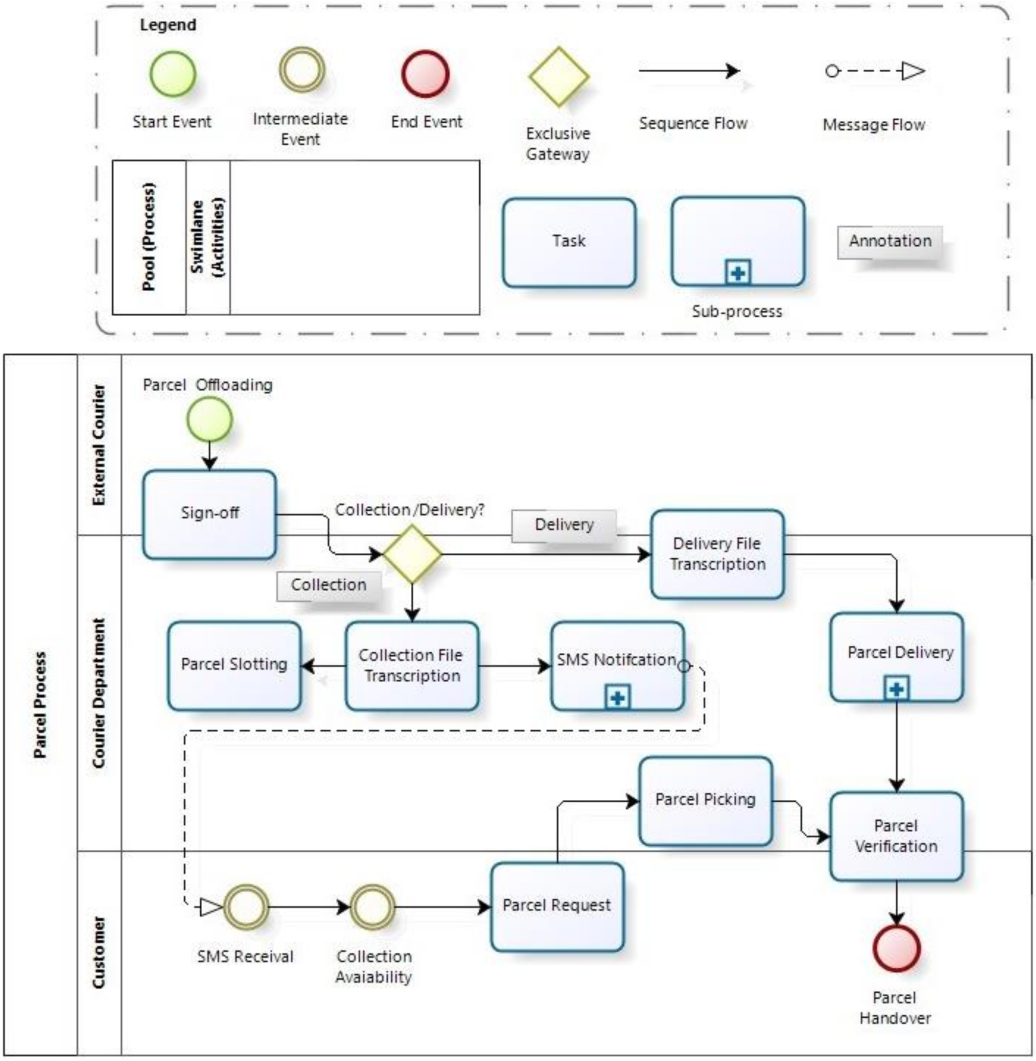

Figure 2: Parcel BPMN process model

The processes defined in the (Figure 2), established the value stream mapping framework which was incorporated within the following (measure) phase.

4.2 Measure

As discussed in Section 3.2, the measure phase entailed a 5S Kaizen event, time motion studies and the construction of the current state TVSM.

4.2.1 Kaizen event

A 5S Kaizen event (explained in Section 3.2) served as a platform for introducing lean principles within the courier department. The housekeeping practise was standardised and sustained by means of routine checklists and documentation. 5S training brochures informed employees on how to execute each stage. In addition, a standardised 5S audit checklist was created, and introduced as a bi-monthly procedure. The 5S training material was developed to ensure that a platform for knowledge transfer and training is established for forthcoming employees.

4.2.2 *Time-motion studies*

Time-motion studies evaluated a sample of 30 parcels. The results are included in the current state TSVM (Figure 4) and Pareto chart (Figure 5). As discussed in Section 3.2.2, a sample size of 30 parcels were selected, assuming the average processing times were normally distributed. The Normal Q-Q plots for the total parcel registrations (file transcribing) and parcel collection times for the 30 parcels are illustrated in Figure 3.

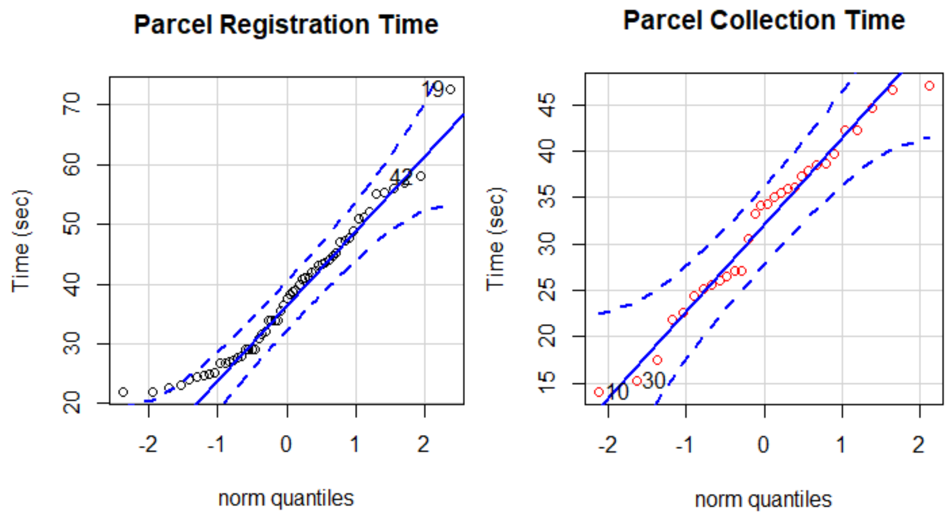

Figure 3: Sample of the Normal Q-Q plots for parcel processes

Based on the Normal Q-Q plots for the parcel registration and collection times, several data points are located near the 45-degree reference line. This evidence suggests that the average parcel processing times for registrations and collection times are normally distributed and representative of its population. Correspondingly, other processes provided similar evidence adhering to the normality test. Therefore, the time motion studies conducted for the future state TVSM (Section 4.5.1) made use of 30 parcels for the sample size.

4.2.3 *Current state Therblig-embedded Value Stream Map*

The Parcel Therbligs (defined in Table 2) were captured using video analytic software. These Therblig classifiers were embedded into the value stream map. The TVSM (Figure 4) identified the value stream and total value adding time associated with the parcel processes.

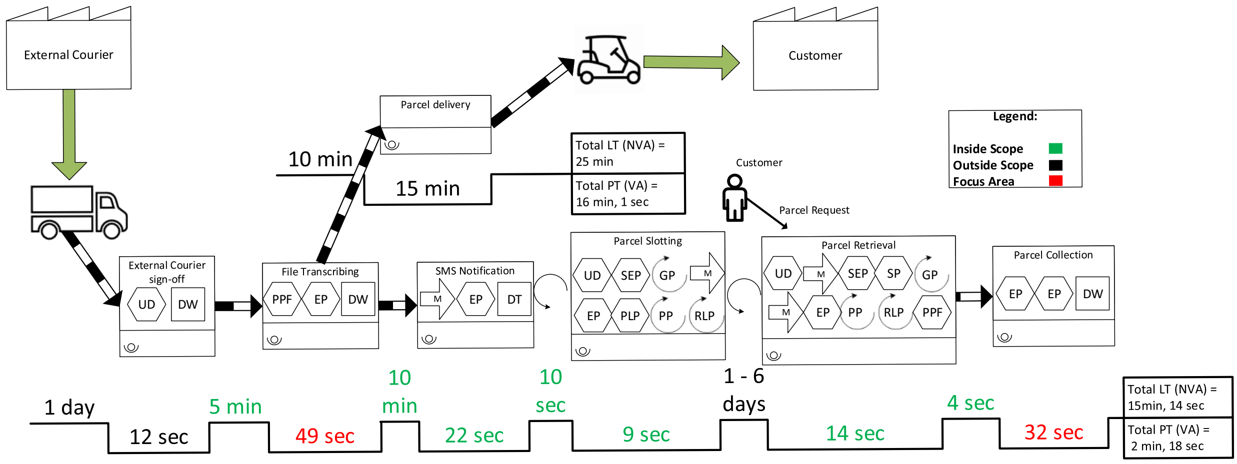

Figure 4: Current state TVSM

The value adding time (VA) is indicated by the lower levelled bar of the VSM, with the non-value adding (NVA) times designated to the upper level. The Parcel Therbligs relevant to each activity are housed within a process block. The average total NVA time was found to be over

15 minutes, while the average value adding time was 2 minutes and 18 seconds per processed parcel. When evaluating these durations, one is able to identify the most time-consuming processes experienced during file transcriptions and parcel collections. Delivery processes were not considered, as this is outsourced to support divisions within the organisation.

4.3 Analyse

As elaborated on in Section 3.3, the analyse phase involved the sequential application of the NIOSH equation and Parcel Therblig analysis according to Pareto's law. The findings were used to identify primary causes detailed within the cause and effect diagram.

4.3.1 NIOSH equation

The NIOSH equation considered the parcel weight influence on processing times. Parcel volumes were studied across an 18-month period. A recommended weight limit of 21.24kg was obtained, corresponding with the 21kg weight limit policy enforced throughout the courier department. The parcel weight was thus excluded as a contributing factor to the long processing times measured.

4.3.2 Pareto chart

The 12 Parcel Therbligs were subjected to further analysis and incorporated into a Pareto Chart (illustrated in Figure 5). By adopting Pareto's law (defined in 0) to the study, four Parcel Therbligs were identified as the most contribute elements, accounting for 80% of the total parcel processing times experienced. When revisiting the Parcel Therbligs (Table 2), the four contributing classifiers were identified as:

- DW: File transcriptions during parcel receivals from external courier companies
- DT: Single SMS notifications sent to customers for parcel collections
- EF: Examining Files for customer verification during collections
- EP: Examining Parcels during file transcribing & collection processes

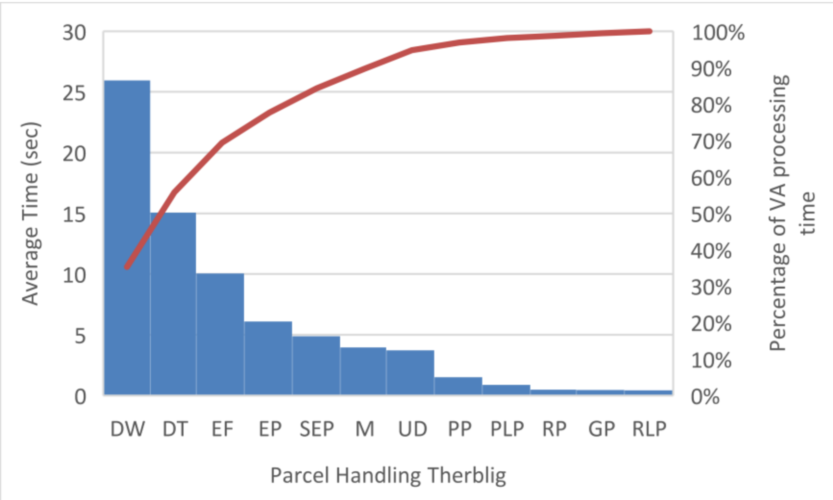

Figure 5: Pareto Chart Analysis

4.3.3 Ishikawa diagram

The cause-and-effect (Ishikawa) diagram [23] depicted in Figure 6 was used to encapsulate the contributing factors identified in the study.

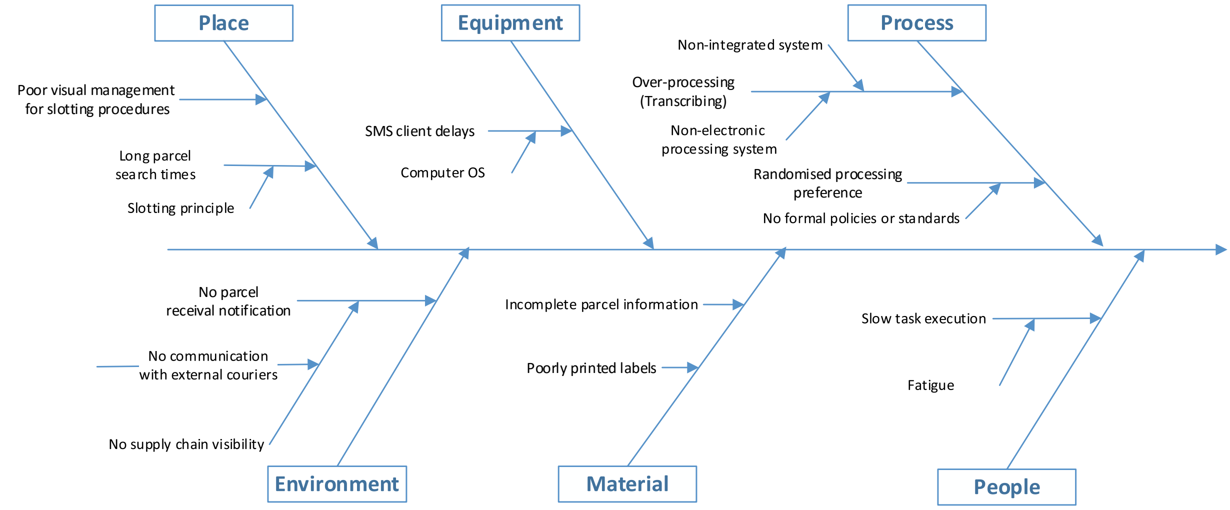

Figure 6: Ishikawa Diagram

The root cause converged towards high levels of transcribing and the low levels of integration between parcel sub-processes. Four artefacts were conceptualised in order to reduce transcribing and enhance integration between data storage, parcel slot and retrieval, SMS notification, delivery and collection processes. These designs also addressed the four Parcel Therbligs identified by the Pareto chart as part of the design requirements.

4.4 Design

After following the left side of the V model (Figure 1), the final design of the artefact was obtained. The information model (Figure 7) showcases all of the functions crafted into the electronic system.

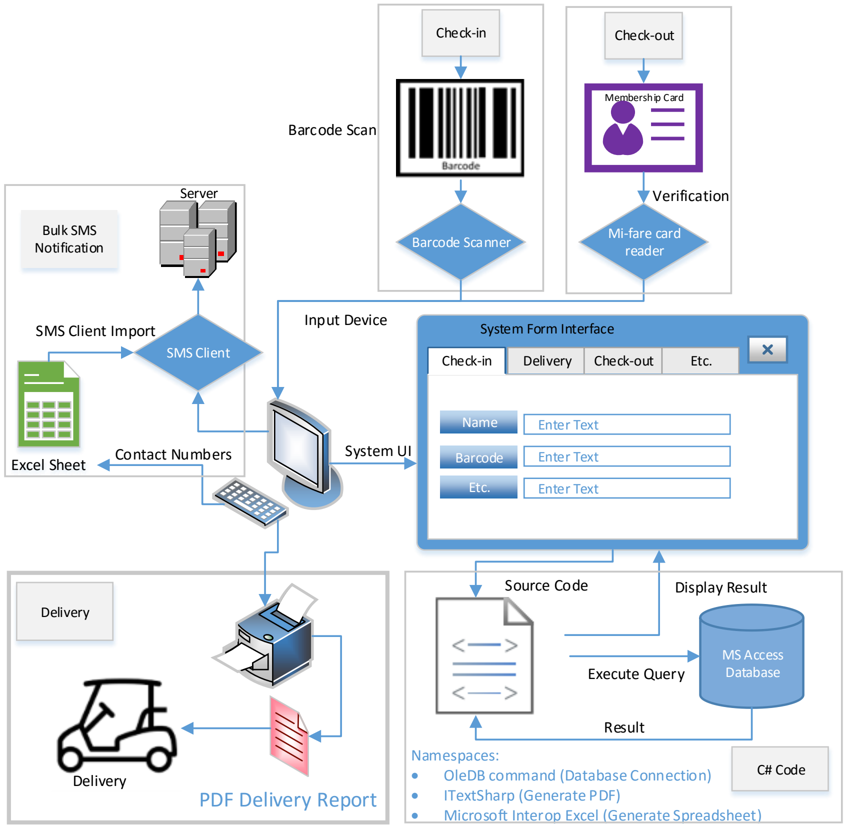

Figure 7: Electronic barcode system information model

Organisational needs were identified when consulting with employees during the initial and final stages of development. The courier department requested that the system adhere to their current software licences, and that all hardware and software should be inexpensive. Therefore, the system comprised of accessible software which was licensed or open sourced. All hardware was budgeted and acquisitioned accordingly.

The electronic system was developed using C# and namespaces provided by the .NET framework. Functionalities were derived from the operational needs identified during the consultation sessions with employees, upon the system's development. The electronic system's architecture was formed using an Entity Relationship Diagram (ERD), which mapped the database created. The program connects the user to a Microsoft Access database, where all parcel information and customer details are stored. Coded functions incorporated MS Access SQL with event trigger handles associated to the graphical user interface (GUI).

The system was designed to address the 4 Parcel Therbligs identified by Pareto's Law, namely file transcribing, single SMS prompts, file examining during parcel registrations and collections. Ultimately, the system was required to reduce manual transcribing and integrate between sub-processes. A barcode scanner feeds parcel information into the system during check-in activities. In order the modify the storage principle used by the department, unique serial bin IDs were created for enhanced space utilisation. The system was designed to track parcels by scanning the parcel barcode or storage bin ID. Additional search arguments include customer name, date of receival and customer information.

Customer contact information in the aforementioned stage, can be exported into an electronic spreadsheet. The spreadsheet integrates with the SMS client to notify customers that their parcel is eligible for collection. This enables the department to alert up to 50 customers in a bulk SMS prompt, as opposed to the single SMS prompts previously utilised. A mi-fare card reader registers customers by storing their personal information linked to their 4-byte UID. This unique identifier is associated to the NXP chip of each card that is compulsory for all members within the private organisation.

For parcel verification, the registered customer would swipe their mi-fare card as a means of authentication during collections. The GUI allows operators to generate pdf delivery reports which can be signed by customers upon delivery. Additionally, the data captured by the system allows for accurate parcel receivals and dispatch to end-customers [24].

4.5 Verify

The right side of the V model was used to assess the performance of the electronic barcode scanning system, using the enhanced levels of integration. A practical training session prepared all employees for operating the new system. During the session, demonstrations and basic task executions were performed using the training material and documentation provided.

4.5.1 Time-motion studies

A new sample of 30 parcels were subjected to time-motion studies, measuring the Parcel Therbligs listed in Table 2, and incorporated in the future state TVSM (Figure 8).

4.5.2 Future state Therblig-embedded Value Stream Map

During the system integration verification phase, the results of the time-motion studies were used to develop the future state Therblig-embedded value stream map (Figure 8).

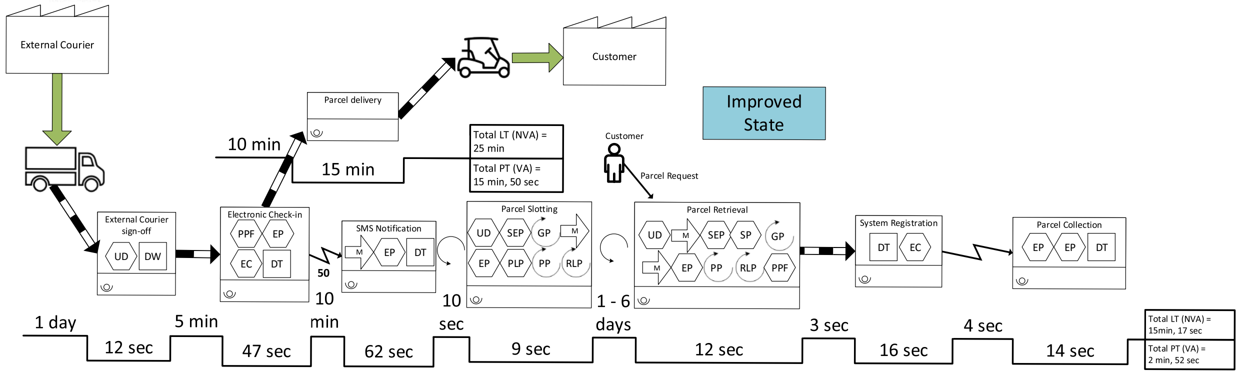

Figure 8: Future state TVSM

In comparison to the current state TVSM (Figure 3), the parcel collection and parcel check-in times were reduced by 18 and 2 seconds per parcel, respectively. While the total value adding time may have increased, the time taken to execute the bulk SMS (1 minute and 2 seconds) ensures 50 customer notifications are delivered in one instance. The results from the TVSM suggest negligible improvements were made, which could be ascribed to the enhanced computer usage that employees were previously unaccustomed to.

The percentage of Therblig classifier and average processing time reductions have been summarised in Table 4. The table compares various process times between the preceding and succeeding systems averaged over the sample of 30 parcels.

Table 4: System integration test results

	Therblig Reductions				Process Time Comparison	
Process	**Therblig**	**Before (sec)**	**After (sec)**	**Improvement (%)**	**Before (sec)**	**After (sec)**
Check-In	PPP	1,02	1,04	-2,20%	49,56	38,42
	EP	11,04	8,53	22,72%		
	DW/DT	37,51	28,85	23,07%		
Registration	DT	N/A	16,03			
Check-out	EP	4,07	2,61	36,06%	31,74	10,73
	EF	5,62	3,11	44,76%		
	DW/DT	22,04	5,02	77,23%		
	Average Therblig Improvement			33,61%		

Customers partake in system registrations each year. During the collection of parcels, verification processes will follow a swift card swipe procedure. The time associated with pre-propositioning parcels increased minimally. The result could be attributed to no workstation re-configurations made during the pilot study implementation.

The electronic system has reduced the parcel processing times. However, it was presumed that the margin of process time reduction would have been more significant, since new technology was introduced for the purposes of process enhancement given that employees were involved during its development. The unexpected time reductions could be attributed to low employee computer literacy levels despite previously operating computers during the SMS notification process.

4.5.3 Survey

The acceptance test incorporated a survey which sampled 100% of the employees within the courier department. The survey granted participants the opportunity to state their level of satisfaction or dissatisfaction, by scoring each statement (out of 5) relating to the electronic system. The results of this survey are presented in Table 5, segmenting the average score and standard deviation for each response.

The survey results revealed a grand mean acceptance rate of 91%. Participants believed that the system compliments tasks and with experience, the processing times will be reduced more significantly. The opinion of employees harmonises with the principles of human learning, which suggest that the relationship between task durations and repetitions share an inverse proportion [25].

Table 5: Acceptance test results

No.	Statement	Average Score [5]	Standard Deviation
1	The electronic system is faster than the transcribing system to check-in and check-out parcels.	4,50	0,58
2	The electronic system will make it easier to complete work tasks.	5,00	0,00
3	With time, workers will become more comfortable with the electronic system and typing.	5,00	0,00
4	With more practice and experience using the software, the check-in and check-out times will improve.	5,00	0,00
5	The electronic system will make it faster for customers to collect their parcels.	4,50	0,58
6	The electronic system will improve customer service delivery.	4,25	0,96
7	The electronic system has better readability than the file transcribing system.	4,75	0,50
8	The electronic system is easier to search for parcels (via bin locations, date, barcode & name) as opposed to the file transcribing system.	5,00	0,00
9	It is easy to understand and use the electronic system.	4,75	0,50
10	The electronic system user-interface (appearance) is clearly understood.	4,50	0,58
11	The electronic system works without any errors.	4,25	0,96
12	The electronic system fits in with the daily operations (tasks) of the department.	4,25	0,50

13	The electronic system works better with the SMS program used	4,75	0,50
14	The equipment for the electronic system is well suited for the nature of work.	4,75	0,50
	Average Acceptance Test Score	4,66	

In contrast to the degree of consensus reached, participants displayed contrary viewpoints to certain statements, quantified by the standard deviation in Table 5. Several members expressed dissent towards the level of customer service improvement attained and errors the system presented. The perception of employees recognising errors could be attributed to insufficient computer skills training conducted before the pilot study implementation. Furthermore, the results suggest that more extensive training should be pursued during full implementation. In conjunction, it could be argued that the employees' view on customer service delivery improvement levels were skewed, since employees initially had to assist customer to register on the new system, causing frustration (as opposed to increasing customer satisfaction). In addition, the employees assisted customers to authenticate the parcel collections in a manner that was previously unknown to both parties.

5 CONCLUSIONS

The long processing times that impeded customer service levels, warranted lean principles being embraced by the department. The DMADV method was followed in order to address this challenge. Business process modelling was used to illustrate the parcel processes performed by the department. During the measure phase, it was found that the file transcribing and collection processes consumed the largest time.

In this study, the root cause analysis identified the need for a solution oriented towards minimising transcribing and showcasing enhanced integration between sub-processes. Various designs were considered. However, a weighted criteria design selection process deemed a barcode scanning and mi-fare card reading system the best suited. The application of the V-model gave rise to an electronic system addressing the long processing times encountered. The system was implemented as a pilot study, which substantiated its process improvement capabilities.

The electronic system integrated between sub-process and was successful in reducing the Therblig classifiers by 33% on average. The system reduced the Parcel Therbligs and process times, which therefore yielded higher customer satisfaction levels within the private organisation. Furthermore, customer collection times were reduced and the survey results revealed that employees believe the system addresses the long processing times.

While the study gave rise to an electronic system meeting the needs of the department, more modifications could have been made. The private organisation possess more than one courier department branched across various cities. While the study focused on a specific department for the purposes of pilot study implementation; the system could be scaled such that the organisation can monitor and control processes between other courier departments located in remote areas. Further integration with the SMS client could have been made via an APN (Access Point Name) and URL script capable of automatically sending a notification during the parcel registration process. With more focus placed on the computer console by means of the electronic system, the study did not investigate a workstation re-configuration or facility planning transformation. The facility layout could have been remodelled using the motion elements measured during the study.

Despite the advantages of barcode scanning technologies [24], the time reductions listed in Table 4 had only succeeded in reducing the average processing time by less than 1 minute. Thus, this study fell short in harnessing the full potential of the electronic system. Despite collaborative system development stages, the study understated the fundamental need for ensuring human skills development parallel to process improvement initiatives by means of new technology. The misalignment between people and technology is conveyed by the unforeseen margin of process time reduction witnessed in the study, concurring with international arguments from the National Research Council in Washington DC:

> *"The importance of learning support for effective computer use was widely acknowledged but rarely manifest in organizations" [26]*

This study has revealed that continuous improvement efforts by means of technology implementations could enhance processes. However, the corresponding continuous improvement efforts should also be applied to employee development for a sustained impact. Therefore, future research should explore key factors essential for developing human resources, while improving processes and technologies during continuous improvement initiatives.

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DEVELOPMENT OF AN INTEGRATED PROJECT LIFE CYCLE MODEL ON GOLD MINING COMPRESSED AIR SYSTEMS

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ABSTRACT

Many South African gold mines are marginal or becoming non-profitable, due to electrical cost increases and unstable commodity prices. Compressed air systems are big contributors to operational costs on ultra-deep level gold mines. Legacy compressed air systems are inefficient with <15% of the compressed air generated effectively used for mining. There is a need to implement optimisation projects to increase the energy efficiency of systems. Previous implementations have shown that capital-intensive projects often fail due to incorrect processes followed during the project life cycle. An integrated project life cycle model was developed from literature, integrated simulations and past knowledge. The model was applied to supply and demand side compressed air projects on an ultra-deep level gold mine. The mentioned projects were designed, implemented and managed successfully with the new model and a sustainable financial impact of more than R11.7 million p.a. was achieved while also improving service delivery.

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1 INTRODUCTION

Gold mining in South Africa has become a marginal operation. The significant decrease in profitability is due to unstable commodity prices and labour issues [1, 2]. The weaker rand, and consequently stronger gold prices, shielded South African mines in the past. Unfortunately, this means that mines will not fund capital expenditures due to the rise in mining costs [1, 2, 3].

Until 2009, South Africa was classified as the world's main gold producer but has since fallen to fifth [4], despite still boasting 30 years' worth of ore deposits [4]. More recently South Africa has lost its status as Africa's largest gold producer to Ghana [5].

South African mines are slowly losing their competitiveness due to socio-economic, technical and operational challenges. The most notable of these are [4, 6, 7]:

- Decline in the head grade of gold-containing ore,
- Labour problems,
- Gold price instability,
- Increased production costs,
- Depth of mines and accordingly dangerous working areas, and
- Social and political uncertainty.

With the influence of these challenges it is critical for mines to operate efficiently in terms of both production output and expenditure reduction [8]. Efficient project management is therefore crucial for sustainable mining. Projects are often neglected and, consequently, they are implemented and managed incorrectly [9].

1.1 Project management processes and integrated simulations in gold mining

Projects are provisional tasks undertaken to achieve an end goal, service or product. Projects are temporary and have a definite beginning and end, the end being reached when the outlined outcomes have been achieved. Although temporary, project durations are not always short [3, 10].

Project management, a temporary organisational form, is considered the application of knowledge and skills to achieve the project outcome(s) [10, 11, 12, 13]. Projects are intended to be on schedule, within budget and on scope, but it is often widely accepted when this is not the case and, consequently, projects fail [14, 15, 16, 17]. In mining, project management is no different.

Various project management models exist, but none are directly relatable to mining. Sustainability in project management has received a lot of attention in recent years [18, 19, 20]. Project management plays a critical role in realising sustainability [18, 21]. Project failures may occur based on how a project achieves its goals [22, 23]. Unfortunately, no project management model exists dedicated to mining-based projects. Project teams on shafts follow either the discretion of the unit manager or a generic project management model. Due to the unique nature of deep-level gold mining, a model is needed to suite the industry and its environment.

The importance of simulations in mining projects has been discussed greatly and proven extensively [24, 25, 26, 27, 28, 29, 30, 31]. Only in recent years have project management simulations been used as a tool, but only in the software industry [32, 33, 34]. The use of simulations in project management in the mining industry could make valuable contributions towards mining projects and possibly help prevent failures.

1.2 Gold mining and the use of compressed air in gold mining

Most mines are divided into two working sections – engineering and production [35]. Engineering must ensure all services are always available and are fully functioning. Services include compressed air, chilled water and ventilation. Production personnel are to ensure that production and development targets are reached [36]. An example of the basic layout of a deep-level mine is shown in Figure 1.

Compressed air is generated in a surface compressor house by multi-stage centrifugal dynamic compressors, preferred by the gold mining community [8, 37]. A typical compressor house on a -3 500 m / 600kg gold/month shaft would use an average of 12 MW daily, resulting in a R 400 000/day cost. Clearly, cost savings projects on compressor systems are crucial for the continued operation of these systems.

From the compressor house the compressed air is sent underground via an intricate pipe network to end users [38, 39]. As shown in Figure 1, compressed air is mainly used for drilling, agitation and refuge chambers. In some cases, compressed air is also used by bushman loaders, loading boxes and for ventilation purposes (although not standard policy) [8, 40, 37, 41].

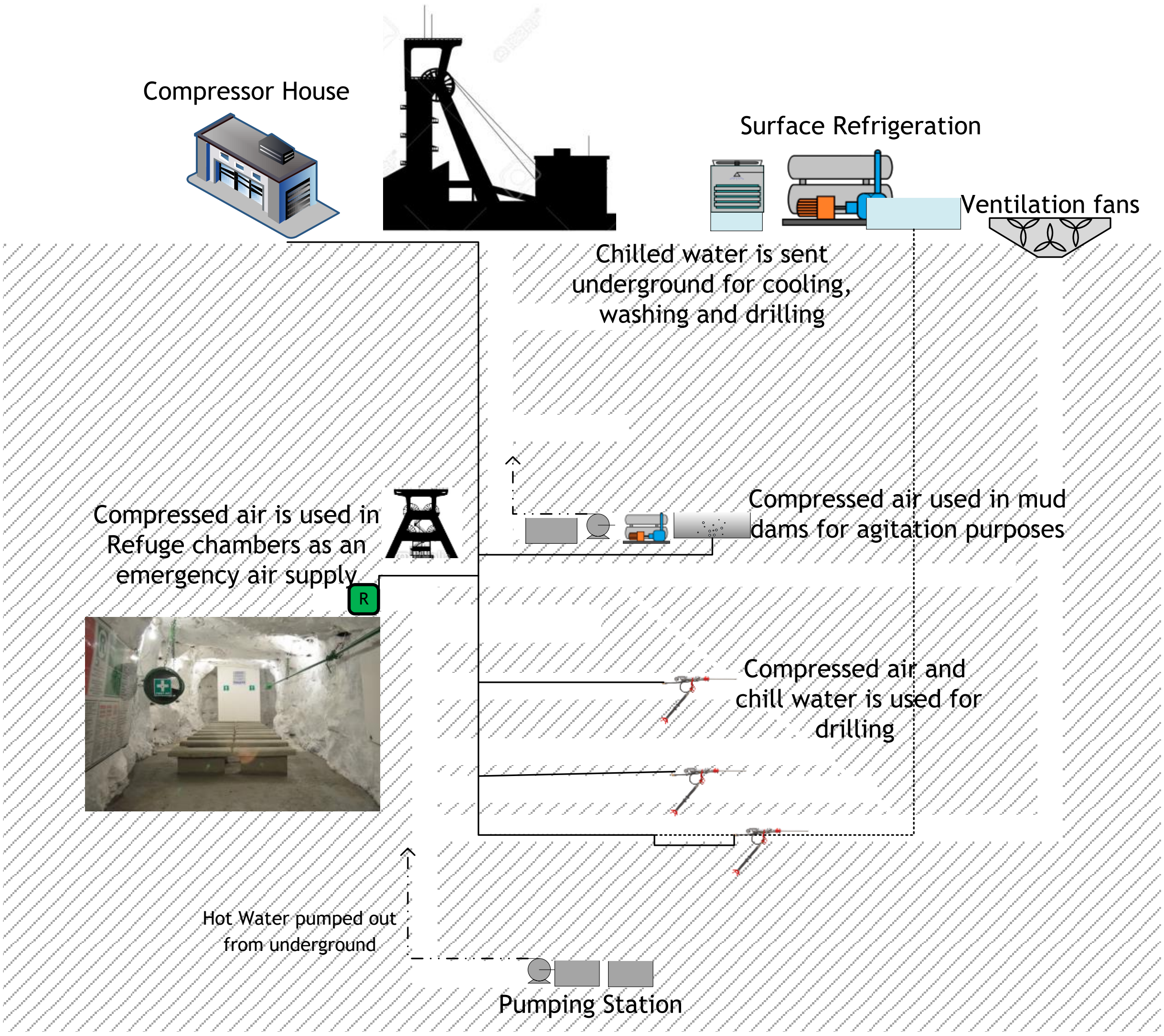

Figure 1: Example of a typical mine layout

Compressed air is used in refuge chambers as emergency ventilation. According to the Mine Health and safety act 16.6(2), the refuge chambers need to be constructed in a way as to prevent smoke and/or harmful gasses entering the chamber [42]. The mines accomplish this by pressurising the refuge chambers with compressed air.

Pressurising of the chambers is done by a 2" (50 mm) ball valve installed inside the refuge chambers. These valves are is supposed to be closed to between 75% and 90% [39]. This limits the rate at which air escapes the chamber. The exact percentage opening depends on the discretion of the shift boss. Installed valves are usually manufactured out of mild steel. It has been found that the ball becomes stuck in the body of the valve due to the highly corrosive underground environment brought about by the humid conditions underground. Consequently, it is common to leave the valve open at 50%.

Compressed air networks are crucial for production and safety reasons [8]. Implementing projects on crucial systems should be done sustainably [3]. This is not always the case though. The model developed will be generic and can be applied to any mining system and is not limited to compressed air. In this article two case studies will be discussed that were implemented on a mineshaft's compressed air system, simultaneously.

2 DEVELOPMENT OF INTEGRATED PROJECT SUSTAINABILITY MODEL

When capital expenditure projects are implemented on compressed air systems, it should be done efficiently and sustainably. A good example of an unsuccessful project that was implemented on a compressed air network was conducted by Bredenkamp, Schutte and van Rensburg [3]. This Demand Side Management (DSM) project was implemented on the mine (and failed) presented for the case study reported in this article. It was stated that the reasons for failure of the project were [3]:

- Practical challenges,
- Delays,
- Control limitations, and
- Maintenance.

From literature and past experiences, projects in the gold mining sector are not implemented sustainably [3], further emphasising the need for this study.

2.1.1 Model development

A list of projects that have been implemented on deep-level gold mines throughout South Africa is reported in Table 1, along with the project life times and reasons for failure. These projects are only projects in which the author was directly or indirectly involved. By studying the mistakes made in the past, it is possible to derive a model and mitigate the possible failure of future projects. The full results and details of each of the projects are not listed in this study.

Table 1: Past failed mining projects, along with corresponding lifetimes and reasons for failure

Projects	Initial success	Lifetime	Reason for failure
Pumping load shift	Yes	Several months	Maintenance
Closed loop bulk air cooler	None	None	Management
Head gear compressor installation	Yes	2 years	Maintenance
Compressor surface set-point control	Yes	2+ years	Maintenance
Optimisation of air networks	Yes	3 months	Equipment

Fridge plant evaporator VSD's	Yes	6 months	Control philosophy
Surface refrigeration load shift	Yes	3 months	Management
Underground refrigeration load shift	Yes	3 months	Management
BAC load shift	Yes	3 months	Management
115L flocculation change over	No	0 months	Equipment
Ventilation fan peak clipping	No	0 months	Equipment
Pre-cool dam actuator	Yes	6 months	Control philosophy
BAC control philosophy change	Yes	3 months	Management
Surface refrigeration control philosophy shift	Yes	6 months	Management
Stope isolation valves	No	0 months	Equipment
Underground turbines	Yes	Continuous but ineffective	Management
Stand-alone compressors	No	3 months	Equipment

It can be seen from Table 1 that projects fail due to four commonly occurring reasons:

- Equipment – Incorrect equipment is used during the installation and design phase, commonly due to budget constraints or uninformed decisions made by mining personnel.
- Management – Due to the constant turnover of engineers and technical personnel on shafts, some projects fall out of favour by the newer personnel and often become neglected.
- Maintenance – Due to the harsh economic circumstances, maintenance budgets are cut on “less important” projects not related to production.
- Control Philosophy – Due to the dynamic nature of gold mining it is crucial that the control philosophy be updated periodically to accommodate process changes [24].

It is important to note that there is a clear difference between project failure and project management failure as stated. Figure 2: Sustainable project management model summarises and provides a possible mitigation strategy to prevent the different reasons for failure and challenges experienced when implementing projects.

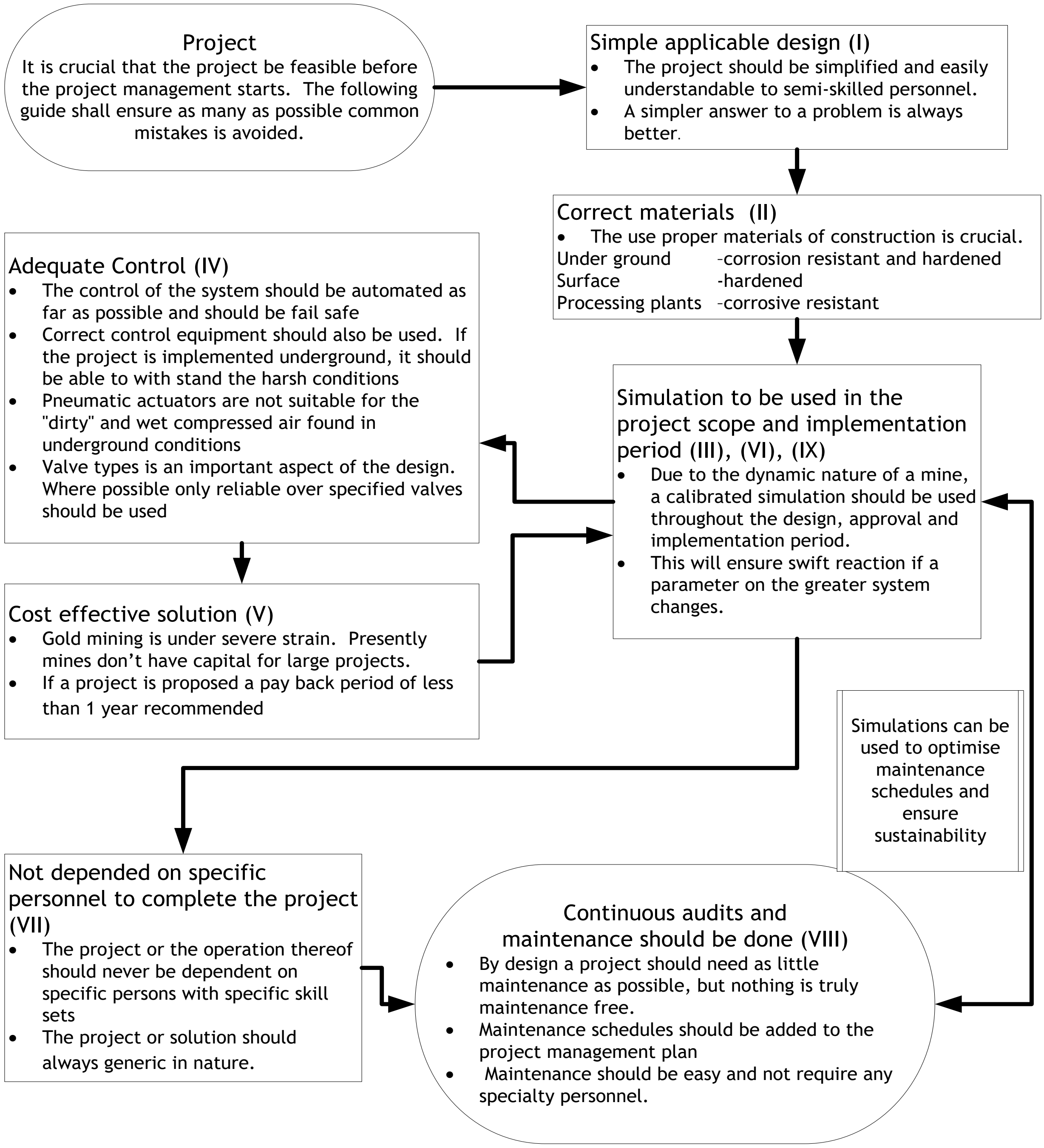

Figure 2: Sustainable project management model

Common practice in the mining environment entails dedicated personnel focussing on different sections [36]. The shortfall of this practice is that the personnel do not communicate with each other. This leads to a tug-of-war between departments. A holistic approach is essential for the future of the mining environment.

Unfortunately, the separate management of systems leads to the challenges faced when implementing projects on these systems. There are no true independent systems or procedures on a mining system. By following the stated model, most problems in the mining environment can be avoided.

3 RESULTS AND VALIDATION THROUGH CASE STUDIES

The model was applied to two projects on a deep-level gold mine. The first project was a completely new design, and the second model was a re-evaluation and re-installation of an old unsuccessful project. The results of the projects will be discussed together since the projects were implemented during the same financial year and overlapped during installation and control optimisation. The project sustainability model was followed in the projects and will be indicated by the roman numerals.

3.1 Integrated simulation

An integrated simulation was built of the entire compressed air network of the mine as shown in Figure 3 (III). Due to the size and complex nature of the simulation, it will only be used as a supporting tool in this paper.

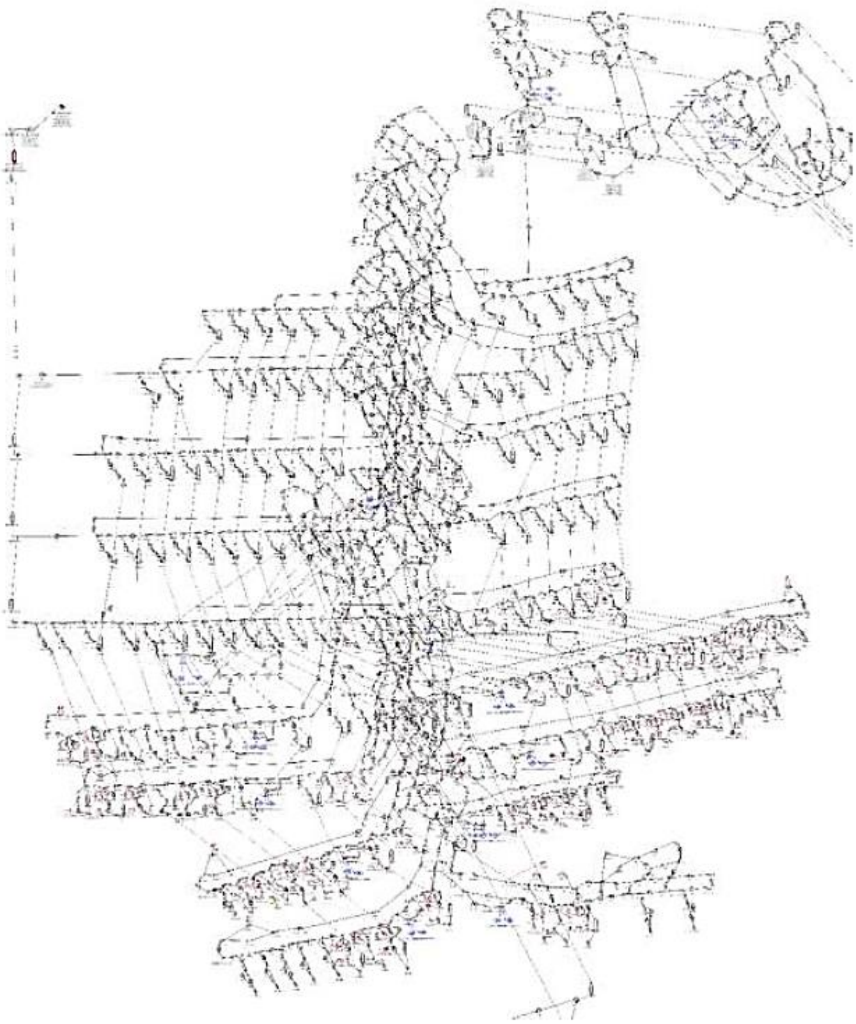

Figure 3: Integrated simulation showcasing the complexity of modelling an entire compressed air network

Based on test results, refuge bay leaks were added to the mine's compressed air simulation model. Using Supervisory control and data acquisition (SCADA) data for validation, the system was modelled with an accuracy of 98%. Subsequently, the simulation was used to simulate the effect of the reconfiguration and re-installation of the bypass valves.

3.2 Case study 1

Of the 160 underground refuge chambers, 90% of the refuge chamber valves were either completely open or stuck on 50%. This resulted in major inefficiencies and placed unnecessary strain on the compressed air network. In this configuration the compressor systems were over budget constantly, and supply pressures on the corresponding levels were insufficient. A large savings and service delivery improvement potential was identified on the shaft. By following the stated model, it became evident that a full redesign of the valve was necessary.

3.2.1 Refuge chamber valve re-design

After comprehensive research into alternative refuge chambers and refuge chamber pressurisation techniques, it was decided to design and install a valve with a hole in the ball (IV) to ensure continuous air flow into the refuge chamber(I). As stated by the model, a full stainless-steel construction valve (II) was recommended with either a flange or threaded connector to ease installation (I).

The valve design calculations were done to establish the size diameter (IV) of the hole to be drilled in the valve. A ball valve containing an opening through the ball is commonly called a crack valve in mining. Figure 4 shows the flow through the hole drilled in the ball valve. A 3 mm hole will give enough flow to pressurise the refuge chamber but for this project a 4 mm hole was chosen to ensure adequate flow and ease of manufacture (IV,V).

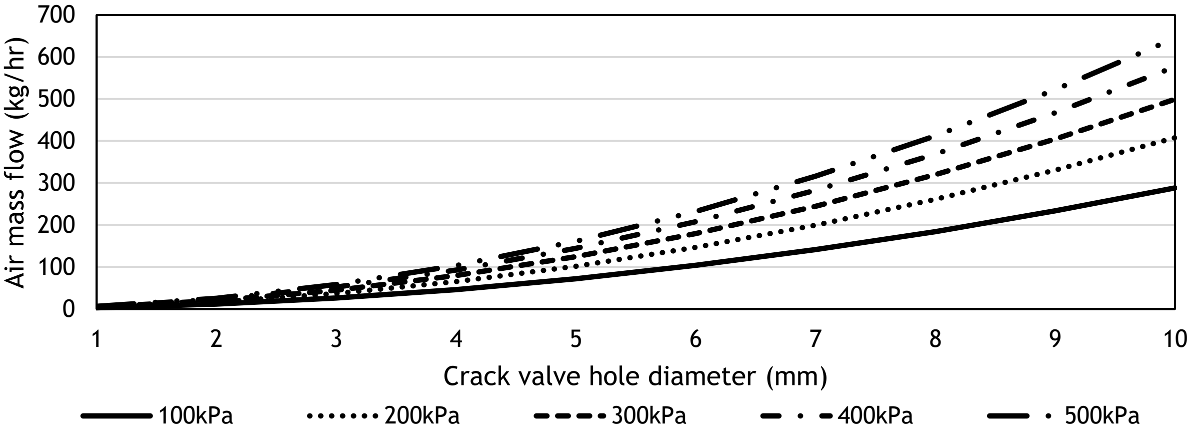

Figure 4: Compressed air mass flow rates through valve

3.2.2 Refuge chamber valve simulation and costing analysis

A simulation was done to test what effect closing-off all the refuge bays has on the system's energy- and air usage (VI). The difference between the baseline and the optimised simulations were compared to determine the total savings obtainable and system impact.

Table 2: Simulated results of replacing all the refuge chamber valves

Simulation scenario	Simulated power saving	Compressed air reduction	Drilling shift pressure increase	Cost saving p.a.
Closing refuge bays on all levels	840 kW	6 158 m^3/h	15 kPa	R 5.1 million

The compressors are presently unable to reach their set-points during drilling shifts. The simulation indicated that by reducing the airflow to all refuge bays, the service delivery can be increased. The refuge chamber project was fully implemented at nearly the same time as a bypass valve configuration project. The proposed solution was cheap and beneficial for both mining- and engineering personnel which ensured full support from both departments.

3.2.3 Installation and project management

The ball valve design drawing was sent to various manufacturers and the best candidate was chosen based on cost and delivery time. Due to the simple nature of the solution a regular 2” stainless steel ball valve could be modified and supplied (I, II, IV and V).

Due to the simple nature of the project, installation could proceed without isolating any lines or hindering work elsewhere (VII). Also, the change of a 2” ball valve does not require specialised artisans. The work was done and completed by fitter assistants (VII). After each installation was completed on a refuge chamber, the valve was audited by the section shift boss as part of their daily audit (VII, VIII), required by law [42].

When an entire level was completed it was audited by a specialised team, pressure readings and photos were taken of each of the refuge chambers and handed to management at the mine (VIII). This meant that every refuge chamber was audited three times to confirm installation, once by the fitter assistant, once by the specialised team, and daily by the section shift boss (VIII).

The continuous nature of the audits (VIII), along with the simple design (I), will ensure long term functionality and sustainable cost saving. Due to the low price of these valves it was also possible to acquire spares and store them on the levels (V). This ensures that when a valve fails it can be replaced within a time frame of a single shift (VII).

From inception until full installation the project took 6 months with the budget approval accounting for most of the time. The full cost benefit is discussed later. The model was followed clearly throughout the investigation, simulation and project management phases of this project.

3.3 Case study 2

A previous similar project was done on the mine, but the project soon deteriorated. The model developed was used to blow new life into the project and restore the initial goal of the project. Automated valves are installed on the main compressed air pipelines of all the production levels (levels 98 – 113) at the mine. The valves are installed in a bypass configuration with a smaller bypass pipeline over an automated shutoff valve in the mainline.

3.3.1 Bypass valve redesign

The initial project entailed controlling the valves during the Eskom evening peak periods (18:00-20:00), when electricity is more expensive, to reduce the pressure downstream of the valves to a certain pressure set-point. This was achieved by closing the mainline valve and controlling the downstream pressure with the bypass control valve. The configuration of the bypass valve setup and the mentioned control philosophy is illustrated in Figure 5.

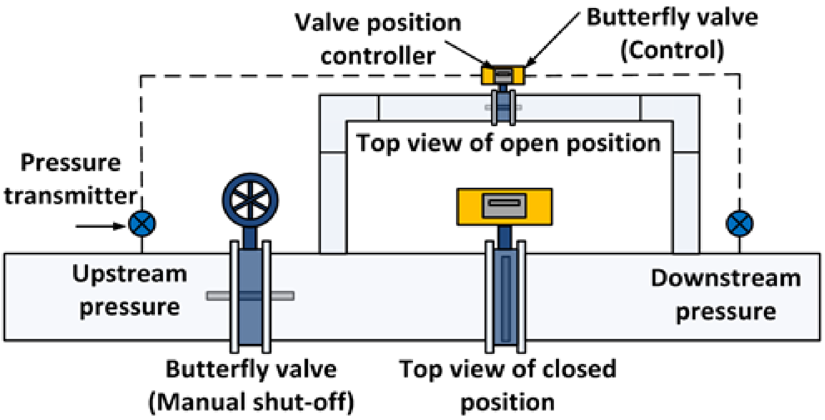

Figure 5: Illustration of bypass valve setup

The valves were installed as part of an old DSM project. Since the implementation of the project, the valve control has been disabled. This was mainly due to the large pressure drop caused by the 2” bypass pipelines when the mainline shut-off valves are closed.

Investigations on the previous configuration of the compressed air control valves on the production levels of the mine were completed. The pressure control with the valve configurations is limited due to inadequately sized bypass pipelines. This results in large pressure drop when the control is enabled on the valves.

The control is only enabled between 18:00 and 20:00 as this period aligns with the blasting shift. During the other periods of the day the valves cannot be controlled due to the higher pressure demand on the production levels.

The aim of the project was to develop and simulate a new bypass configuration (I,II,VI,IV) that will enable valve control over a 24-hour profile, while accommodating the required demand flow. The new configuration must satisfy the compressed air demand on the production levels (VII), while increasing the upstream system pressures, which in turn will lead to energy savings on the compressors. Most of the valves and infrastructure also require minor refurbishment to enable the recommissioning of the control over the valves (V).

3.3.2 Bypass valve simulation and costing analysis (III,VI)

Prior to the recommissioning of the control of the valves, it is recommended that larger bypass pipes and valves be installed. This will allow sustainable valve control over a 24-hour profile, increasing the energy savings potential on the mine’s compressors. The following section focuses on the simulated results to specify the correct sizes of the bypass pipelines and valves.

A simulation model was constructed to predict the pressure loss over various butterfly valve sizes based on their respective flow coefficients (C_v). The C_v values are based on manufacturer specifications of a certain butterfly valve.

The pressure and flow demand of 105 level were used to develop a baseline simulation. This level was used because it has the highest pressure and flow demand of all the production levels at the mine. The assumption was therefore made that the simulated pipe and valve sizes for this level would be sufficient for all other levels. A standard size of valve control configuration will be beneficial to the mine (IV).

The simulation model used was shown previously in Figure 3. It should be noted that six different sets of inputs were used to obtain the correct bypass configuration (I,VI). The simulation was also used to quantify the electricity cost savings, when such a bypass valve configuration is installed (IX).

The assumption was made that the mainline pipe dimensions and valve flow coefficient (C_v) remain constant for all six models. The bypass pipe and valve sizes were however changed from 2” up to 14”, in 2” increments. Note that there are three butterfly valves on the bypass sections. One manual valve at each end of the bypass pipeline and a control valve in the centre for maintenance purposes (I, II, IV and VII).

Figure 6 illustrates the proposed pressure set-point for the control of the compressed air pressure on the various levels. The proposed set-points are based on the existing compressed air requirements and mine schedules.

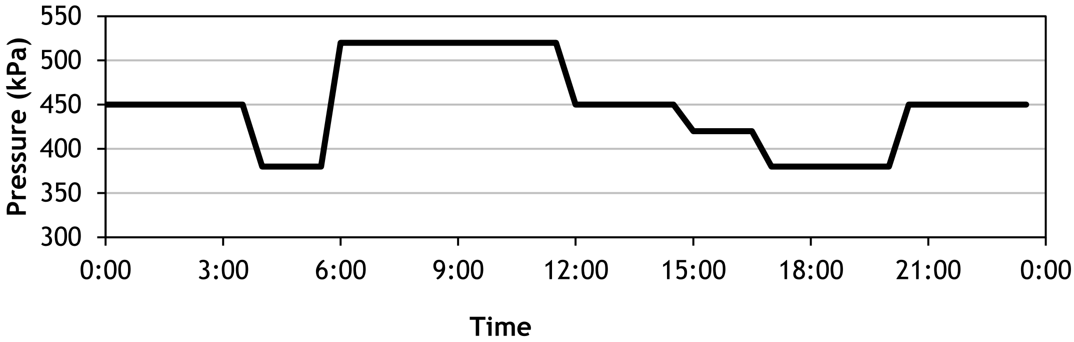

Figure 6: Proposed pressure control set-point for various levels

The proposed pressure set-points and required compressed air demand profile were used to simulate the impact of the different valve sizes on the pressures downstream of the valves on the production levels. Table 3 illustrates the simulated station pressure and airflow after the bypass valve configuration for different bypass pipe and valve sizes. With the available supply pressure and required demand pressure, the available pressure and flow through the bypass valves are reported in Table 3.

Table 3: Available pressure and flow after the bypass valve configurations

Bypass size	Average available pressure (kPa)	Average available air flow (kg/s)	Valve flow coefficients (C_v)
2" (Present configuration)	238.4	5.7	105
5"	442.6	9.5	930
8"	456.3	10.6	2, 854
14"	459.1	10.6	11, 917

From Table 3, it is evident that only 5.7 kg/s of compressed air at a pressure of 238.4 kPa is available if the present configuration is implemented throughout a normal mining weekday. This shows that the installed 2” bypass valve configuration restricts the flow and results in a large pressure drop when the control is enabled.

Figure 7 illustrates the average daily downstream pressure profiles for the bypass valve sizes that were simulated. The valves were controlled according to the pressure set-points depicted in Figure 6.

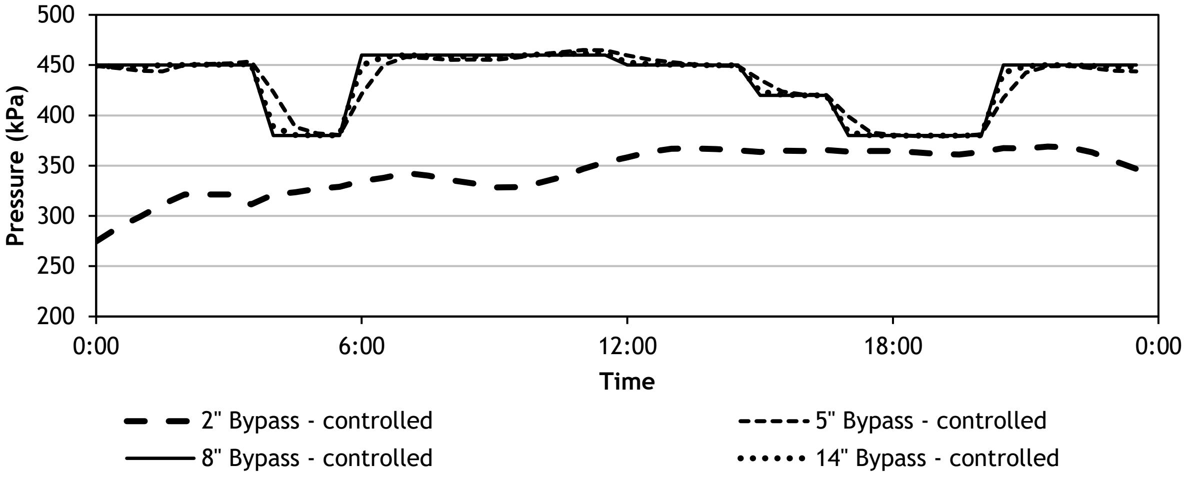

Figure 7: Controlled pressure for various bypass valve configurations

From Figure 7 it is evident that the 2” bypass valve configurations are not sufficient to maintain the pressure set-point with the present compressed air demand on 105 level. However, the 5”, 8” and 14” valve configurations are sufficient. It is important to consider that the 5” and 6” configurations do not have much more capacity for effective control when the compressed air demand at the mine increases. Bearing this in mind, it is advised to install an 8” bypass pipe valve configuration. The project was proposed and approved, the 8” pipeline will also ensure that the project remains feasible even with an increase in production and/or compressed air usage.

3.3.3 Installation and project management

To mitigate possible construction and installation challenges the bypass configurations were made up off-site by an external contractor and married with valve setups before going underground for installation (II, IV, V AND VII). This ensured that the bypass set-up was onsite and working before the delivery date. Installation of the valves was scheduled during a weekend when no mining occurred (VII). With support from both engineering- and mining personnel the installations happened swiftly.

It was decided to start the installation on levels with a higher consumption (IV). As the installations were completed the control philosophy was tested and implemented. This meant that by the time the second bypass set-up was installed the control philosophy was already tested and implemented resulting in a “copy and paste” process for the rest of the valves (IV).

3.4 Case study 1 and 2 results

The projects also increased pressures on production levels, which theoretically would increase production. After the projects were implemented, an increase in production was seen, but this could be attributed to other factors as well, although the compressed air pressure increases likely had an influence.

The implementation period of the projects overlapped. The installation of the refuge chamber crack valves started in February 2018 and continued until May 2018 while the new bypass valve configuration started in May 2018 and was completed in July 2018. Due to the parallel implementation period separating the results would be challenging.

The energy consumption of the compressor house is used to measure the success of the project. This is done since the compressed air flow meters on the shaft were found to be very unreliable. The compressor house energy measurements are reconciled monthly with the Eskom invoice, making the values traceable.

Figure 8 shows the total monthly energy consumption of 2017, 2018 and 2019. The previous year's actual data is also used for the budget for the next year. It is clear from the graph that the energy consumption reduced greatly after both and even during the project implementation.

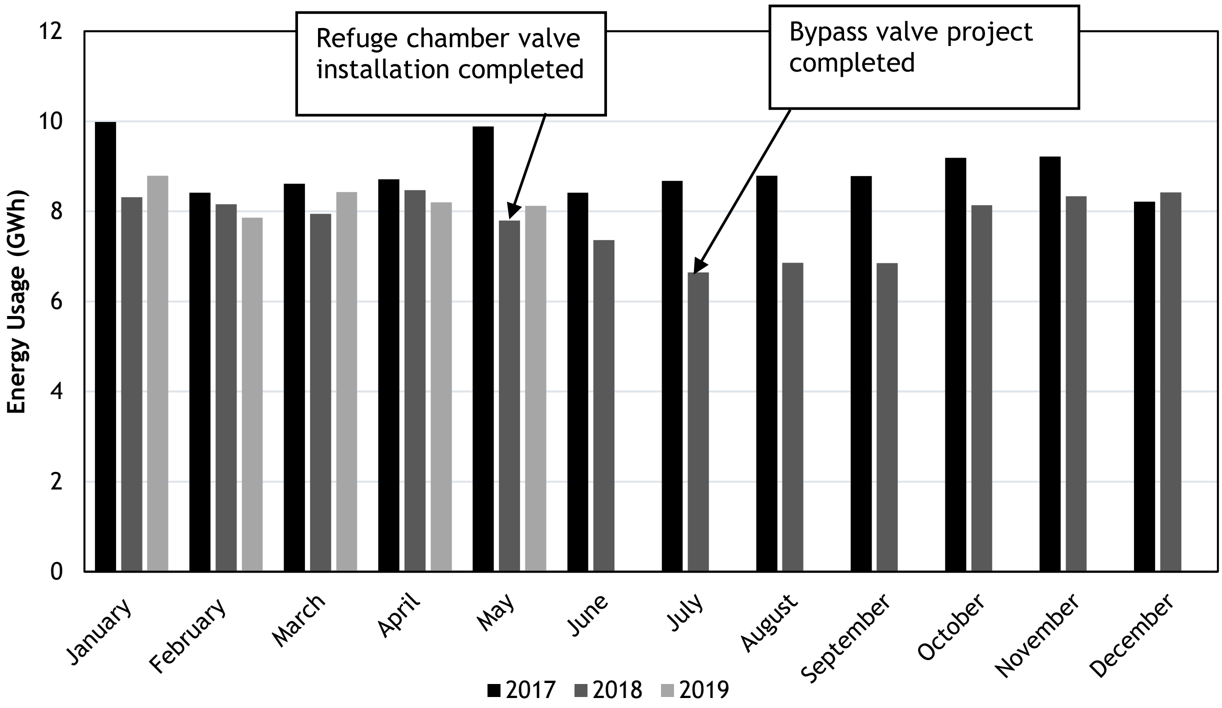

Figure 8: Case study 1 and 2 results depicting reduction in energy usage

It is notable that the power consumption increased from October 2018. This is due to 10 additional mining crews that were appointed on the mine. During January 2019 follow-up audits of the refuge chamber valves were completed and handed to management. It was found that some of the crack valves were being used in the same way as the old normal 2" valves. The valves were closed and discussed in safety meetings, from February 2019 it can be seen that the usage stabilised to relatable values.

This decline in energy usage can be directly attributed to the projects implemented during this period. If taken from the final installation date the payback period of the combined project was 2 weeks, fulfilling the criteria of the model stated. From inception of both projects the electrical cost savings that have been realised amounts to R 11.7 million (May 2018 – May 2019). Continuous savings are being realised, proving the sustainability of the model. The results show the positive effect of the continuous involvement of consultants.

4 CONCLUSION

Mines are hesitant to implement large capex projects, and the unsuccessful nature of project management in mining contributes to the lack in confidence in large scale capex projects. Sustainable project management have been discussed in resent year's but not in the deep level gold mining industry of South Africa. A model was developed with the help of simulations and investigations into past failed projects. The model focussed on the practical challenges faced in the past and offered mitigation.

The model was thereafter applied to two projects implemented on a deep level gold mine. A new refuge chamber valve was designed to solve a problem involving legal compliance and wastage. Due to the simple nature of the project it was highly successful. The model was also applied on a failed project, after reconfiguration the project was brought back from the grave. The results of both projects prove the success of the model. The saving to date amounts to

R 11.7 million and will stay sustainable. Even with the addition of 10 mining crews the project keeps performing. Project management in mining crucial in the current economic climate, with the project sustainability model stated in this study project in mining will be implemented with a higher success rate.

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A FRAMEWORK FOR A DECISION SUPPORT TOOL IN AN AGILE AGRICULTURAL ENVIRONMENT

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Abstract

Supply planning in table grape production is difficult due to long lead times from planting to production with variable yields. Market agility for producers is important due to market volatility while diversified income streams and markets lower a producer's risk. Strategic managers need to ensure market demand match the harvest available through planning cultivar diversity. Tactical managers need to realise the strategy by carefully scheduling harvest and labour plans. These plans are created manually following a cumbersome and sub-optimal process. Operations managers need to implement this plan, however face day-to-day challenges not accounted for in the tactical plan. Agile decision making at tactical and operational levels is needed to work around obstacles in a complex decision space. In this work the characteristics of a decision support system (DSS) needed for tactical and operational decisions are explored and a framework for creating such a DSS based on current literature is provided. A real alternative in the South African fresh produce sector is addressed which requires everyday industrial engineering solutions such as systems design, optimisation, simulation and scheduling.

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1 INTRODUCTION

The production of fresh fruit is a complex business with many factors to consider. Large agricultural companies are shifting focus from pure crop-driven to a more holistic business approach in order to stay competitive. Locally, South African farmers are faced with policy and resource uncertainties, driving business and investment decisions. This is no different for table grape producers, with approximately 21 000 hectares of table grapes under production, competing for export opportunities [1]. South American countries such as Peru and Chile, with approximately 28 000 and 48 200 hectares of table grape respectively, are direct competitors to local producers [2]. Local producers therefore need to differentiate or focus strategy in order to compete [3].

The subject of this study, Company X, focus on the niche packaging of high-quality grapes to clients with unique product specifications. This is a market differentiation strategy to distinguish them from bulk, lower cost producers. The unique specification of each client allows Company X to increase revenue per hectare, but it also brings in complexity when scheduling the harvest and pack plans for the season. Added to this complexity is the uncertainty of harvest size and date for individual production units. Grapes will ripen at various time periods, which is dependent on weather patterns for that year and the specific cultivar planted. A table grape producer, such as Company X, can have several farms and might be limited by the packing capacity within their business or by the ripeness of the stock. This complexity coupled with sudden changes due to uncertainty results in sub optimal harvest and pack scheduling decisions. Logistical scheduling is therefore needed to pack to maximise revenue for the company and its shareholders.

In this article, the characteristics of a scheduling decision support system (DSS) for table grape harvesting and packing will be explored. Company X requires a comprehensive solution to coordinate many disparate teams. The objectives of this study will therefore be to 1) understand and frame the complex decision environment for Company X during the harvest season; 2) clarify the characteristics and business requirements for a scheduling DSS at company X and then to 3) document the design requirements for a DSS which will be built as part of ongoing research work.

Section 2 of this article will explore the history and characteristics of DSSs. Section 3 will provide details on the methods used to gather data from Company X to determine the design requirements for a DSS. Lastly, sections 4 and 5 will summarise and discuss the requirements for a DSS following end user interviews.

2 BACKGROUND AND LITERATURE REVIEW

In this section, DSSs will be explored through background literature on the types of DSS, the decision-making process in an organisation as well as well as the characteristics that make up a DSS.

2.1 DSS classifications

Decision support systems is a general term used for many different types of software products. Power [4] classifies five types of DSSs based on a previous classification by Alter in 1980 [5]: communication driven DSS, data driven DSS, document driven DSS, knowledge driven DSS and lastly model driven. This classification has since been adopted by the Association for Information Systems Special Interest Group on Decision Support Systems (AIS SIGDSS). Further to this classification, Power identifies three secondary axes that can be used for classification: the intended user, the purpose and lastly the enabling technology. Turban *et al.* [6] notes that most applications are a combination of two or more types of DSSs. Table 1 illustrates the various types of DSSs with their respective use cases, users and components. Section 5 will use this framework to demonstrate the combination of DSSs needed by Company X based on the requirements analysis in section 4.

Table 1: An expanded DSS framework [4]

DSS Type	Target Users	Purpose	Enabling Technology
Communications-driven DSS *(communication)*	Internal, geographically distributed teams	Meetings Collaboration Facilitate information exchange	Video and audio conferencing Cloud storage Online word processing applications
Data Driven-driven DSS *(Database and visualisation systems)*	Managers and staff, partners and suppliers	Query a data warehouse	Relational databases Multidimensional databases
Document-driven DSS *(Document storage)*	Specialists and managers	Search web pages	Search engines, HTML
Knowledge-driven DSS *(Artificial intelligence and knowledge base)*	Internal users and customers	Management advice	Expert systems
Model-driven DSS *(quantitative model)*	Managers and staff, customers and suppliers	Scheduling and forecasting	Linear programming, MS Excel

2.2 DSS and the decision-making process

There are different layers of decision making in an organisation. Operational decisions are routine, well-structured, function specific and internally focussed. These decisions are easier to automate due to the routine and structured nature of the decision. Tactical decisions might have less certainty and not all the decision variables are always known. These decisions are semi structured, also internally focussed, but will incorporate factors from external sources, such as suppliers or clients. Computerized decision support is used for semi-structured decisions and is the reason why DSSs are explored to aid in harvest and processing decisions for Company X. Lastly, strategic decisions are unstructured and could be ad-hoc in nature. These decisions can alter the landscape of an organisation entirely. They are the most difficult to automate and typically make use of ad-hoc models or special studies [7,8].

When considering the decision-making process, Simon's [9] model of decision making is still relevant nearly 30 years after initial publication. The model identifies four phases in the process, namely intelligence, design, choice and implementation. In today's world, Business Intelligence (BI) and big data visualisation can be used to make sense of internal and external data sources during the *intelligence* phase. The *design* phase is used to explore various courses of action, facilitate discussion and provide the users with options. Decision makers need to design possible solutions in this phase based on data in the intelligence phase. The *choice* phase builds on the previous two and focus on choosing the best course of action based on the information available. What-if questions, goal seeking, and scenario testing are often used as examples to help derive the best alternative. Lastly, data from the *implementation* phase is used to determine the success of the decision [6,10].

2.3 Characteristics and capabilities of DSS

Various authors have defined the characteristics of successful DSSs. Table 5 compares the various characteristics mentioned by Alter [5], Delen, Sharma and Turban [6], Power [10] as well as Holsapple and Whinston [11]. The combined attributes described by the above-mentioned authors allude to the type of decisions which DSSs typically support, the decision attributes, the power of the decision maker as well as the DSS infrastructure and architecture. Key themes from these four frameworks include:

- A DSS should support a decision through the phases of decision making mentioned above (intelligence, design, choice and implementation). Power [10] recommends that the DSS provide specific capabilities that support one or all of the four phases of decision making.
- Alter [5] as well as Power [10] agree that a DSS should support a specific decision process. Turban et al. [6], however, recommends that it supports a variety of processes.
- A DSS should improve the effectiveness of a decision. This includes the timing, accuracy and quality of decisions.
- A DSS should support managers at any level of the organisation, but not replace them. A recurring theme in all four studies is that the decision maker/s should be capacitated by the DSS and not made redundant.
- This then also implies that the decision maker should have relative control over the output of the system and have the power and flexibility to change variables that determine this output.
- The user should have easy access to the underlying body of knowledge and raw data contained in the system. This access should be easily manipulated and clearly articulate the underlying business rules.
- Lastly, the DSS can be an independent system that is networked with other systems but contains its own storage and modelling mechanism.

These characteristics provide a framework to use when designing a DSS. Hartono and Holsapple [12] summarises the outcomes of using a DSS by the impact it has on one of the elements described under the acronym PAIRS (productivity, agility, innovation, reputation or satisfaction). It will also help evaluate whether or not this design is successful in practice.

2.4 Designing a DSS

In the previous sub section, the characteristics of a DSS were discussed. In this section the focus will shift to the design of a DSS. This will establish the components needed to describe the DSS for Company X. Given the repeated use and non-technical nature of the end user for this DSS, a special emphasis will be placed on model DSSs, although the final DSS will contain aspects of a combination of DSS [7]. Historically DSSs consisted of a user interface, a database and a model or analytical tool [13]. In recent years, due to changes in technology, network architecture is an essential component of DSSs [14].

An easy to use user interface helps non-technical users to control the input variables and influence the output of the model. A well-designed user interface will empower the user to easily change variables based on the unique situations they face. A poorly designed user interface might eliminate key variables needed for a model and as such disempower the user.

A database is needed to store data generated by the analytical model. Data from underlying systems can be used to feed the model, however a specific history of the DSS needs to be stored in order to build a body of knowledge over time. Input variables and various scenarios can also be stored to reflect on at a later stage.

Models are a simplified representation of reality and capture the essence of the decision through careful deliberation of the parameters involved. Power and Sharda [7] mentions three techniques used in model-driven DSS: 1) Decision analysis, 2) mathematical programming and 3) simulation. Decision analysis involves the quantification of alternative options. This may include decision trees or analytic hierarchy processes. Mathematical programming includes the optimisation of decision criteria given the objectives and constraints of a decision. Simulation involves the recreation of a physical system in a quantitative model. This can then recreate a system electronically when certain parameters are changed and "run" over certain scenarios. The user can then create an imaginary situation and understand the outcomes on the system.

Lastly, it is important to consider the architecture for the DSS as it will typically function in a network of other systems. Data or input variables can be obtained from sub systems. This can be available real-time or more ad-hoc than the DSS will require it posing potential constraints on the end user. It is also important to consider where the tool will be hosted given the infrastructure of the current network and computing requirements of the model. The next section will explain the process of eliciting the requirements for a harvest and production DSS at Company X.

3 METHODS

This study is part of ongoing research to design, build and implement a DSS for harvest and production decisions. In this study the requirements for such a DSS is defined using decision maker requirements. To this end, one on one interviews with key decision makers in Company X were conducted, transcribed and analysed using a six step process of thematic analysis suggested by Braun and Clarke [15,16]. The sample of respondents was selected based on purposive sampling as respondents were selected based on their role and decision-making authority in the company. In total, eight interviewees were selected from operational, tactical and strategic roles namely the production unit manager, packhouse manager, production manager of managers, operations and logistics manager, tactical finance manager, chief marketing manager and strategic finance manager. Interviews were transcribed and coded to extract themes. Relevant themes relating to planning and decision making during the harvest season were extracted and elaborated on in the next section

4 RESULTS

The previous section explained the in-depth decision maker interviews performed at Company X. This section summarises these interviews and illustrates the complexity that exists in the harvest and packing process.

Harvest and pack planning is a year round activity. Figure 1 illustrates the factors that influence harvest and pack decisions. Arrows represent the flow of information between the various plans. Table 2 illustrates the level of authority and frequency of decision of each element in Figure 1. These decision nodes are interconnected and dependent on one another. A recurring issue that emerged from the interviews was the impact one decision node will have on another. A paraphrased quote from one of the interviewees gives an example of the negative impact changing harvest estimates has on the market plan:

> *If one thing changes, it disturbs everything else. (Author translated verbatim)*

Similarly, the changes in market priorities make operational planning difficult. A translated and interpreted quote by one of the respondents who commented on the difficulty in planning:

> *The problem that confuses the pack programs is the changes to the original plan.*
> *It is difficult to plan around (a changing plan).*

The harvest and pack plan bring together operational and tactical activities. The interviews provided insight to the challenges experienced by Company X in planning harvest and pack activities. Each of the elements influencing the harvest and pack plan will be discussed next.

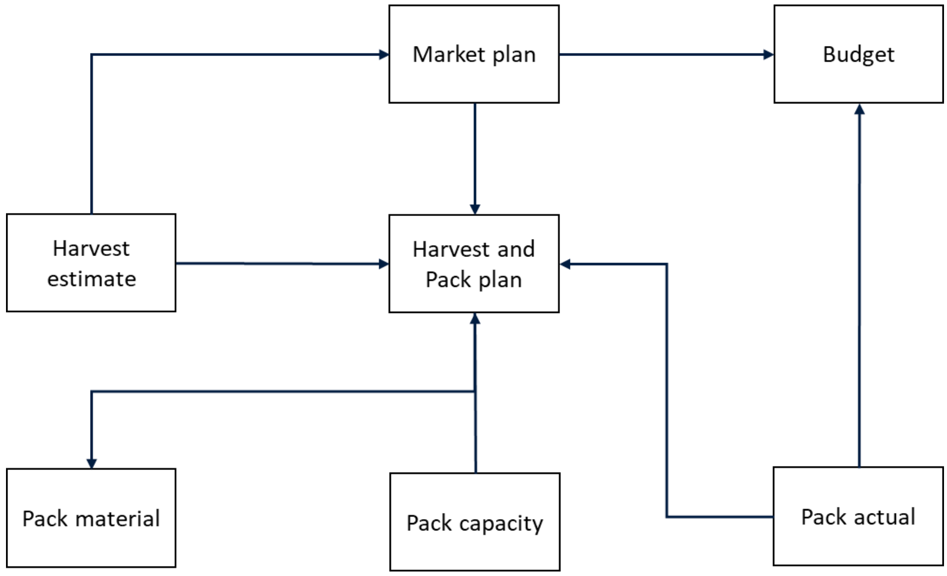

Figure 1: Factors influencing the pack and harvest plan

Table 2: Frequency and decision level of key activities influencing pack and harvest decisions

		decision type		
		strategic	***tactical***	***operational***
frequency	***seasonal***	budget		
	weekly		market plan	harvest estimate
	daily		pack and harvest plan	
			pack material	

4.1 Market plan

The market plan is negotiated with clients throughout the year. It is never finalised and is constantly updated depending on availability and quality of produce, price and the strategic importance of a client. High value produce will be reserved for prime clients after discussion between the marketing and logistics team and the production unit manager. Clients have specific requirements regarding produce which include cultivar (or cultivar group), size, packaging, quality and delivery timeline as influenced by their clients, the consumers. The company needs to adhere to these guidelines as strictly as possible to avoid paying a fine. In the case where these requirements cannot be met internally by Company X, they will in-source from other producers in order to meet the client requirement. Although priority clients get preferential treatment, all client requests must be met as a company policy.

4.2 Harvest estimate

An initial harvest estimate is done approximately six months before harvest based on historic trends. More accurate estimates are done closer to the packing season and weekly during the packing season. This remains a problem to Company X as precision of the estimates is not reflective of reality. The harvest estimate does not reflect third party (in-sourced) produce availability which leaves Company X dependent on strong market relationships to source appropriate produce in time. In season harvest estimates are dependent on the harvest readiness of a production unit and can often be a few days later or earlier than expected. This has a knock-on effect for delivery of produce to clients. Environmental factors, such as rain or extreme temperature conditions, can also affect the outcome of production. The allocation of produce to clients is dependent on the marketing team.

4.3 Pack material

The pack material plan is dependent on the pack and harvest plan. If it changes, the pack material plan should change as well. Pack material is often client-dependent, meaning that material with unique printing is needed for a specific client. Currently, pack material planning is a manual process driven by a single person. Due to the pack and harvest plan being based on a weekly basis, pack material is difficult to adapt to sudden changes in demand or supply within a week. Company X stores and manages all pack material centrally and will distribute to the various pack houses based on the pack plan. This limits the risk of losing pack material in a pack house but adds complexity when scheduling pack activities.

4.4 Pack capacity

Pack capacity is different for each of the pack houses. A theme that emerged 12 times from the interviews was that each pack house has specific constraints. A translated and interpreted quote that refers to daily pack planning illustrates this:

> *Not only should you know the production unit and client requirement, you should also be conscious of the combination of programmes planned on a line.*

Pack house capacity is therefore dependent on (in order of importance):

- station setup: different equipment is used throughout the business. As a result some pack houses can only pack boxes and others only punnets, while some can pack both;
- number of staff: each worker can pack a certain amount per day,
- quality of produce: good quality produce requires less preparation than poor quality produce;
- number of changeovers: changeovers result in downtime whilst new pack material is loaded into the system;
- packaging type: boxes are easier to pack than bags;
- combination of programs being packed: certain station setups cannot pack weights that are too close to one another as the equipment cannot distinguish between the weights and will log an incorrect weight. An example given is a 500g punnet or a 600g punnet. Their relative weights are close and can be logged as under or over weights. This slows the packing time significantly;
- the size of the pack house: worker productivity is dependent on the physical space and energy levels of the workers;
- lastly, management was also given as a factor which might influence worker productivity and flow through the pack house.

4.5 Budget

The budget is a seasonal estimate of income and expenses. It is completed by all production units and the marketing team to simulate capacity, produce availability and market demand. It is used as a reference throughout the year to measure under or over delivery. The budget provides the marketing team with detail such as whether they should sell more or less produce and if they are reaching their financial obligations for the year.

4.6 Pack actual

Pack actual is a historic ledger of everything that has been packed and shipped. It is used to deduct remaining harvest from completed programs daily.

4.7 Pack and harvest plan

The harvest and pack plan is one of the greatest challenges for Company X. It represents the junction between two evolving plans, namely the market plan and the harvest estimate or harvest readiness. It also represents the junction between tactical planning and operational realities. Currently, the pack and harvest plan guide the production managers on which client programs to service at a weekly level. However, realities often result in sub optimal decisions and down time for the pack house. Problems that were identified in this research include among others:

- The tactical planning manager often does not have real-time feedback on the capacities for each pack house;
- Sudden changes in priority from the market can cause confusion regarding priorities;
- Pack house capacities are complicated by pack station setup not accounted for in aggregated capacity data used by the tactical manager. Pack houses have specific station set-ups for the type of packaging being packed. Certain combinations of packaging types cannot be packed together due to the equipment used by the pack house. This is not seen at an aggregated weekly packing level and can result in down time;
- Produce quality and packaging type influence capacity constraints. This changes daily.

The analysis above indicates that the manual process of planning result in sub-optimal decisions over both the tactical and operational functions of the company. Although highly competent people drive the process, an increase in complexity due to the size of the undertaking makes it difficult to keep track of all the factors influencing decision making. Time and availability of information at the correct aggregation level complicate decisions further. The next section discusses a proposed DSS solution that will span over both tactical and operational functions.

5 DISCUSSION

The problems discussed in the previous section illustrate that an integrated solution is needed to aid companywide decisions [17,18]. This section describes the proposed solution for such a system in the context of the characteristics mentioned in section 2.3. Section 2.1 is referenced to classify the proposed DSS provided to its users.

In Table 3, the first column illustrates key business requirement themes which emerged from the interviews at Company X. Due to the complexity and timeliness of a required solution, a combination of DSS types is suggested in the second column. The interdependence of the decision space lends itself more towards a Turban et al.[6] solution where multiple decision functions are supported. The company needs a quicker, more granular way of planning harvest and packing activities to get the best from a harvest period. An optimisation model, which accounts for the multiple and specific constraints, is suggested. To help predict potential bottlenecks or opportunities, a simulation model that uses an underlying body of knowledge to map the system in working or suggested is also recommended. In order to empower users with knowledge of underlying business rules, assumptions and knowledge of the system, a visualisation and continuous monitoring system should be added as recommended by Holsapple and Whinston [11].

Table 3: Proposed solution

Requirement	Category	Solution
Daily scheduling of harvest and pack plans	Frequency	Optimisation
Allocate to predetermined client-block	Constraints	
All programs should be serviced		
Timing: red grapes to be cut in natural light		
Timing: shipment date determines harvest restriction		

Packhouse specific constraints		
Orchard sugar levels must be ready on date of schedule		
Transportation: limited number of cold trucks		
Limit changeover/downtime as much as possible	Penalise	
Exchange rate	Decision variables	
Price		
Labour utilisation		
Transportation distance of grapes: orchard to packhouse		
Transportation distance of grapes		
Outsource grapes: illustrate potential gaps		
Poor quality produce should be excluded		
Include BOM and resource requirement	Output	
Suggestions ready by 10 am		
Forecast suggestion and flag potential bottlenecks or opportunities		Simulation
Compare seasonal and historic versions of harvest estimate Illustrate the rationale behind decisions through data visualisation Give the user easy access to pallet traceability		Visualisation
Continually update norms of harvest activities Continually update norms of pack activities Norms and standards of activities Continually update harvest estimate		Continuous monitoring

Table 4 uses the DSS classification discussed in section 2.1 to categorise this DSS based on the purpose of each solution and the target users. The optimisation model will aid the tactical manager to assign client needs to company produce in a more effective manner. It will also help production managers communicate capacity and prioritise work on a daily level. The simulation model is intended to inform the Tactical manager if a solution is feasible. A data visualisation system will help make information available to the tactical as well as operational staff. Lastly, the continuous monitoring system will inform the models as well as users with insights regarding norms and standards. All four proposed solutions have a specific use case and is made up of two or three types of DSSs. In all four proposed solutions, the system will aid decision makers, and never aim to replace valuable positions. In terms of the PAIRS model proposed by Hartono and Holsapple [12], the proposed DSS will contribute improvements in productivity, agility and reputation to Company X. It will do this by providing relevant information to key decision makers, recommending solutions to complex scheduling problems and verifying plans before being sent out to the operational teams. It will also help the production manager be more effective in communicating restrictions and bottlenecks to the tactical team.

Table 4: DSS classification

Solution	Purpose and users	DSS classification
Optimisation	***Purpose:*** Schedule harvest and pack plans in order to provide a solution to the company. ***Target users:*** Tactical manager and production managers	Model-driven DSS Knowledge-driven DSS
Simulation	***Purpose*:** Gives feedback to tactical manager whether a suggested solution is feasible or not. Indicates if potential bottlenecks and non-delivery is a possibility. ***Target users:*** Tactical manager	Model-driven DSS Knowledge-driven DSS Communications-driven

Visualisation	***Purpose***: Users should have access to underlying assumptions influencing the DSS. The users should also have access to historic and current data in an easily palatable manner. ***Target users:*** Tactical and operations managers, data analysts	Data Driven-driven DSS Communications-driven DSS
Continuous monitoring	***Purpose:*** Continually update and build on a body of internal knowledge based on historic and predicted data. This will form the basis for the optimisation and simulation models. ***Target users***: Tactical manager	Knowledge-driven DSS Communications-driven DSS

This article outlined the requirements for a DSS to be implemented at Company X. It is part of ongoing research where the next steps will include the build of a bespoke DSS based on these requirements. The system will integrate with existing infrastructure and act as a free-standing tool to improve tactical and operational decision-making. This work addresses a real alternative in the South African fresh produce sector which requires everyday industrial engineering solutions such as systems design, optimisation, simulation and scheduling. It stipulates the design and intended implementation of a solution that will make a difference.

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Table 5: Characteristics of DSS

Categories	Characteristic theme	Characteristic	Alter [5]	Holsapple and Whinston [11]	Delen, Sharda, Turban [6]	Power [14]
Decision type	**Repeatability**	DSS are intended for repeated use. A specific DSS may be used routinely or used as needed for ad hoc decision support tasks.				x
	Structure	Support for decision makers in structured and unstructured decisions.			x	
Decision attributes	**Decision dependence**	Support for interdependent and or sequential decisions.			x	
	Decision phases	Support in **all phases** of decision making (intelligence, design, choice and implementation).			x	
		DSS provide specific capabilities that support **one or more tasks** related to decision making, including intelligence and data analysis, identification and design of alternatives, choice among alternatives, and decision implementation.				x
	Decision process	DSS's should be designed to **facilitate a specific decision process**.	x			
		Support for a **variety of decision-making processes and styles**.			x	
		DSS facilitate and support **specific decision-making activities or decision processes**, or both				x
	Effectiveness	DSS are intended to improve the accuracy, timeliness, quality, and overall effectiveness of a specific decision or a set of related decisions.			x	x
Decision maker	**Decision maker: level or structure**	DSS can support decision makers at any level in an organization. They are not intended to replace decision makers.	x		x	x
	Control	The decision maker has complete control over all steps of the decision-making process. A DSS supports and does not replace a decision maker.		x	x	x
	Interactive	Interactive ease of use.		x	x	x
	Flexibility	A DSS should be flexible and respond to the changes in environment experienced by the end user.	x	x	x	
	Modify	End users should be able to modify to a certain extent.		x	x	
System	**Record keeping**	DSS need a recordkeeping capability that can present knowledge on an ad hoc basis in various customized ways as well as in standardized reports.		x		
	Data access	DSS should have capabilities for selecting a desired subset of stored knowledge either for presentation or for deriving new knowledge.		x	x	
	Model / intelligence	DSS must have a body of knowledge.		x		
		Modelling and analysis.			x	
	Architecture	DSS may be independent systems that collect or replicate data from other information systems or subsystems of a larger, more integrated information system.			x	x

AN APPLICATION OF THE CONTROL CHART AND FISHBONE DIAGRAM FOR MINIMIZING DEFECTS IN SAND CASTING PROCESS

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ABSTRACT

The sand casting process is widely used in most foundries in South Africa (SA) for the production of large and small castings. The sand casting process involves pattern making, moulding, metal pouring, shake out and fettling. The quality of the produced casting depends on the quality of the sand used during the casting process. This means that sand control must be put in place to monitor and control the properties of the casting sand. The Sand testing process is traditionally employed in the foundry industry as a quality control method for sand casting process essentially for the green sand system. The primary aim of sand testing is to check the regularity of the ready to mould sand and the properties of green sand to control defects in the production process.

The purpose of this study is to explore the benefits and application of control chart and fishbone diagram in sand casting process to decrease the amount of casting defects. Sand casting data was obtained from a local sand casting foundry, the data included casting defects and sand properties. The control chart was used to study and measure the amount of variation in sand casting properties due to the observed casting defects in the foundry. The fish bone was then used to find out the sources of variation that lead to casting defects. This paper presents the analysis of variation in sand properties using the control chart to explain the observed casting defects and the sources of both variation and defects using the fish bone diagram. Control charts and fishbone diagram could contribute an alternative reality in sand control in the foundry industry.

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1 INTRODUCTION:

Sand casting is a process that involves pouring molten metal into a mould cavity and allowing it to solidify. The sand casting process involves sand mixing, pattern making, moulding, metal melting, pouring, shake out and fettling. Figure1.1 shows a summary of the sand casting process. As observed from Figure 1, the sand casting process starts with sand preparation, which involves mixing the sand with a binder, water and additives (dextrin or any starch). The sand is then rammed around the pattern to create an imprint of the part to be cast. The pattern is then stripped off and the mould is then vented to allow gases to escape during casting. After venting, the mould is air cleaned and a refractory coating is applied on the surface of the mould. The refractory mould coating is applied to improve the surface finish and prevent surface defects on the casting. The metal is then poured into the mould cavity and allowed to solidify.

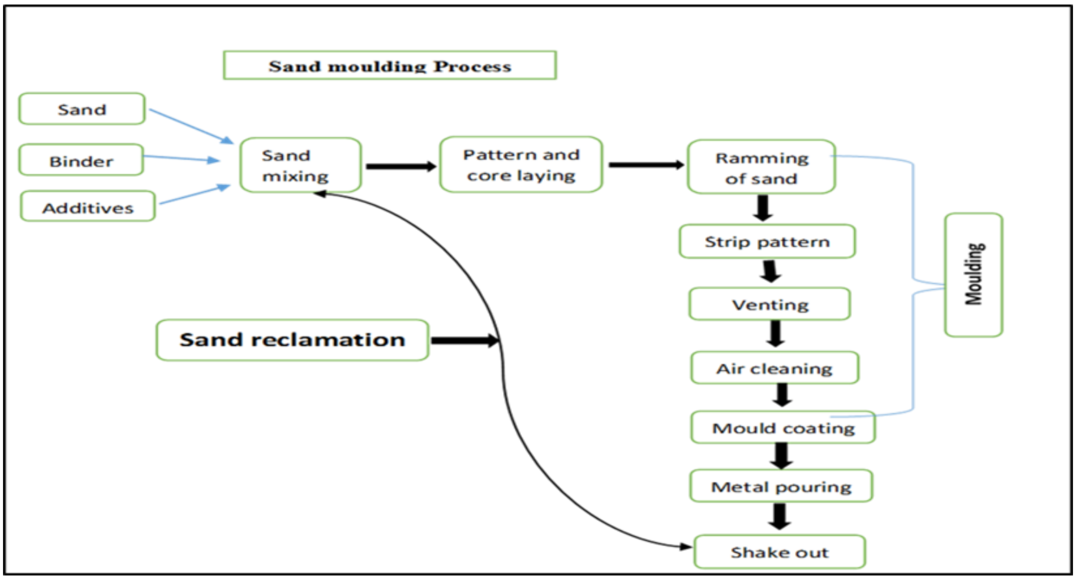

Figure 1: Typical sand moulding process Adopted from [1]

After solidification the mould is broken down during the shakeout, the casting is removed, and the sand is recycled in the reclamation stage of the process. This process is repeated over again in sand casting. Sand casting is widely used in the foundry industry due to its advantages which included cost-effectiveness, production of complex shapes and production of any casting size; small or large [2]. Sand casting processes are complex and contain many variables that should be controlled to produce castings of good quality. The quality of castings in sand castings process depends on the quality of the sand, the moulding process and the strength of the mould [3]. Sand testing is employed in the sand casting process to check the consistency of the sand in terms of the defined sand properties.

Albeit, it is applied as a moulding sand control measure, this type of sand control method is very limited. It does not allow for minimization of casting defects. Through this sand control, it is always challenging to associate the casting defects to the root causes in the foundry. Furthermore, the recorded sand results cannot easily be used for prediction of sand properties in the foundry. The constraint of the current sand control method is rooted in its inability to eliminate casting defects in the foundry. Although control charts and fishbone diagram have been exploited in the manufacturing industry, it has not been understood and applied appropriately in the sand casting process in the South African foundry industry. This paper seeks to provide a guide on how to use the control chart and the fishbone diagram in green sand casting to improve quality. For this reason, the application of control chart and the fishbone diagram could present a new reality in sand casting foundries in South Africa considering the above constraints.

Control charts are used to observe the trend in the data and to measure the amount of variation in production processes [4], while the fishbone diagram is used to find the root causes of deficiencies in the production environment that affect the quality of products [6]. Control charts allow the graphical presentation of collected results. The graphical results presentation using control charts indicates whether the results are within control limits and also check the trend in the data to give an overview of the production process [5]. This paper shows how the control chart and the fishbone diagram can provide additional information for sand control in greensand foundries. The purpose of this paper is therefore to outline the importance of control charts and fishbone diagram for minimizing casting defects in sand casting foundries in South Africa. The paper also emphasises on the importance of monitoring process variation for defects minimization in local foundries.

2 CONTROL CHARTS IN SAND CASTING PROCESS

The use of a control chart entails determination of a sampling method, a sampling frequency, the interval between sample collection and the determination of control limits for the chart and this process is called the design of a control chart [6]. The green sand foundries already have these factors in place of which can facilities the smooth application of these tools in SA foundries. The design of a control chart poses economic implications including the cost of sampling, testing, cost of examining the out of control signs and perhaps cost associated with rectifying assignable causes as well as the cost of sending casting that does not meet customer specifications [6]. The selection of these controlled parameters affects the total quality of products; due to this, the design of a control chart is important for productivity and profit in a foundry. The design of the control chart and the fishbone diagram is critical because it will also ensure that adequate data is collected, interpreted properly and appropriate corrective action is taken to avoid the risk of poor quality. A control chart assumes that a process will operate randomly when there are no assignable causes in the system and will produce a contemporary level of quality as the process continues. If that level of quality is not acceptable, a major modification of the process is essential [7].

Control charts are statistical tools used to differentiate between natural and unnatural variation in process variables by checking which data point is within control limits [5]. According to Foster (2013), control limits are used to assess the existing variation in a given process [8]. Process variation is a measure of process deviation concerning the derived process parameters specifications [9]. The sand casting process variables range from the moulding sand parameters to the parameters of the molten metal. Variation is present in production processes because a random process combines machine, material, people and environment to transform input materials into output [9]. It is therefore important to note that, process variation influence product quality. In this case, sand testing in green sand foundries should be performed to monitor the amount of variation in the controlled process parameters which includes the moisture content, the permeability, green strength and clay content of the sand. According to Brown(2000), a variation that is within control limits is allowed in sand control but if the sand results should appear to be out of control, then corrective action should be taken [8]. Due to this, regular testing of casting sand is essential to ensure that the sand properties are in statistical control [10]. Figure 2 shows a typical control chart and data interpretation at different data points.

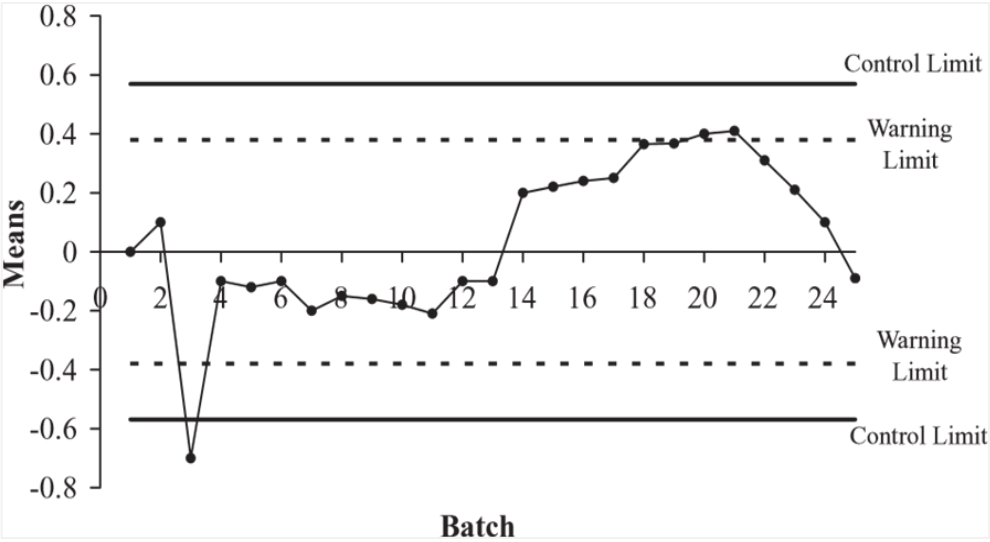

Figure 2: Control chart [11]

The control chart in figure 2 shows how the parameters' data is interpreted from the different points in the control chart [11]. According to Omor (2010), the above chart shows a process which is out of control. An out of control process chart is observed when one or two points is out of the derived control limits in the chart, at least eight consecutive points are in one side of the chart and when two or three consecutive points are inside the two sigma warning limits but inside the control limits [11]. Based on the above information it is therefore important to know and understand control charts as well as its interpretation to be applied in the sand casting process. The understanding of a control chart and its interpretation will allow proper corrective action to be taken to improve quality by ensuring minimum defects in the process.

According to Brown (2000), in sand control corrective action can be accomplished by either increasing, reducing clay content or adding new sand [10]. Due to the resistance of the sand process to change, a quick change in the sand properties can only be observed by increasing and reducing the water addition in the mixer [8]. However, it is important to know the root causes of deviation in the production process to eliminate the possibility of defects. A Fishbone (Ishikawa) diagram also called cause and effect diagram is used to find the root causes of quality-related problems in a process by studying the observed effects.

3 CAUSE AND EFFECT (FSHBONE) DIAGARM FOR THE SAND CASTING FOUNDRY

The fishbone (Ishikawa) diagram is a tool used to investigate the root causes of a quality-related problem in production environments. The diagram offers an organised way of observing the effects and the causes of quality problems [12], due to the utilisation of the diagram it is also referred to as the cause and effect diagram [12]. The fishbone diagram focuses on highlighting the problem under study and systematically identifies and list the root causes that could be ascribed to the problem [13]. According to Ilimu (2016), the fishbone diagram assists in determining several causes that have a great effect on the problem [13].

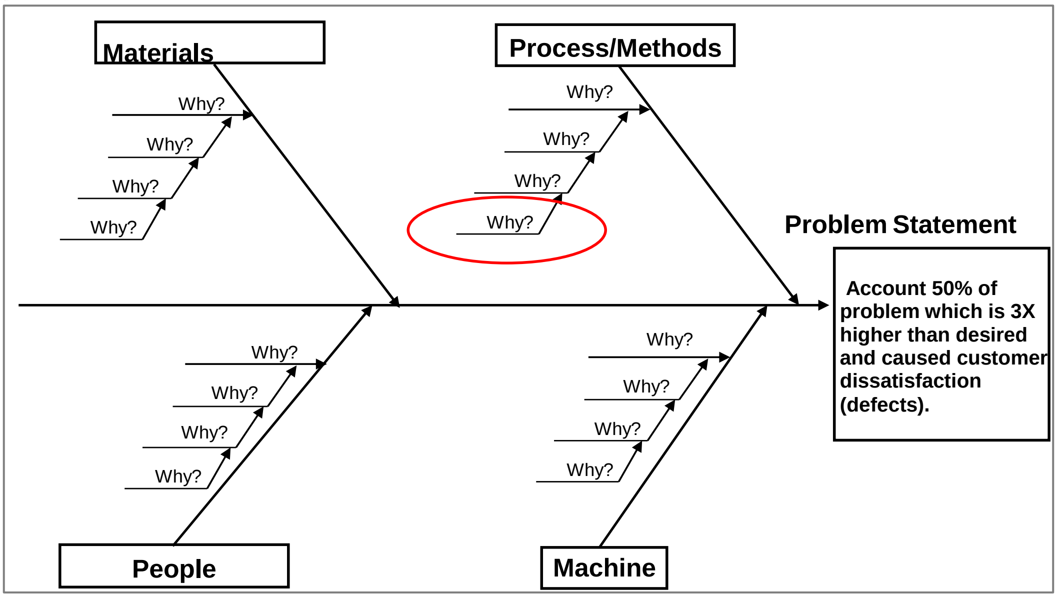

Figure 3: Fishbone Diagram

According to Illie (2010), the benefits of using the fishbone diagram include assistance in determining the root causes using the structured approach, the fishbone fosters group participation, and utilises group knowledge of the process in question and identifies areas of improvement [12]. Figure 3 shows a fishbone diagram and the methodology followed for identifying the solution. The fishbone diagram breaks the identified problem and the team involved participates in solving the problem [14]. As observed from the figure 3 the figure shows that the fishbone bone diagram also applies the 5whys methodology to find the root causes.

4 METHODOLOGY

The work was conducted in a local automotive foundry concentrating on the green sand plant. The methodology consisted of four steps as shown in figure 4.

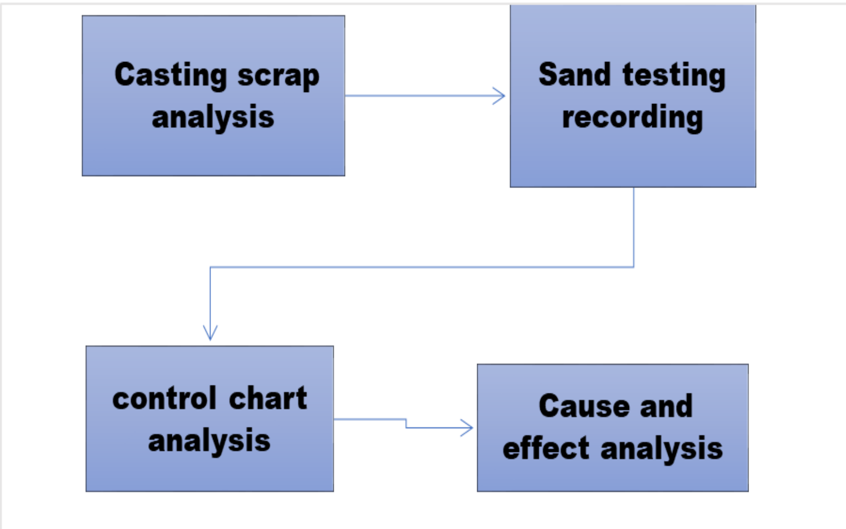

Figure 4: Methodology

Casting scrap analysis

The casting scrap analysis was conducted over a period of three months on all castings produced in the foundry in this period. The results are presented in the form of a percentage frequency graph.

The sand testing recording

The moulding sand/ green sand was tested for the following properties; permeability, moisture content, compactibility, shear strength, compression strength, and green strength. The samples were obtained from the green sand mill. Sand samples were collected every hour during a shift to check for the regularity of the green sand parameters.

The control chart Analysis

The control charts were then used to plot the recorded sand casting process parameters data. The control limits used in the control chart are the actual process parameters specifications for the greensand process. The UCL in the chart represents the actual sand parameter's upper control limit, and the LCL the lower control limit.

The cause and effect analysis

The fishbone diagram was then used to find the sources/ the root causes of deficiencies in the foundry process. The highest sand casting defects in the foundry were outlined as the main defects affecting the greensand foundry process. The identified root causes were used to explain the observed casting defects.

The next section presents the results obtained from applying the above-mentioned methodology in the foundry.

5 RESULTS AND DISCUSSION

This section presents results obtained after analysing the foundry's greensand data and the recorded defects.

Foundry Defects

The casting defects in the foundry were measured and studied using a distribution graph. Figure 5 shows the distribution of foundry process defects in percentage.

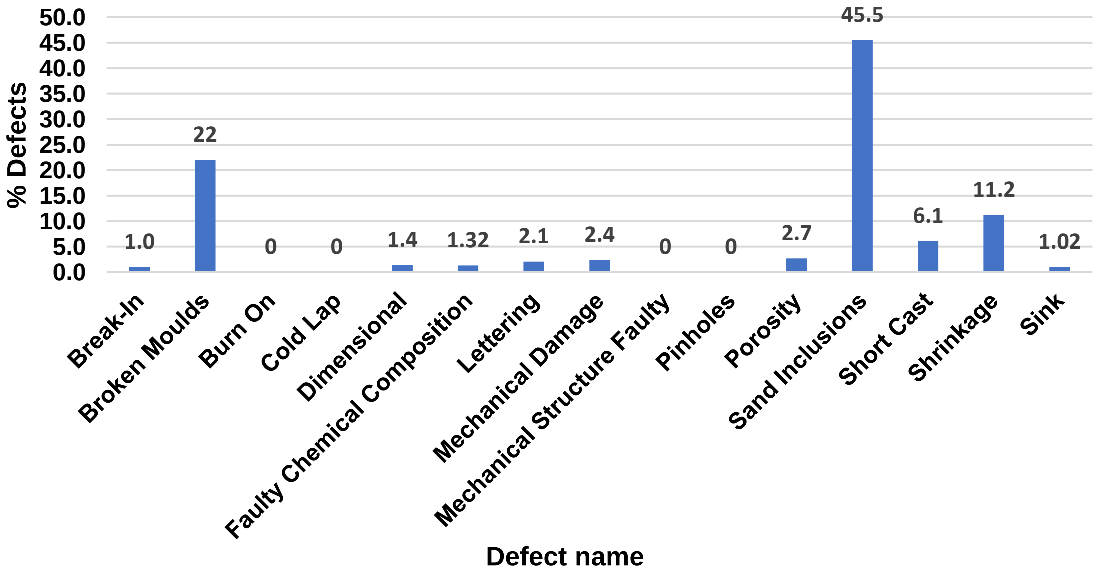

Figure 5: Percent sand casting defects in the foundry

As observed from figure 5, the foundry was experiencing a high amount of sand inclusion, broken mould and shrinkage defects. The graph also shows minimal amount of porosity, mechanical damage, sink, lettering and dimensional accuracy defects. The observed major defects in the foundry process indicate that there are deficiencies in the moulding sand. The deficiencies in the moulding sand are validated by the observed high amount of sand inclusion and the broken mould defects. The sand casting process parameters needed to be analysed to understand the causes of theses defects in orders to come up with remedial actions to minimize and prevent future occurrence of these defects. The next section presences results obtained after analysing the sand casting process parameters.

Control charts results

This section presents the sand casting process parameters results for the moulding sand and are presented in a control chart format. The control charts were used to study the moulding sand parameters; compactability, compression strength, permeability, green strength, shear strength and moisture content of the sand to explain the observed defects in the foundry. According to Prajapati (2012), Control chart assist to detect assignable causes of variation in parameters that could affect the quality of final products and can be used to determine the process capability [7]. Figure 5 shows the control chart of the sand casting process parameters respectively.

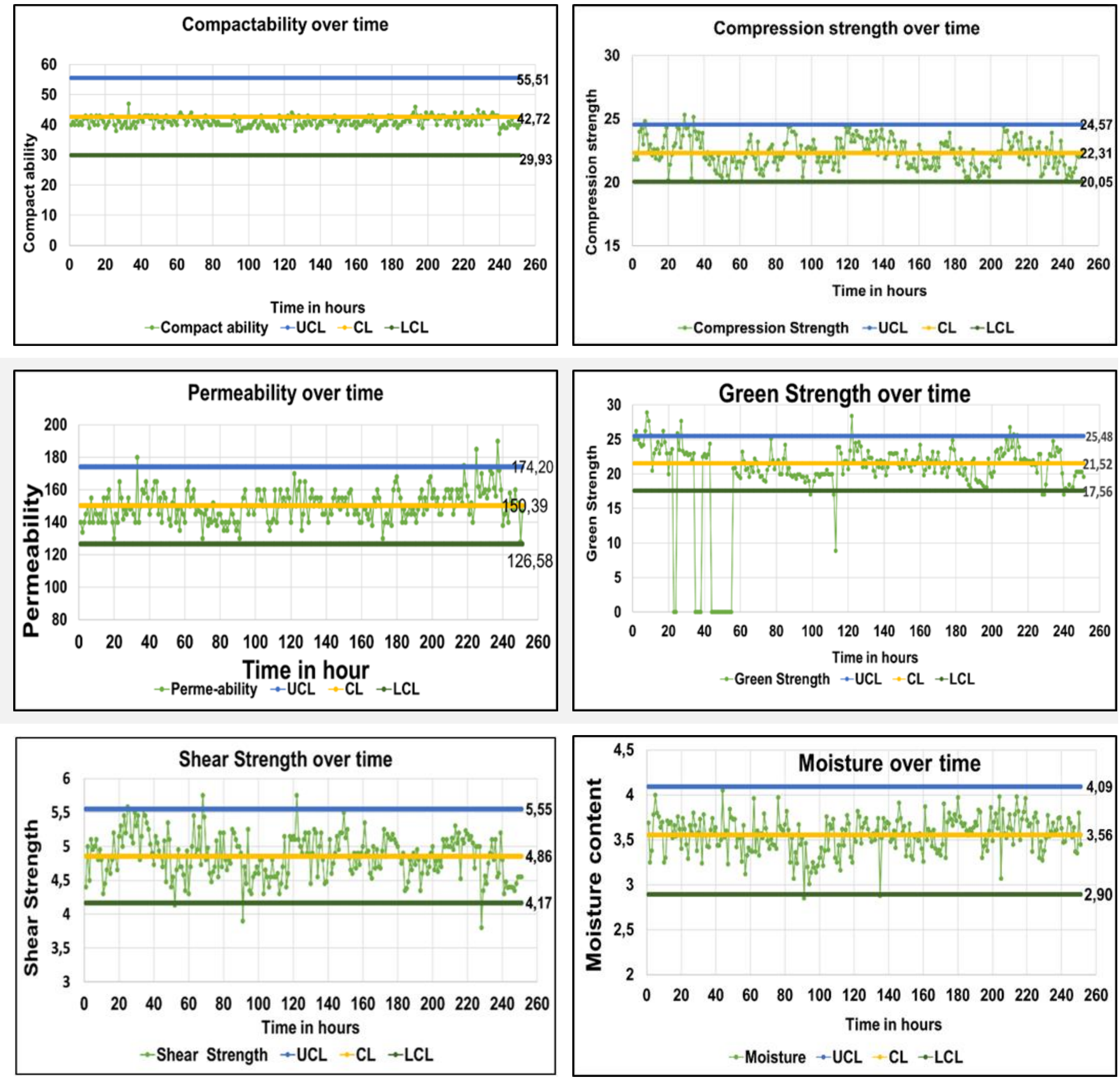

Figure 6: Control Charts for Sand Casting Process Parameters

The control charts in figure 6 show the sand casting process parameters trend over time. Based on the above figure, the sand casting process is unstable over time and possess a high amount of variation. As observed from the above control chart for the moulding sand process parameters, the control chart for compactibility, compression strength, permeability, green strength, shear strength and moisture content shows data instability over time, high amount of variation and out of control limits. The control chart for green strength, shear strength and permeability also show outliers, this means that the sand parameters do not meet the foundry's sand specifications and the sand casting process is out of control due to these parameters. The sand casting process is not stable over time due to the moulding sand parameters and it poses a high amount of Non-random variation. As explained earlier, high variation in production environment could be associated with product quality. The moulding sand parameters instability and high amount of Non-random variation could be linked and be responsible for the above-observed defects. Process variation that may impede the quality of the finish casting or service can be noticed and improved [7].

The main sand parameters contributing to the observed deficiencies in the foundry is green strength, shear strength and moisture content. The Moisture content is critical in green sand casting because it controls all other sand parameters. The presence of a high amount of non-random variation means that there are assignable causes in the foundry process that leads the sand parameters to be out of control. The non-random variation in the sand parameters could be used to explain why there is a high amount of sand inclusion and broken mould in the foundry castings. The sand parameters control the quality of the mould which then affects the quality of the final castings in the foundry. The root causes of the non-random variation that lead to major defects were investigated using the Fishbone diagram. The next section presents the results obtained from the fishbone diagram.

Fishbone diagram results

This section provides the fishbone diagram results. The fishbone diagram was used to analyse and present the sources of non- random variation observed in the foundry process. The fishbone shows that the observed foundry process variation originates from the machine, the process, material and the operators in the foundry. Figure 7 shows the fishbone diagram. According to Joshi and Kadam (2014), the application of a fishbone diagram makes it easy to understand the causes and sources of defects in production environment and can be used to find appropriate corrective measure [15].

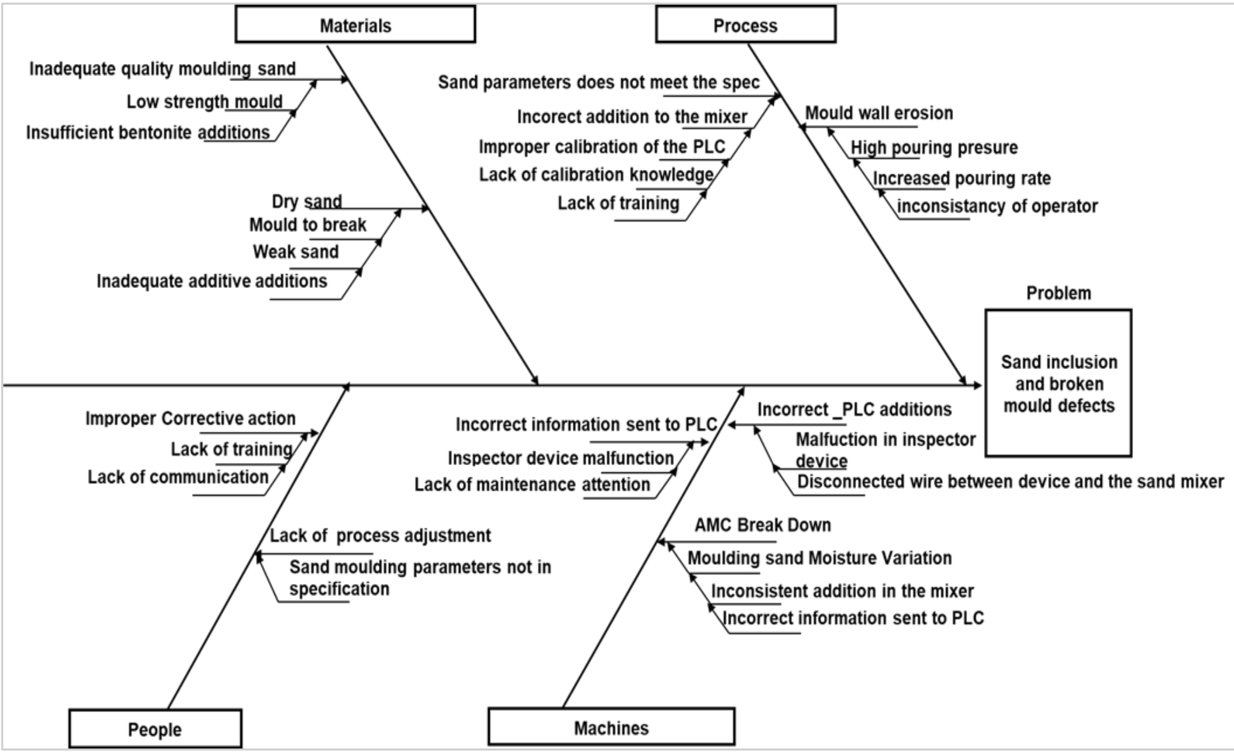

Figure 7: Fishbone Diagram for the Foundry Defects

As observed from the fishbone, the foundry defects are influenced by lack of training, the inconsistency of the operator and lack of maintenance attention. The diagram also shows incorrect information sent to the Programmable logic controller (PLC), inadequate additions in the mixer, sand parameters not meeting the specifications, the disconnected wire between the sand inspector devise and the sand mixer in the process, lack of communication between departments as other causes of deficiencies in the foundry. The above-listed factors affect the moulding sand properties in the greensand foundry, which then influences defects in the foundry process. It is also evident from the fishbone diagram that foundry needs to address these issues to minimize defects and optimize the foundry process.

6 CONCLUSION

This paper has presented the application and the importance of the control chart and the fishbone diagram in the production environment regarding a greensand foundry. The findings obtained in this paper collaborate with the referenced work on both the control chart and the fishbone diagram in the manufacturing industry. The application of these tools in greensand foundries can foster alternative realities. Based on this work's findings and the referenced work, the control chart and the fishbone diagram can be used to justify deficiencies and find the root of causes of quality-related problems in sand casting foundries. These tools are used to understand the performance of the production process to improve quality and profit in the production environment. This work was done over a limited period at only one foundry. Future work will attempt to extend the period of data collection, challenge the existing knowledge on the control chart and fishbone diagram and will include another type of foundries beside a green sand foundry.

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A DECISION MODEL TO SUPPORT THEATREALLOCATION FOR NON-ELECTIVE PATIENTS IN A PRIVATE HOSPITAL

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ABSTRACT

Operating theatre planning is a very complex process due to the involvement of many stakeholders and the influence of variability on output performance measures such as financial indicators, waiting times, throughput and utilisation.

In addition to this, the unforeseen arrival of patients in need of non-elective surgeries may cause a thoroughly planned operating theatre schedule to change with each arrival. This may have an influence on efficiency, utilisation and waiting time between surgeries. The purpose of the study is to offer a solution to this problem by determining which allocation policy for patients in need of non-elective surgery will be best suited for this private hospital. The policy should ensure a balance between scheduling patients for elective surgery and responding to the arrival of patients in need of non-elective surgery, and should contribute towards the utilisation of the operating theatres.

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1 BACKGROUND

In South Africa, healthcare has to be provided to all citizens as set out by the Constitution as part of their human rights. Public healthcare is therefore available to all South African citizens, although there are individuals who prefer the private healthcare sector instead. One of the systems in the South African healthcare environment that could benefit from improvement through innovation is operating theatre scheduling.

A preliminary overview of literature shows that research has been done over the last decade on information technology within healthcare, leading to the improvement of systems and making data capturing much more cost effective and accessible. As such, the benchmarking of health performance standards among countries has become a popular trend [1]. Since hospitals benchmark amongst each other , it has become a crucial objective of hospitals to ensure more efficient and effective practices within their healthcare delivery system [2].

It can be argued that improving healthcare systems will benefit the level of medical care provided to patients. However, the implementation of these improvements may in some cases be costly and time-consuming. How can the effect of innovation and change on healthcare systems be predicted? Holleman, Poot [3] asserts that the *"implementation of innovation is a complex and intensive procedure in which different strategies can be successful"*. The implementation can be done by implementing new ideas such as adding resources and making observations on how this influences the utilisation. This could also include making changes to schedules and analysing the effect of the changes on various components of the system. This can be seen as a continuous improvement approach and it is important to know that in real life, improving processes with this approach can become expensive.

One way of predicting the effect of information technology innovations on a healthcare system is by means of simulation modelling. The use of simulation modelling in healthcare is becoming a very popular trend. Simulation models can be beneficial in several ways. They can be valuable when it comes to the observation of the performance measures of different systems and sub-systems within healthcare, it can also be beneficial as a decision support tool and a planning tool [4].

Hospitals usually manage the use of operating theatres by making use of one of the following types of scheduling: open scheduling, block scheduling and modified block scheduling [5]. Using simulation modelling as a technique to help with forecasting and analysis of various scenarios could be much more cost effective than experimenting with various scenarios in real life. When a theatre schedule is designed, it is important to look at the balance between scheduling elective surgeries and responding to the arrival of patients who are in need of non-elective surgeries (from here "onwards non-elective patients").

2 TYPES OF SIMULATION MODELS

Simulation is one of many different tools and techniques used within the healthcare sector for the purpose of analysing, improving processes and providing support to enable better operational decision making [6]. Simulation modelling is used due to its ability to mimic real-life scenarios and how they change over time [7]. It is also very useful when exploring the relationship between human-oriented variables and infrastructure-oriented variables [8]. This tool and technique allows the researcher to test many different scenarios and variables before actual implementation. This minimizes factors such as wasting money and resources on implementing scenarios not tested thoroughly. Not only does the use of simulation modelling save costs, it also saves time and it provides the opportunity to evaluate different scenarios without disrupting the day-to-day procedures and operations in the hospital [9]. It is important to take into consideration that simulation is a prediction model of the reality and not necessarily a model generating the optimal solution for the problem.

There are different types of simulation models used within the field of healthcare. According to Sweetser [10] the different simulation modelling approaches that can be used are as follow:

- System Dynamics Simulation
- Discrete Event Simulation
- Monte Carlo Simulation
- Agent-based Simulation

2.1 System Dynamics Simulation Modelling

System dynamics is an abstract method of modelling and according to Sweetser [10] system dynamics can be defined as “a methodology used to understand how the systems change over time.” With this modelling technique the focus is not placed on individual characteristics but rather placed on the representation of the system as a whole and is therefore system-oriented. From a system dynamics perspective behaviour of the system will not be influenced by the actions of individuals. System dynamics modelling can be a very useful tool to model continuous processes of non-linear changes and it can be helpful when making long term strategic decisions. The main objective of a system dynamics simulation model is to determine under what conditions the process modelled will change and to what extent will it change. The nature of a system dynamics simulation is deterministic in other words outcomes can be precisely determined due to random variables not taken into consideration. With this simulation model a Top-down approach is followed.

This simulation modelling technique can be used in healthcare to:

- Model chronic disease preventions
- Determine the effect of drug-resistant infections.
- Determine the effect if ineffective management of chronic illness
- Investigate the decline in health related quality.

2.2 Discrete Event Simulation Modelling

Discrete event simulation is used to model processes that consist of discrete events in time thus is process-oriented. This method of modelling are much more focused on detail opposed to systems dynamic simulation modelling method. According to Sweetser [10] a discrete event simulation is used to understand a process, how it works and to observe how its behaviour will change when changes are implemented thus the behaviour of entities are determined by the system itself. The nature of a discrete event simulation is stochastic in other words it may happen that with the same set of data and initial conditions set different outcomes output can be obtained due to variability taken into consideration. Note that since historical data will be used for this study, pre-defined theatre schedules will be used. According to Jun, Jacobson [11] discrete-event simulation has been widely used to:

- Solve resource allocation problems;
- Improve of patient flow;
- Reduce costs; and
- Increase patient satisfaction.
- Compare and evaluate medical interventions

- Investigate operating theatre schedules

2.3 Monte Carlo Simulation Modelling

Monte Carlo is a modelling technique used to determine and illustrate the potential outcomes related to decisions made and the probability of the outcome occurring. Monte Carlo can be used to develop forecasting models. Results are very transparent for it doesn't only indicate all the potential outcomes but also the likeliness of each outcome.

This simulation modelling technique can be used in healthcare to:

- Forecast the number patients that will arrive at healthcare centres in the near future.
- Determine the effect of medicine on sample size of patients of the same nature.
- Improve inventory decisions by predicting the demand of different medicine

2.4 Agent-based Simulation Modelling

Agent-based simulation is a modelling technique where individuals, in this case agents, can interact with one another and with the environments. The output then represents this interaction and the effect thereof. Agents in an agent-based simulation model has their own behaviour other than with a discrete event simulation. Agent-based simulation modelling follows a bottom-up approach and the concept of queues is therefore not considered. . The nature of an agent-based simulation model is stochastic and individual-oriented.

This simulation modelling technique can be used in healthcare to:

- Simulate a hospital emergency department taking the human factor into consideration.

For the purpose of this study the focus is on discrete-event simulation to take into consideration the uncertainty of non-elective patients arriving. With a discrete-event simulation we will also be able model patients as individual and independent individuals to whom attribute information can be assigned and with this type of simulation it is assumed by the model that there is no change to the systems in between events.

3 SIMULATION METHODOLOGY

The research method used for this study is a step-by-step approach adapted from Ülgen, Black [12]. Broadly speaking, the research method used to develop a decision model to support theatre allocation for non-elective patients arriving at a private hospital consists of 6 phases.

- Phase 1: Define the problem
  A thorough understanding of the research problem and complexities influencing the scheduling of non-elective surgeries in a private hospital was obtained during the first phase
- Phase 2: Design the study
  Activities associated with this phase of the research method includes determining the boundaries of the simulation model, the number of models required, the software to be used as well as ascertaining the availability of data.
- Phase 3: Conceptual design
  In the conceptual design phase of the research, a broad overview of the decision model's elements were determined. This include the elements that drive the system

and the nature thereof (i.e. dynamic or static). This subsequently led to the level of abstraction that was determined. The relevant object flow diagrams together with the required performance measures concluded this phase.

- Phase 4: Define the inputs, assumptions and processes
  The fourth phase of the simulation methodology is concerned with the finer details of the decision support model. Business process models (BPMN) was used to capture the necessary level of detail where after the operating and functional specifications and assumptions were established. This was followed by an analysis of the input data and runtime parameters were finally determined.
- Phase 5: Build and verify the simulation model
  The fifth phase of the simulation method culminated in the construction of the simulation model by means of the input of all the previous phases. Verification of the model was also done during this phase by comparing theoretical calculated cumulative utilisation with that of the cumulative utilisation obtained from the respective simulation models.
- Phase 6: Document the simulation results
  The final phase of the six phase process was to thoroughly document results and make recommendations for further studies.

4 SIMULATION MODEL

4.1 Models Required

The following models were developed to depict the different allocation policies for the arrival of non-elective patients arriving:

- Model 1: Simulation of the flexibility policy
- Model 2: Simulation of the dedicated policy
- Model 3: Simulation of the hybrid policy

The simulation software that was used in this research is FlexSim 2017. It is important to note that the fundamental solutions of algorithms within the simulation model doesn't fall within the scope of this research.

4.2 Boundaries

The system that was simulated is the operating theatres of a private hospital. This private hospital consists of four operating theatres. To enable the researcher to formulate the boundaries for this simulation model the following assumptions are made:

- Patients leave the operating theatre directly after their surgery has been completed, no post-operation processes are taken into consideration with this simulation model due to the fact that it doesn’t form part of the operating theatre and information regarding this is not collected.

The boundaries of the simulation model are subsequently restricted to the flow of patients through the operating theatre.

4.3 Operating and Functional Specifications and Assumptions

4.3.1 Source

When the simulation starts, it can be assumed that the system is empty. Flow items (patients) are then developed at the source upon arrival. Patients will move through the system and exit when they reach the end of the system. As soon as the last patient exits, the simulation will stop.

As soon as patients are developed and enter the system, certain attributes are assigned to them. According to the attributes that are assigned to patients, they will enter the system and follow different paths through the system.

For simulation model 1-3, elective patients arrive according to a pre-defined arrival schedule roughly 30 minutes prior to their scheduled surgery. Therefore, it can be assumed that all elective patients have an average waiting time of 30 minutes before they receive their scheduled surgery. No other waiting times are taken into consideration because their arrival time at the hospital is not captured in the theatre's information system. The theatre only captures the time the surgery starts and is completed, and patients are then billed according to this exact time.

For simulation model 1, the pre-defined arrival schedule is determined from historical data provided by the hospital. The reason for using the historical data for simulation model 1 to simulate the flexibility policy is that it enables the researcher to develop a simulation model that accurately depicts the real-life scenario. This model can be verified and used as a base case to construct the other simulation models. Non-elective patients also arrive according to a pre-defined arrival schedule.

Using simulation model 1 as base case model, certain assumptions for simulation model 2-3 was made with regard to elective and non-elective patients arriving.

For the purpose of this simulation model it is assumed that:

- All patients arrive for their surgeries, therefore there are no no-shows.
- Patients always arrive on time for surgeries, therefore they are never late.
- Elective and non-elective patients (urgent & emergent) surgeries that take place after the operational time of the operating theatres are not taken into consideration in the simulation model.

The patients entering the system are divided into the following types:

- Elective patients: are patients whose surgeries can be planned and scheduled well in advance.
- Non-elective patients: are patients whose surgeries cannot be planned or scheduled well in advance due to the emergent and unforeseen nature of the surgeries. Here both urgent and emergent patients arriving are taken into consideration.

As shown in Figure 1, elective and non-elective patients are further divided into the following categories:

- Category 1: General surgery
- Category 2: Orthopaedic surgery
- Category 3: Obstetrics and gynaecology
- Category 4: Urology
- Category 5: Ear, nose and throat

4.3.2 Queue

As the patients arrive they entered a queue. The queue they entered corresponded to the specific operating theatre to which they were allocated. Patients stay in the queue until the operating theatre they were allocated to was no longer occupied and operational. It can be assumed that all patients have an average waiting time of 30 minutes before they receive their scheduled surgery.

4.3.3 Processor

With regard to the different simulation models, the operating theatre allocation are as follows to simulate the different policies for the arrival of non-elective patients:

Flexibility policy (Model 1): With a flexibility policy all surgeries, both elective and non-elective, are grouped together, the hospital currently has four operating theatres. The simulation model representing the flexibility policy used all four operating theatres for both elective and non-elective patients.

The hospital makes use of the scheduling method known as block scheduling. Block scheduling means that slots are allocated to a surgeon or surgical group as per availability [13]. When using this method, blocks are allocated to both surgical groups and surgeons and the schedule is repeated weekly. To keep surgeons' details confidential, Figure 1 only indicates the surgical groups and their allocated blocks in the operating theatre schedule.

DAY	THEATRE 1			THEATRE 2			THEATRE 3			THEATRE 4		
TIME	07:00 13:00	13:00 16:00	16:00 19:00	07:00 13:00	13:00 16:00	16:00 19:00	07:00 13:00	13:00 16:00	16:00 19:00	07:00 13:00	13:00 16:00	16:00 19:00
MONDAY	General Surgery			General Surgery			Orthopedic Surgery	Obstetrics and Gynaecology		Orthopedic Surgery		
TUESDAY	Orthopedic Surgery			General Surgery			Obstetrics and Gynaecology	Urology		Orthopedic Surgery		
WEDNESDAY	General Surgery			General Surgery				Orthopedic Surgery		General Surgery		
THURSDAY	Urology			General Surgery				Orthopedic Surgery		Orthopedic Surgery		
FRIDAY	Ear, Nose and Throat			General Surgery			Obstetrics and Gynaecology			Orthopedic Surgery		

Figure 1: Theatre Block Schedule (flexibility policy)

This schedule forms the general guidelines for compiling weekly schedules. Surgeons and surgical groups try to keep to their allocated blocks as far as possible. With this hospital using the flexibility policy, non-elective patients are sent to the first available theatre upon arrival. There are no dedicated theatres for non-elective patients. Therefore, white spaces in the schedule help to accommodate non-elective patients and in many cases surgeons or surgical groups do not always use their blocks or utilise the entire block allocated to them. This is therefore used to accommodate non-elective patients.

All four of the existing theatres are equipped to handle surgeries of category 1 – 5. This is important to take into consideration for the allocation of elective and non-elective patients to operating theatres in the simulation model. If there had been restrictions, it will have to be taken into consideration when building the simulation model to accurately depict the real-life scenario of the operating theatre.

Dedicated policy (Model 2): In this policy the operating theatres are dedicated to serve specific categories of patients. The simulation model representing the dedicated policy dedicated one operating theatre to the arrival of non-elective patients and three operating theatres to elective patients.

In the simulation model operating theatres 1, 3 & 4 is dedicated to elective patients and operating theatre 2 to non-elective patients. It is assumed that for this simulation model the hospital was using the scheduling method known as block scheduling.

The block that was allocated to surgical groups in operating theatre 2 was divided into the white spaces observed in Figure 1. The theatre block schedule used for simulation model 2, simulating the dedicated policy, is shown in Figure 2. By making this assumption and dedicating operating theatre 2 to non-elective patients, it is clear that 21 hours allocated to general surgery is lost.

DAY	THEATRE 1			THEATRE 2			THEATRE 3			THEATRE 4		
TIME	07:00 13:00	13:00 16:00	16:00 19:00	07:00 13:00	13:00 16:00	16:00 19:00	07:00 13:00	13:00 16:00	16:00 19:00	07:00 13:00	13:00 16:00	16:00 19:00
MONDAY	General Surgery						Orthopedic Surgery	Obstetrics and Gynaecology		Orthopedic Surgery		
TUESDAY	Orthopedic Surgery		General Surgery				Obstetrics and Gynaecology	Urology		Orthopedic Surgery		
WEDNESDAY	General Surgery						General Surgery	Orthopedic Surgery		General Surgery		
THURSDAY	Urology						General Surgery	Orthopedic Surgery		Orthopedic Surgery		
FRIDAY	Ear, Nose and Throat	General Surgery					Obstetrics and Gynaecology	General Surgery		Orthopedic Surgery	General Surgery	

Figure 2: Theatre Block Schedule (dedicated policy)

Hybrid policy (Model 3): The hybrid policy is a policy that consists of a combination of characteristics from the flexibility policy and the dedicated policy. Applying the dedicated policy to one of the operating theatres by dedicating 1 operating theatre to elective patients and applying the flexibility policy to the other 3 operating theatres, using them for both elective and non-elective patients.

In the simulation model the flexibility policy was used for operating theatre 1, 3 & 4 therefore used for both elective and non-elective patients. Operating theatre 2 was dedicated to elective patients and to general surgeries only. It is assumed that for this simulation model the hospital used the scheduling method known as block scheduling.

The same allocated blocks in the operating theatre schedule used for the flexibility policy were used here. Refer to Figure 1. The only difference is that no non-elective patients were sent to operating theatre 2.

4.4 Data Required for the Simulation Model

The data used to build this simulation model had been directly retrieved from the hospital's information centre. The hospital information centre is used to capture all the patients' information. Due to the fact that patients' information is kept confidential, the researcher was not able to access the information themselves. The HOD accessed the data and data for the month of July (1 July – 31 July) was provided. The researcher was provided the following information on the theatre schedule:

- Physician specialities and surgical groups
- Theatre used
- Starting time of the operation
- Finishing time of the operation

- Elective or non-elective surgery

After the data was received and compiled the simulation model was built. It is important to note that daily datasets where inserted into the simulation package and the results where then verified in order to determine whether this simulation model will be able to process the data and deliver accurate results. The simulation model adds value by providing a visual representation of the process and the results that can be understood on different levels of employment within a hospital.

4.5 Dynamic and Static Elements within the Simulation Model

Flow items are the dynamic elements that are developed at the source of a static element within the simulation model. They also move through different fixed resources and are finally terminated at the static element, known as the sink within the simulation model. The different elements that are used in the simulation are as follow:

Table 1: Dynamic and static elements within the simulation model

Simulation entities	Purpose of element within the simulation model	Static / dynamic
Flow Items	Patients (Elective & Non-elective)	Static Element
Source	Where flow items (patients) are developed upon arrival	Dynamic Element
Queue	The queue is where flow items (patients) will wait to be processed by the processor (operating theatre)	Dynamic Element
Processor	The processor is the operating theatre where flow items (patients) will be processed	Dynamic Element
Sink	The sink is where the flow items (patients) are terminated	Dynamic Element

Flow items in the simulation model have different characteristics to represent the different types of elective and non-elective patients entering the operating theatres.

4.6 Performance Measures

The following performance measure are relevant for comparing the results of the different simulation models, representing the different theatre allocation policies for non-elective patients, to the theoretical calculated utilisation:

- Daily Utilisation: In the context of this study, utilisation measures the time that an operating theatre is used against the time that the operating theatre is indicated available. The theoretical daily utilisation is calculated in Excel from the data in Appendix F.
- Cumulative Utilisation: In the context of this study, cumulative utilisation measures the time that an operating theatre is used against the time that the operating theatre is indicated available throughout the duration of the time taking into consideration adding each day as a new addition.

4.7 Runtime Parameter

The simulation model simulated the operational time of the theatre for a period of one month. The operational time of the theatre is 7AM until 7PM. Any surgeries scheduled after this time was assumed to be overtime and non-elective surgeries. The simulation model did not include overtime due to the complexity of overtime costing. This was done to determine the utilisation for the different allocation policies for non-elective patients during the operational time of the operating theatre only. Surgeries scheduled over weekends were also not taken into consideration as it is also seen as overtime. The time unit used for the simulation model is set to minutes, so it is important to note that the performance measures indicated in the simulation model are also represented in minutes.

5 RESULTS

5.1 Flexibility Policy

The research results, daily and cumulative utilisation obtained from simulation model 1 for operating theatre 1 by means of the flexibility policy simulation modelling as shown in Figure 3. Note that the y-axis is given as a percentage of total utilisation therefore cumulative results can decrease over time.

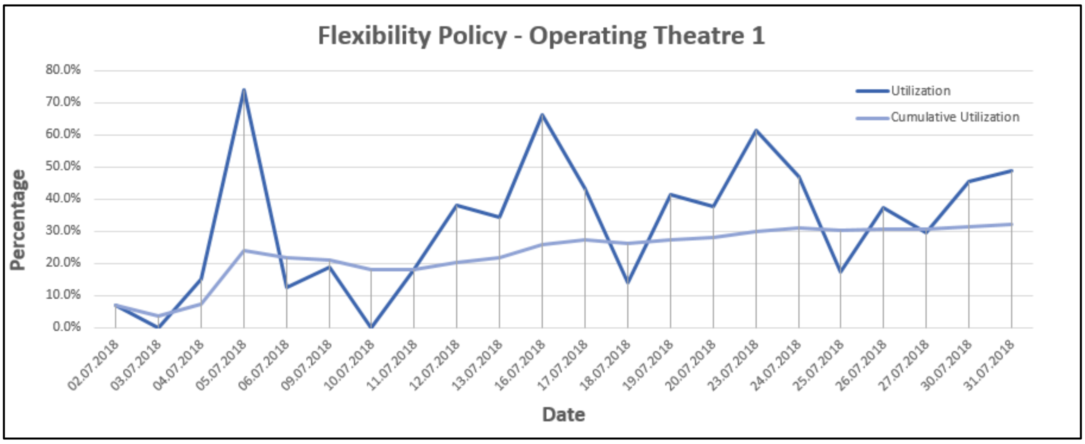


Figure 3: Flexibility policy - Daily and Cumulative Utilisation (Operating Theatre 1)

The figure clearly indicates that operating theatre 1 was not used on 03.07.2018 and 10.07.2018, therefore the utilisations for those days are 0%.On the 05.07.2018, operating theatre 1 was utilised 74%. According to the operating theatre schedule for that day the schedule is full, why then is the utilisation for the day not 100%? This is due to the fact that out of the 12 hours the operating theatre was operational, only 9 hours and 21 minutes was used on surgeries, the remaining 3 hours and 8 minutes are not utilised due to change overs between surgeries.

The daily and cumulative utilisation for operating theatre 2, simulating the flexibility policy is shown in Figure 4. The average daily utilisation for operating theatre 2 is 39.5%, with 0% as the lowest utilisation and 88.3% the highest utilisation for the month.

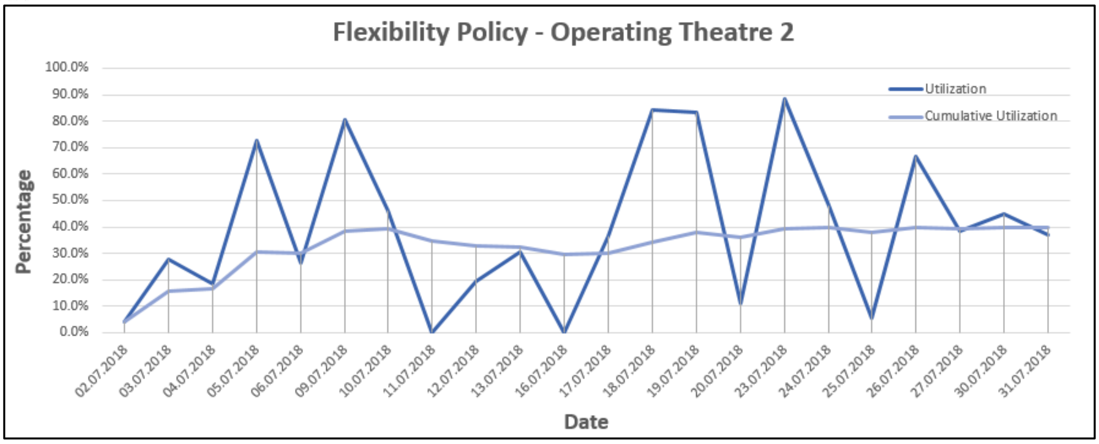


Figure 4: Flexibility policy - Daily and Cumulative Utilisation (Operating Theatre 2)

The daily and cumulative utilisation for operating theatre 3, simulating the flexibility policy is shown in Figure 5. On the 27.07.2018, operating theatre 3 was utilised 89%. Out of the 12 hours the operating theatre was operational, 11 hours and 27 minutes was used on surgeries and the remaining hour and 19 minutes are not utilised. The last surgery scheduled for that day did not finish within the operational time of the operating theatre and finished 20 minutes later causing overtime.

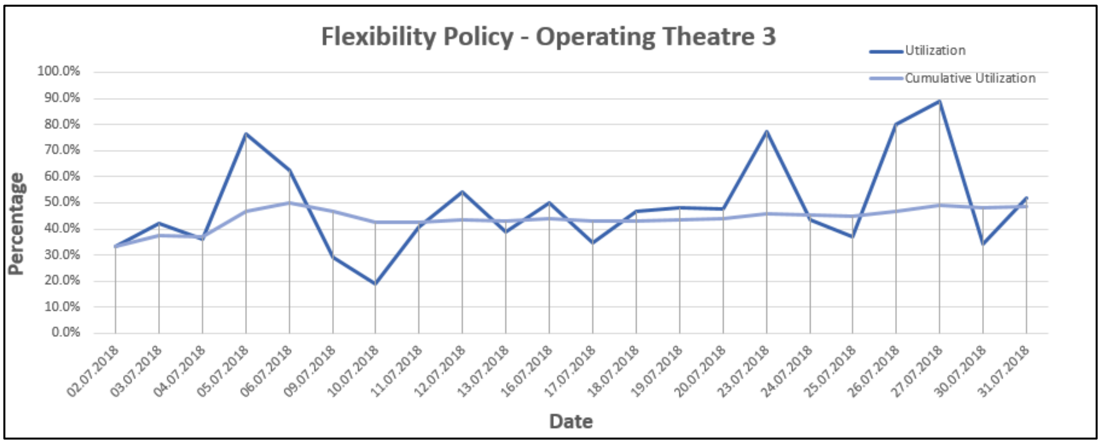


Figure 5: Flexibility policy - Daily and Cumulative Utilisation (Operating Theatre 3)

The daily and cumulative utilisation for operating theatre 4, simulating the flexibility policy is shown in Figure 6. The average daily utilisation for operating theatre 4 is 39.9%, with 0% as the lowest

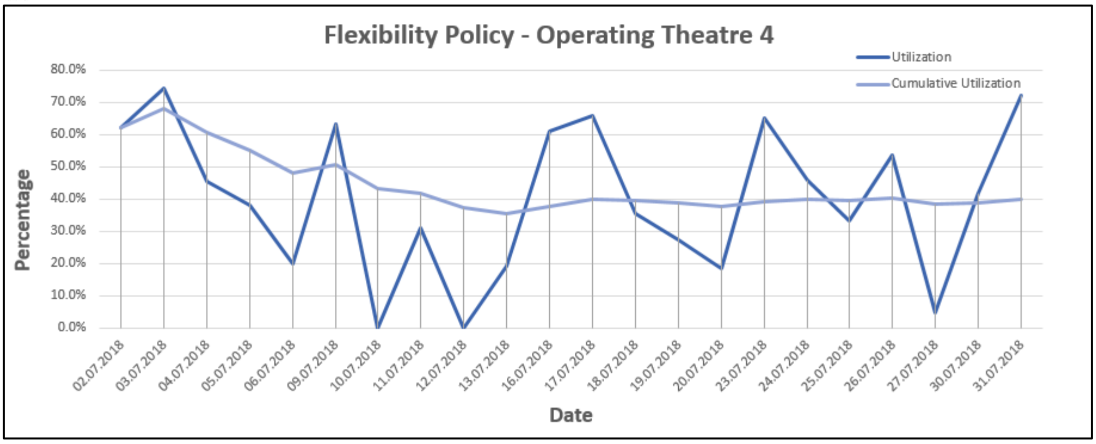


Figure 6: Flexibility policy - Daily and Cumulative Utilisation (Operating Theatre 4)

In addition to the above, Table 2 provides an overview of the operating theatre utilisation of the flexibility policy as currently implemented.

Table 2: Overview of Operating Theatre Utilisation - Flexibility Policy

Operating Theatre	Surgical Category	Day of the Week	Hours Allocated per Week	Hours Allocated per Month	Utilised [%]			Not Utilised [%]
					Allocated Surgical Group [Elective Patients]	[Non-Elective Patients]	Other Surgical Group [Elective Patients]	
1	1	Monday	12	60	29%	11%	-	60%
1	2	Tuesday	9	45	37%	-	-	37%
1	1	Wednesday	6	24	14%	8%	-	8%
1	4	Thursday	12	48	40%	5%	10%	45%
1	5	Friday	6	24	12%	25%	-	63%
2	1	Monday	12	60	42%	1%	-	57%
2	1	Tuesday	12	60	27%	12%	-	61%
2	1	Wednesday	12	48	27%	-	-	73%
2	1	Thursday	12	48	56%	4%	-	40%
2	1	Friday	12	48	10%	4%	-	73%
3	2	Monday	12	60	42%	3%	-	55%
3	2	Tuesday	12	60	25%	7%	6%	62%
3	2	Wednesday	6	24	74%	5%	-	21%
3	2	Thursday	12	48	62%	3%	-	35%
3	2	Friday	6	24	27%	20%	-	53%
4	2	Monday	6	30	50%	-	-	50%
	3		6	30	66%	-	-	34%
4	3	Tuesday	6	30	68%	-	-	32%
	4		6	30	13%	7%	15%	65%
4	1	Wednesday	12	48	14%	22%	-	64%
4	2	Thursday	6	24	29%	19%	-	52%
4	3	Friday	6	24	24%	7%	-	69%

5.2 Dedicated Policy

The research results, daily and cumulative utilisation for operating theatre 1, simulation model 2, simulating the dedicated policy is shown in Figure 7. The average daily utilisation for operating theatre 1 is 37.3%, with 0% as the lowest utilisation and 100% the highest utilisation for the month. In comparison with the average daily utilisation for operating theatre 1 for the flexibility policy that is 32.2%, with 0% as the lowest utilisation and 73.9% the highest utilisation for the month it can be seen that there is an increase in the average utilisation by 5.1%.

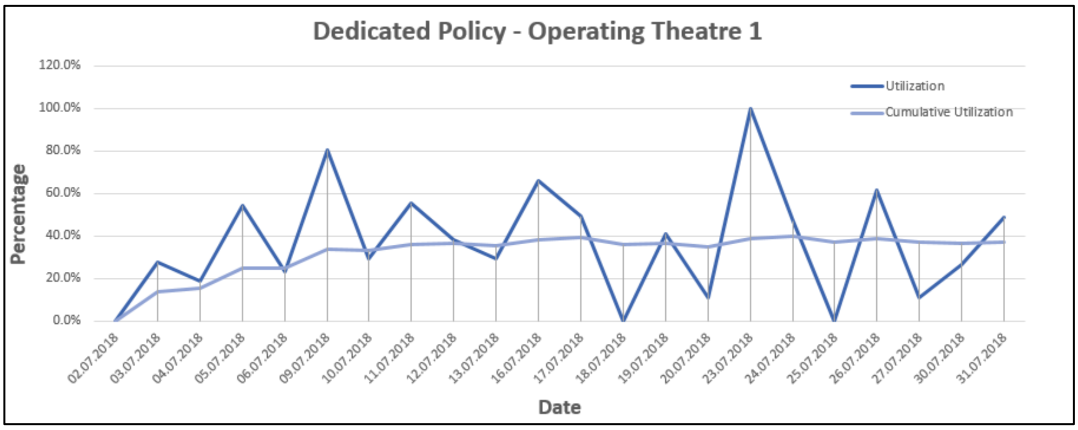


Figure 7: Dedicated policy - Daily and Cumulative Utilisation (Operating Theatre 1)

The daily and cumulative utilisation for operating theatre 2, simulating the dedicated policy is shown in Figure 8. The average daily utilisation for operating theatre 2 is 32.8%, with 4.3% as the lowest utilisation and 87.8% the highest utilisation for the month. In comparison with the average daily utilisation for operating theatre 2 for the flexibility policy that is 39.5%, with 0% as the lowest utilisation and 88.3% the highest utilisation for the month it can be seen that there is a decrease in the average utilisation by 6.7%.

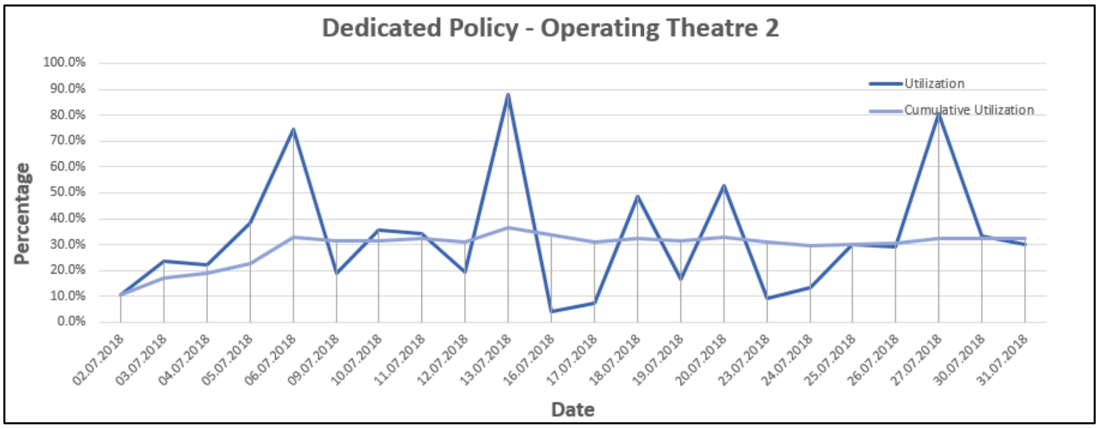


Figure 8: Dedicated policy - Daily and Cumulative Utilisation (Operating Theatre 2)

The daily and cumulative utilisation for operating theatre 3, simulating the dedicated policy is shown in Figure 9. The average daily utilisation for operating theatre 3 is 44.8%, with 0% as the lowest utilisation and 84.4% the highest utilisation for the month. In comparison with the average daily utilisation for operating theatre 3 for the flexibility policy that is 49.5%, with 29% as the lowest utilisation and 89% the highest utilisation for the month it can be seen that there is a decrease in the average utilisation by 4.7%.

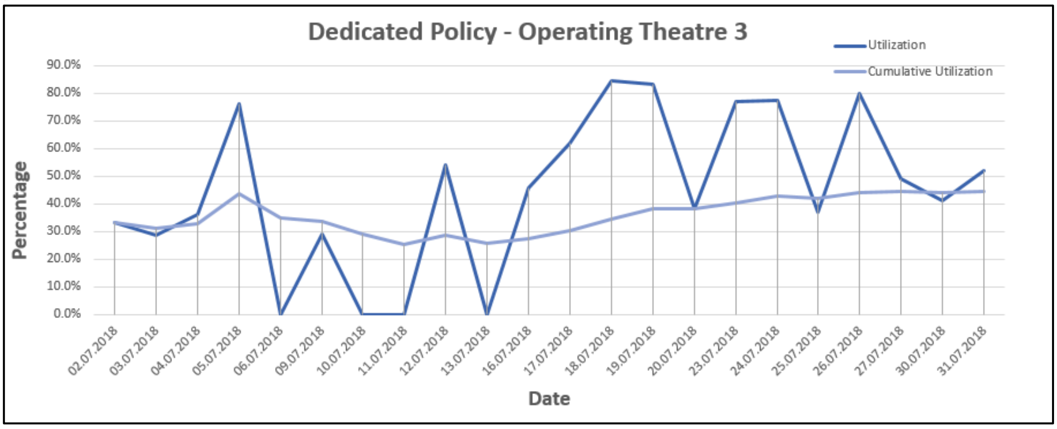


Figure 9: Dedicated policy - Daily and Cumulative Utilisation (Operating Theatre 3)

The daily and cumulative utilisation for operating theatre 4, simulating the dedicated policy is shown in Figure 10.

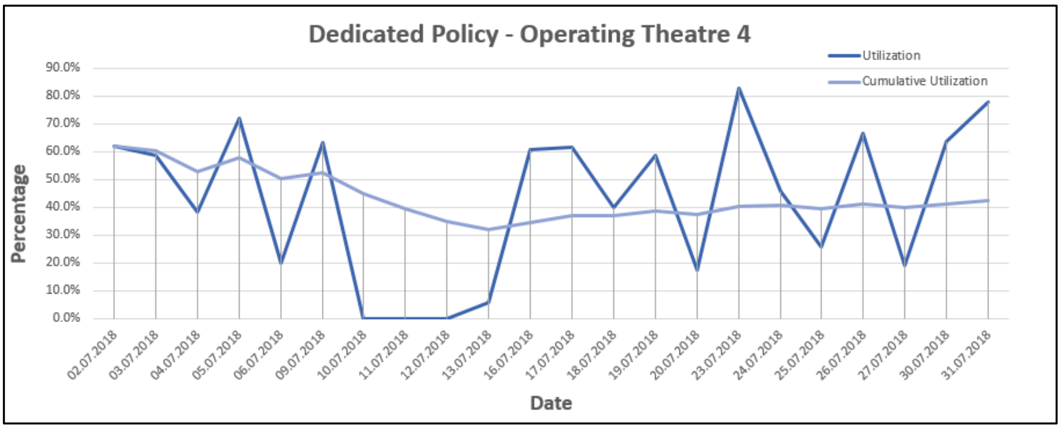


Figure 10: Dedicated policy - Daily and Cumulative Utilisation (Operating Theatre 4)

The average daily utilisation for operating theatre 4 is 42.8%, with 0% as the lowest utilisation and 83% the highest utilisation for the month. In comparison with the average daily utilisation for operating theatre 4 for the flexibility policy that is 39.9%, with 0% as the lowest utilisation and 74.3% the highest utilisation for the month it can be seen that there is an increase in the average utilisation by 2.9%.

5.3 Hybrid Policy

The research results, daily and cumulative utilisation for operating theatre 1, simulation model 3, simulating the hybrid policy. Here both the daily and cumulative utilisation for the month of July (2 July – 31 July) are presented.

The daily and cumulative utilisation for operating theatre 1, simulating the hybrid policy is shown in Figure 11. The average daily utilisation for operating theatre 1 is 33.1%, with 0% as the lowest utilisation and 73.9% the highest utilisation for the month. In comparison with the average daily utilisation for operating theatre 1 for the flexibility policy that is 32.2%, with 0% as the lowest utilisation and 73.9% the highest utilisation for the month it can be seen that there is an increase in the average utilisation by 0.9%. In comparison with the average daily utilisation for operating theatre 1 for the dedicated policy that is 37.3%, with 0% as the lowest utilisation and 100% the highest utilisation for the month it can be seen that there is a decrease in the average utilisation by 4.2%.

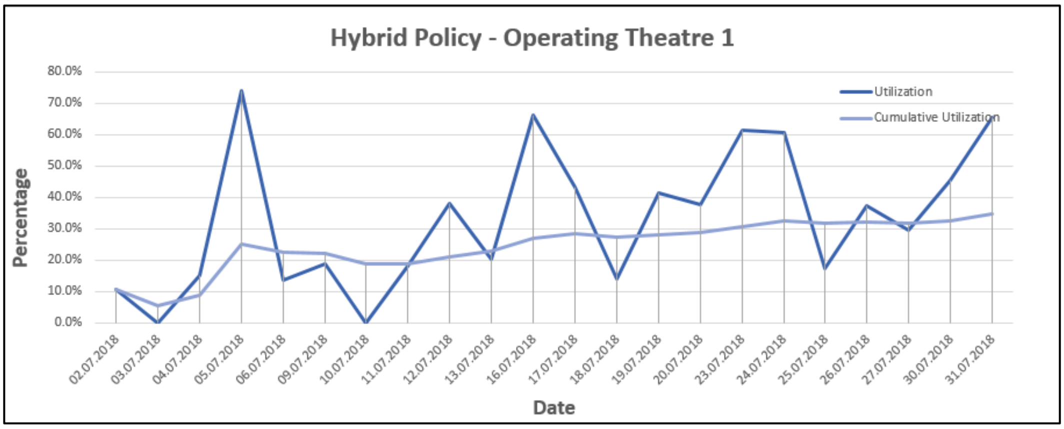


Figure 11: Hybrid policy - Daily and Cumulative Utilisation (Operating Theatre 1)

The daily and cumulative utilisation for operating theatre 2, simulating the hybrid policy is shown in Figure 12. The average daily utilisation for operating theatre 2 is 33.9%, with 0% as the lowest utilisation and 88.3% the highest utilisation for the month. In comparison with the average daily utilisation for operating theatre 2 for the flexibility policy that is 39.5%, with 0% as the lowest utilisation and 88.3% the highest utilisation for the month it can be seen that there is a decrease in the average utilisation by 5.6%. In comparison with the average daily utilisation for operating theatre 2 for the dedicated policy that is 32.8%, with 4.3% as the lowest utilisation and 87.8% the highest utilisation for the month it can be seen that there is an increase in the average utilisation by 1.1%.

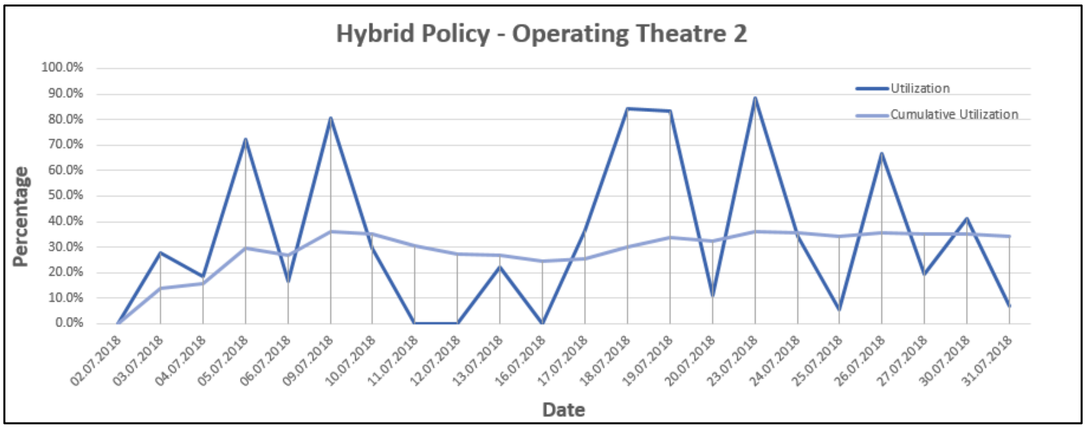


Figure 12: Hybrid policy - Daily and Cumulative Utilisation (Operating Theatre 2)

The daily and cumulative utilisation for operating theatre 3, simulating the hybrid policy is shown in Figure 13. The average daily utilisation for operating theatre 3 is 50.7%, with 33.3% as the lowest utilisation and 89% the highest utilisation for the month. In comparison with the average daily utilisation for operating theatre 3 for the flexibility policy that is 49.5%, with 29% as the lowest utilisation and 89% the highest utilisation for the month it can be seen that there is an increase in the average utilisation by 1.2%. In comparison with the average daily utilisation for operating theatre 3 for the dedicated policy that is 44.8%, with 0% as the lowest utilisation and 84.4% the highest utilisation for the month it can be seen that there is an increase in the average utilisation by 5.9%.

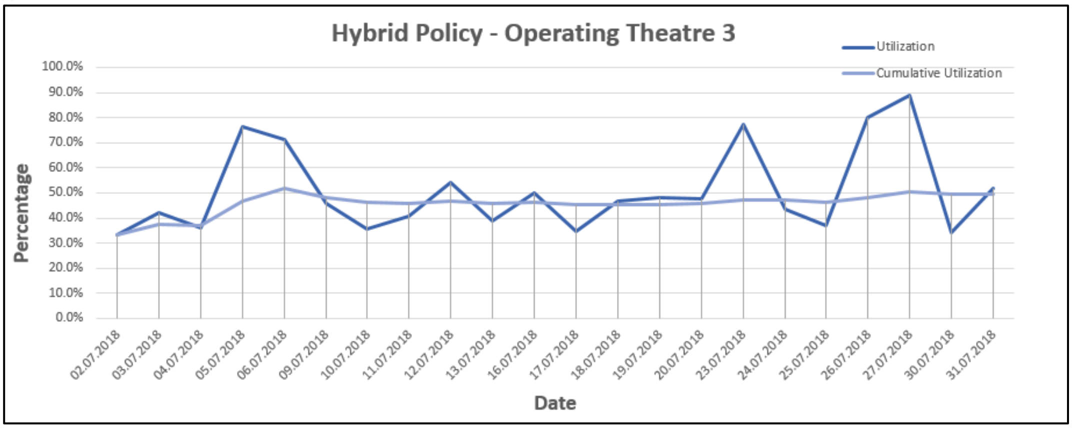


Figure 13: Hybrid policy - Daily and Cumulative Utilisation (Operating Theatre 3)

The daily and cumulative utilisation for operating theatre 4, simulating the hybrid policy is shown in Figure 14. The average daily utilisation for operating theatre 4 is 41.4%, with 0% as the lowest utilisation and 72.1% the highest utilisation for the month. In comparison with the average daily utilisation for operating theatre 4 for the flexibility policy that is 39.9%, with 0% as the lowest utilisation and 74.3% the highest utilisation for the month it can be seen that there is an increase in the average utilisation by 1.5%. In comparison with the average daily utilisation for operating theatre 4 for the dedicated policy that is 42.8%, with 0% as the lowest utilisation and 83.1% the highest utilisation for the month it can be seen that there is a decrease in the average utilisation by 1.4%.

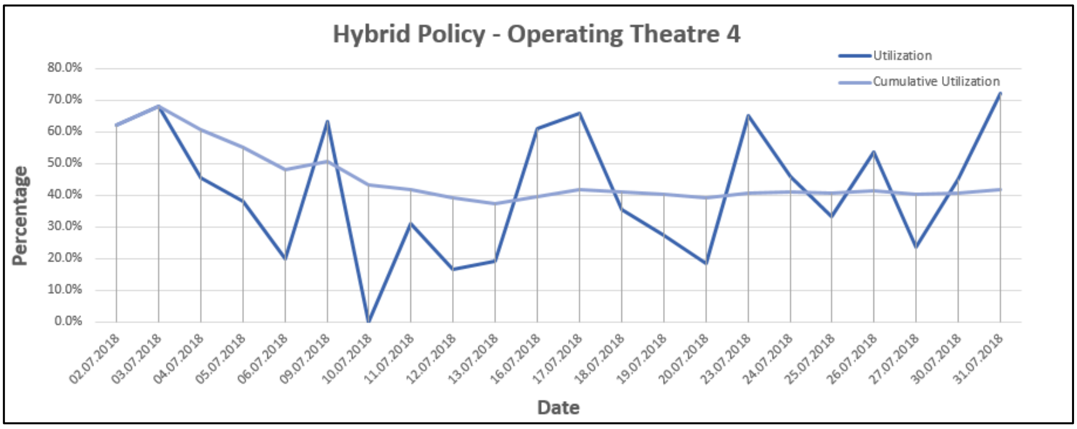


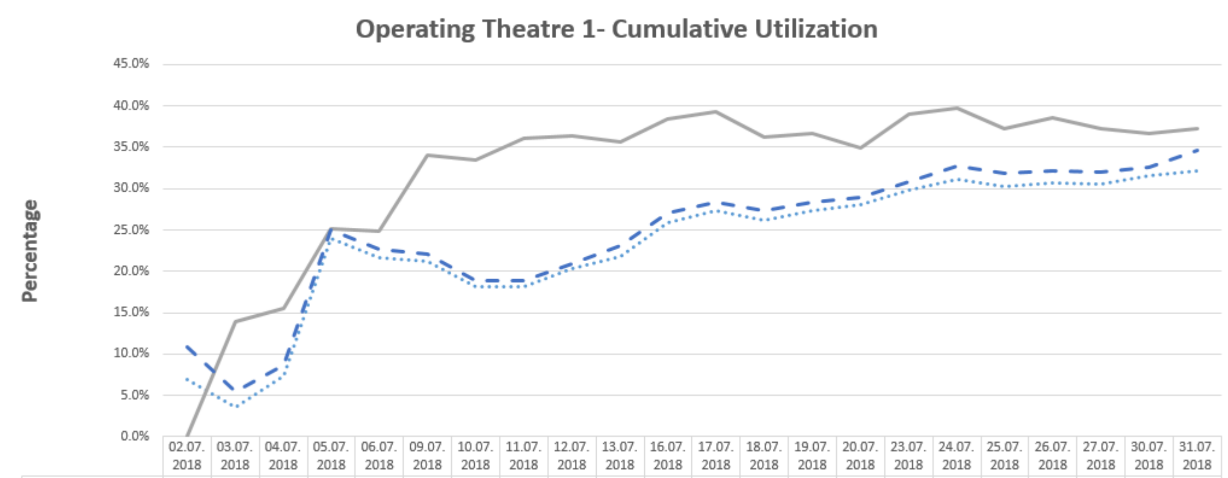
Figure 14: Hybrid policy - Daily and Cumulative Utilisation (Operating Theatre 4)

5.4 Results Comparison

The cumulative utilisation results obtained from model 2, simulating the dedicated policy clearly indicates that by dedicating operating theatre to non-elective patient only causes the cumulative utilisation of operating theatre to go down with 7.1% resulting in a cumulative utilisation of 32.6% in comparison with the 39.7% obtained by the flexibility policy. It can also be observed that by dedicating operating theatre 2 to non-elective patients only and moving all other surgeries that was scheduled in operating theatre 2 for elective patients to operating theatre 1, 3 and 4 caused an increase in the cumulative utilisation of those theatres. Even though the cumulative utilisation increased for operating theatre 1 and 4, it is important to keep in mind the delays and overtime caused for surgeries when the dedicated policy was implemented.

The cumulative utilisation results obtained from model 3, simulating the hybrid policy clearly indicates that by dedicating operating theatre to elective patient and to general surgeries only causes the cumulative utilisation of operating theatre to go down with 5.7% resulting in a cumulative utilisation of 34.0% in comparison with the 39.7% obtained by the flexibility policy. It can also be observed that by dedicating operating theatre 2 to elective patients and general surgeries only and moving all other surgeries that was scheduled in operating theatre 2 for elective and non-elective patients to operating theatre 1, 3 and 4 caused an increase in the cumulative utilisation of those theatres. Even though the cumulative utilisation increased for operating theatre 1, 3 and 4, it is important to keep in mind the delays and overtime caused for surgeries.

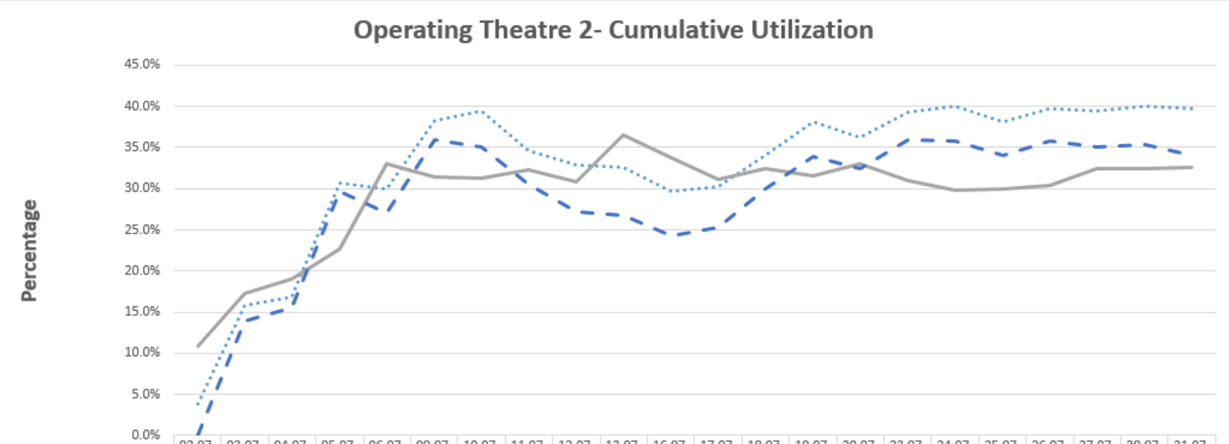
The cumulative utilisation of the flexibility policy, dedicated policy and the hybrid policy for operating theatre 1, is shown in Figure 15.



	02.07. 2018	03.07. 2018	04.07. 2018	05.07. 2018	06.07. 2018	09.07. 2018	10.07. 2018	11.07. 2018	12.07. 2018	13.07. 2018	16.07. 2018	17.07. 2018	18.07. 2018	19.07. 2018	20.07. 2018	23.07. 2018	24.07. 2018	25.07. 2018	26.07. 2018	27.07. 2018	30.07. 2018	31.07. 2018
Flexibility Policy	6.9%	3.5%	7.4%	24.0%	21.7%	21.2%	18.2%	18.2%	20.4%	21.8%	25.9%	27.3%	26.2%	27.3%	28.0%	29.8%	31.1%	30.3%	30.7%	30.6%	31.5%	32.1%
Dedicated Policy	0.0%	13.9%	15.5%	25.2%	24.8%	34.1%	33.4%	36.1%	36.4%	35.7%	38.4%	39.3%	36.3%	36.7%	34.9%	39.0%	39.7%	37.3%	38.6%	37.2%	36.7%	37.2%
Hybrid Policy	10.8%	5.4%	8.7%	25.0%	22.7%	22.1%	18.9%	18.8%	20.9%	23.1%	27.0%	28.4%	27.3%	28.3%	28.9%	30.9%	32.7%	31.8%	32.1%	32.0%	32.6%	34.7%

Figure 15: Cumulative Utilisation - Flexibility Policy, Dedicated Policy and Hybrid Policy (Operating Theatre 1)

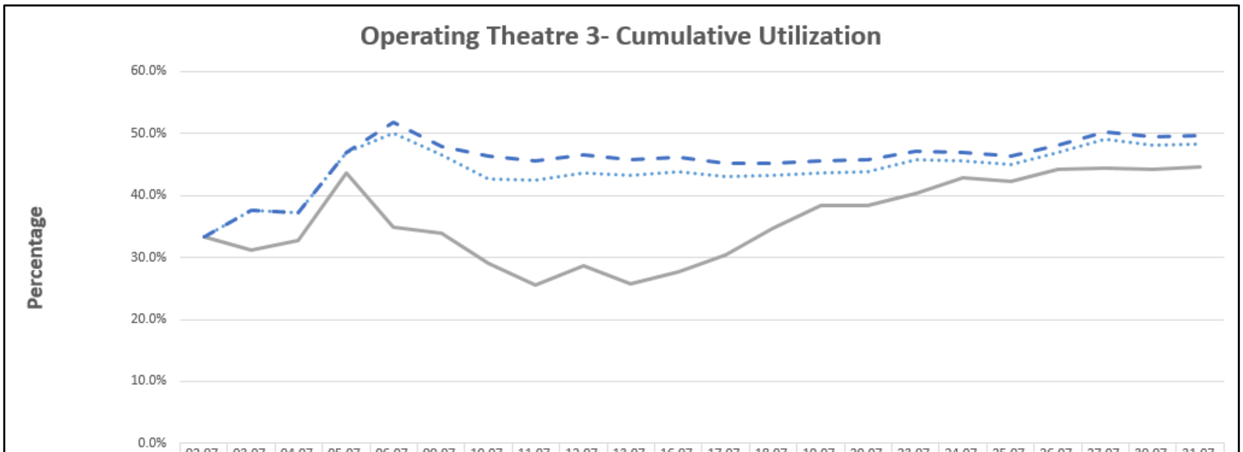
The cumulative utilisation of the flexibility policy, dedicated policy and the hybrid policy for operating theatre 2, is shown in Figure 16.



	02.07.2018	03.07.2018	04.07.2018	05.07.2018	06.07.2018	09.07.2018	10.07.2018	11.07.2018	12.07.2018	13.07.2018	16.07.2018	17.07.2018	18.07.2018	19.07.2018	20.07.2018	23.07.2018	24.07.2018	25.07.2018	26.07.2018	27.07.2018	30.07.2018	31.07.2018
Flexibility Policy	3.9%	15.8%	16.8%	30.7%	29.9%	38.3%	39.5%	34.6%	32.9%	32.6%	29.7%	30.2%	34.0%	38.1%	36.3%	39.3%	40.0%	38.1%	39.7%	39.5%	40.0%	39.7%
Dedicated Policy	10.8%	17.3%	19.0%	22.6%	33.0%	31.4%	31.3%	32.3%	30.9%	36.6%	33.7%	31.2%	32.4%	31.6%	33.0%	31.0%	29.8%	30.0%	30.4%	32.5%	32.5%	32.6%
Hybrid Policy	0.0%	13.9%	15.5%	29.6%	27.0%	35.9%	35.0%	30.6%	27.2%	26.7%	24.3%	25.3%	29.9%	33.9%	32.4%	35.9%	35.8%	34.1%	35.8%	35.0%	35.3%	34.0%

Figure 16: Cumulative Utilisation - Flexibility Policy, Dedicated Policy and Hybrid Policy (Operating Theatre 2)

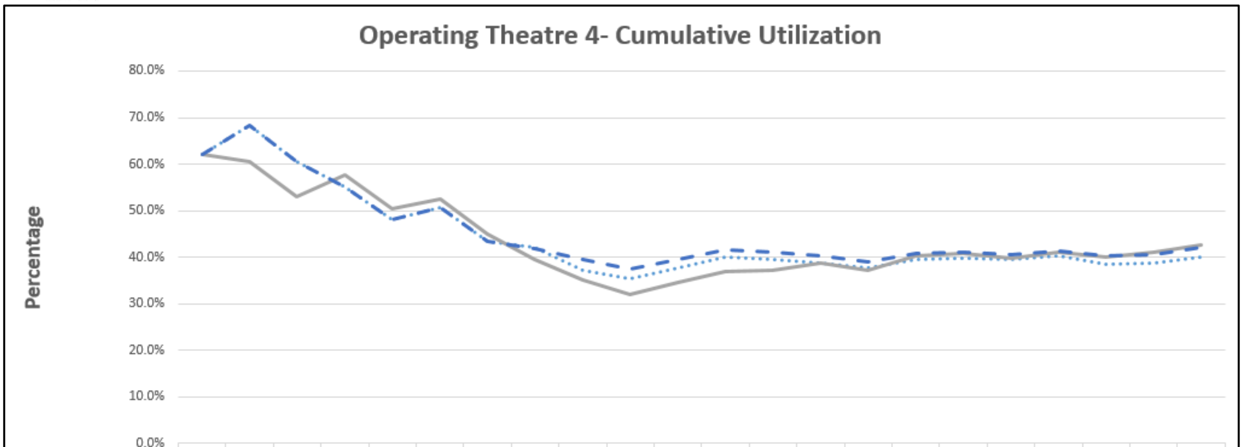
The cumulative utilisation of the flexibility policy, dedicated policy and the hybrid policy for operating theatre 3, is shown in Figure 17.



	02.07.2018	03.07.2018	04.07.2018	05.07.2018	06.07.2018	09.07.2018	10.07.2018	11.07.2018	12.07.2018	13.07.2018	16.07.2018	17.07.2018	18.07.2018	19.07.2018	20.07.2018	23.07.2018	24.07.2018	25.07.2018	26.07.2018	27.07.2018	30.07.2018	31.07.2018
Flexibility Policy	33.3%	37.7%	37.2%	46.9%	50.1%	46.6%	42.6%	42.5%	43.7%	43.2%	43.9%	43.1%	43.2%	43.7%	43.9%	45.8%	45.5%	45.0%	46.9%	49.0%	48.1%	48.4%
Dedicated Policy	33.3%	31.1%	32.8%	43.6%	34.9%	33.9%	29.1%	25.5%	28.7%	25.8%	27.6%	30.5%	34.6%	38.3%	38.3%	40.3%	42.8%	42.2%	44.2%	44.5%	44.3%	44.7%
Hybrid Policy	33.3%	37.7%	37.2%	46.9%	51.8%	48.0%	46.3%	45.6%	46.5%	45.8%	46.1%	45.2%	45.3%	45.5%	45.7%	47.2%	47.0%	46.4%	48.2%	50.3%	49.5%	49.6%

Figure 17: Cumulative Utilisation - Flexibility Policy, Dedicated Policy and Hybrid Policy (Operating Theatre 3)

The cumulative utilisation of the flexibility policy, dedicated policy and the hybrid policy for operating theatre 4, is shown in Figure 18



	02.07. 2018	03.07. 2018	04.07. 2018	05.07. 2018	06.07. 2018	09.07. 2018	10.07. 2018	11.07. 2018	12.07. 2018	13.07. 2018	16.07. 2018	17.07. 2018	18.07. 2018	19.07. 2018	20.07. 2018	23.07. 2018	24.07. 2018	25.07. 2018	26.07. 2018	27.07. 2018	30.07. 2018	31.07. 2018
Flexibility Policy	62.2%	68.3%	60.6%	55.1%	48.1%	50.6%	43.4%	42.0%	37.2%	35.4%	37.8%	40.1%	39.5%	38.8%	37.8%	39.4%	39.9%	39.5%	40.3%	38.5%	38.7%	40.1%
Dedicated Policy	62.2%	60.6%	53.1%	57.8%	50.3%	52.5%	45.0%	39.4%	35.0%	32.1%	34.7%	36.9%	37.2%	38.7%	37.3%	40.2%	40.8%	39.7%	41.1%	40.0%	41.2%	42.5%
Hybrid Policy	62.2%	68.3%	60.6%	55.1%	48.1%	50.6%	43.4%	41.9%	39.4%	37.4%	39.5%	41.7%	41.2%	40.2%	39.1%	40.7%	41.0%	40.6%	41.3%	40.4%	40.6%	42.0%

Figure 18: Cumulative Utilisation - Flexibility Policy, Dedicated Policy and Hybrid Policy (Operating Theatre 4)

With hospital cost increasing very rapidly very important strategic decisions needs to be made with regard to the allocation of operating theatres to ensure they are efficiently utilised. By using the flexibility policy it helps to ensure that theatres are utilised by both elective and non-elective patients, not causing a specific operating theatre to be fully dependant on the arrival of non-elective patients like in the case of the dedicating policy where one operating theatre is dedicated to non-elective surgeries only. However, with the flexibility policy it may happen that there can be a delay in starting with a non-elective surgery that arrived due to the fact that the non-elective surgery will have to wait for the first available operating theatre for there are not a specific operating theatre dedicated to non-elective surgeries in this case. When using the dedicated policy it will help to reduce the uncertainty and chances of a delay in the theatre schedule for elective patients due to the fact that they will not be interrupted by non-elective surgeries for non-elective surgeries in this case has its own dedicated operating theatre, By looking at the results obtained by this study it is clear that when one move from the flexibility policy to the dedicated policy the waiting time for patients both elective and non-elective increases in terms of the delay caused in surgeries but the uncertainty in operating theatre schedules decreases, With the results in mind it is recommend that the hospital consider implementing the hybrid policy. By implementing this policy a combination of the flexibility and dedicated policy can be used to help ensure a balance between scheduling elective patients, responding to the arrival of non-elective patients and to contribute towards the utilisation of the operating theatres.

6 CONCLUSION

The problem that was addressed in this study was that the unforeseen nature of non-elective patient arriving causes a thoroughly planned schedule to change having an influence on high efficiency rates, good utilisation and minimized waiting time between surgeries. Therefore, the purpose of this study was to determine which non-elective patient allocation policy will best suit this private hospital ensuring a balance between scheduling elective patients, responding to the arrival of non-elective patients and to contribute towards the utilisation of the operating theatres.

The following objectives were to be followed to achieve the purpose of this study: investigating the current non-elective patient allocation policy used in this private hospital, explore and extract the standards, rules and regulations that should be taken into consideration when designing a theatre schedule and finally selecting a non-elective patient allocation policy to ensure the highest scheduling efficiency, resource utilisation and minimized waiting time between surgeries.

A simulation model was developed based on the flexibility policy to investigate the current non-elective patient allocation policy used by the private hospital. The cumulative utilisation for the month of July (2 July – 31 July) was determined since this was the data collected. After the model was verified by comparing the simulation results and the theoretical calculated utilisation and verifying the patient's pathway thru the simulation it was used as decision model to evaluate different policies such as the dedicated and hybrid policy, testing various scenarios and their effect on the key performance indicators. Three simulation models in total was developed. Building this models, the important standards, rules and regulations related to operating theatres has to be taken into consideration. By simulating the different policies, it enabled the researcher, to make a recommendation of which theatre allocation policy for non-elective patients arriving in a private hospital would be best suited for this hospital. The simulation model was setup in such a way that new data for different scenarios can be copied into the model and with minor changes you will be able to obtain results.

The cumulative utilisation results obtained for the dedicated policy clearly indicates that for the month of July (2 July – 31 July) by dedicating an operating theatre to non-elective patients it would have caused the cumulative utilisation of that specific operating theatre to go down with 7.1% whereas implementing the hybrid policy the cumulative utilisation only went down with 5.7% with an increase in the cumulative utilisation of the other operating theatres. The flexibility policy may cause a delay for non-elective surgeries to start because they have to wait for the first available operating theatre. Whereas using the dedicated policy it will help to reduce the uncertainty and chances of a delay in the theatre schedule for elective patients due to the fact that they will not be interrupted by non-elective surgeries for non-elective surgeries in this case has its own dedicated operating theatre.

Thus, in conclusion, based on the results obtained in this study, it is recommended that the hospital should consider implementing the hybrid policy for it will help to ensure a balance between scheduling elective patients, responding to the arrival of non-elective patients and to contribute towards the utilisation of the operating theatres.

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A CONTROL PROCESSES TO SUSTAIN ELECTRICITY COST SAVINGS ON A MINE WATER RETICULATION SYSTEM IN SPITE OF CRITICAL COMPONENT FAILURES

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ABSTRACT

Equipment failure is common in mining. Failures may create unsafe scenarios and result in optimised control strategies being abandoned. This may lead to loss of savings due to extended repair periods. A technology management process was thus developed to mitigate this problem by using actual data to develop strategies to ensure safe future underground conditions when critical component failures occur. This also provides an alternative process to improve real life scenarios while achieving electricity cost savings. The selected strategy, for a given scenario, will firstly avoid dangerous conditions and, secondly, obtain a portion of the electricity cost savings, which would otherwise be lost due to critical component failures. This process was implemented on a gold mine in South Africa, which led to an annual electricity cost savings of approximately R3.8 million. These savings were possible without incurring dangerous scenarios and without capital expenditure required for implementation.

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1 INTRODUCTION

The South African utility company, Eskom, generates approximately 95 % of the country's electricity [1]. Various studies [2],[3],[4] have found that Eskom cannot generate the required electricity consumption and will likely continue to stuggle to meet consumption needs in future. To help counter this problem, an initiative was introduced to reduce electricity consumption by the end-users within the Eskom evening peak periods, from 18:00 to 20:00 in summer periods and 17:00 to 18:00 in winter periods [5]. This initiative is called Demand Side Management (DSM) [5].

The initial energy savings target set for the DSM initiative was approximately 4.23 GWh, to be obtained within a 20 year period [6]. This target was achieved approximately 10 years earlier in 2014. DSM initiatives were also implemented in the mining industry since this is a high energy-intensive environment. Platinum and gold mines are the focus of most of the DSM initiatives to be implemented [5].

South African gold mines contain up to one-third of the total gold reserves in the world [7]. Due to the vast amounts of gold reserves, these mines are consequently some of the deepest mines reaching depths up to 4 000 m [7]. High underground temperatures are an unavoidable result of these extreme depths and can reach as high as 70 °C [8]. These dangerous underground conditions are a major concern for the safety of mining personnel, but also contribute to critical equipment failures [3]. Consequently, energy-intensive cooling -and ventilation systems are required to lower these severe temperatures [2].

It has been shown that premature critical component failures lead to production loss [9]. When critical component failures occur in the mining industry, process control prioritises safety over efficiency. To ensure safe operating condition, control of the remaining operational equipment will be overridden until the component failure has been mitigated. This is not necessarily necessary since some cases do exist where the control of operating equipment can still be improved even with component failures.

Subsequently, electricity cost savings initiatives are often neglected until the critical failure is rectified. This can lead to a significant decrease in electricity cost savings. An opportunity can therefore be realised to improve the contol of large energy-intensive systems in the mining industry, in the event of critical component failures, through technology management.

Figure 1 shows how energy is distributed in the gold mining industry of South Africa. When combining refrigeration, dewatering and part of the mining operations it totals, to 42 % of the total energy consumption in this industry. This combination is known as the water reticulation system [7].

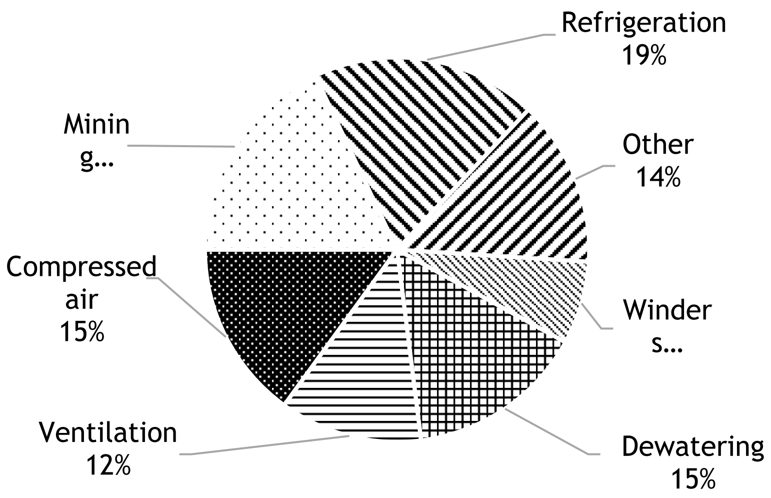

Figure 1: Distribution of energy in the South African gold mining industry [4].

2 WATER RETICULATION SYSTEM

The water reticulation system is traditionally divided into the following subsystems:

- Dewatering,
- precooling towers (PCTs),
- fridge plants, and
- bulk air coolers (BACs).

Each of the water reticulation subsystems are important in the deep-level mining industry. Each subsystem is thus discussed here to convey its function, as well as highlight possible component failures and their consequences.

2.1 Dewatering

Figure 2a shows an example of a dewatering subsystem within a water reticulation system. Water is pumped in a cascading manner to the surface because the dewatering pumps are not able to pump hot water from the bottom level directly to the surface since the height between two dewatering levels can be as high as 1.3 km [10]. Various studies have thus been undertaken on mine dewatering subsystems to improve control [4],[11],[12].

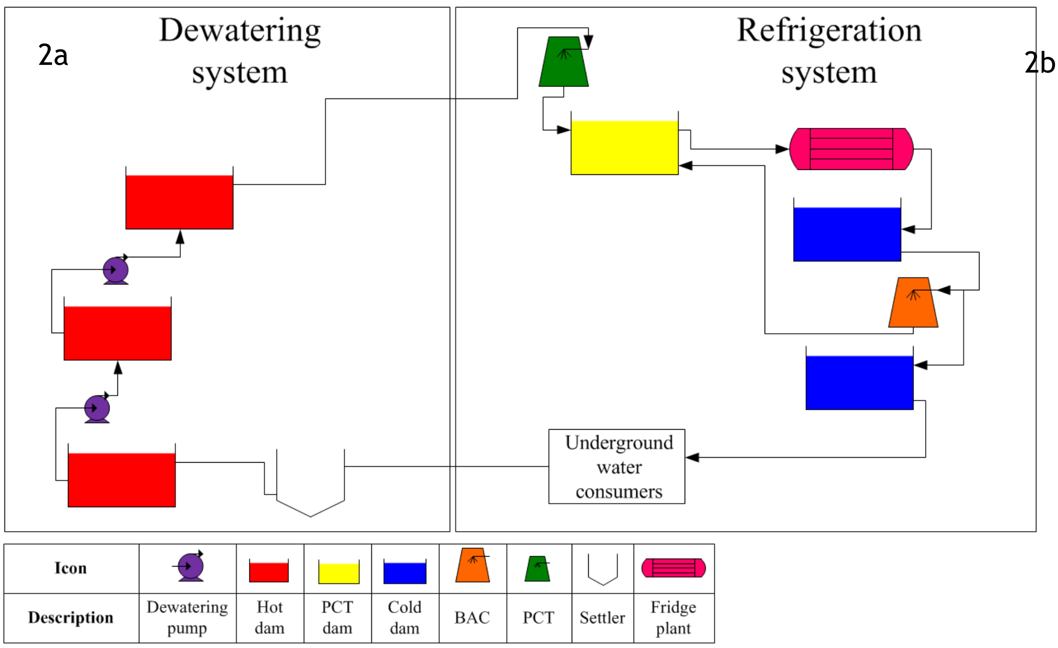

Figure 2: Simplified water reticulation layout (adapted from [11]).

The DSM initiatives will draw focus to improvements in control, which entails shifting the load from Eskom peak periods, which are expensive tariff periods, to Eskom off-peak periods [12]-[15]. Other studies/initiatives were implemented where unneccesary water usage was limited [16]-[19]. This is also beneficial to the dewatering subsystem since a reduced amount of hot water needs to be pumped to the surface.

These studies showed that improvements in the dewatering subsystem can lead to a reduction in electricity costs. However, all the studies shown focussed on improving the control of the system to reduce the electricity consumption while all dewatering pumps are operational. None of these studies considered the effect of malfunctioning components.

When one or more dewatering pumps fail, the potential pumping capacity is reduced. This leads to less water being pumped and can lead to underground dams flooding. This creates dangerous underground scenarios, which should be avoided at all cost. Therefore the most commonly adopted control philosophy in such scenarios necessitates the operation of all working dewatering pumps until the failed pump is fixed. This philosophy prioritises safety, while accepting additional electricity costs.

2.2 Precooling towers

When water is pumped to the surface, it is cooled before re-use. PCTs are used as a cost-effective method to lower the water temperature before it is sent for further cooling. Hot water from underground is usually in the temperature range between 25 °C and 30 °C [1]. These high temperatures are lowered to temperature ranges between 15 °C and 20 °C [20] in the PCTs before re-use. This reduction in temperature is achieved by using nozzles to spray hot water, while fans draw ambient air through the tower [21]. This is the first refrigeration component shown in Figure 2b.

PCTs reduces the temperature of water, which leads to less cooling required by fridge plants. This means that a reduction in elecricity costs is realised when using these towers. Past studies were done to improve the entire water reticulation system, which included the PCTs [22],[23]. These improvements reduces the water usage, which reduced the electricity cost of the water reticulation system. However, all components were operational within these studies, thus no focus was given to scenarios where PCT failures occur.

When a PCT fails the water temperature entering the fridge plants will be higher. This means that an increased amount of energy is required from the fridge plants to cool the water to acceptable temperatures before it can be used. Consequently, the electricity costs will increase. However, no control philosphy is currently in place to try and counter the effect of a failing precooling tower.

2.3 Fridge plants

The next step in the refrigeration system (shown in Figure 2b) is to cool water to acceptable temperatures. Fridge plants are complex components, although the specific working principles are not relevant for this study. The complexity of fridge plants, however, creates opportunities for improvements. A number of DSM-based studies have been conducted to improve the control of the refrigeration system [22],[24]-[26].

However, no studies currently account for failures within the refrigeration system. When a fridge plant fails, other fridge plants recirculate water until the desired water temperatures are obtained. This control philosophy could lead to potentially dangerous scenarios since the operational fridge plants might not necessarily have the capacity to cool the required amounts of water.

2.4 Bulk air coolers

In some cases the ambient air temperatures are too high to be sent underground. In these cases bulk air coolers are used to reduce ambient air temperatures [27]. BACs are the least expensive method of cooling underground air [28] although they do consume large amounts of cold water [27].

When the load on the BACs is reduced, it also reduces the total load of the fridge plants [27] since less cold water is required.

However, currently no studies focus on mitigating the effects of a failing bulk air cooler. When a bulk air cooler fails, less cold air is available for underground usage. This can have a negative effect on underground conditions.

2.5 Component failure process

Based on the identified shortcomings from literature, this study aims to produce a process, based on the water reticulation system, to ensure safe operating conditions in the event of a component failure. This process therefore provides a generic method to develop site-specific strategies, which could ensure safe conditions. These strategies are specifically designed to improve current control in the case of failures without incurring additional capital expenditures. Ultimately, a real alternative is developed to improve current control philosophies in the case of component failures specific to the gold mining industry.

3 FAILURE CONTROL STRATEGY

Alternative control processes are required in the mining industry when failures occur since current methods entail running all operational equipment until the malfunctioning component is fixed. In some cases this is unnecassary since safe operations can still be maintained by improving the control of the remaining operational equipment. The process developed here therefore provides an alternative method compared to current control, and is shown in Figure 3. The figure is split in two, where Figure 3a portrays a once-off process and Figure 3b a continouos process. Each indicated step will be discussed in Table 1.

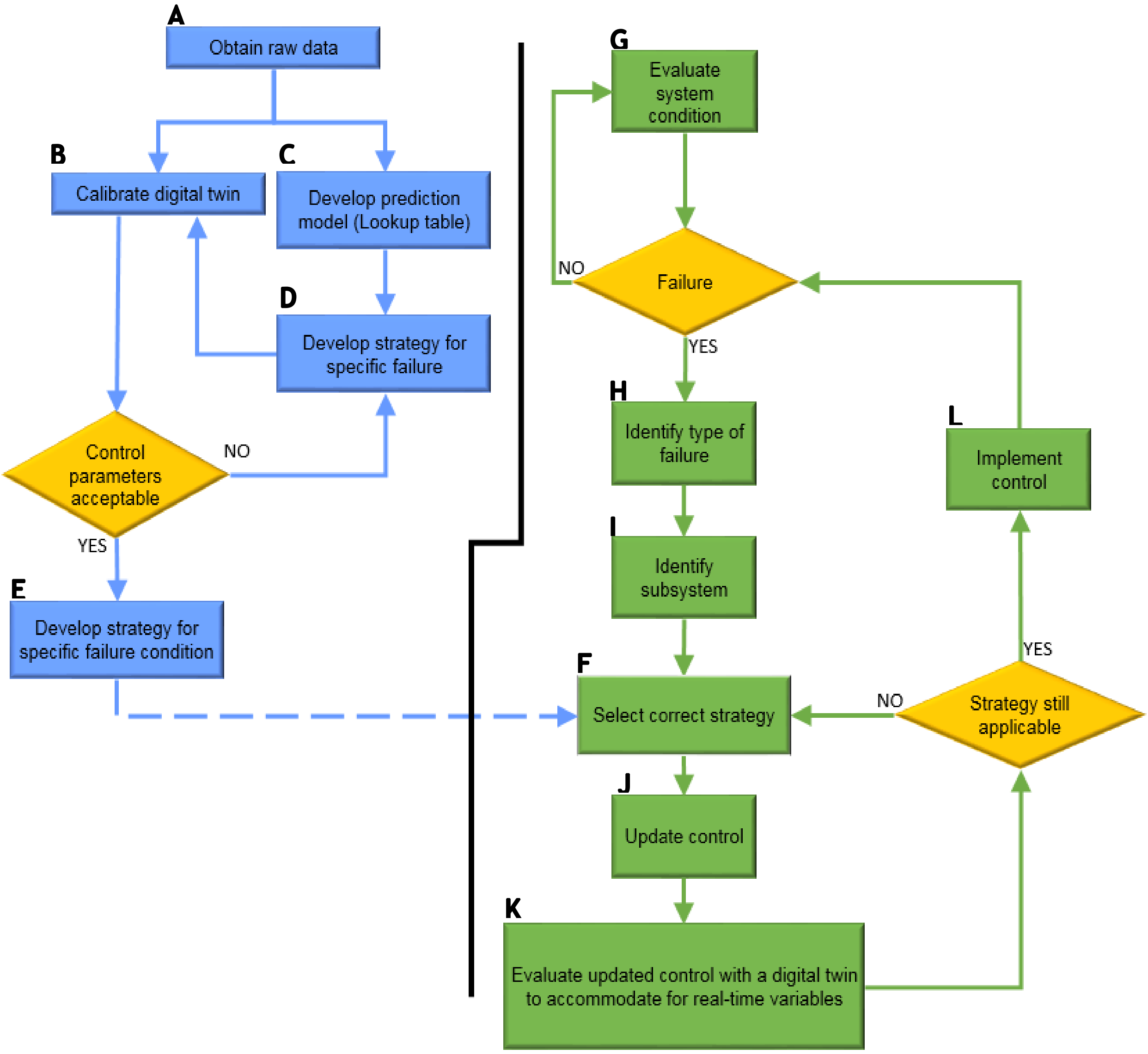

Figure 3: Failure process.

Step	Description
A	Reliable raw data is required to create a calibrated simulation (discussed in Step B) and to develop prediction models.
B	A calibrated simulation is required to be able to predict future scenarios within a mine. When a simulation is calibrated it is seen as a digital twin for the sake of this study. The calibration should thus be validated with the raw data obtained in Step A.
C	Using the data obtained in Step A, a dam-level prediction model is developed. The purpose of this is to be able to predict dam water levels when the number of operational components change.
D	A failure strategy should be developed for a specific component failure. This preliminary strategy should be developed by using the digital twin and dam level prediction model. The preliminary strategy and failure should be implemented into the digital twin. When analysing the results of the implemented strategy into a digital twin, it should ultimately result in no possible dangerous conditions. A strategy is also required for all possible component failures.
E	Once a strategy is developed where no dangerous scenarios are predicted with the digital twin it can be added to a list of possible strategies for use during component failures. Each of these strategies should include the control of all remaining operational equipment until the failures are mitigated. This list of strategies should be available for any given failure combination. It should be noted that the strategies developed in Step D must be able to avoid dangerous scenarios when multiple failures occur within multiple subsystems. These strategies should also be developed to have a minimal effect on other water reticulation subsytems. This is the final step for the once off section of the process. These steps will only be done once, unless changes to the site occur. These changes might include obtaining new equipment or new infrastructure development.
F	Once the list of all possible strategies is complete, the process should be able to select an appropriate strategy according to a specific real-time scenario. This will form part of the continuous section of the process since this step will be required when a failure occurs.
G	Real-time evaluation of the conditions on the water reticulation system should be done. This will provide the necessary information as to whether a failure is identified within the system. It should be noted that the real-time system should be in working condition. Normal control operations can continue when no failures are identified. In the scenario where a failure is identified, the system should be flagged.
H	The system will be flagged when a failure is identified. This means that the specific component failure is identified.
I	When the failure is identified, the subsystem is also identified. The reason for this step is that each subsystem has various control strategies developed for when failures occur, thus this step will also be used to identify the relevant control strategy for the identified failure scenario.
J	The control strategy selected in Step I requires that various control parameters be adjusted. These adjustments and current real-time conditions should be

	implemented into the digital twin. This is to ensure the correct strategy is selected before it is implemented into the water reticulation system.
K	The simulated results of the updated control strategy in the simulation should be evaluated. This will be used to ensure that no dangerous scenarios are predicted by the digital twin. A decision block will request if the current strategy is still a viable solution. If not, the process will return to Step F (select a strategy). If the current selected strategy is still relevant, the process will continue to Step L.
L	When the selected strategy is still a viable strategy for the given scenario, it will be implemented on the water reticulation system. This will continue until Step G identifies a change in real-time conditions.

4 IMPLEMENTATION OF PROCESS

As shown in Figure 3, the once-off section of the process is the first step (Step A). When reliable raw data is obtained the digital twin can be developed [29]. The next step develops the prediction model, stipulated in Step C.

This prediction model is then used to predict dam levels according to the time of day and number of operational equipment. Dam level predictions can be done for each water reticulation subsection since each of these subsections are controlled according to dam levels. This prediction is beneficial when developing control strategies for failure scenarios since predicted future dam levels are required to determine how the remaining operational equipment should be controlled. The methodology of the dam-level prediction model was however developed elsewhere [3].

The failure process was implemented on a case study comprising a deep-level gold mine reaching a depth of more than 3km. This leads to the use of all the water reticulation components discussed in section 2 on the mine, allowing the process to be fully tested on all components. This mine has three dewatering levels with three dewatering pumps per level. The refrigeration system consists of five fridge plants, three precooling towers and three bulk air coolers.

Table 2 shows the dam-level prediction values used for the case study.

Table 2: Dam level prediction table.

Dewatering level	Number of pumps	Dam level percentagedifference (%)
Pumping Level 1	0	2.95
	1	−3.95
	2	−7.77
Pumping Level 2	0	1.15
	1	0.17
	2	−0.98
Pumping Level 3	0	5.50
	1	0.07
	2	−2.83

Utilising Table 2 the dam level can be predicted according to the number of operational components. When pumping level 1 has no operational pumps, the dam level is predicted to increase by 2.95 % each hour. This model is used to ensure that the preliminary control strategy will accommodate dam levels, since the flooding of underground dams is extremely dangerous. It is thus important to verify this model before it is used.

Figure 4 shows the prediction model and compares the dam level profile to the actual dam levels for a period of five days. The shaded regions indicated the Eskom evening peak periods. The absolute percentage error between these two profiles is 0.71 % which is within acceptable limits according to literature sources indicating that a percentage error lower than 10 % is satisfactory [30],[31].

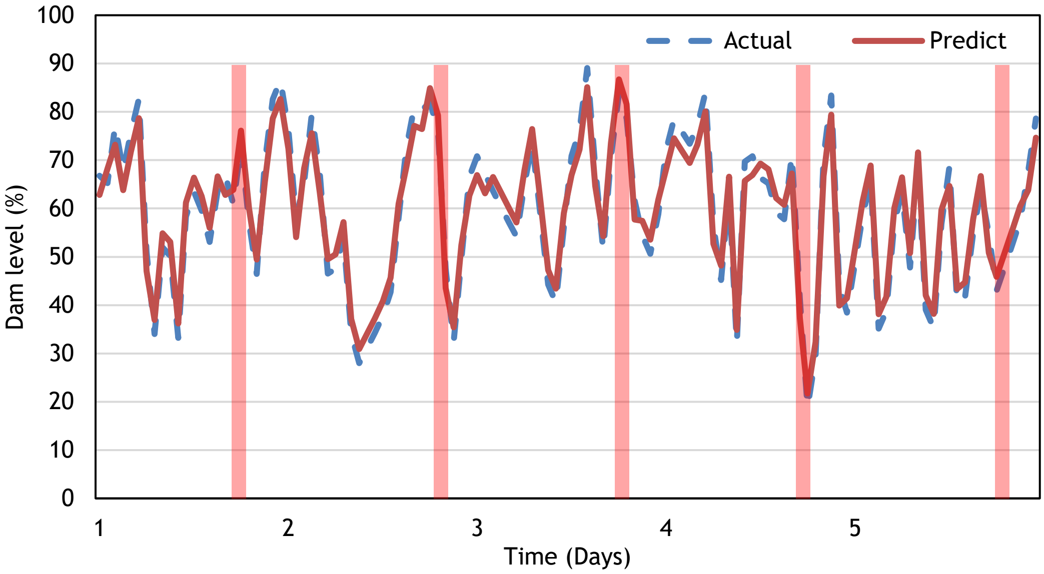

Figure 4: Dam level prediction model verification.

When the dam level prediction model is considered accurate, attention is given to the verification of the digital twin, which is used to improve each preliminary strategy.

Figure 5 shows an actual power profile and the simulated power profile for a three-day period for the entire water reticulation system. This information was used to verify the digital twin, where the average percentage error between these profiles was 6.77 %. This provides adequate assurance to use the digital twin in developing and predicting strategies developed when component failures occur.

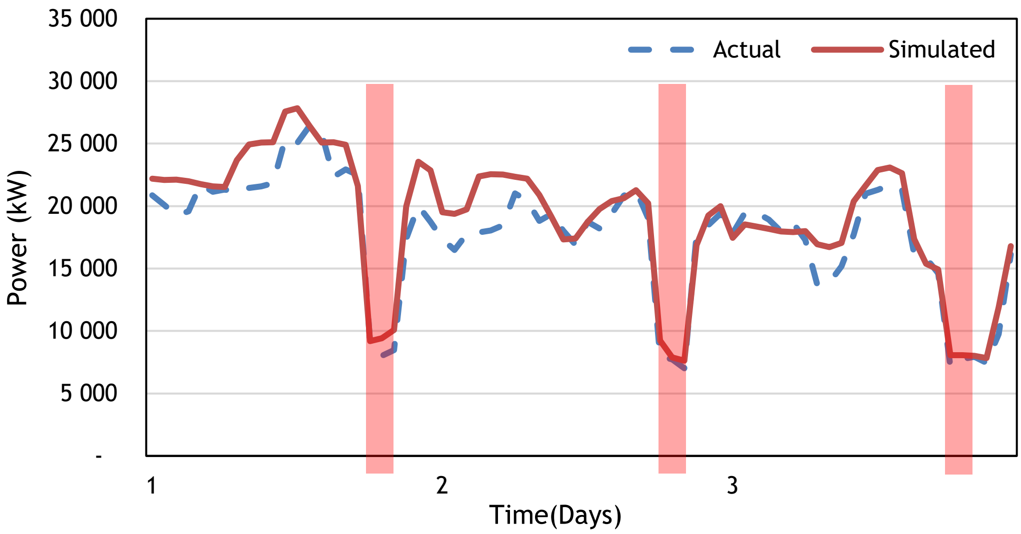

Figure 5: Digital twin verification.

5 RESULTS & DISCUSSION

A total number of 10 strategies was developed for the case study. The number of strategies was derived according to the number of water reticulation components, and was thus site specific. Each strategy was developed to control the remaining critical equipment to ensure load shift savings could be obtained in a safe manner.

Utilising Table 3 the strategy number is identified according to the location of the failure and amount of component failures. Strategies were developed for a maximum of two failures per location as more failures will ensure normal failure procedures are implemented.

Table 3: Strategy numbering.

Strategies	Dewatering			Fridge Plant	BAC	PCT
	Pumping Level 1 Pump	Pumping Level 2 Pump	Pumping Level 3 Pump			
1	1					
2		1				
3		2				
4			1			
5			2			
6				1		
7				2		
8					1	
9					2	
10						1

The failure rates of all the components were obtained from the previous year (2017) to calculate the percentage occurances (likelihood) of each strategy.

It should be noted that Strategy 3 and Strategy 5 could not be tested since the necessary failures required to trigger these strategies did not occur during the testing period. The percentage occurance for each strategy correlates to a specific component failure within the period of one year.

Table 4 shows the percentage occurance (frequency) each of the strategies would have been required over the previous year. This information is used to predict the probability of each strategy being necessary for the following year. This gives an indication as to the relevance of the study, which will decrease significantly when the number of failures decreases. When summarising the total percentage occurance of all the strategies it equates to more than 100 %. This is possible since various failures occurred simultaneously. This also indicates that the process could be very beneficial for multiple failure occurences.

Table 4: Percentage occurance per strategy.

Strategy	Occurrence (%)
1	2.19
2	10.14
3	0.27
4	10.68
5	0.27
6	16.74

Strategy	Occurrence (%)
7	2.24
8	16.16
9	39.72
10	3.87

For the study to be relevant in the mining industry, it is important to verify the actual savings obtainable per strategy. Table 5 shows the acual load shift savings obtained for each of the strategies after implementation.. The test date of each of the strategies and whether the strategy was actualy tested or simulated is also shown in Table 5. Power savings can be directly translated to electricity cost savings.

Table5: Load demand shifting achieved.

Strategy	Load Demand Shifting (MW)	Date of Failure	Actual/Simulated
1	3.26	2018-06-12	Actual
2	2.99	2018-01-22	Actual
3	1.98	N/A	Simulated
4	2.05	2018-03-15	Actual
5	3.34	N/A	Simulated
6	4.07	2018-04-23	Actual
7	3.64	2018-09-25	Actual
8	3.16	2018-10-03	Actual
9	2.54	2018-01-10	Actual
10	4.14	2018-03-28	Actual

Table 6 gives the cost savings achieved per startegy and is used to calculate the achieved annual electricity cost savings when the failure process is implemented on a case study. When approximately 260 working days a year is used to calcualte the annual electricity cost savings, the values are shown in column three.

It is therefore estimated that this failure process can reduce the annual electricity cost savings of the case study by R3.8 million. These annual savings can be realised with no capital expenditure since the existing control of the components is merely improved in the event of failures.

Table6: Cost savings achieved.

Strategy	Daily cost savings (R)	Annual cost savings (R)
1	342.30	88 998
2	1 453.63	377 943
3	26.01	6 762
4	1 049.71	272 924
5	41.38	10 758
6	3 266.58	849 311
7	390.92	101 640
8	2 448.34	636 568

9	4 837.11	1 257 650
10	768.17	199 723
Total	**14 624.14**	**3 802 276**

6 CONCLUSION

Deep-level mines in South Africa have harsh conditions for mining personnel as well as equipment. These harsh conditions are due to the high underground temperatures and humidity. This leads to premature failures of critical equipment, which also has an effect on production. In addition to the negative effect on production, premature failures of equipment can also lead to unsafe working environments for mining personnel.

Water reticulation was focussed on in this study since this system contains multiple subsystems, which are vital for underground safety. This subsystem includes dewatering pumps, fridge plants, bulk air coolers and precooling tower. These subsystems will empty the hot underground dams and reduce underground temperatures.

It was seen that various studies have been done on each of these subsystems to improve the control thereof and reduce the electricity costs. However no studies were found where focus was given to scenarios in the cases where these critical components fail.

In this study a method was thus developed to create and select the best suited control strategy for a given scenario. The methodology contained a once-off and a continuous section, where the once-off section focussed on creating control strategies for failure scenarios. The continuous section of the methodology was developed to focus on real-time scenarios to select the best suited control strategy for a given critical component failure.

Most of the strategies were tested when this methodology was impemented on a deep level mine. The electricity cost savings achieved by creating and selecting the most suitable control strategy for a given scenario was extrapolated to a year and it was found that it could save R3.8 million per year. This was possible without creating any unsafe scenarios and without any capital expenditures being required.

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SOCIAL MEDIA: A KNOWLEDGE SHARING TOOL IN ORGANISATIONS

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ABSTRACT

Knowledge management entails more than just the capturing, storing, and disseminating of knowledge. It is the actual sharing and use of knowledge that makes knowledge management a success. Social media has become an integrated part of our daily lives and with the Internet of Things we are being connected to a network of some sort at any given point in time. With the use of the mobile internet, social awareness and the availability of information, whether real or fake, is increasing. Companies need to investigate ways in which they can make use of social media platforms to share knowledge and improve the productivity and effectiveness of their employees but also address certain social media concerns. A framework, indicating key requirements for a social media knowledge sharing platform is proposed through a literature study and thereafter evaluated using a Delphi technique. The framework entails five key requirements for a social media platform to be used as a knowledge sharing tool within organisations. The study also highlights some important personal and organisational traits needed to support the use of a social media platform as a knowledge sharing tool.

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1 INTRODUCTION

Knowledge management entails more than just the capturing, storing, and making the knowledge available. It is the actual use and sharing of information that is the key to knowledge management success [2],[14]and[43]. In the mining industry, knowledge is captured, stored and available for use, but the sharing between individuals are lacking. Social media has become an intricate part of every person's daily life. With the increasing availability of the mobile internet and social awareness, companies need to look into ways in which they can make use of these platforms to improve productivity and effectiveness of employees [29],[31],[45],[46]and[49]. There are some concerns with social media and the list is extensive. They include security, personal information, auditability, and of course validity of the information shared on it to name a few.

This research will focus on how social media can be used to improve the sharing of information and increase the knowledge management activities of an organisation by understanding the minimum requirements for a social media platform to assist in knowledge management.

The primary objective of this research is to establish a framework that will propose the minimum specific requirements for a social media platform that can be utilised as a means for knowledge sharing within a project-based organisation. The research will be exploratory of nature and will be based on a literature survey on knowledge sharing, social platforms and factors influencing the sharing of knowledge on such a platform. These identified elements will thereafter be confirmed or rejected by means of an empirical study using a simplified Delphi technique. A secondary objective to this research will be to identify specific issues and influences, related to the use of social media in sharing knowledge, as seen from the organisational environment in which the members of the Delphi group function. These issues will be viewed from both a potential user as well as a management perspective.

2 -BACKGROUND

2.1 Knowledge Management

Knowledge management is the art of gathering data, transforming data into information and applying the information in a manner that will enhance or increase the effectiveness of the organisational decision-making process [9]and[19]. Contrary to belief, and what is experienced in the workplace today, knowledge empowers the individual by transforming information and sharing it with other people and not from keeping it to oneself [16]. Knowledge must be captured and re-used as it is the organisation's most important weapon and the arsenal for innovation and continuous improvement [19].

What can be done and why? Chai & Kim [8] identified blogs as the best platform for sharing knowledge based on trust between the collaborators. Problem-solving techniques like TRIZ [20] makes use of previous solutions to solve the same problem in different functional groups, while Yates & Paquette [55] identify that transferring of knowledge can lead to a significant reduction in the duplication of work.

2.2 Social Media

Social media has become a part of our daily life with mobile devices connected to the internet in every sphere and location. Status updates occur instantaneously and anywhere in the world [12],[30]and[32]. The ability of the mobile internet encompassed with Big Social Data, allows organisations to gain knowledge from individuals and employees, and thus enabling their ability to increase customer satisfaction in real-time [29]. The main difference between social media and more conventional knowledge-sharing platforms, e.g. databases, is that they are live, instant, and can be accessed by almost anyone and almost anywhere [33].

Social media is constantly evolving and can be placed into four different groups, Wiki's, Web blogs, online communities, and social networks [41]. Of the four groups wiki's, blogs, and online communities can create, store and share information between collaborators while social networks only allow for the sharing of information. The biggest challenge in social media sharing is the comments and feedback received from perceived experts [41]. This feedback from experts can be done in closed groups on specific projects, updating the project clients, stakeholders and steering committee within minutes, storing and sharing what is going on at a specific time and place in the project. Clear communication throughout the life cycle of a project is required for good stakeholder engagement and keeping people in the loop of what is happening at all times [6].

Social media enhances social behaviour between collaborators which is key in building trust and respect. These are key requirements for the sharing of knowledge [8]and[25]. Over and above building trust, it breaks down cross-functional boundaries, physical location and enables the sharing and collaboration between individuals no matter what and where they come from [22]and[41]. It is clear that social media promotes a diverse view on many a topic. This is instrumental in stakeholder engagement within projects. It can greatly assist in the start of a project when brainstorming and scoping is taking place.

3 REQUIREMENTS FOR KNOWLEDGE SHARING ON SOCIAL MEDIA PLATFORMS

Brambilla, Fraternali & Vaca Ruiz [7] identified key aspects of a knowledge management tool. They blame the poor sharing of knowledge on the exploitation of implicit knowledge, the lack of participation, active distribution, and social feedback between individuals for the ineffective management of knowledge. They continue and state that knowledge is best transferred within the interaction between individuals and the active exploration of information. Social media can overcome this issue, and blogs and social networks provide evidence as continuous interaction is observed on social media sites. Social media platforms create a perfect space where individuals can interact and collaborate to increase innovation and communication at any point in time.

To understand which requirements are needed for social media platforms, five key factors were identified from a literature review. Within each of these factors, key elements were also identified to establish the conceptual framework. The following sub-sections will elaborate on these factors and explore important elements for each of the factors.

3.1 Group Creation

One of the first steps in both social media and knowledge sharing will be to create a group that is specific to the information being shared [4]. It is clear from previous sections that knowledge can only be shared through collaboration and exchange of information in formal or informal ways. The research focused on two important elements under group creation. These are group size and the type of group that will focus on a subject area. Social media has enabled a person to create a group in seconds while older knowledge sharing platforms do not always allow the creation of groups.

Group creation was classified by Kietzmann, Hermkens, McCarthy & Silvestre [24] into two main types namely open and closed groups. Open groups are generally used in social instances and everyone can join in the conversation, they are not governed with little to no hierarchical structure to them. In contrast, closed groups are more for sharing confidential information or topic-specific information [23]. Closed groups are more likely to be used in knowledge sharing as they target a specific audience, increase trust and validation by administrative personnel monitoring the group [23].

There is no consensus in the literature concerning the perfect number of participants for knowledge sharing groups. It is clear that social groups tend to be larger than groups specifically created for the sharing of information.

3.2 Usability

There is a saying that wisdom comes with age. The importance of obtaining knowledge from the older generation cannot be ignored. Perrin [37] however indicates that only younger generations are making use of social media, while older people only use it to view what is going on with the family. She indicates that there is a trend in older people making use of social platforms over the past 10 years. Zhen, Wang and Li [57] identify three basic principles for managing knowledge on any platform namely, knowledge supply, demand, and the maintenance of the knowledge. If knowledge is not supplied then there will be nothing to share, the demand needs to exist with a specific need generated by individuals of the group, while maintenance needs to occur on the knowledge available on the platform.

Panahi et al. [32] identified five major themes that contribute to the sharing of tacit knowledge, which include socialising, practising, networking, storytelling and encountering. Social media makes use of almost all of these themes as it involves social interaction by the different individuals and therefore networking and telling each other what they are doing on a real-time basis. They also believe that social media can close the gap between face-to-face interactions for knowledge sharing.

A challenge using social media groups are the different views and opinions each individual has on the topic under discussion. These opinions, however, will need to be validated and individuals in a group should have clear roles and responsibilities for the effective use of the sharing platform [57].

3.3 Governance

It can be argued that the majority of people that have a social account has either read or written something about an organisation. Whether this is good or bad can be debated but it is unfortunately happening, Dreher [15] indicated that employees can become the best brand ambassadors for their own company on social media. She continues by highlighting the importance of guidelines, training and controls on how and when to make use of social media.

Governance on knowledge sharing groups is important, as decision making can be done based on the posted information. Good structure is required on these platforms where Wikipedia can be seen as an example, as the promotion of an individual depends on the validation of the posted information of another individual, who in turn also adds to the type of information being shared. Other social media platforms, for example, LinkedIn makes use of endorsement by other employees or people in their network which can also increase the validity of information shared.

3.4 Maintainability

In knowledge management, the storage of information is important. By ensuring information is kept safe, but easily retrievable, maintained and updated, it will remain available and current. Where the information is stored will also depend on the sensitivity of the information shared. Lumb [27] identifies cloud technology, which includes social media, as a safe place for information to be stored and maintained so that it does not get lost. Using cloud technologies may, however, lack confidentiality which might force an organisation to rather opt for internal controlled storage and sharing technologies.

The gathering of information or knowledge should be obtained through different means. Review sessions at project or contract end are only as good as the relationship between the employee and employer. Information gathering can be accomplished through storytelling and works well with the gathering of tacit knowledge by enabling the individual to tell his own story [26],[32]and[51]. Panahi et al. [32] indicate how storytelling provides a personal experience and opinion of the actual event in his/her own words. They highlighted the ability of Blogs when it comes to storytelling and how the knowledge sharing assisted the medical industry. From a maintenance perspective, Blogs are also easier to maintain and update than a web page within a learning environment where knowledge needs to be current and applicable [21].

3.5 Security

Security or privacy is a topic of importance and relevance for the use of social media as a knowledge-sharing platform. Research has highlighted security as a great concern and needs to be addressed especially in social media [5]and[18]. Pei and Grace [36] indicates that the selection of freeware versus proprietary software will become more important. The choice and selection of most social software is freeware and web-based. Companies might opt for an internal social platform of some sort to increase the security of information. This will eliminate most of the security concerns for both the individual and the organisation. An internal social platform will most probably have a limitation in external inputs and learnings from outside the organisation.

The main concern for the organisation will be the leakage of privileged information. For the individual, it will be getting exposed to leaking information about the company unknowingly. This emphasises the importance of guidelines or a code of conduct in an organisation to enable and empower the individual to share information knowing what is allowed and what not. Gritzalis et al [18] shared their concerns around personal information and the right of an individual to privacy on social networks. Before using a social platform, it is important to read and understand all the terms and conditions before acceptance. Taking current applications on mobile devices as an example, you need to accept or give access to personal information before you are allowed to make use of the application [54] and without one knowing you might have provided the application access to all your information on your mobile device.

An even bigger concern with Industry 4.0, and the internet of things, the mobile internet and cloud technology are that everything is connected with anything. Employees have access to organisational information on their device with multiple applications sharing key personal files, documents and even organisational information by allowing these social applications access to your mobile device [1],[11]and[27].

Chen et al. [11] refer to BotCloud technology that could be loaded onto your mobile device, and without you knowing it could access and transmit personal and privileged information.

You might be working on a patent, and before you know, someone else comes up with the same concept. The information may even be sold, and unknowingly you may be identified as an information leak in the organisation. Security might be the most important aspect when using a social platform and is a crucial element of such a knowledge sharing framework.

3.6 Personal and Organisational Traits

Chai and Kim [8] identifies trust and a positive relationship between bloggers as key factors that will affect knowledge sharing positively. Trust is evidently one of the biggest and most researched topics when it comes to general sharing and sharing and dissemination of knowledge on social media [1],[25],[28]and[52]. Self-efficacy and the attitude of the individual towards sharing of his/her personal experiences [33] and organisational commitment [25] are also factors that can positively influence the sharing of knowledge and rank among the highest [39].

Šajeva [44] analysed the impact of both intrinsic and extrinsic rewards on the sharing of knowledge. Šajeva concludes that the biggest impact on sharing of knowledge is seen with intrinsic rewards, as it forms part of the psychological aspect of people where internalisation increases and the awareness and importance of sharing the knowledge also increase [34].

According to Serenko and Bontis [48] job insecurity decreases people’s ability to share information. They state that the organisation's ability to ensure job security positively promote knowledge sharing activities and enhance knowledge sharing between teams and individuals. Job security also promotes an ethical requirement for knowledge sharing from each employee [25] as it becomes the obligation of the employee, and not the organisation, to share information with other individuals [56].

Other drivers which will enhance knowledge sharing are the willingness to share [1],[3],[38]and[44], leadership and organisational culture [3]and[40]. In addition, the individual’s ability to enjoy helping others, monetary rewards, management supports and management motivation, all play a role in promoting the sharing of knowledge. This can be achieved through the recognition of participating individuals in the knowledge sharing event[42]and many other reasons as mentioned by Prinsloo et al, [39] and Van Waveren et al. [53].

4 CONCEPTUAL FRAMEWORK

This research proposes a conceptual framework for social media to be used as a knowledge-sharing platform. The framework considers the five requirements identified from literature namely group creation, usability, governance, maintainability and security as the basis of consideration for the use of a social platform. Each of the requirements is divided into elements of importance and relevance to the requirement. The requirements and elements were identified through a literature review. The framework proposed is depicted in Figure 1.

From the outset, the framework has some limitations as it does not include the organisational and personal traits that also affect knowledge sharing. The reason is that the framework had to identify important requirements to consider a social platform for knowledge sharing and that the underlying enablers which are part of the organisational and personal traits need to support such framework, otherwise the social media platform as a knowledge sharing tool will not be successful.

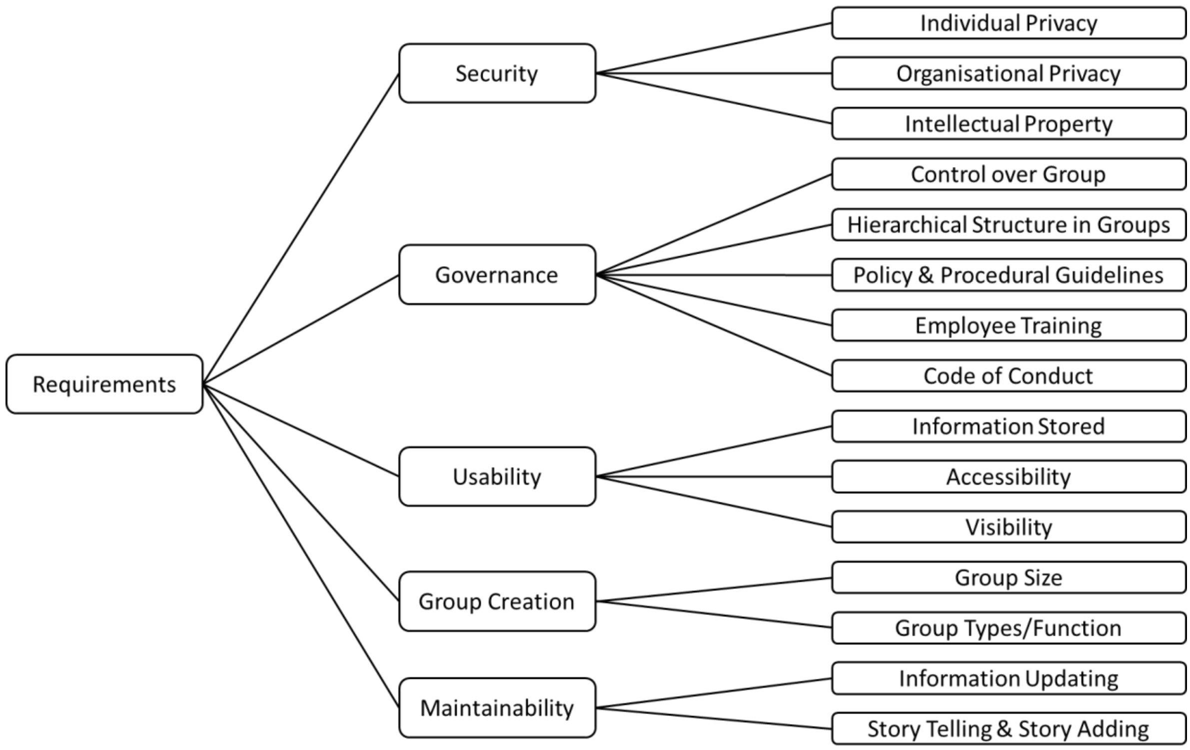

Figure 1: Requirements for a Social Media Knowledge Sharing Platform

5 RESEARCH METHOD

The research was approached by doing an initial literature review of the key topics as discussed earlier. The review assisted in identifying the conceptual framework as proposed in Figure 1. As the research focused on model building, a research method to verify a new model or framework's suitability will be to have it reviewed and improved upon by inputs and consensus from a group of experts.

For this purpose, an expert panel was identified by means of selection criteria in the initial stages of the research. It was essential that the panel consisted of individuals with both project and mining experience. Experience in using social media was generally accepted as most people make use of some sort of social platform today. Some experience in the use of and participation in social groups was however considered important as this experience can help justify the importance of the proposed requirements suggested in the framework. The criteria of importance to the identification and selection of the expert panel are depicted in Table 1.

Table 1: Panel Selection Criteria

Description	Experience
General organisational and work experience	>10 years
Experience of knowledge management with specific emphasis on knowledge sharing	>5 years
Experience in participating in multiple social media accounts or groups	>2 years

The research made use of a Delphi technique using a structured questionnaire that consisted of 54 questions of which some were open-ended. Per definition, a Delphi technique is a structured communication technique that relies on a panel of experts. The experts answer a questionnaire in two or more rounds. After each round, the answers, including a motivation, are summarised in an anonymous way. Through the next round, the individual experts can review their initial answers in light of the summary of replies from the previous round's panel members. By doing several rounds, it is believed that answers to the questions will converge towards a final answer whereafter the process is stopped [53].

To identify individuals to partake in the study and complete the questionnaire, a snowball sampling method was applied. The initial responses indicated and guided the researchers to other individuals that completed the questionnaire online. Making use of the snowball sampling method greatly assisted the gathering of information on the topic and positive results were obtained during the data gathering process. Of the 20 experts identified through the snowball sampling method, only nine individuals completed the questionnaire. The questionnaire's 54 questions took on average of 52 minutes to complete. The panel composition consisted of five members working in mining consultancy, three were engineers working full time in mining, while one panel member was predominantly working in the IT industry. All panel members had over 7 years' experience in both projects and knowledge management fields.

For this research, the aim was to complete two rounds of the Delphi technique should the first round not deliver a 75% consensus on the acceptance of the framework. The first round entailed the answering of the questions provided in the structured questionnaire. The expert panel needed to judge the importance and applicability of the individual requirements and also discuss reasons for the perceived success or failure of social media as a knowledge-sharing platform. The second round consisted of face-to-face interaction with the different panel members. Face-to-face interaction supported by Sutherland et al. [50] which states that an in-person conversation during a Delphi study increases the correctness of the information shared by the panel members.

The questionnaires that were completed by the panel members captured useful information and indicated good consensus at the end of the first round. For this reason, the second round of face-to-face discussion was not required as the framework was accepted by all panel members. Using a single round during a Delphi technique can be acceptable as long as good consensus has been reached and a single round has been recorded earlier in another study [53].

From a research methodology perspective, it must be noted that some difficulty was encountered by the researchers to get the individuals to complete the questionnaire. The number of questions listed in the questionnaire and the estimated time that it would take to complete the questionnaire seemed to scare respondents away and therefore some of them were unwilling to even start with the questionnaire.

6 RESULTS

Although general consensus was reached, some individual members of the expert panel made some comments on the questions and some suggestions for improvement were also identified. These are discussed in this section.

Only one respondent disagreed with the author's initial statement that the mining industry is not effective when it comes to knowledge sharing. There is however a consistent understanding amongst the respondents to the reasons for why knowledge sharing is not taking place in the mining industry. Fear of change, scepticism, lack of knowledge sharing platforms, the silo effect, competition, time, the use of outside experts rather than improving knowledge within the company all play a role. Pearlson and Saunders [35] confirms that fewer companies develop and maintain in-house capabilities, and rather outsource specific tasks or activities. This causes the younger generation to have difficulty in learning from previous projects, as the captured lessons learnt are incomplete and the reason why the project succeeded or failed and what were the shortcomings are not always clear.

Almost all the respondents indicated that they use social media and other platforms for catching up with relatives, and use it as a viewing tool for acquiring information rather than sharing knowledge. Two respondents indicated that they do contribute to knowledge sharing using social media, while one indicated that he corrected some information that he found was incorrect.

Overall the response for making use of a social media platform had positive and negative feedback which can be summarised as follows:

Positive

- The current and younger generation is more inclined to trust the information on social media than the older generation. Social media, however, is not focused and focuses more on niche topics which can change daily.
- Changed the way in how communication takes place.
- Ability to share views, thoughts and captures countless people within seconds. It has revolutionised the way in how we share information.
- Easy to share and record, learn, communicate, advertise.
- Social media is still maturing and many knowledgeable people are not part of it. They perceive social media as being useful for social reasons only and not for sharing of knowledge. A change in perception is required.
- Baby Boomers are leaving the industry which can change the way people think about social media and help increase social media as a knowledge sharing tool.
- Create a social community of practice for mining will certainly drive and assist as well as motivate participants to share freely.
- Social media have the ability to quickly set-up a group for sharing of information compared to the older static, or internal company networks. People have the ability to comment immediately or at their own leisure.

Negative

- Not the right audience and the wrong target group can play a major role. This indicates that there are no topic-specific groups formed for knowledge sharing.
- Some indicated that social media is more a social platform as the word indicates. The only platforms used for knowledge sharing are LinkedIn and internal company networks.
- Social media removes the people interaction; people tend to share more knowledge with face-to-face interaction where you can see the person and experience his/her response.
- One respondent provides caution on how views can easily be shaped or twisted on social media.
- The questioning on the person’s credibility who is posting the content, vetting of information is difficult.

- The other aspect of junk mail on social media was a major concern, what is real and should be rejected.

All respondents believe that knowledge can be shared if there is a common knowledge-sharing platform created for specific information. They indicate that the provision of specific groups to share information in a focussed way is lacking. People tend to share less as competition increases and the time available decreases. The majority of feedback indicates that a lack of participation from experts on or within knowledge sharing groups in the mining community causes a low sharing culture.

Aspects like security in the social media environment, when it comes to information and the accuracy of information plays a big part in people viewing rather than participating. They indicate that the accuracy of information only increases with more control, structure and the ability for information to be reviewed.

The importance of training on the use of social media came through strongly. It is a requirement and will assist in a positive outcome with alignment and understanding around knowledge sharing. It will assist in making use of the tools and technologies that are available to share information. It will also provide the ideal platform for the rules and conduct of employees on such platforms.

All respondents agreed that the older generation share less knowledge using social media. Social media can, however, provide a means to start sharing knowledge already at a younger age, as the younger generation is more familiar with the technology.

7 CONCLUSIONS

The framework with requirements depicted in Figure 1 was accepted by all of the respondents and the initial criteria for final approval were met. No additional elements were added by the respondents although some suggestions were made. These suggestions were as follows:

- A feedback loop on the security section of the model
- The original requirement of "Back-up of Information" to be changed to "Information Updating"

The first suggestion was investigated but it was found that it was not required based on the interactive and live update of social media or web 2.0 applications [13]. This suggested change was accepted as it would be more correct and aligned with its discussion about storage, retrieval and updating of the knowledge.

All respondents were in agreement that the model on its own will not promote knowledge sharing and that it is only a tool to be used as guidance and requirements for setting up a social media platform for knowledge sharing opportunities. They all indicate that personal and organisational traits are required to efficiently and effectively share information and knowledge. This is also confirmed by the study of Chen and Popovich [10], which states that three aspects must always be taken into account when it comes to information or knowledge sharing. The aspects are people, process and technology as depicted in Figure 2.

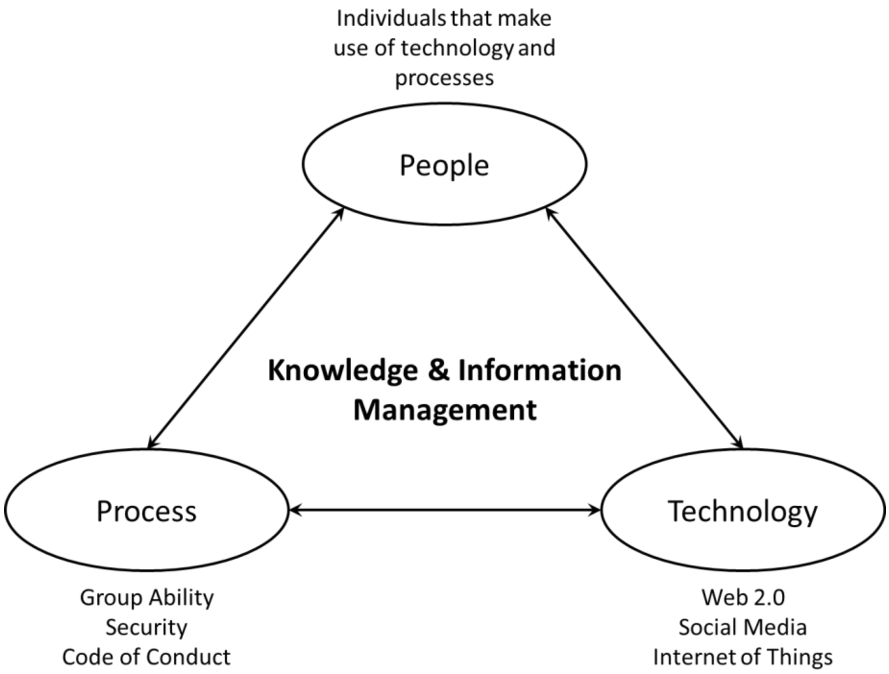

Figure 2: Information and Knowledge Triangle (Adapted from Chen and Popovich [10])

From Figure 2, the speed at which a group can be formed can be much faster than was previously possible, in some knowledge management systems a group could not even be created. The downside to social media as a knowledge-sharing platform is the security aspects, not only for individuals but also the intellectual property of the organisation. This corresponds with the research done by Fang et al. [17] and Gritzalis et al. [18].

A strong case can be made for companies to increase their own social awareness around the technologies available to individuals for information and knowledge sharing. A code of conduct and the way in which companies view individuals' social activities will become a norm in the not too distant future.

All information that has something to do with the organisation must be governed. This is clear from the security as well as the maintenance requirements. The organisations must know what is being said by their own employees and others. This is confirmed by Scott and Jacka [47] which states that organisations should monitor the social pages to identify what is said of them.

The literature and results both indicate that the older generation does not make use of social media [37]. Both Lin [25] and Perrin [37] indicate that a move in social media usage has taken place over the past 10 years. It is therefore important that this move is being expedited to improve the ability of individuals to share information through storytelling and interacting with younger generations that want to continue learning as fast as possible.

In conclusion, this research study has its limitations, as it was exploratory in nature and might not include a complete and rigorous set of all user and management criteria that is important to the use of social media as a knowledge-sharing platform. The Delphi panel was also relatively small and a larger panel would have been preferred. A larger panel might have also reduced initial consensus which might have triggered additional rounds to get consensus. As the members of the Delphi panel were mainly selected from the mining industry, the results of the research study may also be limited to the mining industry as well.

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MISSION-READY RESOURCE ALLOCATION AS A DYNAMIC PROBLEM

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ABSTRACT

The mission-ready resource allocation (MRRA) problem is well known and well defined in Operations Research. Resources are available and can be used to complete missions, while each resource has an associated lifting cost, and the aim is to minimise the total lifting cost to complete all missions. From a literature study in this domain, a gap was found that allows for further research. It was found that the MRRA problem has been formulated and solved as a static problem, however, real life problems are often dynamic and stochastic, i.e. several missions must be completed over a time period, while resource availability varies from mission to mission. In this study, we consider long-term resource allocation so that the overall cost is minimised, and not only for one mission. Also, after a mission is executed, some resources become unavailable for some time – the resources and the consequent unavailable times are not known to the decision-maker. Simulation and meta-heuristics are combined with the knowledge of the static MRRA problem to solve the dynamic, stochastic version of the MRRA problem.

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1 INTRODUCTION

This paper reports on a study concerning the Mission-ready Resource Allocation (MRRA) problem. Although this problem originally stems from the military, it is shown how it can be applied to business decision-making. In MRRA problems, a *mission-ready resource* (MRR) is defined as a combination of resources, such as equipment, ammunition, personnel and fuel. These are combined to execute a mission to achieve one or more objectives. An MRR has task suitability for each task, which is an indication of the degree to which the MRR is suited for that specific task [1]. In essence, it shows how well the resource is expected to perform when tasked with that specific mission.

Each MRR also have a cost associated with it. This is the cost of using that specific resource during a mission and it is known as the *lift cost*. The aim of solving the MRRA problem is two-fold: to 1) minimise this cost while still successfully completing all required missions with 2) high overall task suitability.

During the First World War, there were many attempts to apply mathematical techniques to the analysis of military operations [2]. These techniques can, in some cases, be very useful when attempting to outwit the enemy and gain a strategic advantage. The use of scientists within military command structures proved to be crucial in the outcome of the Second World War. Although they had many great scientists working on military projects, Germany could not integrate scientists into strategic military decision making as well as the Allied forces did. Many believe that it is because of this difference that the allied forces ultimately managed to defeat the Germans during the Second World War [2].

As time went on and more complex problems required attention, proper problem structuring methods were required before people could use mathematical principles to find solutions using Operations Research (OR) [3]. This allowed many problems to be mathematically examined to find good solutions, like the MRRA problem. This technique was used by battle commanders during the Second World War to allocate resources in a strategic manner. It influenced military decision-making during the war and for the years to come.

The original MRRA problem is a static multi-objective problem [1]. A solution is found for a stated mission at a point in time, and once allocation has been done, the problem ends there. In many real life scenarios this is not the case, because in most cases it is often not a once-off problem that needs solving since many missions must be executed over time. Resources are often required for further missions at a later stage and the cost implications of future missions often need to be considered from the start of a campaign.

We show the effect when optimising at several individual time stages versus optimising the overall result with future decisions in mind by presenting a simple example problem, shown in Table 1. In this problem, there is only one of each type of resource available and each resource becomes unavailable for the next time stage when it is used. One mission that requires one resource must be completed at each time stage. The cost and suitability of each resource-mission combination is shown in Table 1. These costs and suitabilities vary from time stage to time stage, because the cost and suitability associated with a resource to complete different tasks naturally differ. The aim of the problem is that the cost over all four time stages must be minimised, while the total overall task suitability must be maximised.

Table 1: Deterministic example problem setup

	Time stage 1		Time stage 2		Time stage 3		Time stage 4	
Resource	Cost	Suitability	Cost	Suitability	Cost	Suitability	Cost	Suitability
A	200	0.6	80	0.8	180	0.6	190	0.6
B	120	0.6	170	0.8	170	0.3	120	0.5
C	100	0.6	80	0.7	170	0.2	190	0.5

It can be seen that if each time stage is optimised individually, a logical decision will be to choose resource C at time stage 1, since it is clearly the best solution at that time stage (cheapest, with same suitability). This means that resource C will become unavailable for time stage 2. The logical choice at time stage 2 will be to use resource A, since it is clearly cheaper than resource B and also produces a suitability of 0.8. This means that resource A will become unavailable for time stage 3. At time stage 3, resource B will then be chosen, since it has a better suitability than resource C for the same price (resource C is now back in contention). At time stage 4, resource B will be unavailable and resource A produces a better suitability than resource C at the same cost.

Table 2: Resource choices when each time stage is considered individually

Time stage	1	2	3	4	Total:
Resource used	C	A	B	A	
Cost	100	80	170	190	540
Suitability	0.6	0.8	0.3	0.6	2.3

As can be seen in Table 2, the total cost is 540 and the total task suitability is 2.3 for all four time stages. This seems to be a good solution, but if sub-optimal solutions were selected at time stages 1 and 2, a better overall result can be found, as shown in Table 3.

Table 3: Resource choices when future time stages are taken into account

Time stage	1	2	3	4	Total:
Resource used	B	C	A	B	
Cost	120	80	180	120	500
Suitability	0.6	0.7	0.6	0.5	2.4

This solution shows that by taking a more expensive option at time stage 1 and 2, the overall cost and suitability can be improved. This small example illustrates that static solution techniques cannot always be used to solve dynamic problems. Although we introduced the MRRA problem from a military point of view, our ultimate aim is to show that businesses also encounter missions that require resources, while these have associated cost of use and task suitability. In modern times many OR methods have been successfully implemented in several business fields. Similarly, MRRA problem solutions could also be useful within business environments.

To explain our proposed extension of the MRRA problem to a stochastic, dynamic problem, we suppose the battle commander of an army base needs to plan the usage of resources over a period of time with several expected attacks that need to be fended off. This means that there will be multiple missions at different time periods, which makes the problem *dynamic*. In this example, some or all resources that were used to complete missions might take time before they become available again after being used, and these availabilities are dictated by *stochastic* elements. This more complex problem is thus termed the *dynamic, stochastic MRRA problem*. The problem is harder than the static MRRA problem with one epoch, and the decision and solution spaces are much larger. This problem still is of combinatorial nature, which can be solved with meta-heuristics.

In order to achieve this, a good understanding of multi-objective meta-heuristics is necessary, since the problem has two conflicting objectives (lift cost and task suitability), while the combinatorial nature of the problem results in many possible feasible and infeasible solutions. Multi-objective meta-heuristics have risen in popularity [4] and can be used in this case to balance the minimisation of lift costs and the suitability of resources for possible future missions.

The static MRRA problem can be mathematically defined as

Maximise $f_1(x) = \sum_{i=1}^{m} \sum_{j=1}^{n} \delta_{ij} \, x_{ij}$

and

minimise $f_2(x) = \sum_{i=1}^{m} \sum_{j=1}^{n} \varphi_{ij} \, x_{ij}$, where $\sum_{i=1}^{n} x_{ij}$ = Number of resources required for each mission, for all i

$\sum_{i=1}^{n} x_{it}$ ≤ number of resources of type t available, for t = 1, 2, …, n

$$x_{ij} \epsilon \mathbb{N}_0$$

δ_{ij} = Task suitability of resource j, when assigned to mission i

φ_{ij} = Lift cost of resource j, when assigned to mission i

The total number of types of resources is represented by *m* and the total number of missions is represented by *n*. This formulation essentially applies at each epoch when a mission is to be completed, but with varying number of resource types available.

This paper will discuss the basic elements of the MRRA problem and provides an example in Section 2. Thereafter, the different problem classes will be discussed in Section 3. This is to highlight the difference between the traditional Static MRRA problem and the Dynamic MRRA problem that can be applied to different business environments. Section 4 will focus on these business environments and the challenges that some of these present. Finally, in Section 5 the solution model to the Dynamic MRRA problem will be discussed.

2 EXAMPLE OF A SIMPLE, STATIC MRRA PROBLEM

To increase understanding of the MRRA problem, a simple example of a static MRRA problem is presented. Suppose a battle commander has the following resources at his disposal for a certain mission:

- Four tanks
- Three fighter planes

The battle commander now has to attack an enemy base nearby and is thus faced with resource allocation that is efficient but at lowest cost possible. The enemy base has one each of the following assets that the commander wishes to destroy:

- Control tower
- Ammunition storage area.

Both of the enemy assets must be destroyed by using the available resources. Each military resource has a task suitability associated with it, which is an indication of the ability of that resource to destroy that specific threat if the resource is assigned to attack that asset. Let δ_{ij} be the task suitability when resource j is assigned to task i. The task suitability for each resource is shown in Table 4.

Table 4: Task Suitability

	Tank	Fighter Plane
Control Tower	0.4	0.8
Ammunition Storage Area	0.5	0.7

The battle commander's first objective is then to optimise the total task suitability for the mission when assigning the resources to enemy assets. For *m* tasks and *n* resources, the first objective function can therefore be formulated as

$$\text{Maximise } f_1(x) = \sum_{i=1}^{m} \sum_{j=1}^{n} \delta_{ij}\, x_{ij}$$

where x_{ij} is the number of resources of type j assigned to task i. This is also the decision variable.

However, the problem is further complicated since each resource also has a lift cost φ associated with it. This is the cost of using that specific resource to complete a specific mission. The lift costs for this example are shown in Table 5.

Table 5: Lift Cost

	Tank	Fighter Plane
Control Tower	60	70
Ammunition Storage Area	40	80

The military commander also wants to minimise the cost associated with this mission. Therefore, the second objective function is to minimise the total lift cost of the mission, and the objective is

$$\text{Minimise } f_2(x) = \sum_{i=1}^{m} \sum_{j=1}^{n} \varphi_{ij}\, x_{ij}.$$

Furthermore, suppose that for some reason the battle commander wants to assign exactly two resources to each enemy asset. It is also important to note that the number of resources of type j that are assigned cannot exceed the available number of resources and that the decision variable x_{ij} values must be integers. The constraints will therefore be

$$\sum_{i=1}^{2} x_{ij} = 2 \text{ for all } i$$

$$\sum_{i=1}^{2} x_{i1} \leq 4$$

$$\sum_{i=1}^{2} x_{i2} \leq 3$$

$$x \epsilon \mathbb{N}_0.$$

The objective functions can now be optimised by using multi-objective optimisation techniques. This problem is small, so all eight feasible solutions can be considered for illustration. The feasible solutions are shown in Table 6 and Figure 1.

Table 6: Feasible Solutions of example problem

Feasible Solution	x_{11}	x_{12}	x_{21}	x_{22}	$f_1(x)$	$f_2(x)$
1	1	1	1	1	2.4	250
2	2	0	1	1	2.0	240
3	0	2	1	1	2.8	260
4	1	1	2	0	2.2	210
5	2	0	2	0	1.8	200
6	0	2	2	0	2.6	220
7	1	1	0	2	2.6	290
8	2	0	0	2	2.2	280

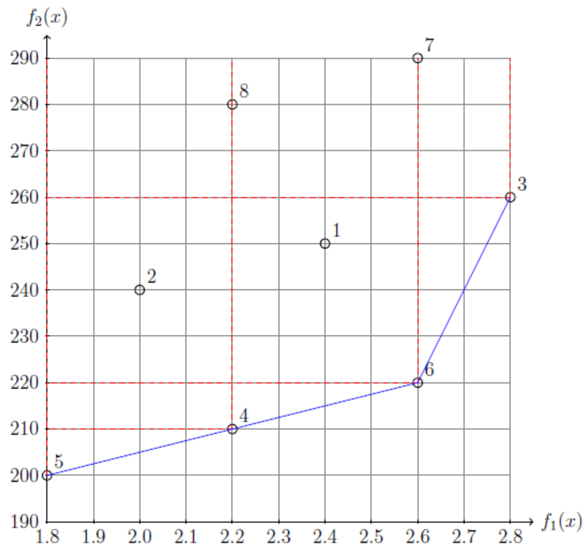

Figure 1: Objective space plot of feasible solutions of example problem

In Figure 1, it can be seen that only solutions 3, 4, 5 and 6 are not dominated by any other solutions. This set of non-dominated solutions is called the *Pareto set*. This means that the battle commander can choose any one of these four solutions and know that no other feasible solution combination will result in a better value for both objective functions.

The battle commander should, therefore, choose one of the following options:

1. He can assign two fighter planes to attack the control tower, and one tank and one fighter plane to attack the ammunition storage area. This will result in a total task suitability of 2.8 and a lift cost of 260, shown as Solution 3 in Table 6.
2. The battle commander can assign one tank and one fighter plane to attack the control tower, as well as two tanks to attack the ammunition storage area. This will result in a total task suitability of 2.2 and a lift cost of 210, shown as Solution 4 in Table 6.
3. The battle commander can assign two tanks to attack the control tower two more tanks to attack the ammunition storage area. This will result in a total task suitability of 1.8 and a lift cost of 200 (Solution 5, Table 6).
4. The battle commander can assign two fighter planes to attack the control tower and two tanks to attack the ammunition storage area. This will result in a task suitability of 2.6 and a lift cost of 220 (Solution 6, Table 6).

In this example, one can also determine how many non-feasible solutions there are. Four tanks and three fighter planes can be assigned to two enemy assets. Since no resources of a specific type can also be assigned to an enemy asset, it means that 0, 1, 2, 3 or 4 tanks will be assigned to each enemy asset. This means that there are five different options when assigning the four tanks and, with the same logic, four different options when assigning the three fighter planes. The result is that there are $(5(4))^2 = 400$ different ways to assign these resources to the enemy assets. Out of these 400 possible combinations, only eight are feasible solutions to this specific problem. This adds to the complexity of the problem, since there are only a small proportion of feasible solutions that need to be found, which is even harder in the case of large problems.

Next, the problem classes of MRRA are briefly discussed to put the research into perspective.

3 MRRA PROBLEM TYPES

An MRRA problem can be classified according to at least four properties. A *static* MRRA problem is considered to be a problem that is solved once, and the resources used to execute a mission. A *dynamic* MRRA problem is one that evolves over time, with at least two consecutive missions to be carried out. It is required that resource allocation is done for all missions so that the total lift cost and task suitability are optimised. A solution at a point in time might not be optimal at that point, but taken as a whole, the final objectives are optimal. This problem case thus focus on the long-term, so dynamic models are very powerful when used to make decisions that will also influence future decisions.

An MRRA problem is deterministic when all variables take on exact values, while in a stochastic problem at least one variable follows a probability distribution. The four properties can now be combined to describe more realistic albeit complex MRRA problem types:

	Static	Dynamic
Deterministic	A problem with decision variables taking on specific possible values is solved once at a point in time, e.g. the number	A series of problems with decision variables taking on specific possible values is solved at different points in time, e.g. the time intervals are

	of resources available is certain, and so are the tasks to be done, the lift costs and the suitabilities of resources.	known, number of resources available at each point in time is certain, and so are the tasks to be done, the lift costs and the suitabilities of resources.
Stochastic	A problem with decision variables taking on values from distributions is solved once at a point in time, e.g. the number of resources available is certain, and so are the tasks to be done, the lift costs and the suitabilities of resources. The problem solutions are quantified by repeating the assignments of values for decision variables, in order to determine estimations for point and interval estimators of the objective functions.	A series of problems with decision variables taking on values from distributions is solved once at a point in time, e.g. the number of resources available is certain, and so are the tasks to be done, the lift costs and the suitabilities of resources. The problem solutions are quantified by repeating the assignments of values for decision variables, in order to determine estimations for point and interval estimators of the objective functions. At any point in time, resources may be unavailable for some time, following some probability distributions.

4 STOCHASTIC DYNAMIC TOY PROBLEM

The Stochastic Dynamic MRRA problem will now be explained by means of a toy problem. This problem deals with scenarios where the availability of resources at specific time stages is uncertain. This can be because resources take longer than expected to return from previous missions, or resources get damaged during previous missions, or missions must be done earlier than planned. It can also be a combination of these occurrences. However, for planning purposes, the model only considers whether or not a resource is available when a mission is to be planned. It is not concerned with the reason, only the fact that a planned allocation might not be possible because of some unforeseen event.

If there is a chance that certain resources might not be available by the time they are estimated to be available again, this is something that the decision-maker will be interested in. To show how this can affect the outcome of the eventual total lift cost and suitability, the worst-case scenario can be considered. For this, it is assumed that each resource only becomes available at the time stage after it is expected to become available. Each solution is then looked at individually and if changes need to be made to accommodate for the resources that return later than expected, it is done to ensure that the solution will be feasible, even if resources arrive one time stage later. This “worst-case scenario” can then be used to see the risk of deciding on a solution that relies on resources returning on time.

To explain the Stochastic Dynamic MRRA problem, a toy problem is used where there is uncertainty as to when the resources will be available for further use. In this example, a logistics company in Port Elizabeth must decide which type of truck to allocate to specific routes. Three different types of trucks are available, while there are five routes (or missions) that each requires one truck to complete. Each truck-route combination has its own specific task suitability and lift cost, given in Table 7 and Table 8 respectively. In this problem each resource will become unavailable for one or two time stages after being assigned and used. This is what gives the problem a stochastic nature.

Table 7: Toy problem Task Suitability

	PE - Cape Town	PE - Durban	PE - Johannesburg
Long Truck (A)	0.7	0.8	0.8
Small Truck (B)	0.7	0.6	0.5
Refrigerator Truck (C)	0.8	0.9	0.9

Table 8: Toy problem Lift Cost

	PE - Cape Town	PE - Durban	PE - Johannesburg
Long Truck (A)	300	330	450
Small Truck (B)	250	280	300
Refrigerator Truck (C)	320	380	400

Since this is a small problem, all the feasible solutions (if all resources become available again after one time stage) could be and are shown for illustration. The results are shown in Table 9, while Figure 2 shows all the feasible solutions. The Pareto front is shown with the blue lines. The optimal set, therefore, consists of Solutions 3, 9, 10 and 11.

Table 9: All feasible solutions of toy problem

Solution Nr	Allocation combination			Lift Cost	Task Suitability
	PE - Cape Town	PE - Durban	PE - Johannesburg		
1	A	B	C	980	2.2
2	A	C	B	980	2.1
3	B	A	C	980	2.4
4	B	C	A	1080	2.4
5	C	A	B	950	2.1
6	C	B	A	1050	2.2
7	A	B	A	1030	2.1
8	A	C	A	1130	2.4
9	B	A	B	880	2.0
10	B	C	B	930	2.1
11	C	A	C	1050	2.5
12	C	B	C	1000	2.3

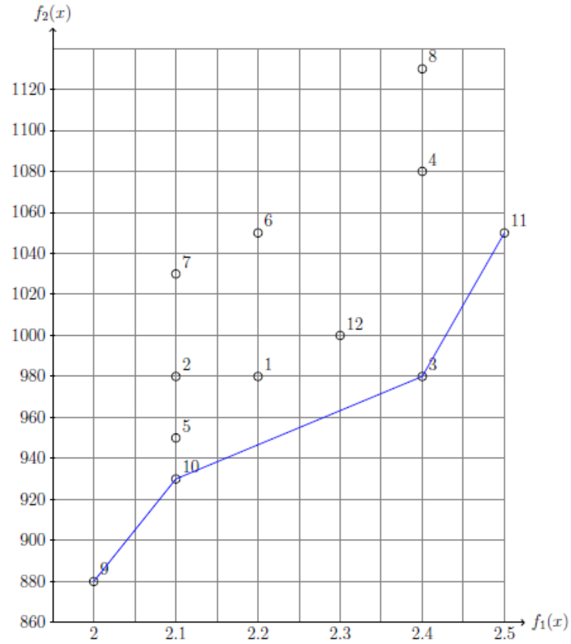

Figure 2: Pareto front and dominated solution of toy problem

These results represent the "best-case scenario". These solutions are only feasible if all resources become available again one time stage after being used. But from the problem description, it is known that this is not always the case. Therefore, the "worst-case scenario" must also be taken into account.

For example, solution 9 will be infeasible if resource B (the small truck), is not available at time stage 3. The result will be that resource C (the refrigerator truck) must be used instead. This change will mean that the total task suitability will increase from 2 to 2.4, but since this is a more expensive option (cost will increase from 880 to 980), the company will have to pay more. Therefore, it is important for them to consider the risk of choosing this allocation and know that there is a chance that the overall cost can increase.

If the company only has a budget of 950 and cannot afford to pay 980, they can consider solution 5. This solution does not have any risk associated with it, since no allocations will have to be changed if resources do not return in time. In that case the company will know exactly what to expect, but it will cost them more than the risky original option that only costs 880 if resource B returns in time. This decision is left to the decision-maker of the company. The model only provides the options and identifies the risks.

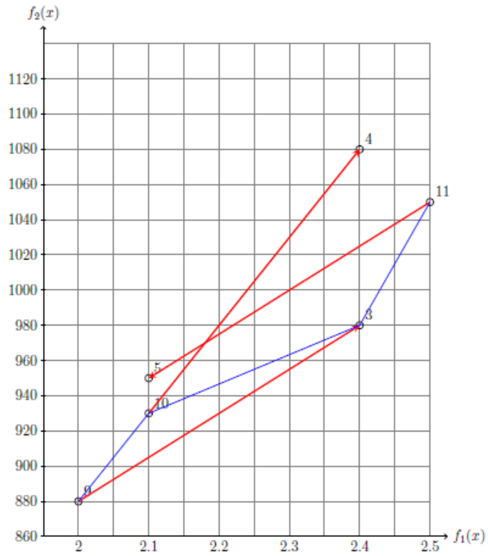

Figure 3: Feasible solutions to the stochastic toy problem

Figure 3 shows how each non-dominated solution can be affected by a "worst-case scenario". Solution 3 stays feasible, even if all resources become available again one time stage later than initially expected. Solution 9 produces a similar result to solution 3 if resources only become available two time stages after being used. Similarly, solution 10 produces a result similar to solution 4 and solution 11 produces a result similar to solution 5 if the correct resources do not arrive in time for their original allocations. The solution numbers, allocation details, lift costs and task suitabilities can be seen in Table 9.

These results can be used to make an informed decision regarding the allocations. Now that all the potential outcomes are known, the company's budget for these delivery routes can be taken into account by management when choosing between these solutions. These "worst-case scenario" solutions are important to consider, because they show a potential outcome of certain earlier decisions and the decision-maker should be aware that this other outcome is a possibility. They must, therefore, be prepared for any outcome within the range of the "best-case scenario" outcome and the "worst-case scenario" outcome.

5 THE USE OF STATIC AND DYNAMIC MRRA SOLUTIONS IN INDUSTRY

In this section we show application of various problem classes in business environments, and to illustrate the need for a dynamic version of the MRRA problem.

Static and dynamic models satisfy different needs. Static models are typically used to allocate disaster management teams; there is thus a need to solve a single allocation problem at a specific point in time. On the other hand, many businesses need to consider future opportunities when making resource allocation decisions. Therefore, many business decisions are in need of a proper dynamic resource allocation technique or model to suit their needs as these evolve over time. A dynamic MRRA problem solving technique will aid them when assigning their resources in such a way to maximise their potential over the medium to longer term.

It is known that the MRRA problem originated within a military environment. However, in more modern times this is not the only need for resource allocation problem solving. Many resource allocation problems exist in the modern business, social and political environments. These include logistics management and project management, which are briefly discussed next.

5.1 Example of a dynamic MRRA problem (Case 1): Logistics

Businesses have the need to optimise the work done by their workers by allocating them in such a way that they complete an optimal number of tasks, or missions, at a minimum cost. This will allow them to maximise their profits by maximising the utility of their workers.

Many logistical problems can also be solved by using MRRA problem solving techniques. Missions need to be executed at a minimum cost and the MRRA problem is perfect for solving such problems. However, many logistical problems extend over a longer period of time with several time-points where decisions must be made.

5.2 Example of a dynamic MRRA problem (Case 2): Project Management

Dynamic resource allocation problems will help businesses to do medium to long term planning better. For example, project managers can implement these techniques to manage the resources at their disposal with more ease and to ensure that the required work gets done in time by a team that is well suited.

Another example of where dynamic MRRA problem solving techniques can be useful in the business environment is the task allocation within a factory or distribution centre. Factory workers and forklift drivers can be allocated tasks in such a way that they work more efficiently. The improved efficiency can be achieved by choosing the workers or drivers that are more suitable for the tasks. The dynamic quality of the problem can help floor managers to plan the most efficient assignment decisions for an entire day or week, depending on their needs.

There is also a great need for efficient resource allocation within the medical environment. Hospitals will be able to serve the needs of their patients better if they make use of the MRRA techniques to allocate their resources. Since medical care is often expensive it is also important to consider the cost of using the hospital resources.

Similarly, government work often needs improvement. This can be addressed by using dynamic MRRA problem solving techniques to optimise the allocation of resources within these fields and ensure that the correct resources are allocated to important projects or missions.

6 MODEL DEVELOPMENT AND TEST RESULTS

The design of the model to solve the dynamic MRRA problem will be presented in this section. After that, the model will be tested by using it to solve various larger example problems. To test this model comprehensively, it must be subjected to different types of problems, each problem being designed to test specific abilities of the model. Due to space limitations, only test work in the dynamic problem domain will be presented.

6.1 Dynamic MRRA problem solution model

The proposed model to solve dynamic MRRA problems was developed, and the basic build is shown in Figure 4. In the first step, a decision variable is randomly populated with the assumption that all resources will be available during all the time stages, even though this is known not to be the case. This initial decision variable is then repaired to find a feasible solution, by using simulated annealing to optimise a penalty function.

The penalty function is used to determine whether solutions are feasible or not. Each solution is checked and penalised if it is infeasible. If for example, a proposed solution allocates three resources of a certain type at a certain time stage, but only two are available at that specific time stage, the penalty value will increase by one. In doing so, the penalty function gives an indication of how close a non-feasible solution is to being feasible. By using this penalty function, a nearby feasible solution can be found from any solution by simply changing the decision variable of the solution to minimise the penalty function until it is zero for a specific solution.

Once a feasible solution is found, that solution is used as a starting mean for the multi-objective optimisation cross-entropy method (MOOCEM, [5]) to ensure that the algorithm starts with a feasible solution. This will help the algorithm to find feasible or near-feasible solutions easier. MOOCEM is then used to find a non-dominated set of solutions. Non-feasible solutions are repaired to become feasible solutions by using simulated annealing and the penalty function to find the nearest feasible neighbour of any solution, resulting in an entirely feasible set of solutions. These solutions are then presented to the user.

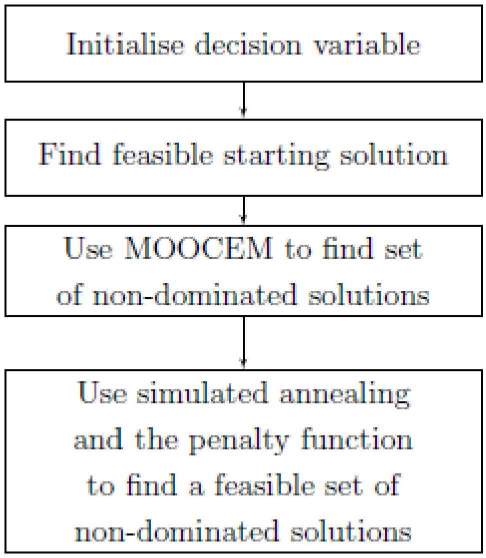

Figure 4: Solution model design

6.2 Finding feasible solutions when resources are scarce

It is important that the model is able to find feasible solutions successfully, even when the resources are relatively scarce. This is important, since in most real-life problems there are not many idle resources waiting to be used. This means that finding feasible solutions is more difficult, since there are fewer.

To illustrate the solution methodology, a Deterministic Dynamic MRRA problem is first used, and a construction company is considered. This company has three different machines available for construction jobs. There is one excavator, one bulldozer and one backhoe loader and there are nine jobs, one executed each day over a nine day period, at five sites that need to be completed, each one at a different time stage. Table 10 shows the site where the job needs to be completed at each time stage. One piece of machinery is required at each job and once that resource is used it becomes unavailable for the next day. This is to give it enough time to return to the company storage area and do maintenance or repairs after completing the job.

Table 10: Jobs to be completed

Day	1	2	3	4	5	6	7	8	9
Job	Site 1	Site 2	Site 3	Site 4	Site 5	Site 1	Site 2	Site 3	Site 4

Table 11 shows the lift costs for each piece of machinery to visit the different sites to complete jobs, while Table 12 shows the task suitability.

Table 11: Construction company lift cost

	Site 1	Site 2	Site 3	Site 4	Site 5
Excavator	300	250	320	420	380
Bulldozer	330	280	380	430	370
Backhoe Loader	450	300	400	510	470

Table 12: Construction company task suitability

	Site 1	Site 2	Site 3	Site 4	Site 5
Excavator	0.7	0.7	0.8	0.8	0.5
Bulldozer	0.8	0.6	0.9	0.6	0.6
Backhoe Loader	0.8	0.5	0.9	0.7	0.7

For the purpose of experimentation, the optimisation procedure was executed 100 times, and the (approximate) Pareto set of each repetition recorded. Then the final Pareto set was formed by finding the non-dominated solutions from the 100 Pareto sets, and this set was assumed to be true, and acted as reference set.

Figure 5 shows the estimated Pareto set (in red) and the dominated solutions from the 100 repetitions (in black). It can be seen that there are not many dominated solutions. This is because there are only a small number of feasible solutions to this example problem, while many solutions from the 100 iterations overlapped.

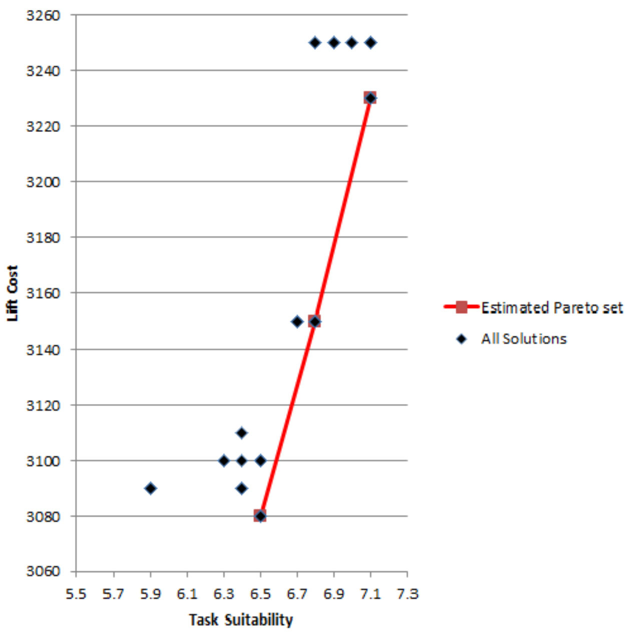

Figure 5: Construction company estimated Pareto set

The estimated ("true") Pareto set can now be used to compare the performance of a single solution set.

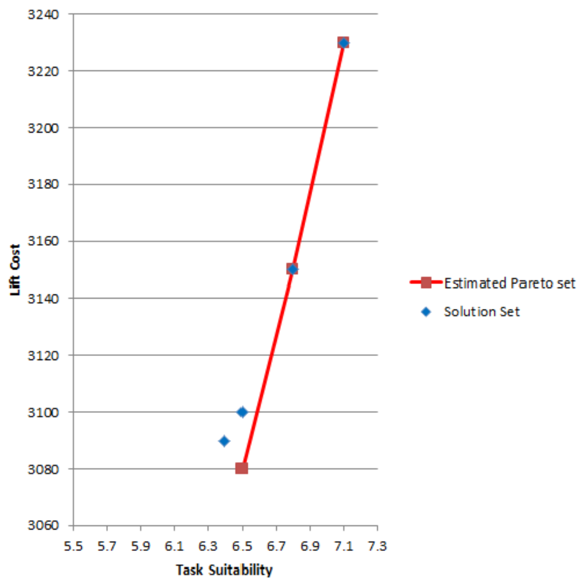

Figure 6: Construction company solution set

The results of choosing a set of solutions, then compare them to the true Pareto set are shown in Figure 6, while the numerical values are shown in Table 13. The decision-maker from the construction company must then decide on one of these solutions. If, for example, the decision-maker wishes to have a task suitability of 6.8 at a cost of 3 150 (solution 3 in Table 13), the decision variable for that solution is given in Table 14. This shows how that task suitability and lift cost can be achieved.

Table 13: Construction company solutions

Solution Nr	Lift Cost	Task Suitability
1	3090	6.4
2	3100	6.5
3	3150	6.8
4	3230	7.1

Table 14: Construction example decision variable for solution 3

Day	Site	Machinery	Lift Cost	Task Suitability
1	Site 1	Bulldozer	330	0.8
2	Site 2	Excavator	250	0.7
3	Site 3	Bulldozer	380	0.9
4	Site 4	Excavator	420	0.8
5	Site 5	Bulldozer	370	0.6
6	Site 1	Excavator	300	0.7
7	Site 2	Bulldozer	280	0.6
8	Site 3	Backhoe Loader	400	0.9
9	Site 4	Excavator	420	0.5
Total:			3150	6.8

This example shows that the model can find good feasible solutions, even if there are only limited resources available.

6.3 Problems with more complex allocation requirements

In this section the model is tested on a Stochastic Dynamic MRRA problem. This means that there is uncertainty about when resources will be ready for use again after they are allocated. An example from an auditing firm is considered.

The auditing firm has five types of people working for them and five companies that must be audited, each at a different time. This is shown in Table 15. In this example, it is also uncertain for exactly how many time stages resources will be unavailable after being assigned and used. It will vary between one and two time stages. This will depend on how long the audits take and when the next time stage's audit is due to begin.

Table 15: Companies to be audited

Time Stage	1	2	3	4	5
Company	Company 1	Company 2	Company 3	Company 4	Company 5
Resources required	3	3	3	8	5

Five types of resources are available to the audit firm. These are two directors, eight managers, three third year clerks, five second year clerks and 10 first year clerks. The lift cost and task suitability of each type of resource are given in Tables 16 and 17 respectively. The objective of this problem is to minimise the total lift cost and maximise the total task suitability over the five time stages.

Table 16: Audit firm example problem lift cost

Company	Company 1	Company 2	Company 3	Company 4	Company 5
1st year clerks	300	250	320	420	380
2nd year clerks	330	280	380	430	370
3rd year clerks	360	270	350	360	410
Managers	450	300	400	510	470
Directors	590	450	610	460	580

Table 17: Audit firm example problem task suitability

Company	Company 1	Company 2	Company 3	Company 4	Company 5
1st year clerks	0.7	0.7	0.8	0.8	0.5
2nd year clerks	0.8	0.6	0.9	0.6	0.6
3rd year clerks	0.6	0.7	0.7	0.6	0.7
Managers	0.8	0.5	0.9	0.7	0.7
Directors	0.9	0.9	0.9	0.9	0.8

The Pareto set is estimated similarly to the construction problem in the previous section. The solutions from 100 solution sets were used to estimate the Pareto set, as seen in Figure 7. All solutions from the 100 solution sets are shown in black, while the red line connects coordinates of solutions in the estimated Pareto set.

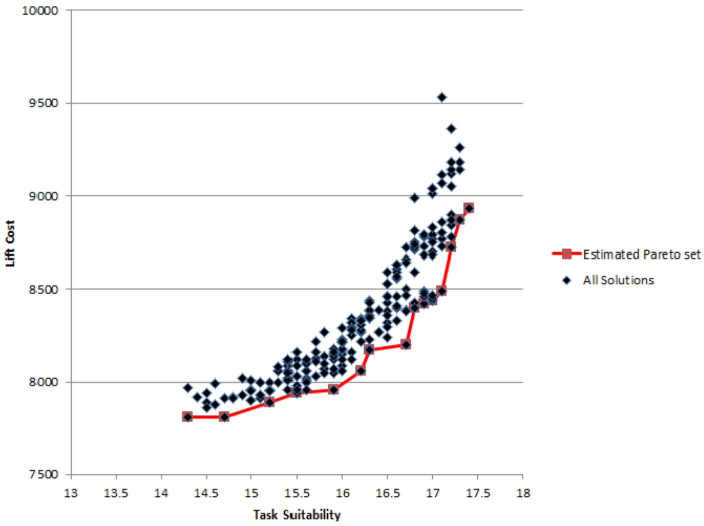

Figure 7: Audit firm example estimated Pareto front

Now a randomly selected solution set is compared to the estimated Pareto set. This is shown in Figure 8. The different solutions in the set are shown as blue diamonds, while each solution's corresponding “worst-case scenarios” are shown with green arrows. The estimated Pareto set is, once again, shown with red squares.

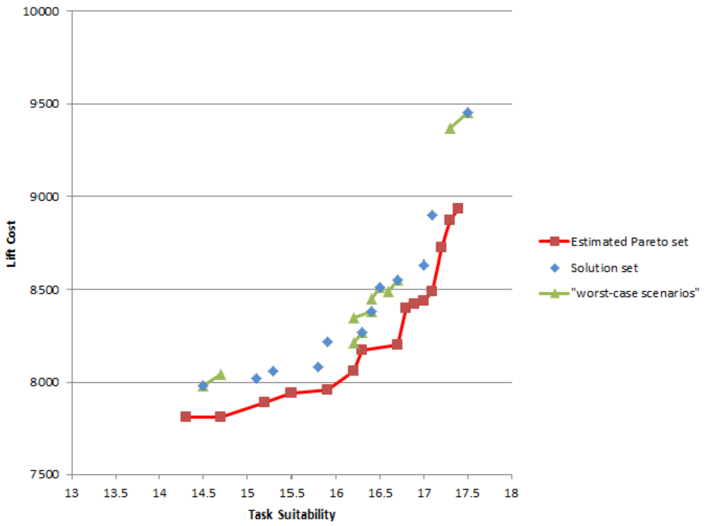

Figure 8: Audit firm problem solution set

The results from the different solutions in the solution set are shown in Table 18. The “worst-case scenarios” are also included in Table 18 to help the decision-maker to make a more informed decision. The “worst-case scenario” shows the results that the solution will have if resources only become available two time stages after they were used.

Table 18: Audit firm solutions

Solution Nr	Lift Cost	Worst Cost	Task Suitability	Worst Suitability
1	7980	14.5	8040	14.7
2	8000	14.6	8000	14.6
3	8020	15.1	8020	15.1
4	8060	15.3	8060	15.3
5	8080	15.8	8080	15.8
6	8220	15.9	8220	15.9
7	8270	16.3	8210	16.2
8	8380	16.4	8350	16.2

9	8510	16.5	8450	16.4
10	8550	16.7	8490	16.6
11	9630	17.0	8630	17.0
12	8900	17.1	8900	17.1
13	9450	17.5	9370	17.3

It can be seen in Table 18 and Figure 8 that most of the "worst-case scenario" solutions only produce worse results in one of the two objectives (cost or suitability) or stay the same as the "optimistic" solution that will be feasible only if each resource become available again after only one time stage. This is because the model must assign a different resource at some critical point. This resource is usually either more expensive and more suitable, or less expensive and less suitable than the one in the "optimistic" solution. However, it remains important for the decision-maker to know and understand the chance of potentially having a different result. If for example, the audit firm only has a budget of 8 000 and is looking for the cheapest option, it will be safer for them to choose solution 2, rather than solution 1 in Table 18. Although solution 1 is cheaper than solution 2, there is a risk that choosing solution 1 would result in a more expensive outcome in the end if resources take more than one time stage to become available again after being used.

A decision-maker from the Audit firm must then select a solution from that set will suit their needs. If, for example, the decision-maker wishes to implement solution 9 in Table 18 and all resources become available again after one time stage, the values of the decision variable are shown in Table 19. This will result in a lift cost of 8 510 and a task suitability of 16.5. If, however, some resources do not become available again in time, the decision variable values can change. This alternative decision variable is shown in Table 20. This will result in a lift cost of 8 450 and a task suitability of 16.4.

Table 19: Audit firm example: decision variable for solution 9

Time stage	Audit	1st year clerks	2nd year clerks	3rd year clerks	Managers	Directors
1	Company 1	0	3	0	0	0
2	Company 2	3	0	0	0	0
3	Company 3	0	3	0	0	0
4	Company 4	2	2	2	0	2
5	Company 5	0	0	1	4	0

Table 20: Audit firm example: "worst-case scenario" decision variable for solution 9

Time stage	Audit	1st year clerks	2nd year clerks	3rd year clerks	Managers	Directors
1	Company 1	0	2	0	1	0
2	Company 2	3	0	0	0	0
3	Company 3	1	2	0	0	0
4	Company 4	2	2	2	0	2
5	Company 5	0	0	1	4	0

Tables 19 and 20 show how the decision variable can change if the second year clerks working on the Company 1 audit do not finish in time to start working on the Company 3 audit. In this case, since there are only five second year clerks available and three of them work on the Company 1 audit, only two will be available for the Company 3 audit. The result is that a first year clerk must be used to satisfy the requirements of having three people working on the Company 3 audit. It is because of this change that the "worst-case scenario" is cheaper but produces a worse suitability.

7 CONCLUSION

This study presented a proposed solution methodology for the Stochastic Dynamic MRRA problem. This methodology can improve the fields of project management, logistics and long term business decisions, while also contributing to the ever growing field of operational research. It is more realistic to consider resource allocation over a longer term as short-term allocations may result in higher cost in the longer term.

This article reported on on-going research work in solving the dynamic, stochastic MRRA problem. Future work includes investigations of solutions to large problems (many resources and many possible allocations), and improved solution repair methods. The events at different points in time must be realised through simulation to alter the resource pool. The final goal with this research is to provide a real alternative to strategic decision making which could make a difference.

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HEALTHCARE DATA MANAGEMENT CHALLENGES IN DEVELOPING COUNTRIES: A SYSTEMATIC REVIEW

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ABSTRACT

There are many healthcare data management challenges in developing countries. These challenges have a major effect on the quality of healthcare service delivery. Therefore, it is very important to determine the most prominent healthcare data management challenges in developing countries to be able to address the right challenges effectively and efficiently. This paper discusses some of the prevalent healthcare data management challenges in developing countries through a systematic literature review. Scopus was used to retrieve literature on these healthcare data management challenges. The initial search was done on 16 April 2019 and yielded a total of 162 articles. The search terms included “data processing”, “data management”, “data administration”, “data handling”, “data control”, “information management”, “healthcare”, “Health care”, “south africa*”, “developing countr*”, “challenge*”, “problem*” and “issue*”. After the exclusion process the eventual number of articles was 62. The structured literature review was used to scope all the different healthcare challenges. The challenges were categorised into different data management categories and data management challenges subcategories using Excel. The most prevalent healthcare data management challenges were identified from literature using the Excel scope of challenges. The literature review methodology is explained, then the study selection and characteristics of the results are described, followed by the analysis and discussion of the scope of healthcare data management challenges.

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1 INTRODUCTION: HEALTHCARE DATA MANAGEMENT IN DEVELOPING COUNTRIES

Good data management is imperative for the effectiveness of any healthcare system. Despite this fact, developing countries struggle with the proper management of healthcare data. The poor management of healthcare data has an adverse effect on the effectiveness of healthcare systems, especially in developing countries.

Data management mainly entails the collection, storage, security and sharing of data gained from diverse sources [1]. According to Evariant*, an enterprise solution in healthcare, data management in healthcare is the basis that enables the holistic views of patients, personalisation of treatments, improved communication and enhancement of health outcomes. To achieve this, data must be aggregated and standardised [3]. After it is collected and aggregated, its accuracy, completeness and consistency must be ensured. Therefore, a data management plan is needed, coupled with the necessary platform to integrate data, manage its quality and utilise it productively.

Data is used in all aspects of the healthcare system. Data is collected, stored and used for patient record keeping, monitoring, diagnosis and treatment. It is also used in other parts of the healthcare system such as tracking medicinal stock levels and patient billing. Healthcare data is located everywhere: clinical and claims systems, Human Resources and financial applications and third-party sources [3]. Therefore, without the management of data, many of these healthcare system components will not be able to function properly.

There are some key healthcare data management challenges that cause the ineffectiveness of the healthcare system. These lacking data management components, discovered from literature, consist of data collection, storage, processing, transmission, retrieval, monitoring, reporting, utilization and analysis challenges. There are also many challenges with ensuring the security and quality of data. The integration of these various components is also very challenging. The various aspects causing the integration challenge are also discussed. Furthermore, the poor governance of data also contributes to the dysfunctional system. Effective and efficient data management is very dependent on technology and infrastructure, but there exist some challenges with technology and infrastructure that impede the effective healthcare data management in developing countries. Data management cost and the available financial support are also aspects contributing to the healthcare data management problem in developing countries. Humans also pose as a contributing factor to the dysfunctionality and lastly, the implementation of new data management systems are also very challenging, answering the question of why these challenges are not addressed sooner to improve data management and thereby improving the delivery of healthcare services.

This paper will discuss the different healthcare data management challenges in developing countries from literature. This enables the visualisation of the scope of challenges in healthcare data management challenges.

2 LITERATURE REVIEW METHODOLOGY

A structured literature review was conducted 16 April 2019. The search followed the process described in this section. This study followed the systematic review process as described by

* www. evariant.com/faq/why-is-healthcare-data-management-important

Pickering and Byrne [4]. Firstly, the electronic search platform and the search terms that were used are described in section 2.1. Secondly, in section 2.2, the exclusion process is described from the initial search results to the eventual number of search results. The required data will be extracted, as described in section 2.3, which will be analysed to draw conclusions from. Some variations to the process are made in section 2.3 as the steps in the process are inherent to how the study was carried out. The variation is explained in section 2.3.

2.1 Search Strategy

The first steps were to define the topic, formulate the research question, identify the keywords and identify and search databases [4]. The topic was defined as "Healthcare data management in developing countries". The research question was "What are the scope of healthcare data management challenges in developing countries?" The electronic search platform used for this structured literature review is Scopus. It was decided to use only Scopus, because it is the largest abstract and citation database of peer-reviewed literature that includes scientific journals, books and conference proceedings. Scopus consists of an extensive database with good quality and diverse sources which ensures good worldwide research coverage. Scopus developers claim that it is the largest single abstract and indexing database ever built [5].With Scopus it is possible to enter multiple search requirements with different search operators. This allows Scopus to search for results in a very specific field, while maintaining objectivity with regards to the inclusion of all results in that field. Scopus was developed by Elsevier and the characteristics of both PubMed and Web of Science were combined. This allows enhanced utility for medical literature research and academic needs [6].

The search terms were chosen to cover the research field of healthcare data management challenges in developing countries, and to specifically include South Africa. To ensure the comprehensiveness of the initial Scopus search, different keywords were used for the same concept. The variants of the term "data management" for this study include "data processing", "data control" and "information management". These terms were used in inverted commas to return only articles where the words of the terms are used in conjunction. Furthermore, healthcare was searched as one word and as two words enclosed in inverted commas to accommodate articles with the spelling difference. The search terms "developing countr" and "south africa" was used to narrow the search down to only developing countries and South Africa. These search terms were used with an asterisk to include articles where variants of these search terms are used. Lastly, synonyms of challenges were used with asterisks to ensure comprehensive coverage of articles that identifies healthcare data management challenges. These synonyms include problems and issues. Therefore, the relevant literature was retrieved with the following search keywords:

(TITLE-ABS-KEY ("Data processing" OR "data management" OR "data

administration" OR "data handling" OR "data control" OR "information

management") AND TITLE-ABS-KEY (healthcare OR "Health care")

AND TITLE-ABS-KEY ("south africa*" OR "developing countr*") AND

TITLE-ABS-KEY (challenge* OR problem* OR issue*))

2.2 Exclusion Criteria

The next step was to assess the publications to ascertain if it is relevant and whether it should be included [4]. The first exclusion criterion was to exclude articles that were published prior to 2008. Data management has evolved tremendously over the years and including articles that are too old will result in including irrelevant challenges in this study. This study strives to address relevant healthcare data management challenges of developing countries.

The second exclusion criterion was by document type. Books were excluded from this review.

Lastly, the abstracts of the remaining articles were read through to determine whether they are truly relevant to this study field. Articles were excluded during this phase based on whether they clearly mentioned any healthcare data management challenges in the abstract. Sometimes, articles were included in the initial search because the study used data management to address a totally different challenge than what this study addresses. Such articles, for example, were excluded during this phase.

This method ensured that only publications that are truly relevant to healthcare data management challenges in developing countries were included.

2.3 Data Extraction

After it was determined which articles to include in the study, the next step was to develop the structure for a personal database on the topic [4]. After the completion of the article selection process, data was extracted using MS Excel. Excel was used to develop a healthcare data management scope of challenges. The aim of the scope of challenges is to identify all the possible healthcare data management challenges of developing countries and to categorise these challenges into appropriate categories and subcategories. This scope of challenges enables the quantitative analysis of the extracted data. Other relevant data extracted from literature into the Excel sheet include:

- Year of publication
- Author(s)
- Article title
- Country or geographic area the study focused on

Whenever an article mentions a healthcare data management challenge of developing countries, an 'x' was marked under the category which that challenge belongs. Articles address multiple challenges and some challenges fall under multiple categories. The categories change and more categories were included as the data is extracted. This caused the scope of challenges to expand. At the end of the data extraction process, the categories were assessed to merge very similar challenges in the different categories. Challenges were classified under different data management components.

Due to the evolving nature of the scope of challenges, steps seven to 10 as described by Pickering and Byrne were automatically carried out in the reading of all the publications. As new challenges were found the structure of the database was updated until the final database was complete.

After the personal database was completed, the rest of the steps were carried out from analysing the findings, writing the discussion and evaluating the results and conclusions for the writing of this article.

2.4 Data Synthesis

The year of publication and the country the article focused on was included in the data extraction to map the literature studied. It gives an understanding of the landscape of the research done on healthcare data management challenges in developing countries. From the year of publication, the distribution of when the articles on this topic was published, can be determined, and from the country the articles focused on it is possible to determine the distribution of where studies have been done on this topic.

The scope of challenges gives a holistic view of all the healthcare data management challenges that developing countries face. These challenges were categorised according to the different data management components. These data management components can be regarded as the main categories. Challenges were designated to subcategories under these categories. Other main categories are additional to data management components, but also have an impact on data management. The main categories that the challenges were designated to are:

- Poor governance
- Integration challenges
- Data collection challenges
- Data storage challenges
- Data processing challenges
- Data transmission challenges
- Data retrieval challenges
- Data utilization challenges
- Data monitoring challenges
- Data reporting challenges
- Data analysis challenges
- Data quality challenges
- Data security challenges
- Infrastructure and technology challenges
- Cost and financial support challenges
- Human factor challenges
- System implementation challenges

The subcategories under the categories were determined as they surfaced in the literature. When a new subcategory appeared in literature, it was added under the appropriate category. A subcategory, general challenges were, included under most categories if the challenge was mentioned without a specific regard of a subcategory.

3 RESULTS

This section of the paper focuses on the results yielded from the structured literature review. The results from the study selection is discussed and the characteristics of these results are presented.

3.1 Study Selection

The initial Scopus search, using the previously mentioned search terms, amounted to 162 articles. From there the search results were narrowed, excluding articles prior to 2008. This yielded 108 articles. Excluding books resulted in 106 articles. Furthermore, after the abstracts were read to determine the articles' relevance to healthcare data management in developing countries, the eventual result amounted to 62 articles. Figure 1 illustrates the process of starting at the initial search protocol, to how the search results were narrowed down to the eventual number of search results through the different exclusion steps.

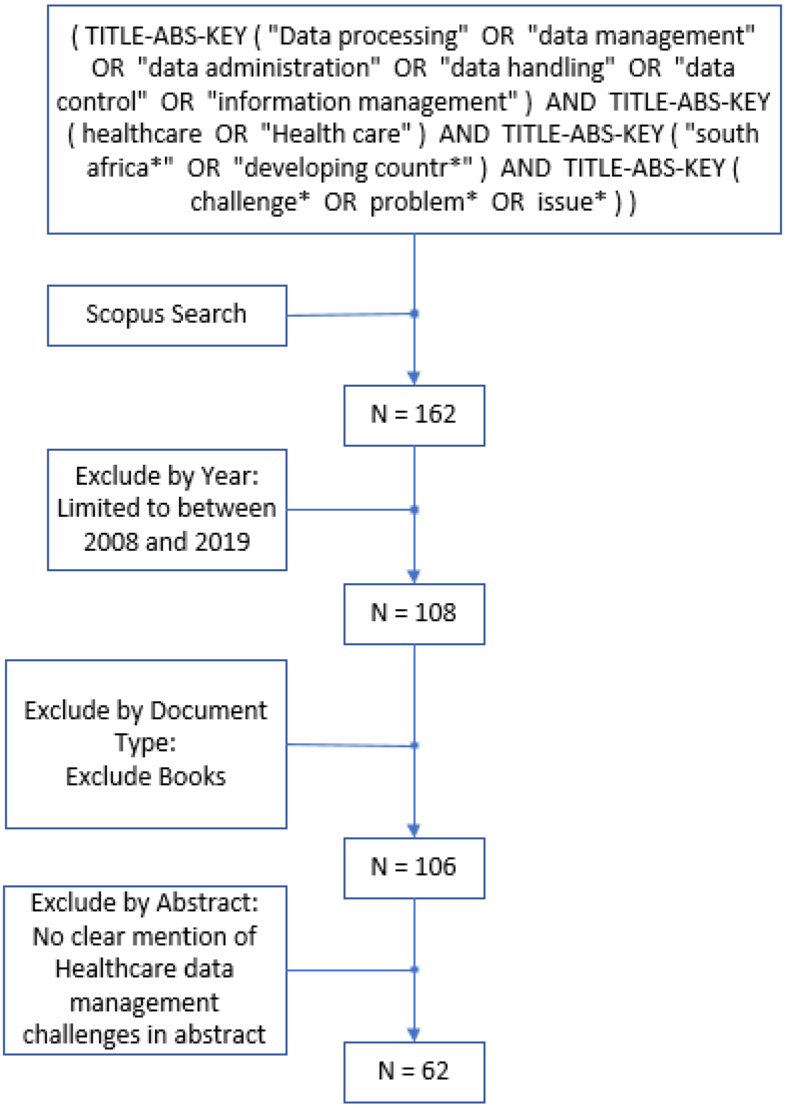

Figure 1: Structured literature review process

3.2 Study Characteristics

More than half of the articles relevant to this study were published from 2015 to 2019. This shows an increase in interest in this research over recent years. 2019, however, yielded only one article, but the reason for this can be attributed to the fact that the structured literature review was carried out early in 2019. 2015 and 2017 both yielded the most articles with a total of 12 articles each. During 2011 no articles relevant to this study was published. Figure 2 illustrates the number of articles published yearly. This figure indicates when the most and the least of the articles relevant to this study were published.

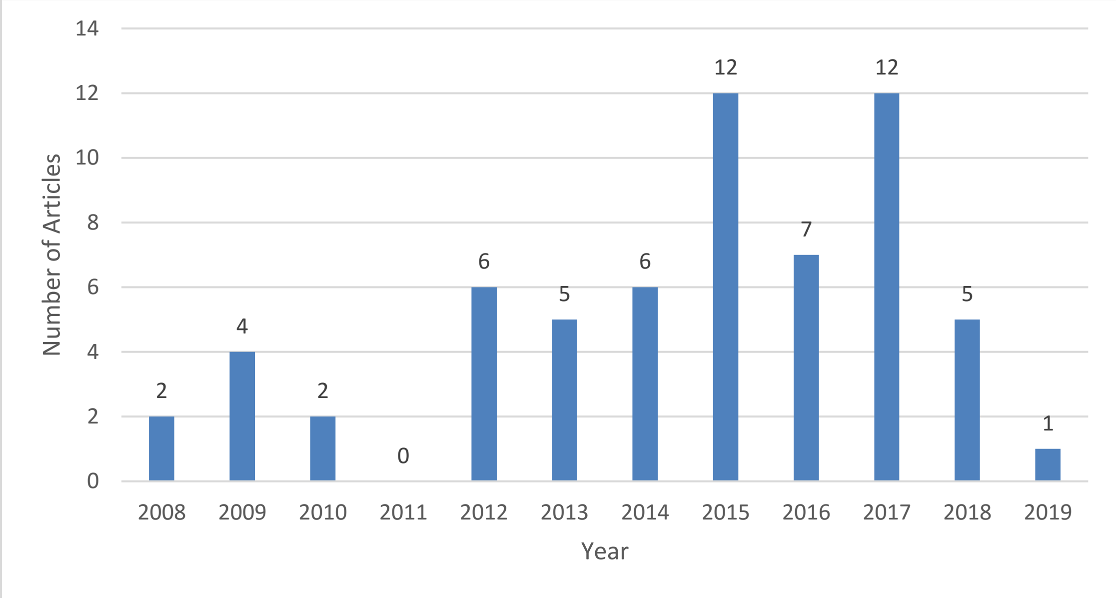

Figure 2: Number of articles published yearly

The countries or geographic area that the articles focus on were also captured. This indicates where the perspectives come from. This study focuses on developing countries, thus all countries included in this study are developing countries. Some articles did not state the country that it focuses on and addressed healthcare data management challenges for developing countries in general. When an article mentioned a country specifically, it was documented. Some articles did not mention a country, but referred to low- and middle-income countries, resource limited countries and sometimes it mentioned a larger geographical area such as Sub-Saharan Africa. As can be seen in Figure 3 the country that was focused on most, is South Africa with a total of 13 articles, followed by India with 10 articles. Four articles focused on Ethiopia and three on Bangladesh. There are many other countries like Tanzania, Uganda, Mexico, etc. included in the study that only one or two articles mentioned. It is interesting to note that 6 of the 13 developing countries mentioned is in Africa and that the country with the most articles, which is South Africa, is also on this continent. The other regions mentioned in articles can be described as:

- Low- and middle-income countries: these consider all countries with low or middle incomes.
- Developing countries: these consider countries around the globe that are not classified as developed.
- Resource limited countries: these are countries that have limited resources. This also includes all countries around the globe.
- Southern Africa: this includes Angola, Botswana, Lesotho, Malawi, Mozambique, Namibia, South Africa, Swaziland, Zambia, and Zimbabwe.
- Sub-Saharan Africa: the area of the continent of Africa that lies south of the Sahara. It consists of all African countries that are fully or partially located south of the Sahara.
- African countries: All countries in the African continent.

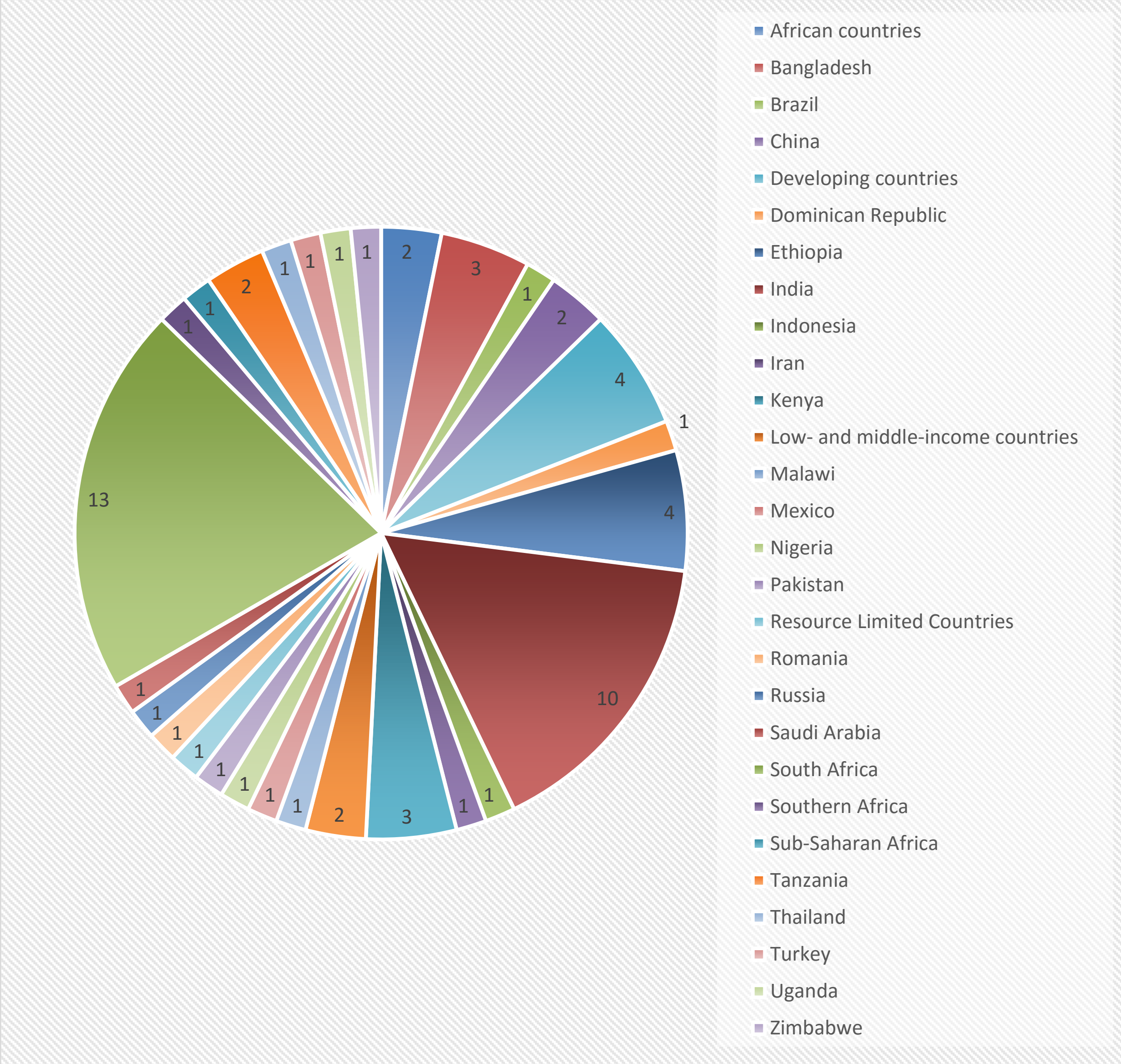

Figure 3: Reviewed articles' geographic focus

4 SCOPE OF HEALTHCARE DATA MANAGEMENT CHALLENGES IN DEVELOPING COUNTRIES

This section describes the healthcare data management challenges in developing countries. First, the healthcare data management challenges in developing countries are quantified through the data retrieved from the systematic literature review that was extracted in Excel on a scope of challenges spreadsheet. After that, the different healthcare data management challenges are explained according to their prevalence ranking.

4.1 Quantitative Analysis of Healthcare Data Management Challenges

The challenges found in the literature were categorised as stated earlier in the paper. The challenges were documented on an Excel spreadsheet as a scope of all the healthcare data management challenges identified from literature. An abstract of the spreadsheet can be seen in Figure 4 showing the article name, author(s), date of publication and how the subcategory challenges of the integration challenges category are scoped. Quantifying the number of times that challenges fall into each category gives an indication of which healthcare data management challenges are the most prominent. The total number of occurrences recorded for all the categories combined is 1147.

Title	Author(s)	Year	Country	Integration Challenges 168																			
				General challenges	System unsustainability	System design	Multiple not linked patient records	Lack of system standardization	Lack of interoperability	Variety of heterogeneous systems	Fragmented systems	Data organization challenges	System complexity	Lack of data aggregation	Lack of centralised data storage	Lack of data warehouse	Data sharing security issues	Paper based system	Incompatible infrastructure	Lack of local ownership	Flexibility	Decentralization	Meta-data governance
				10	6	2	9	16	11	15	24	6	10	14	11	2	7	13	3	1	5	2	1
Health Management for Sustainable Development	Reshetnikov, A., Fedorova, J., Prisyazhnaya, N., Sotnik, A., Shamshurina, N., Kolesnichenko, O.	2019	Russia		x								x										
Real-Time ECG Monitoring over Multi-Tiered Telemedicine Environment using Firebase	Mukhopadhyay, A., Xavier, B., Sreekumar, S., Suraj, M.	2018	India																				
Factors Affecting the Successful Adoption of e-Health Cloud Based Health System from Healthcare	Idoga, P.E., Toycan, M., Nadiri, H., Çelebi, E.	2018	Nigeria							x							x						
Private cloud solution for Securing and Managing Patient Data in Rural Healthcare System	Ganiga, R., Pai, R.M., Pai, M., Sinha, R.K.	2018	India								x						x	x					
Investigating TOE Factors Affecting the Adoption of a Cloud-Based EMR System in the Free-State, South Africa	Masana, N. & Muriithi, G.M.	2018	South Africa								x		x		x			x					
Understanding health worker data use in a South African antiretroviral therapy register	Jobson, G., Murphy, J., van Huyssteen, M., Myburgh, H., Hurter, T., Grobbelaar, C.J., Struthers, H.E., McIntyre, J.A.	2018	South Africa																				
Feasibility Analysis for Deploying National Healthcare Information System (NHIS) for Pakistan	Yaqoob, T., Mir, F., Abbas, H., Shahid, W.B., Shafqat, N., Amjad, M.F.	2017	Pakistan	x				x	x		x		x										
Lessons from implementation of ecohealth projects in Southern Africa: A principal investigator's perspective	Chimbari, M.J.	2017	Southern Africa					x			x	x											
Quality of routine health data collected by health workers using smartphone at primary health care in Ethiopia	Medhanyie, A.A., Spigt, M., Yebyo, H., Little, A., Tadesse, K. Dinant, G.-J., Blanco, R.	2017	Ethiopia					x															

Figure 4: Abstract of Excel scope of challenges spreadsheet

For each category the challenges were further categorised into subcategories. This section will discuss the distribution of the challenges between the different categories and subcategories. Figure 5 illustrates the number of challenges that occurred in each category and Figure 6 illustrates the top 10 subcategories across the different categories.

As can be seen in Figure 5 the six categories with the most challenges are integration, data collection, human factors, data security, technology and infrastructure and data quality challenges. Integration challenges is the highest by far scoring 168 occurrences. Data collection challenges had the second-most occurrences with 127 occurrences. The category with the third most challenges was human factors with 124 occurrences, followed by data security with 107. Technology and infrastructure had 91 occurrences and data quality had 89 occurrences.

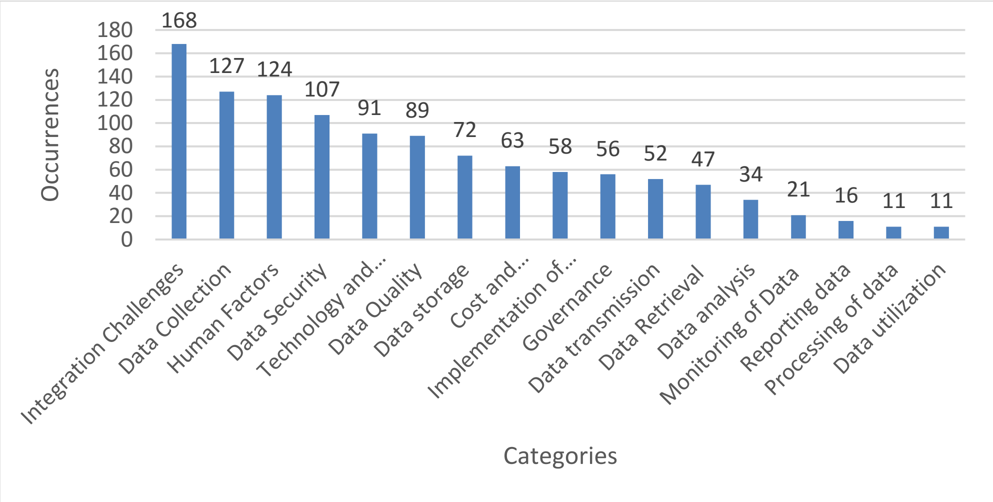

Figure 5: Number of challenges occurred in different categories

It is clear from Figure 6 that data not shared between different users is the subcategory with the most occurrences. This is followed by fragmented systems. Lack of digital data storage and missing or partial data is tied in third place. Lack of infrastructure is the next subcategory with the most occurrences. From there on it is no digital data capturing, patient privacy challenges, inaccurate data, general security challenges and network unavailability.

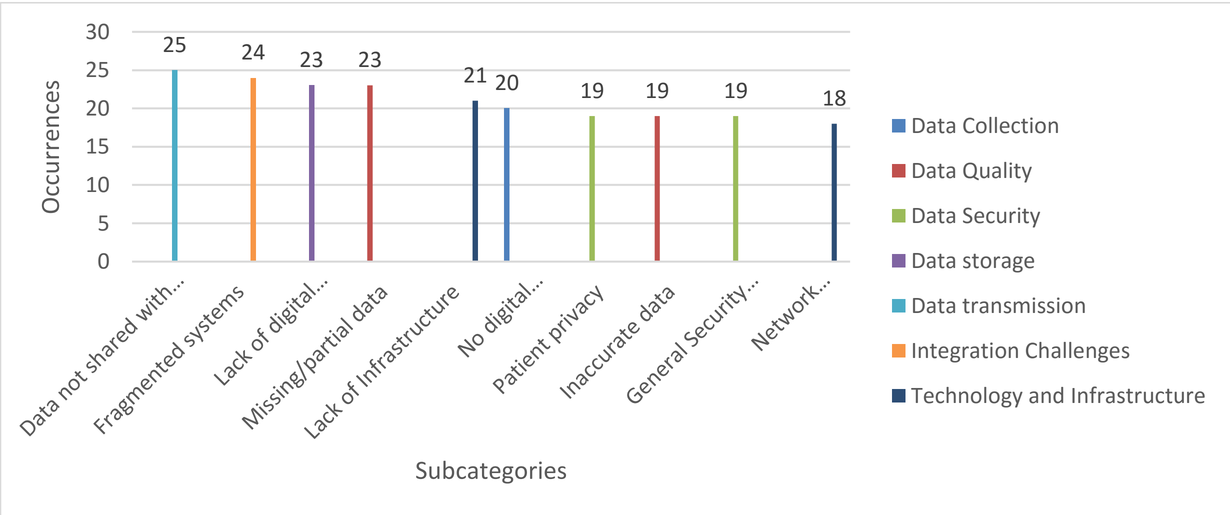

Figure 6: Top 10 most occurring subcategory challenges

It is interesting to note that the category data transmission did not have a high number of occurrences, but one of its subcategories, data not shared with different users, is the subcategory with the highest score. Out of the top ten data management subcategory challenges, categories data quality, data security and technology and infrastructure featured twice, while the other categories featured only once on the top 10. It is also interesting to note that integration challenges, the category with the most occurrences, also featured only once on the Top 10 subcategory list. All these findings convey the intricacy of the healthcare data management challenges in developing countries.

4.2 Discussion of Healthcare Data Management Challenges

This section describes the different categories challenges as found in literature. The discussion is presented according to the ranking of the highest scoring categories of healthcare data management challenges. The categories are presented in the order of highest scoring category to the lowest scoring category. Each category is introduced, followed by a discussion from literature of the different subcategory challenges of that category.

4.2.1 Integration challenges

In section 4.1 it was found that integration challenges was the category with the most occurrences. Challenges that contribute to the complication of integrating healthcare data management systems were designated to this category.

There are many factors contributing to integration challenges. There are many standalone information systems [7] and different systems have heterogeneous forms that make them even more difficult to integrate [8]–[10]. Often the necessary standardization and interoperability between systems are missing [11], [12]. Standardization and interoperability will enable different systems to share data among them.

Data is complex [13], and to manage data effectively it needs to be organized and aggregated. Aggregated data can help to make better decisions based on holistic views of data [10], [14].

Paper based data management systems make integration basically impossible [15], [16]. Incompatible technologies further complicate integration [15], [17].

Another issue is that even when it is possible to integrate systems and share data, new security issues arise [18]. Integration or sharing data should not compromise the security of the data.

As stated in section 4.1 it was found that fragmented systems is the second biggest challenge on the top 10. It is also the integration challenge with the most occurrences compared to other subcategories. It was found that in many developing countries fragmented systems was due to different subsystems operating separately and oftentimes even vertically [19]. Integration between governmental bodies or within the Ministry of Health is also missing [15]. Fragmented and heterogeneous systems traps data needed for proper decision making [20] and Sharifi *et al*. [21] stated that fragmented and inaccessible clinical information have a negative effect on healthcare quality and cost.

4.2.2 Data collection challenges

This category had the second-most challenges documented. The data collection challenges subcategories with the most occurrences are no digital data capturing, errors with collection, inefficient collection processes and methods, lack of proper entry forms, time constraint, duplication and different healthcare facilities collecting different data. It is also important to note that no digital data capturing was sixth on the top 10 subcategory list.

No digital data capturing mostly entails that data is captured on paper and documentation are done on paper as well [22], [23]. Sometimes there are systems that convert the paper-based data into digital format, but usually there is a lag before that is done [24]. Paper-based capturing makes it very difficult to exchange and access information and to monitor patient's progress [7]. Masana and Muriithi [7] also stated that the lag before data is digitalized prevents real-time data accessibility.

Oftentimes handwritten data is illegible affecting the quality of the data [25]. Data capturing errors also affects the quality of data. These errors include partial data collection or entry mistakes by the capturer [9], [26], [27].

There is also a concern about the suitability of data entry forms [21]. Sometimes forms do not allow the entry of relevant data in the way that it is structured [28]. There exists a need to standardise these forms to ensure all relevant data is captured [25].

There are different data entry points. This causes the same data to be captured multiple times. This data is aggregated only later. Data is therefore duplicated by different data capturers [29], [30].

It has also been found that different healthcare facilities collect various types of data [31]. Different sub-districts and many healthcare facilities have different interpretations of how data should be captured and managed [32].

Another data collection challenge is the limited time available to collect data [15], [31], [33]. In developing countries, it takes long to collect data and often data capturers do not have enough time to collect the necessary data. Overworked healthcare personnel has multiple responsibilities and does not have the time to collect data [33], especially when paper-based data capturing is used which is very inefficient and not time effective [34].

4.2.3 Human factors

According to the analysis of section 4.1 human factors is the third biggest challenge category. It is interesting to note that none of its subcategories are in the top 10, but still it is the third biggest healthcare data management challenge category. All human related data management challenges were designated to this category. The five most prominent human related challenges are the low skill level of staff, the lack of training, the lack of staff, digital illiteracy and lack of participation.

Many healthcare workers do not have the required skill to do the data management tasks they need to do. They make mistakes with data collection, do not know how to use the routine health information system, and lack data security, data management and data analysis skills [35].

There also exists a lack of training [21]. A lack of training means that healthcare workers are not trained before they must do their work and it also means that their skills will not improve in the future, because there are no training opportunities. Even in cases where there were training, there are no ongoing data management training available [27].

Digital literacy is another major challenge [18], [19], [35]. For healthcare workers to manage data, they need to be able to use the necessary information and communication technologies. Healthcare workers do not have the expertise to operate equipment such as tablets, computers, and smart phones [36].

Not only is the skill level or the digital literacy of the staff low, there is also a major shortage of staff [37]. This includes a shortage of data capturers [25]. The shortage of staff influences data quality [32].

Another factor is that humans do not participate in the data management system as they should. Braa and Sahay [30] found that sometimes health managers lack faith in the health management information system. A lack of collaboration of doctors and health personnel can lead to poor data quality [15].

4.2.4 Data security challenges

Data security had the fourth most challenges identified. Any challenge regarding the protection of data or protection against data breaches is included in this category. The subcategory with the most occurrences is patient privacy. General data management challenges also has just as many occurrences and both these subcategories shares the seventh place on the top 10 subcategory challenges list. Authorization, confidentiality and data integrity is the other major data security challenges.

Medical systems are more connected and networked. It is necessary to have identifiable health data in health data repositories across these systems for data accessibility and sharing, but the increase in connectivity and identifiable health data causes an increase in patient privacy risks and security breaches [9], [20]. Electronic documents have many privacy and security risks because they are accessed and transferred easily [15]. Unmanaged servers endanger data, bandwidth and other devices on the network [38].

Preservation of anonymity and security of patient records are major concerns, but in some developing countries there are no privacy laws that protect identifiable data [12], [36]. There also exists a need for well-coordinated regulatory frameworks for proper governance of the privacy and security of patient health information [19].

Another major concern is unauthorized access [18]. Authorization services include policy management, role management and role based access control [39], but sometimes even authorized users can use data maliciously [10].

4.2.5 Technology and infrastructure challenges

This category is the fifth biggest challenge category. It involves all data management challenges related to the technologies and infrastructures needed for data management in healthcare. The highest scoring subcategories were infrastructure challenges, network availability, software issues and power supply problems.

The infrastructure required for data management is lacking [11], [28], [31], [40]. Some of these infrastructures needed for data management include information technology infrastructure [39], communication infrastructure [17], and technological infrastructure to allow appropriate information storage and sharing [12]. New technologies cannot be introduced to healthcare data management systems because the current infrastructure is unable to support it [14]

Network availability is also a big problem. Ganiga *et al.* [39] found that there is a great need for high speed internet connectivity, but often the internet connection is unreliable. The unreliability of internet forces lower level subsystems to be completely paper-based [41]. Internet signal strength is often weak [34] and bandwidth costs are high, inhibiting the health systems' effectiveness [19].

Power supply has been found to be epileptic [18]. In many resource limited areas healthcare facilities do not have a reliable electricity supply to support data management activities such as electronic data storage [14], [38].

4.2.6 Data quality

Data quality is the sixth biggest data management challenge category and it has two subcategories in the top 10 subcategory challenges list. Missing data is tied in third place and inaccurate data shares the seventh place. These are the two main data quality subcategories, but poor data quality in general was also often mentioned [11], [15], [42]. Other data quality issues were data duplication, unstructured data and data discrepancy or inconsistency.

Quality data is important for many healthcare functions. Missing and inaccurate data impedes functions such as record linking, proper diagnosis and analysis, patient monitoring and clinical and public health decision-making [43].

Causes of missing or inaccurate data are nurses that simply do not write out all patient data [21], doctors that do not write diagnosis, but only symptoms and prescriptions [14] and errors made by less qualified staff [20].

4.2.7 Data storage challenges

This challenge category has the seventh most challenges documented. Challenges is designated to this category if it posed problems to the storage of data. The highest data storage subcategory, lack of digital data storage, is ranked second on the top 10 list for subcategory challenges. Loss of data is the second biggest data storage concern. Other data storage subcategories include unstructured storage, inefficient storage, reliability of storage and the lack of storage infrastructure.

Many healthcare systems in developing countries are still managing data in traditional paper-based systems [29], [39], [44]. This makes it difficult to access patient information [45] and gives rise to problems in data aggregation, transmission and analysis [29]. These paper-based stored healthcare data is also located at different geographical locations. This limits the adoption of a system-wide approach to healthcare management [15]. For some manual paper-based systems health statistics that are recorded in log books are sent to regional offices for data capturing of metrics into a centralized database, but these log books are sent infrequently [46].

Loss of data is also a common data storage challenge. Data that is needed for patient care or program management gets lost [47]. In paper-based data storage the loss of health record books are common [48] and in some paper-based systems the record room only maintains five years of patients. This results in the loss of continuous patient data [39]. Chimbari [49] found that datasets are collected at high costs, but are not analysed and gets lost over time. Digital data storage is prone to loss of data in the case of hardware or software failure. Efficient back-up is needed to prevent loss of data [38].

4.2.8 Cost and financial support challenges

This category is the eighth biggest healthcare data management challenge category. All the different cost aspects of healthcare data management are categorised under this category. Implementation cost was mentioned the most in literature. Other data management cost aspects mentioned include infrastructure costs, technology costs, systems costs, data storage costs and training costs.

Cost for implementing healthcare data management systems is the biggest cost challenge and is the main reason why developing countries struggle to adopt digital healthcare data storage [47]. Cost is also the reason why existing digital medical records are not integrated into Information Technology [10]. Additional costs of acquiring, installing and maintaining equipment is needed for integration [12].

Technology expensiveness is also a great concern. Healthcare companies have developed technologies to improve healthcare data management, but the problem is they are too expensive for developing countries [50]. Healthcare data management software and hardware are expensive [21], as well as equipment to monitor patients at healthcare facilities [34].

4.2.9 Implementation of systems challenges

Implementation of systems is ranked ninth from the different challenge categories. Challenges regarding the implementation of systems is designated to this category. Its main subcategories are resistance to change, training, technical infrastructure available to support implementation and the existing culture. The cost of implementing systems is the greatest implementation challenge, but that is categorised under the category cost and financial support.

Healthcare systems users sometimes have negative perceptions about the usefulness and the associated threats regarding new systems. This causes a resistance to adopt the new systems [15]. Threats regarding privacy and security make organizations reluctant to adopt new systems [19]. One example of resistance to change due to perceived usefulness is that reports from radiology is handwritten. Staff objected to typing it in electronically, because it takes too long and workloads are too high [14]. Patients also resist change. Warkulwiz *et al.* [36] found that patients did not want their data to be entered electronically, and preferred paper-based systems instead.

The availability of technical infrastructure is very important for systems implementation [11], but poor infrastructure makes this very difficult [38]. To ensure adoption of widespread implementation, current infrastructure available should be used to support the implementation of systems, rather than having to develop new and sophisticated technologies to support implementation [17].

Another factor is that the need for training makes implementation difficult [25]. When new systems are implemented, it involves training which is very expensive [21]. After implementation, ongoing training of personnel is also needed [27].

4.2.10 Governance challenges

According to section 4.1, this category is ranked tenth. All challenges that relates to the governance of healthcare data management is categorised in this category. Its main subcategories are policies, legislation and standards. Other subcategories include regulations, frameworks and leadership.

Policies are needed at a national level to ensure coherence [12], but there exists a lack of adequate policies and procedures [31]. Some common policies that are missing are policies regarding security [15], Information and Communication Technologies [51] and well-defined access policies to ensure authentic users can access data [45]. Policies for the use of information systems are also important, for it grants access to the systems to authorized users anywhere and at any time [16]. Kaposhi *et al.* [32] recommended changes in knowledge translation, data verification, programme management and standardization policies.

Having the necessary standards are also very important to have a system-wide approach to patient healthcare management [15]. It is found that many developing countries do not have informational and care standards and have limited existing regulations [14]. Digital health record standards have also been adopted only recently [52].

It was also found that there is an absence of legislation regarding data management [12]. Health data is collected from public and private hospitals, but because the required legislation is not in place, this data cannot be shared or used [15]. Turan and Palvia [15] also found that there are no legislation safeguarding personal health information.

4.2.11 Data transmission challenges

Data transmission was quite a low scoring challenge category, but one of its subcategories, data sharing with different users, had the highest number of occurrences of all the subcategories. Challenges regarding the transmission of data from one place to another by whatever means were included in this category. Other data transmission challenges are difficulties with disseminating data to patients, data transfer latency, unreliable network availability for transmission and transmission errors. In some cases, data was transferred in paper form.

A key challenge in developing countries is to make healthcare data accessible from rural to urban [39]. Paper based systems only allows data to be accessed from one place [53]. Therefore, there exists a need to digitalise data for data accessibility and data sharing, but if digital systems are not linked or integrated, data accessibility and exchange to different users will still pose as a major challenge [7].

Some clinical information technologies do not allow data sharing between clinicians, labs, hospitals, pharmacies and patients [54] and data is not shared between different levels of healthcare either [37]. Different healthcare facilities use their own systems with their own localized data networks. This inhibits data sharing and the adoption to a system wide approach to patient healthcare management [15]. Data is isolated in silos which impedes data sharing between care providers [10].

Legislative frameworks and an unwillingness of companies to share data are yet some other factors contributing to the lack of data sharing [19].

4.2.12 Data retrieval challenges

Data retrieval ranked twelfth. Its subcategories consist of challenges regarding the retrieval and accessibility of data. The main subcategories are historical data retrieval, real-time data retrieval, the lack of remote data accessibility and timely data accessibility.

Paper-based and manually filed medical records are difficult to access and impedes good service to patients [55]. Electronic databases can make retrieval of stored data easier [47]. Data retrieval is important to make accurate clinical decisions [10] and inaccessible clinical information has a negative effect on quality if healthcare [21].

Many developing countries use systems that do not allow timely data accessibility. For instance, healthcare systems that are divided into different categories and operating on different system makes access to patient data very difficult [18]. Other example is processes that are error-prone and time consuming causes a delay in data accessibility [53].

Recently, there has been an increase in the need to access data from remote locations [22]. This is needed so that doctors can view patient health records from anywhere and give advice and treatment [45].

5 CONCLUSION

This structured literature review gives a comprehensive overview of the scope of healthcare data management challenges in developing countries. It also quantifies which challenges occurred the most in literature. The quantification of challenges gives an indication of which challenges are the most prominent. Addressing the most prominent healthcare data management challenges will improve healthcare service delivery the most.

It is found that there has been an increase in the interest of healthcare data management challenges over recent years as more than half of the articles are from 2015 onwards. The country that articles focused on most is South Africa followed by India.

The six major healthcare data management challenges categories identified by this study is integration challenges, data collection challenges, human factors, data security challenges, technology and infrastructure challenges and data quality challenges.

The top 10 healthcare data management challenges subcategories are data not shared with different data users, fragmented systems, the lack of digital data storage, missing or partial data, the lack of infrastructure, no digital data collection, patient privacy issues, inaccurate data, general security challenges and network availability challenges.

This paper gives an idea to the scope and complexity of the healthcare data management challenges in developing countries. To solve healthcare data management challenges in developing countries, the challenges identified in this study are the major challenges that should be addressed for effective and efficient improvement of healthcare service delivery.

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AN ANALYSIS OF THE USE OF SIX SIGMA CSF IN THE IMPLEMENTATION OF IMPROVEMENT PROJECTS IN COMPANY A

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ABSTRACT

This paper evaluates how a company a freight rail company, (known as Company A in this study), has used the Six Sigma methodology to improve operational processes and reduce costs. A mixed method was used to gather data. A questionnaire with 22 Six Sigma critical success factors (CSF) was used. Interviews were conducted with project sponsors and project executing team members. Four comprehensive improvement projects that were done in this company were analyzed. Factor 1 accounted for 20.975 percent of data variation and had the following CSFs: problem solving, right tools, cross functional teams, CTQ special processes, right culture, information and communication, appropriate metrics. Factor 2 had the following CSFs: Management commitment, Project leadership, Six Sigma and strategy, Innovation and design, infrastructure and resources, motivating the workforce-this factor accounted for 19.287 percent of the total variation. The findings of this paper contributes to the Six Sigma literature by exploring the CSF that are used to improve operational processes and reduction of costs. However the results of this study cannot be generalized because only one company was evaluated.

Keywords: Six Sigma, critical success factors, improvement projects, business strategy.

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1 INTRODUCTION

Many authors have reported that Six Sigma has become a proven methodology that can be successfully used to carry out improvement projects in both service and manufacturing industries, [1; 2]. Six Sigma is a structured methodology, [3], that focusses on customers and makes use of data in analyzing the viability of improvement project, [4], or development of new products and services, [5]. Six Sigma has been combined with Lean to form Lean Six Sigma, which combines constructs of Six Sigma and Lean in improving the competitiveness of organization, [2]. Six Sigma focuses on the reduction of process variability and improves process control, [1] while Lean is targeted at the removal of waste and encourages process standardization, [4]. However, this study focusses on Six Sigma only.

There are two main tools used in Six Sigma, [5]: define, measure, analyse, improve, control (DMAIC) and define, measure, analyse, design and verify (DMADV). DMAIC provides a roadmap for continuous improvement and DMADV is a structure used in the development of a new product, process or service, [4]. However this methodology requires a human resource infrastructure that comprises of multi-skilled project team usually designated as Champion, Process owner, Master Black Belt, Black Belts, Green Belts and Yellow Belts, [4, 5]. These titles reflect a level of expertise within the Six Sigma projects execution. The project team is expected to have sound knowledge on how Six Sigma projects are implemented, and must understand financial implications of the project, [5]. Just like in other improvement efforts such as Total Quality Management (TQM) and Total Productive Maintenance (TPM), Six Sigma also requires top management support, availability of resources and effective change management, [1; 3; 5].

Most of the available literature, [4, 6], shows that Six Sigma has been implemented more in manufacturing projects than in projects carried out in service organizations such as in a freight rail company. However it has been noted that Six Sigma methodology has spread to service sectors such as banking, [7], healthcare,[8] and higher education, [9],(It is also reported that successful implementation of Six Sigma is dependent on a number of critical success factors, (CSF),[10, 11]. Most companies fail to implement Six Sigma projects due to lack of top management support,[1], weak comprehension of Six Sigma tools and techniques, [3] poor alignment of Six Sigma projects to business strategy, [5] and unclear project objectives, [10]. The aim of this paper is to evaluate through an evaluation of critical success factors (CSF) how Company A has implemented Six Sigma in its continuous improvement projects. Understanding CSF that positively impact Six Sigma implementation will help management of Company A to strategically plan on their future improvement projects.

1.1 Research Objectives

The major objective of this study is to analyse which Six Sigma critical success factors that have influenced positive implementation of improvement projects in Company A.

1.2 Research Questions

What are the CSF that influences successful Six Sigma implementation of improvement projects in Company A?

2 LITERATURE REVIEW

Six Sigma has been used as a well-thought-out approach to achieve continuous improvement, [12]. It employs the use of statistical tools to accomplish far-reaching and company-wide improvements, in processes and product quality,[13]. When correctly implemented Six Sigma has a positive bearing on an organisation's finances, [5],(Refs). Sharma and Chetiya,[11], agreed with the work of other authors when they reported that Six Sigma has proven to be a, "management approach that can be used to improve quality of products and services, increase market share, brings down production costs, increases process yields through reduction of waste and scrap thereby increasing profits".

Six Sigma uses two frameworks DMAIC and DMADV which are data driven methods used to analyse viability of new projects, [7]. Statistical methods are employed to reduce process variations and identify major improvements in either product or service quality. Expected benefits from the Six Sigma projects are identified before the project is carried out. For example in a manufacturing environment if the desire is to reduce costs then the Six Sigma team will look into costs such as of raw materials, scrap, rework, overheads among others, [9].

Marrques et al, [4], highlighted that Six Sigma projects normally follow five steps, namely:

1. Identification of Six Sigma projects;
2. Selection of Six Sigma projects;
3. Six Sigma project planning;
4. Six Sigma project execution and completion; and
5. Post Six Sigma project, where lessons learnt are determined, recorded and archived.

Gilbert et al.,[14], cited in Sharma and Chetiya,[15], identified a project selection criterion, that when followed can bring success:

1. The project should be accurately scoped.
2. The project should have an overall deliverable (Y) defined with a goal.
3. The project should have a measurement system in place.
4. Past data for Y should be obtainable.
5. There must be a strong supporting team for the Black Belt candidate.
6. There must be a sponsor and a Master Black Belt who will work with the Black Belt candidate and are tasked to make sure that the project becomes a success.

Factors that determine Six Sigma project success are, [1, 11, 15]: focus on customer satisfaction, financial benefits and top management commitment, organizational involvement and project governance.

Various authors have summarized barriers to successful implementation of Six Sigma projects, [3,11, 14,16]. Gilbert et al.,[14], highlighted factors that normally causes Six Sigma projects to fail:

- Lack of top management support.
- Too large or too small project scope.
- Project objectives not linked to business strategy.
- Inadequate resources.
- Weak cross functional team formation.

2.1 Six Sigma Critical Success Factors (CSF)

One of the most researched on theme in Six Sigma literature is the study of CSFs, [2; 11; 13], that can impact on the successful implementation of Six Sigma projects. Various authors have identified different CSF that can be regarded as the most influential, [2; 11]. These are the CSF that are considered to be more effective in the implementation of Six Sigma projects. The research gap that has been identified in this study is to find out which CSF has influenced the successful implementation of Six Sigma projects in Company A. Table 1 shows some of the CSFs that were identified to have positively impacted the implementation of Six Sigma projects.

Table 1: Different CSF that have positively impacted Six Sigma implementation

Identified CSF	Study and author
Organizational culture and employee attitude	A study on Korean companies by Cho et al. (2011) as cited in [15].
Linking Six Sigma to business strategy	A study on UK organizations, Anthony and Banuelas (2002) as cited in [15].
Process innovation	A study on Korean Samsung by Lee and Choi (2006) as cited in [15].
Data availability, prior infrastructure and training	A study on Brazil companies by Silva et el. (2018), [10].

It is clear from the above Table that in various organizations different CSFs have influenced the successful implementation of Six Sigma projects, hence the motivation of this study.

In their research on CSF factors that affect Six Sigma project selection and implementation, Sharma and Chetiya, [15], identified 17 CSF, Silva et. al, [10] identified 21 CSF, and Sharma and Chetiya [11], identified 22 CSF. The researchers adopted the CSF presented by [11], shown below, because there were viewed as comprehensive since they incorporated majority of CSF that were identified by other authors. These 22 CSF will be used in this study to analyse how Six Sigma projects were implemented in Company A.

Critical success factors adopted from [11] that will be used in this study are:

Selection of the right project

Choice of the project champion

Intensive education and training of workforce

A good measurement assurance system

A creative problem solving approach

Application of the right tool mix

Formation of cross functional teams

Linking six sigma to suppliers; long-term supplier collaboration linked with Six Sigma goals

Supplier capability assessment and enhancement

Proper identification of CTQ special processes and characteristics

Level of management commitment

Quality of Project leadership

Development of right work culture

An integrated work and process flow and management system for information and communication

Identifying and developing appropriate metrics and deliverables

Linking Six Sigma to corporate business strategy and goals

Innovation management and design capability of the firm

Process mapping and re-engineering

Availability of infrastructure and resources

Motivating the workforce

Linking Six Sigma to Customers;

Linking Six Sigma to employees.

3 METHODOLOGY

A case study approach, [17; 18], which employed a mixed methodology, [19; 20], were both quantitative and qualitative data was collected and analysed through factor analysis, [21]. For the survey data a research instrument with 22 CSF (variables), adopted from Sharma and Chetiya, [11], was circulated among multifunctional project team members. The composition of the respondents included Six Sigma designated experts such as Master Black Belts, Black Belts, Green Belts, Champions and process owners. The targeted respondents have been implementing Six Sigma projects for a minimum of four years with the most experienced ones having worked in these teams for twelve years. Interviews were conducted with Black Belts and process owners.

3.1 Data Collection

The data collection of this study was done at Company A. The research instrument was sent to employees who are familiar with Six Sigma methodology and are working on improvement projects. The respondents hold titles that are supportive of Six Sigma implementation. The questionnaire was filled in by Process owners, Champions, Master Black Belts, Black Belts, Yellow Belts and Green Belts. The researchers' concluded that the respondents have sufficient knowledge and experience in Six Sigma improvement projects. A total of 26 responses were received for analysis. The research instrument used in this study was adopted from Sharma and Chetiya, [11].

The researchers identified Company A for this study because of the following reasons:

- The company has more than five years' experience in applying Six Sigma methodology on their improvement projects.
- The senior manager of the project division is a certified Master Black Belt.
- Majority of the project personnel hold various Six Sigma titles such as Black Belt, Green Belt and Yellow Belt.
- The company has recorded some substantial savings on some of their projects.
- The company has an emphasis on training Six Sigma practitioners.

4 DATA ANALYSIS

The research instrument had 22 variables which were CSFs adopted from [11]. The questionnaire used a Likert Scale which had a five-point rating from 1 to 5: 1- not important, 2- least important, 3-important, 4-very important and 5-highly important. Respondents indicated the importance of each CSF. SPSS version 25 was used to carry out factor analysis on the responses received on these factors. Factor loadings less than 0.5 were not considered due to low correlations that deemed them to be unimportant.

Table 2 shows the value of Cronbach's α, which was obtained as 0.9217. Cronbach's alpha is used to test the reliability of the research instrument that uses a Likert-type scales. The value of 0.9217 is well above the acceptable threshold value of 0.7, [21; 22].

Table 2: Cronbach α for analysis of critical success factors

Reliability statistics Cronbanch α based on standard items	Number of items
0.9217	22

Table 3 shows the communalities of the data of CSFs. All the values are > 0.3, [21]. This shows that despite a low response rate the variables have a higher relation between each other.

Table 3: Table of communalities for critical success factors

	Initial	Extraction
Selection of the right project	1.000	.836
Choice of the project champion	1.000	.847
Intensive education and training of workforce	1.000	.773
A good measurement assurance system	1.000	.842
A creative problem solving approach	1.000	.871
Application of the right tool mix	1.000	.813
Formation of cross functional teams	1.000	.817
Linking six sigma to suppliers; long-term supplier collaboration linked with Six Sigma goals	1.000	.870
Supplier capability assessment and enhancement	1.000	.756
Proper identification of CTQ special processes and characteristics	1.000	.886
Level of management commitment	1.000	.891
Quality of Project leadership	1.000	.806
Development of right work culture	1.000	.810
An integrated work and process flow and management system for information and communication	1.000	.900
Identifying and developing appropriate metrics and deliverables	1.000	.839
Linking Six Sigma to corporate business strategy and goals	1.000	.736
Innovation management and design capability of the firm	1.000	.724
Process mapping and re-engineering	1.000	.785
Availability of infrastructure and resources	1.000	.859
Motivating the workforce	1.000	.826
Linking Six Sigma to Customers;	1.000	.745
Linking Six Sigma to employees.	1.000	.820
Extraction method: Principal component analysis		

Table 4 shows the initial eigenvalues that were obtained through the principal component analysis' Extraction Method. The items with eigenvalues above 1 were retained for the analysis and these are items 1 to 6.

Table 4: Extraction of Factors

	Initial eigenvalues			Total variance explained extraction sums of squared loading			Rotation sum of squared loading		
Item	Total	% of Var.	Cum.	Total	% Var.	Cum.	Sum	% of Var.	Cum.
1	8.867	40.306	40.306	8.867	40.306	40.306	4.614	20.975	20.975
2	2.927	13.304	53.610	2.927	13.304	53.610	4.243	19.287	40.262
3	2.205	10.022	63.632	2.205	10.022	63.632	3.738	16.991	57.254
4	1.609	7.313	70.946	1.609	7.313	70.946	2.067	9.397	66.651
5	1.338	6.082	77.027	1.338	6.082	77.027	1.824	8.292	74.943
6	1.106	5.027	82.055	1.106	5.027	82.055	1.565	7.111	82.055
7	.826	3.756	85.811						
8	.677	3.077	88.888						
9	.531	2.413	91.300						
10	.364	1.655	92.955						
11	.317	1.442	94.397						
12	.291	1.325	95.722						
13	.252	1.146	96.868						
14	.202	.920	97.788						
15	.188	.853	98.641						
16	.162	.738	99.380						
17	.059	.270	99.650						
18	.040	.180	99.830						
19	.024	.109	99.939						
20	.009	.041	99.980						
21	.004	.017	99.997						
22	.001	.003	100.000						
Extraction method: Principal component analysis									

Key: % of Var. = % Variance

Cum. = Cumulative

Figure 1 shows the scree plot with the items along the *x-axis* and their resultant eigenvalues along the *y-axis*. Six items with eigenvalues above 1.0 were retained.

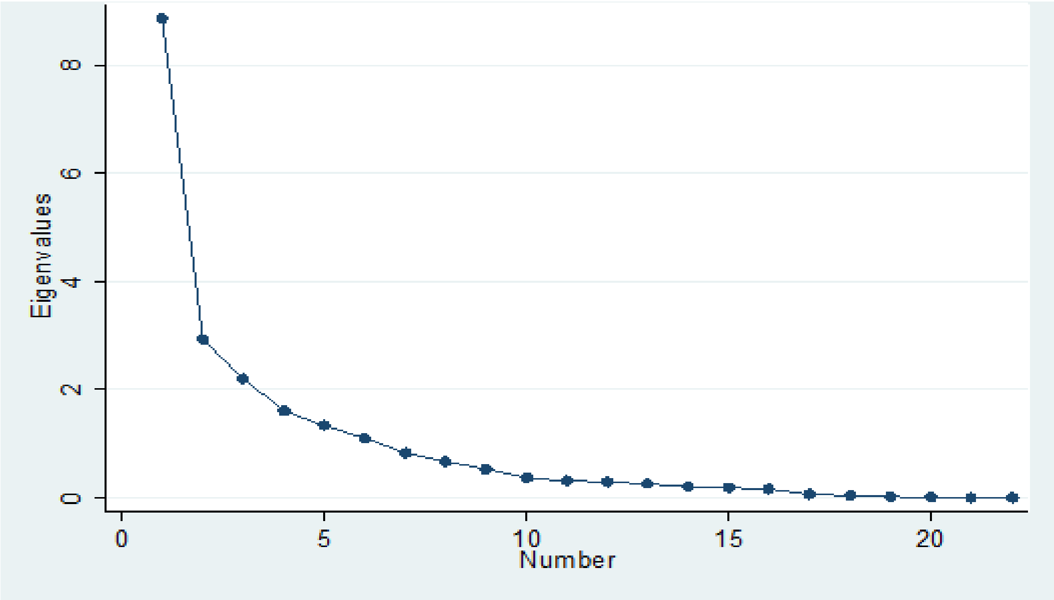

Figure 1: Scree plot for critical success factors

Table 5 shows the rotated component matrix with the correlations between the variable and the factor. Factor loadings less than 0.5 were not considered and were removed to enhance clarity. Correlations below 0.5 were judged to be of no importance, hence there were removed.

Table 5: Rotated component matrix

Rotated component matrix						
	Component					
	1	2	3	4	5	6
A creative problem solving approach	0.736					
Application of the right tool mix	0.867					
Formation of cross functional teams	0.853					
Proper identification of CTQ special processes and characteristics	0.599	0.658				
Development of right work culture	0.787					
An integrated work and process flow and management system for information and communication	0.577		0.521			
Identifying and developing appropriate metrics and deliverables	0.760					

Level of management commitment		0.738				
Quality of Project leadership		0.593				
Linking Six Sigma to corporate business strategy and goals		0.806				
Innovation management and design capability of the firm		0.591	0.545			
Availability of infrastructure and resources		0.886				
Motivating the workforce		0.737				
A good measurement assurance system			0.550		0.547	
Linking six sigma to suppliers; long-term supplier collaboration linked with Six Sigma goals			0.915			
Supplier capability assessment and enhancement			0.648			
Linking Six Sigma to Customers;			0.654			
Linking Six Sigma to employees.			0.671			
Choice of the project champion				0.910		
Intensive education and training of workforce					0.650	
Process mapping and re-engineering					0.754	
Selection of the right project						0.907

From the correlations shown in Table 5, it can be seen that out of the 22 factors only 6 underlying factors were retained.

Factor 1: problem solving, right tools, cross functional teams, CTQ special processes, right culture, information and communication, appropriate metrics- this factor accounts for 20.975 percent of the variation in the data.

Factor 2: Management commitment, Project leadership, Six Sigma and strategy, Innovation and design, infrastructure and resources, motivating the workforce-this factor accounts for 19.287 percent of the total variation.

Factor 3: Innovation and design, Measurement, Supplier collaboration, supplier capability, six sigma linked to customers, six sigma linked to employees- this factor accounts for 16.991 percent of the variation in the data.

Factor 4: Project Champion-This factor account for 9.397 percent of the variation in the data.

Factor 5: Education and training, process mapping and re-engineering- This factor contribute 8.291 percent of the total variation.

Factor 6: Project selection- This factor accounts for 7.111 percent of the variation in the data.

Table 5 depict a summary of the six factors together with percentage variance and factor loading value of each component. Cumulatively, the six factors gives a total of 82.055 percent of the variation in the data.

Table 6: Summary of factor analysis on critical success factors

Factor	% of variance	Scale Items	Factor Loading
Factor 1	20.975	Problem solving	0.736
		Right tools	0.867
		Cross functional teams	0.853
		CTQ special processes	0.599
		Right culture	0.787
		Information and communication	0.577
		Appropriate metrics	0.760
Factor 2	19.287	CTQ special processes	0.658
		Management commitment	0.738
		Project leadership	0.593
		Six sigma and strategy	0.806
		Innovation	0.591
		Infrastructure and resources	0.886
		Motivating the workforce	0.737
Factor 3	16.991	Information and communication	0.521
		innovation and design	0.545
		Measurement	0.550
		Supplier collaboration	0.915
		Supplier capability	0.648
		Six sigma linked to customers	0.654
		Six sigma linked to employees	0.671
Factor 4	9.397	Project Champion	0.910
Factor 5	8.292	Measurement,	0.547

Factor 6		Education and training	0.650
		Process mapping and re-engineering	0.754
	7.111	Project selection	0.907

5 DISCUSSION

The statistical results show that Six Sigma personnel in Company A considers the following CSF as very important to the success of Six Sigma projects implementation. The CSF are shown in Factor 1 and are: problem solving, right tools, cross functional teams, CTQ special processes, right culture, information and communication and appropriate metrics. This factor accounts for 20.975 percent of the variation in the data. Unlike previous studies, [15], that highlighted factors such as top management commitment and availability of resources as most important, [11]. Six Sigma practitioners in Company A value their ability solve problems using right tools in cross functional teams as their strength. Training Company has managed to establish the right culture were they make use of appropriate metrics and have a better way of communicating and sharing information on their projects. Other CSF that were retained as Factor 2 were Management commitment, Project leadership, Six Sigma and strategy, Innovation and design, infrastructure and resources, motivating the workforce-this factor accounts for 19.287 percent of the total variation. It is clear from factor 2 that top management commitment is also important as it guides on issues of leadership, strategy, innovation, resources and motivation of workers.

5.1 Interview Results

This section reports summarised interview results that was obtained from the Master Black Belt, Project Sponsors and Champions. The questions are shown in italics.

How does your organisation identify Six Sigma projects?

Projects normally come from senior managers The Master Black Belt noted that the company continuously checks on its KPI performance, were repetitive deviations are flagged. The KPIs are classified into five categories: capacity, efficiency, cost, risk and supplier efficiency. Once a problem area has been identified a problem definition tree is constructed. Each problem is rated on a prioritisation matrix, were they apply a set criteria and relative weight importance. The project sponsor indicated that they analyse previous year's financial performance and if they are gaps then projects will be mooted to close such gaps. The also use top-down and bottom-up approach in identifying potential projects.

How does your organisation select Six Sigma projects?

The interviewees indicated that not every problem fits into Six Sigma methodology. However the make use of methodology decision tree as shown in Figure 2. They also highlighted that the methodology decision tree makes use of other tools such as brainstorming, 5W1H, Pareto chart and Fishbone diagram.

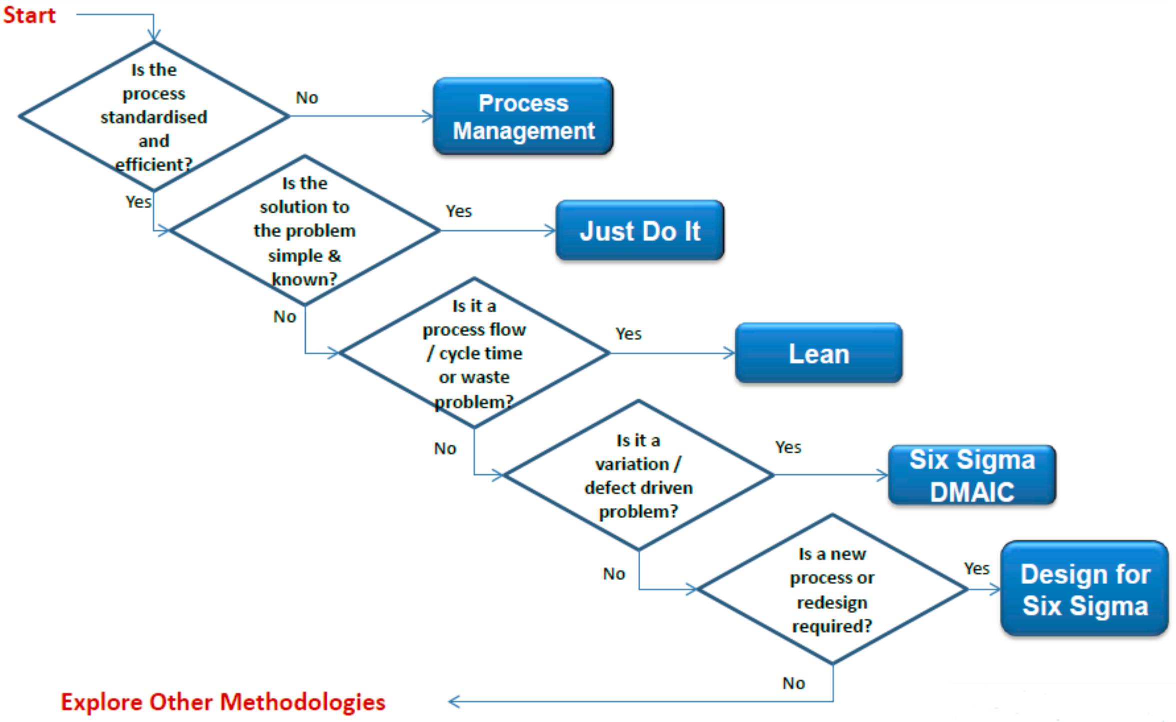

Figure 2: Methodology decision tree used by Company A.

How does your organisation plan for Six Sigma projects?

Planning for projects is done by the business based PMOs. A list of prioritised problems is compared to the list of available Six Sigma practitioners. Practitioners are allocated to problems (projects) that meet their skills and levels of experience. Practitioners that are still under training are also considered for these projects were they will be trained and certified upon successful completion of the project.

Do you always execute projects on time and within budget?

In principle all Six Sigma projects do not have a budget because all resources for example practitioners' salaries are a cost to company which is already budgeted for for the financial year in progress. In very limited cases they incur travelling expenses for projects that will be administered in remote locations. Most of their projects exceed their planned durations due to the fact that practitioners are not assigned full time to those projects.

Does your company carry out a post-mortem on how projects will have been executed?

Project progress/impact is tracked in the 12 month control phase of the project. All projects are required to be documented in a standard reporting template. A template is developed for each Six Sigma methodologies applied in the company.

Due to ethics consideration and confidentiality assured to Company A, the researchers cannot share in this paper projects that have been executed by Company A.

This study established, through interviews with Six Sigma practitioners, that most improvement projects were selected by senior managers who set up the project objectives with targeted financial benefits. This agreed with the work of [2; 7], who studied Korean companies like Samsung and LG and came to the conclusion that a top-down approach was the usual norm.

5.2 Examples of Six Sigma projects done by Company A

Table 7 shows projects that have been carried out by Company A. The results of all the projects indicate that there was some improvement from current yield to yield after Six Sigma projects.

Table 7: Six Sigma projects done by Company A

Project description	Current yield	Required yield	Yield after Six Sigma project
Chrome performance improvement (T1, T2, T3, T4-RTR_RBQ	73 mt	80 mt	78 mt
Export Coal Efficiency Programme	193 Trains	218 Trains	213 Trains
RBTG Efficiency Project	10 Trains	21 Trains	19 Trains
Train Utilisation	1 Train	12 Trains	10 Trains
Majuba Flow Cycle Time Reduction Programme	33 Trains	49 Trains	46 Trains

6 LIMITATION

The limitation of this paper is that CSFs have been used to study dissimilar populations and company sizes, making it challenging to compare results and infer conclusions. Projects from Company A could not be shared in this paper due to company confidentiality and ethics considerations. Only one company was studied hence these results cannot be geralised.

7 CONCLUSIONS

This study investigated and analysed CSFs that have influenced the successful implantation of Six Sigma projects in Company A. A survey was carried out in Company A to gather data on the most influential Six Sigma CSFs that the Six Sigma practitioners considered important. A factor analysis was carried out. The results identified the following CSFs to have influenced successful implementation of Six Sigma projects in Company A: *problem solving, right tools, cross functional teams, CTQ special processes, right culture, information and communication and appropriate metrics*. The content of these CSFs is similar to what is covered in literature although the naming may be different.

In conclusion, companies can focus on these factors to realise positive gains from their Six Sigma implementation efforts. The Six Sigma team must be trained sufficient enough to be able to carry out *problem solving*. The training of Six Sigma Belt system must also emphasise on the use of *correct tools* and identification of *appropriate tools*. Companies must also encourage use of *cross functional teams*. Use of *cross functional teams* enhances the cross fertilisation of ideas and can be used to develop the *right culture* in an organization. The Six Sigma implementation team must understand the *CTQ special processes*.

This paper therefore contributes to the literature on Six Sigma CSFs. The results of this study agrees with the work of other authors who have reported that different CSFs have positive influence on the successful implementation of Six Sigma projects. The contribution of this paper is that successful implementation of Six Sigma projects is influenced by different CSFs that can be considered to be organization dependent. Organizations must therefore identify

CSFs that are applicable to their environment. To practice the results of this paper may improve the way managers implement Six Sigma projects.

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SIMULATING VARIABLES THAT CAUSE DISTURBANCES ON ARTERIAL ROADS

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ABSTRACT

Disturbances on the roadways are a major issue in South Africa especially in busy arterial roads. The arterial roads are already facing severe traffic congestion on a daily basis. This is due to an increased number of people who have opted to reside in urban areas to be closer to their workplace, and this has resulted in an increased number of arterial road users. Arterial streets bear the predominant flow of traffic in the city because they connect important urban centres of activity and neighbourhoods to another. Added to this are disturbances that occur on the arterial road which further perpetuate the problem of congestion. The disturbances include amongst others taxis stopping for loading and unloading, street trading, and traffic lights malfunction. Also, in Johannesburg roads, there is a growing number of recyclers who pull trolleys. The recyclers make a living out of this as it is their source of income, but it unfortunately interferes with traffic flow. These disturbances tend to limit the drivers' choice of speed thereby interrupting the traffic flow, which in turn reduces the entire performance of traffic operations. It is therefore important that the city develops new methodologies to assist in planning and analysing roadways to accommodate these types of disturbances. In this study, we identify all the factors that cause disturbances on arterial roads. We then simulate all these variables to measure their effect.

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1 INTRODUCTION

The level of service usually describes the state of operation of a transportation facility [1]. Generally, this assumes an immediate and forthright relationship between the facility's performance and the average user's experience such that one measure communicates both items [2]. In actual fact, it often does not matter how efficiently a facility operates if available level of service measures do not reveal whether the people who use the facility are unhappy with it.

The urban transportation system is dynamic, stochastic, non-linear and complex [3]. Much attention has been given to traffic problems with a great interest for decades. Since the early 1900s, engineers and practitioners quickly realized that transportation networks, as a system, require control. In Johannesburg, bottlenecks for traffic flows are experienced on a daily basis, on freeways and arterial roads. One of the most majestic problems of traffic dynamics is traffic congestion. Implementing traffic lights in high demand areas assists with improving safety, by inflicting constraints to the systems' natural behavior. Likewise, traffic congestion interventions in the form of control can be utilized to actuate a different desired behavior, for example, better routing choices, controlled access; based on a different set of performance indicators.

The department of transport has implemented some form of intervention by introducing alternative public transport for the middle class to elite commuters; which were the introduction of the Gautrain and the Rea Vae bus. These strategies were meant to reduce the number of drivers on the road and thereby reduce these bottlenecks. Despite this, the number of vehicles on the road remains high as very few people are opting to use these public transport alternatives. This might be contributed to by the fact that for one, the Gautrain charges exorbitant travel fees which only a few elites can afford. Also, the transport connection from each point is very poor. For instance, if one wanted to use a Gautrain and they reside in Northcliff, they have to travel to Rosebank where the Gautrain station is located, and yet there is no Gautrain bus from Northcliff to Rosebank. This means that one must either drive and park at the station or get an Uber, which is again an additional cost. Therefore, a lot still needs to be done to improve the public transport which in a long run might help reduce the traffic congestion on the roads. In the meantime, a lot still needs to be done in terms of data collection to drive policy and decision makers towards the right direction. Various analysis has been done with a different perspective to examine the different characteristics of traffic prodigy in other countries but very few has been done in the South African context.

According to Gaziz and Herman [4] when traffic flow is unstable, small disturbances grow in a traffic stream and can finally lead to traffic jams, which are sometimes called phantom jams. The stop-and-go movements that the instability produces not only are a nuisance to motorists, but also consume more fuel, and likely cause more accidents. Some models developed aim to understand the mechanism of traffic instability with the aim to eliminate it through modifications of driving behavior or traffic control.

South African arterial road operations are vastly different from other roads of other countries. This is due to a number of activities that take place within the arterial roads; on intersections and anywhere on the street. Also, the human factor plays a vital role as it incorporates driver behavior which is a major issue on South African roads. In this study, we identify the factors that cause disturbances on arterial roads.

2 METHODOLOGY

2.1 Site description

The selected site is a large arterial road which is Beyers Naudé Drive and is situated in Johannesburg. It starts at the University of Johannesburg in Auckland Park, travelling through Melville, Roosevelt Park, Northcliff, Blackheath, and traversing N1 Western Bypass at Randpark Ridge and terminates at the N14 freeway near Muldersdrift, stretching a total of 31 km. Beyers

Naudé is one of the busiest arterial roads and is regarded as a main road. It has two lanes on both directions and consists of signalised intersections. It also connects to/from N1 North and South bypass. There are also numerous streets that are connector streets from the surrounding suburbs that connect vehicles to Beyers Naudé. This site was selected first because it is regarded as the main road since users use it to travel to connect to main economic hubs which include the City Centre, Sandton and Rosebank. And second, because the road network data like road geometry, update of new construction, traffic lanes, turn restrictions, and other tags necessary to improve vehicle navigation are readily available. The other surrounding suburbs connecting to Beyers Naudé include Montgomery Park, Risidale, Honeydew, Randpark Ridge, Fairlands, Windsor East, Albertville and Valeriedene.

Within the 31 km stretch, four intersections were selected as the focal point for placement of cameras and data collection, which were about 8 km apart. The intersections were selected because they were identified as the busiest intersections during the planning prior to the actual study. Also, this was done to capture the traffic activities as equally as possible throughout the 31 km stretch. The digital video cameras were then placed in these identified locations and strategically positioned to capture all the traffic activities within the intersections of the stretch.

2.2 Data collection

The survey day was carefully selected. The day selected had to be a normal working day (non-public holiday) and was a normal school day so that we can obtain the true sense of normal traffic. The study was conducted on a Wednesday, in the peak hours of the morning from 7:00 am to 9:00 am and again in the afternoon from 16:00 pm to 18:00 pm. The planning was done prior to the actual study to observe the busy time of the morning and afternoon. It was observed that the peak hours are between 7:00 am and 9:00 am for morning peak, and 16:00 pm to 18:00 pm for afternoon peak; and therefore, we decided to conduct the study between these time for the morning peak and afternoon peak. The field data was collected with the help of digital video cameras to capture the traffic movement and to capture the disturbances in the traffic flow. The morning direction recorded was Eastbound while the afternoon direction was Westbound.

2.3 Data analysis

The video cameras were analysed at a speed of one-eighth of the actual speed to enable recording and measurement of data. In the initial analysis, all the factors contributing to disturbances were noted and recorded. Once the initial extraction of data from the cameras was concluded, the identified factors were ranked according to the most recurring and ones with the highest observed impact on congestion. There were five main factors that were identified as the contributors of disturbances. Each of these identified factors were selected for further analysis. The stopping of minibuses was identified as the highest contributor to disturbances as well as congestion, based on the observations. This factor was then selected for simulation to further analyse its impact.

The data sets were then divided into several parts. The first set of data was to be used as input data for the simulation model. The specific data that was extracted from the video cameras for the simulation includes the vehicle types (minibus or car), the minimum and maximum speed of each vehicle, the amount of stopping time for each taxi, the waiting time for each car, and the number of cars blocked. This field data input was to help feed into the simulation model to find the total number of blocked/ stopped vehicles due to a stopping taxi, and the delay experienced due to a stopping taxi (total waiting time). The other set of data was used to analyse the other causes of disturbances which are discussed in detail under the results section.

To analyse the data for simulation, the speeds of the different categories of vehicles were measured by noting the time taken by the vehicles to traverse a length of 30 m. The observed maximum, minimum and mean speeds of the two classes of vehicles (car and minibus) and the corresponding standard deviations are shown in columns 2, 3, 4 and 5 of Table 1. The buses were eliminated when the data was analysed in order to simplify the model.

The amount of stopped time by each minibus at any given point in time was measured by observing and calculating the time from when it stopped until the time it started moving. The same method was used to measure the waiting time for the cars stopped behind the taxi as shown in Table 2. The number of blocked cars was observed to be five cars for every stopping taxi. The word minibus and taxi are used interchangeably in this paper.

Table 1: Input data for simulation

Vehicle category	Observed speed (km/h)			
Vehicle category	**Maximum Speed**	**Minimum Speed**	**Mean Speed**	**Standard Deviation**
Minibus (taxi)	62	40	53	12.53
Car	69	48	59	9.36

Table 2: Observed stopping time

Vehicle category	Observed average stopping time
Minibus	90 seconds
Car	80 seconds

2.4 Simulation model

The traffic simulation model presented was only for the simulation of stopped vehicles due to a stopping minibus. The traffic simulation model was built with Simulation of Urban Mobility (SUMO). SUMO is a microscopic, inter- and multi-modal, space continuous and time discrete traffic flow simulation tool. The SUMO package has some applications that help to prepare and analyse the simulation. The following are the most important model building principles in SUMO:

- Road Network generation
- Vehicles and routes
- Demand modelling

The base model explicitly represents the operational and design attributes of this study in the simulation model. The operational attributes include traffic flow data and driver behaviour. The design attributes include road configuration which the simulation software, SUMO, can configure when the road network is generated.

The simulation model followed in this study is shown in the flow chart in Figure 1.

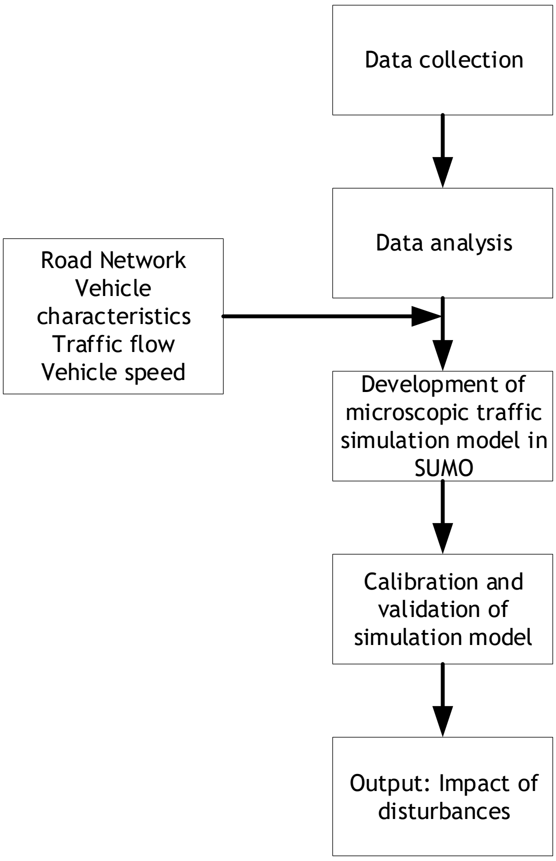

Figure 1:Flowchart for the simulation model

The steps that were followed when developing the model are: development of the network (network generation), defining vehicles and routes, and demand preparation.

2.4.1 Road network

The essential building blocks of a network are nodes, edges (including lanes) and connections. SUMO represents the road networks as graphs, nodes, which are the intersections, connected by edges, which are roads. Netconvert is a road network importer, it can convert networks from other traffic simulators like VISUM or MATSim and can also read other digital road networks such as OpenStreetMap.

2.4.2 Vehicles and routes

Since SUMO is a microscopic traffic simulation, each vehicle is defined using a unique identifier and it is described with departure and arrival properties, like the lane to use, the velocity or the exact position on the edge.

2.4.3 Preparing the demand

The method for demand modelling depends on the research topic under consideration, the study area, and the availability of data about this area's traffic. Since SUMO was designed for the simulation of synthetic population which consists of a single person with distinct routes and explicit departure times, SUMO's "native" demand definition is a list of vehicle departure times with the roads the according trip shall start and end at. Using these definitions, the according complete path through the network can be computed, using a simple shortest route path algorithm.

SUMO uses the time discrete-continuous and space-continuous car following model by Krauß [5]. The speed of a vehicle is governed by the vehicle in front of it called the leader. The model is based on a derivation of a safe gap a vehicle, the EGO, needs to stop behind the leading vehicle without colliding with it. The safe speed can be computed using equation 1.

$$v_{safe}(t) = -\tau.b + \sqrt{(\tau.b)^2 + v_{leader}(t-1)^2 + 2.b.g_{leader}(t-1)} \qquad (1)$$

where

$v_{safe}(t)$ is the safe velocity for time t (in m/s);

τ is the EGO's reaction time (in s);

b is the maximum deceleration ability (in m/s^2);

$v_{leader}(t)$ is the leader's velocity at time t (in m/s);

$g_{leader}(t)$ is the gap (between EGO'S front and leader's back) at time t (in m).

Two simulation models were developed. The first simulation the was run without the disturbances. The second simulation includes all the disturbances (stops).

3 RESULTS

3.1 Factors contributing to disturbances on arterial roads

The factors identified as the main contributing factors to disturbance in traffic flow are:

- Traffic lights malfunction
- Minibus Taxis stopping at random
- Recyclers pushing trolleys on the side of the road
- Trading on intersections and at traffic light junctions
- Driver behaviour factors.

In the following section, we discuss each of these factors in detail.

3.1.1 Traffic light malfunction

In recent months, South Africa has been faced with a dark cloud of electricity blackouts. This has been due the power utility, Eskom, not being able to supply the required demand of electricity to South Africans and the ageing infrastructure. This has resulted in the power utility having to shed some load to relieve the system and to ensure that electricity grid does not collapse. This has been termed as 'load shedding'. Load shedding has left a number of businesses, households, and systems bruised. Businesses have lost income, households have had appliances damaged, and some systems, like functioning of traffic lights disturbed. Most traffic lights' operation depends on electricity with a few operating on uninterrupted power supply (UPS) system, and when there is no electricity they stop functioning.

When there is bad weather, power cuts are experienced, leaving traffic lights malfunctioning. Also, theft and vandalism are such a big problem in Johannesburg. Criminals steal traffic light cables or even the whole traffic light and this leaves a huge problem of traffic flow disturbance. The traffic signal pole is sold as scrap metal; the cables are stolen due to the value of copper wires [6]. With the system already constrained, traffic light disturbances exacerbate the problem of congestion. According the Johannesburg Roads Agency (JRA) [7], most traffic light malfunctions are no longer caused by bad weather and power cuts, but increasingly due to cable theft and vandalism. JRA tried to tighten security by launching a new infrastructure protection unit aimed at cracking down on vandalism and theft syndicates, but since then, the criminals have killed two guards to get their hands on the infrastructure. The agency indicated that on average, it forks out R18 million a year to fix damaged or stolen infrastructure [7]. The UPS systems are also now being targeted by criminals.

3.1.2 Minibus taxis stopping at random

The majority of South Africa's population uses taxis as a transport mode in urban areas. Minibus taxis are the cheapest form of public transport accessing all parts of the city and the majority of poor South Africans depend on this public transport mode [8]. The minibus taxis account for 65% of the public transport in total with approximately 150 000 public minibus taxis [8].

One of the biggest challenges in South Africa is the lack of legal minibus stopping areas. Minibus taxi drivers are forced to stop anywhere on the road due to the nature of their working conditions. They must load and unload passengers, which usually happens at any spot. There are no standard stops as available for the buses. A passenger may request to jump off at any point, and the driver may need to pick up a passenger at any point. This has left other road users frustrated as these stops cause disturbance to traffic flow. Stopping of a minibus taxi in the middle of a lane causes huge disturbances as it blocks the other vehicles from using that lane. This means that if the minibus stops in the middle of a lane, the vehicles behind it are also forced to stop as well, resulting in congestion. Also, the unpredictability of the stopping of the minibus may result in a crash, causing even more delays to the traffic flow.

During peak hours, it was observed that on average, each stop of one minibus in a lane, delays about five vehicles travelling in that same lane, with a recorded delay of one minute 20 seconds per vehicle. Since during peak hours the road is already congested, vehicles are unable to manoeuvre and change lanes because the other lane is also congested. These vehicles are forced to wait for the minibus taxi to finish dropping off/ picking up passengers. Also, due to the operating environment of minibus taxi industry, the drivers are usually in a hurry to make more loads, resulting in reckless driving which in turn causes accidents, thereby contributing to further congestions.

3.1.3 Recyclers pushing trolleys on the side of the road

There has been a growing number of recyclers on the streets of Johannesburg pushing trolleys on the side of the road. The recyclers form part of the informal recycling business in South Africa. The recyclers are from the poor communities, with recycling being their source of income. They must transport their recyclable goods to respective recycling sites to earn some money. Due to lack of formal transportation, they use trolleys to push their recyclables. Because the roads do not have enough sideway space, they are compelled to push their trolleys on the same road that is used by vehicles. This impels the vehicles to reduce their driving speed, thereby causing congestion. Not only does this result in congestion, it is also not a safe environment for recyclers as they could be easily run over by trucks or even smaller vehicles. Sadly, this is how they make their living.

The recyclers are not prohibited from collecting waste and pushing their trolleys. According to JMPD [9], the recyclers are not breaking any laws by pushing trolleys but there are some by-laws which prohibits them to illegally trade or use trolleys unsafely on the road. On the lighter side, the Pikitup has launched a pilot project in which twenty recyclers have been given branded trolleys fitted with reflectors. The city's plan to integrate informal waste recyclers into its recycling programme is still at a pilot phase, and it will be long until the problem is completely eliminated.

3.1.4 Trading at intersections

The National Road Traffic Act [10] prohibits vendors from trading on the roads, but the constitution makes provision for the City to allow regulated informal traders at intersections. Despite this, the city's street trading by-laws [11] has strict regulation when it comes to vendors obstructing the traffic flow.

Again, for most vendors, this is a form of making a living. Informal trading is a result of unemployment and with some people having to put food on the table, they resort to trading on the streets. This causes conflicts because motorists are also travelling on the road to get to their respective workplaces to also make a living and put food on the table. Traffic congestion impacts negatively on their quality of life, because firstly, they arrive late for work, and some have to face consequences for late arrival. Secondly, it impacts negatively on productivity because less hours are being spent at the workplace with people having to leave the workplace early to beat the traffic rush.

3.1.5 Driver behaviour factors

Much research has been done in modelling the Human Factor in traffic modelling. There are various mathematical models for driving behaviour that have been developed. These include work by Hunt et al. [12], Hoogendoorn et al. [13], van Lint et al. [14], and many others. The driver behaviour factor is complex and requires a detailed study and this is not yet sufficiently been understood by the authors to allow detailed discussion and will therefore only highlight the most common findings found in literature. The fact though is that when studying the traffic flow operations, it is difficult to completely eliminate the human factor. Traffic flow operations are regulated by interaction processes, and thereby requires looking at all role players which include human factor and not just vehicles.

According to Kaber et al. [15] the driving task can be treated as a control task with two main processes to perform this task. The first process is the perception process, where the environment is recognized, understood and translated into stimuli, such as distance gaps and speed differences. This process is subject to driver traits which include attitudes, skills, all mental states, preferences, etc and the mechanical characteristics of the vehicle [15]. The second process is the response process, where a driver acts based on the perceived and perhaps predicted stimuli; which is certainly also subject to driver traits. Michon [16] illustrates these processes at the tactical and operational level as shown in Figure 2. Table 3 summarizes a review by Saifuzzaman and Zheng [17]. Although the driving environment in South Africa will differ from other countries, the process (driver perception and response) will remain almost similar.

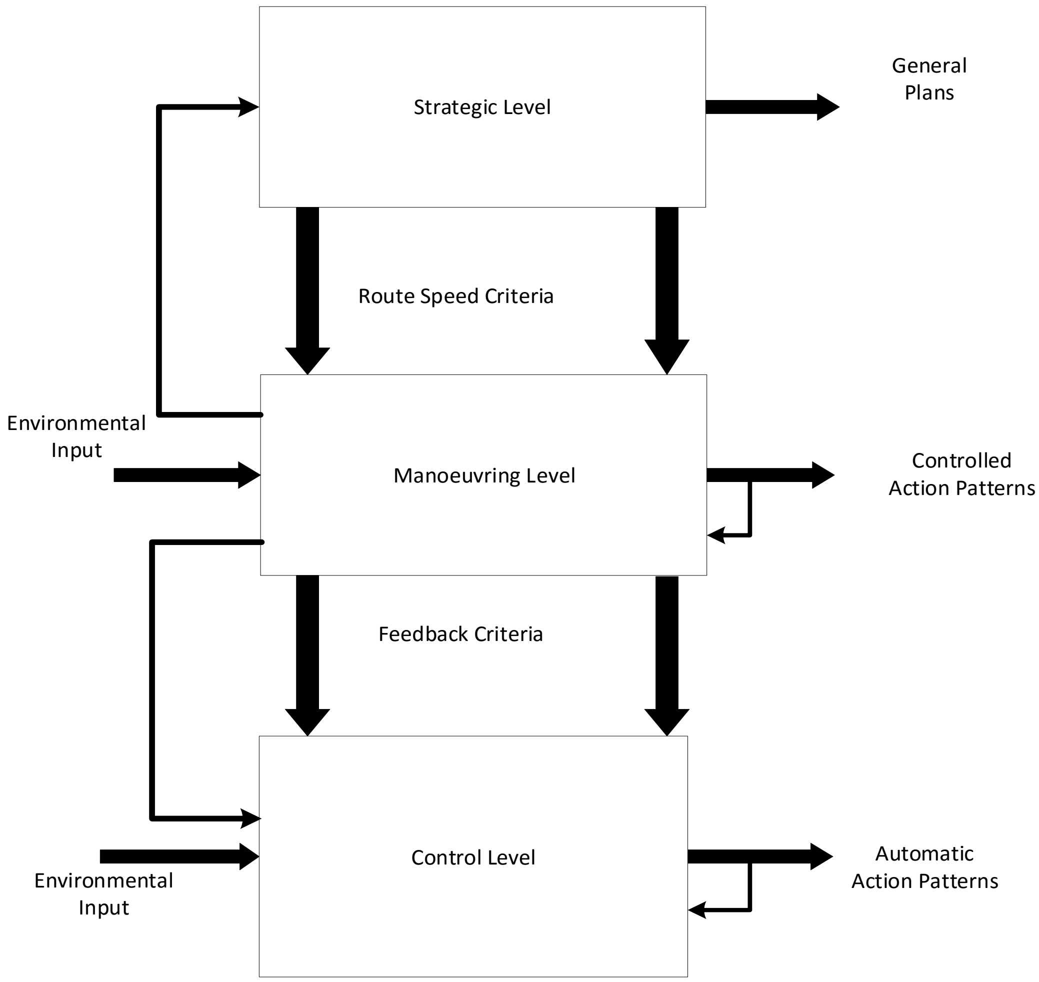

Figure 2: The hierarchical structure of road user task. Source: [16]

Table 3: A review of driver traits [17]

What (process)	**Aspects and driver traits**
Perception	Aspects and driver traits
How drivers translate signals from the environment to (anticipated) stimuli	Reaction time. This involves the physical delay between observing (a braking light) and responding (braking), and the delay caused by diverted attention. Estimation errors. Humans observe stimuli with a limited accuracy as a function of distance and visibility conditions. Perception thresholds. Humans cannot perceive small changes in stimuli. Spatial anticipation. Drivers look ahead (downstream).

	Temporal anticipation. Drivers extrapolate conditions (over space and time). Distractions. Competing information processing activities affect perception.
Response	Sensitivity to stimuli (relative speed, position, etc.)
How drivers dynamically and context-specifically respond to these stimuli.	Preferences. Driver's desired speed, spacing, headway, etc. Context sensitivity. Different contexts may (dynamically) affect driving response. Inertia. Even if drivers perceive (small) stimuli, they may not respond to these. Aggressiveness or risk-taking propensity.

3.2 Simulation results

3.2.1 Development of the Network and model parameters

The Beyers Naudé network was imported from OpenStreetMap and converted into a SUMO file using a tool called NETCONVERT. The network accurately depicts the physical attributes of the selected site. In the present simulation model, a one-way two-lane section link covering 31 km was created representing the study area located at Beyers Naudé as explained above.

The network is shown in Figure 3 and 4.

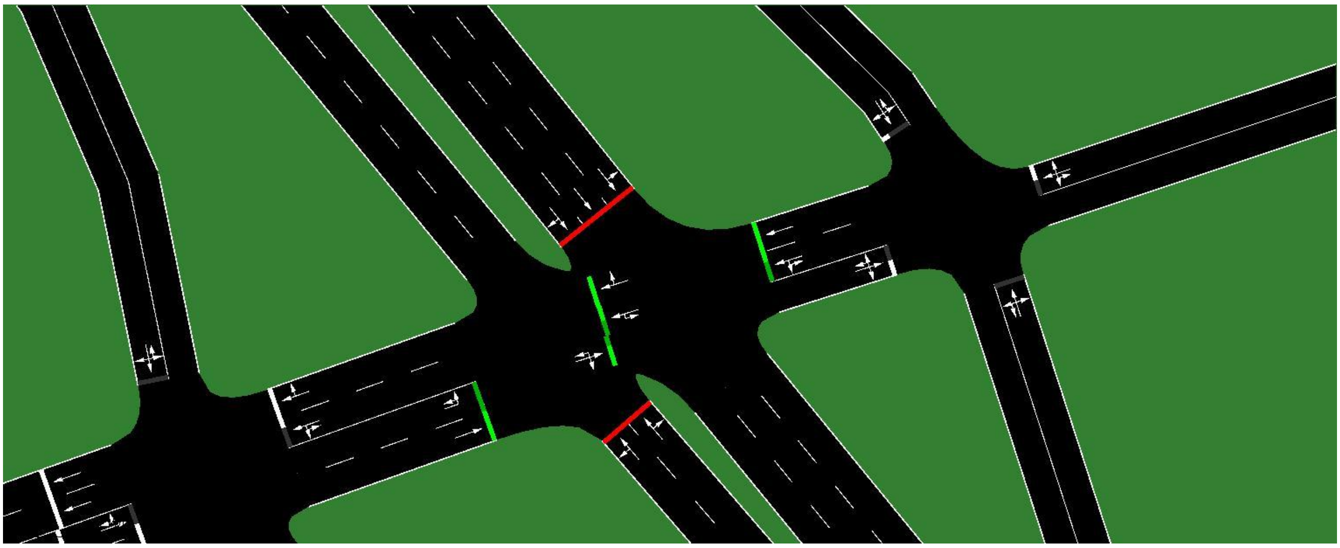

Figure 3: Beyers Naude Road Network 1

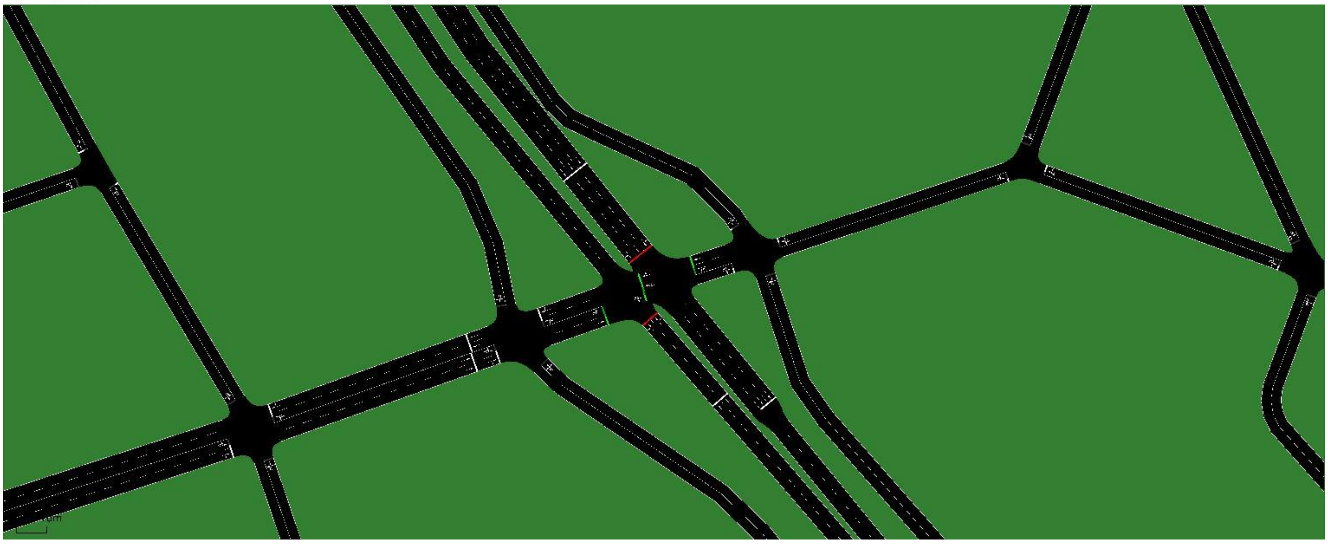

Figure 4: Beyers Naude Road Network 2

The following output files were generated:

- The Floating car data (FCD) is an output file that contains the location, speed, vehicle angle, position and lane for every vehicle in the network at every time step.
- The raw vehicle position dump which contains edges and lanes, each vehicle positions and speeds, for each simulation step.
- The lane change output file. With this file we were able to see how many vehicles made a lane change and the reason for the lane change.

With no disturbance factors entered in the simulation, the vehicles entered and exited the simulation without stopping, stopping only at traffic signals. Normal delays were experienced at intersections. Delays at intersections are experienced due to queue lengths based on vehicle arrival rate. Mpanza and Ncube [18] estimated delay at signalized intersection using queuing models.

3.2.2 Calibration and validation

Calibration is a process of adjusting the model to simulate observed data and observed site conditions to an adequate level to meet the desired objectives. This process involves adjusting the following characteristics: speed distribution, deceleration of vehicle, and stopped vehicles due to stopping minibus. By giving these parameters as an input to simulation model, simulation runs have to be carried out in order to estimate the output. In this simulation model, the outputs generated were the number of vehicles stopped due to stopping minibus, and average deceleration speeds of the vehicles. All the simulations were run for a total time of 2000 seconds to ensure accurate simulation results. The driving behaviour of each vehicle type was taken into consideration to replicate the observed driving behaviour, more especially for the taxis. For each stopping minibus, the car following were also stopped as observed from field. Calibration was also done for lane changing, where a car was permitted to change lanes only when there was no congestion on the other lane. The other values which are defaults in SUMO were selected and they produced similar results to the observed data. The observed values and the estimated values were compared and if any error was computed, the parameters were modified, and the simulation runs were carried out until the error was within the satisfactory limits.

The number of stopped vehicles and the vehicle speeds simulated by the model were compared with observed field values to check for the validity of the model. The dependent sample t-test produced the value of 1.5 (t_0). The critical value of t statistic for a level of significance of 0.05 for 4 degrees of freedom obtained from standard t-distribution table was 2.776. This suggests that there is no significant difference between the observed and the simulated values.

Figure 6 of the simulation snapshot shows vehicles trying to change a lane due to a vehicle that stopped in front them and shows some vehicles driving recklessly.

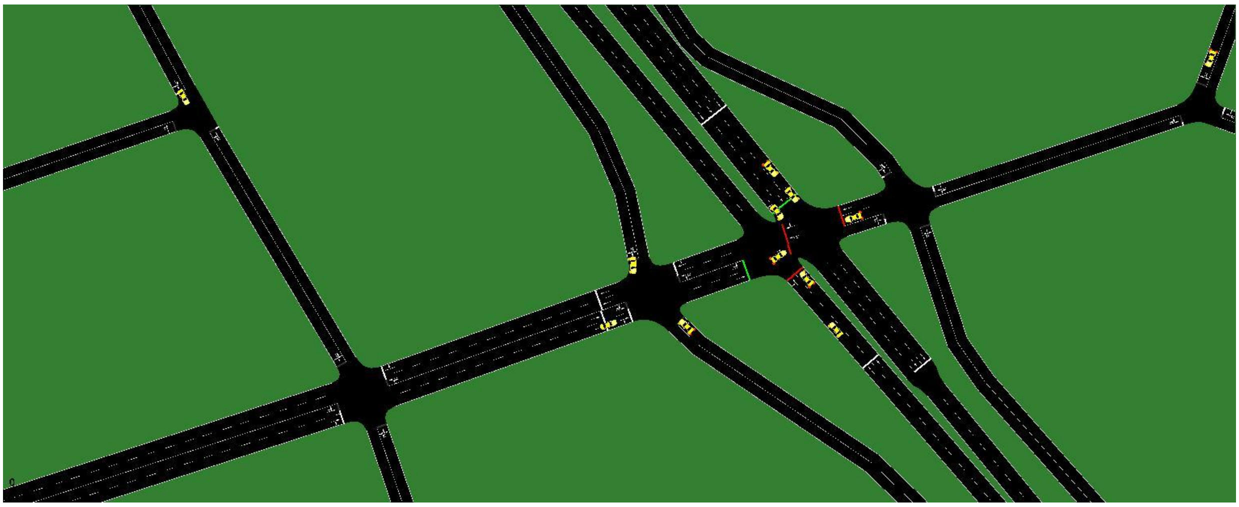

Figure 5: A snapshop of a Simulation run

Figure 6: Simulation run showing stopped vehicles.

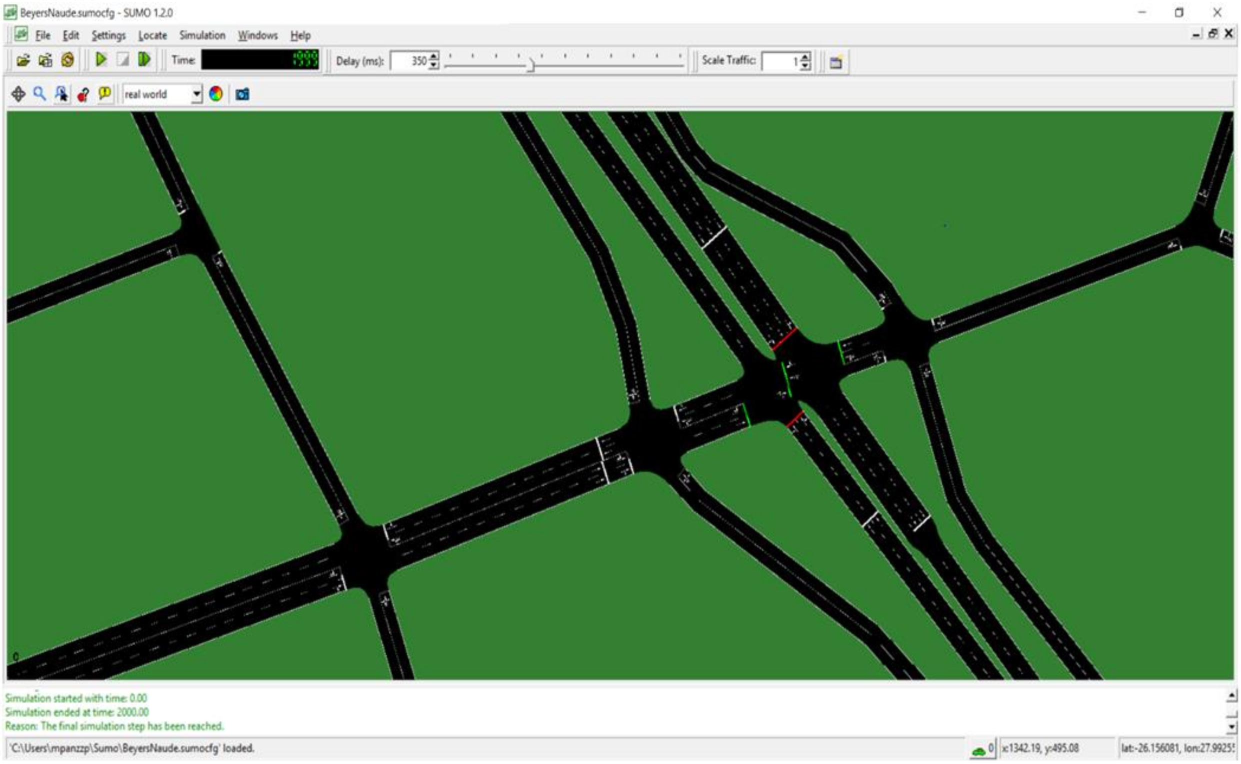

Figure 7: A snapshot of a completed simulation run

The simulation output showed that with one minibus taxi stopping in the middle of a lane, five vehicles were blocked and had to wait for the taxi to start moving again. The average waiting time per vehicle was 1 minute 20 seconds. The output from the simulation run showed that out of the 1100 vehicles that entered the simulation, a total of 540 were stopped, resulting in a total waiting time of 720 minutes. This in turn resulted in high congestion.

4 CONCLUSION

The focus of this study was to identify the factors that contribute to disturbances on arterial roads. Beyers Naudé was chosen because it is one of the busiest arterial roads, and therefore a number of activities will take place here. Hence it was ideal for satisfying the objective of the study. Since Beyers Naudé is a long stretch, four digital video cameras were placed in different intersections to capture the traffic activities. The factors identified in the study are experienced by many road users on a daily basis and they have a negative impact on their quality of life. The taxis stopping in the middle of a lane was identified as the factor causing more disturbances. While there maybe underlying reasons for this type of driving, strong law enforcement still needs to be exercised to eliminate this factor.

Criminality also plays a major role and has a negative impact on road users. Theft of traffic light cables leave motorists with a problem of congestion causing delays. Implementation of improved technology might assist to prevent theft.

The simulation model assisted in simulating the identified factor which is taxis stopping anywhere, causing disturbances. The simulation results showed the number of stopped vehicles.

The discussion around driver behaviour was limited in this study due to its complex nature. This driver behaviour will be extended further in future studies as it was found to be a much more complex factor. Nevertheless, the study provided many interesting insights. For instance, the reasons and the underlying issues of these disturbances' existence need to be investigated further. It will be interesting to unpack each of these issues and tackle the root causes in order to eliminate them.

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EVALUATING LEAN IMPLEMENTATION SUCCESS IN SMALL AND MEDIUM MANUFACTURING ENTERPRISES

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ABSTRACT

This study investigates lean manufacturing among South African small, medium and micro (SMMEs) manufacturing enterprises based in the Gauteng Province. Lean is widely regarded as a proven productivity improvement methodology; yet, its impact on South African SMMEs remains relatively unknown. The study used a mixed method approach. Survey data was analysed using statistical methods from 32 responses received from SMMEs in various manufacturing sectors. Interviews were conducted with management and workshop employees. The results revealed that most SMMEs experienced short-term successes that did not exceed three years, implying that they failed to sustain the gains of lean manufacturing. Factors found to have a positive impact on the success and sustainability of Lean implementations were change management, adequate budget, resources with appropriate skills, senior leadership commitment, and adherence to an implementation plan. These results contribute to the lean implementation theory and can be used as a guide by lean practitioners.

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1 INTRODUCTION

The South African economy has since the 2008 global economic downturn struggled to reach a Gross Domestic Product (GDP) growth target of 6%, [1].

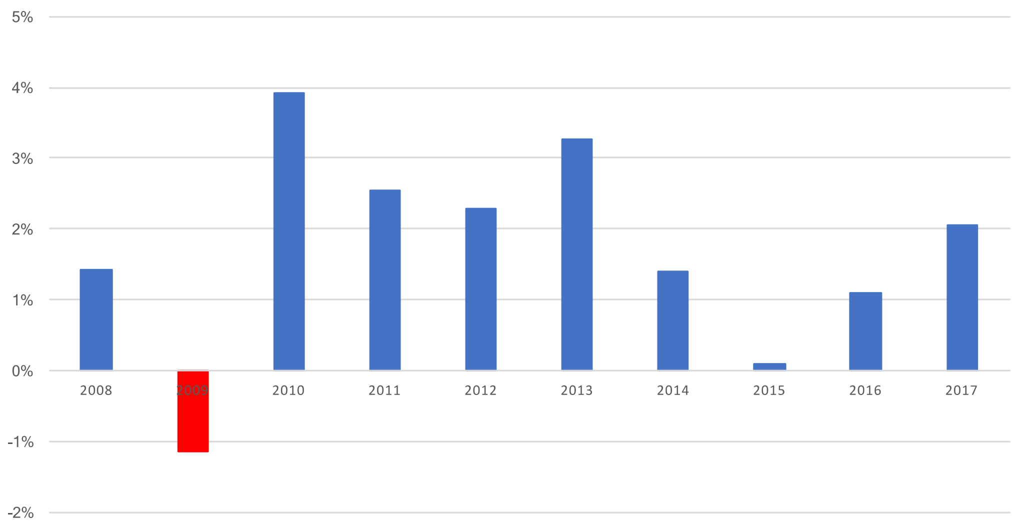

Figure 1: South Africa GDP Growth Rate [1].

The inability of the South African economy to reach the targeted GDP level of 6% has had negative societal consequences resulting in high unemployment, poverty and inequality. According to Amra et, al. [2],_small, medium and micro enterprises (SMMEs) are globally credited for being the main driver of equitable economic and industrial development. South Africa has relatively low levels of entrepreneurship with SMMEs accounting for only 55% of employment compared to 90% in China, India and Indonesia, [3].

To become competitive, companies have looked at means of improving their manufacturing processes by introducing production improvement systems, [4]. These systems include six sigma, lean manufacturing, theory of constraints and process re-engineering. Of all manufacturing improvement systems, lean has been credited for dramatically increasing productivity in companies that have implemented it, [5]. Through lean, improving productivity becomes a continuous pursuit that reduces costs and waste, rather than a series of once-off initiatives, [6].

South African based small, medium and micro-manufacturing enterprises (SMMMEs) have in the last few years embraced and implemented lean manufacturing as a key manufacturing and management approach to improving productivity and managing competition, [2,3, 4]. Little is known about the success rate of these implementations and its impact on the South African SMMEs. With this background, it is critical to understand and evaluate lean implementation success among South African SMMEs. However this paper focusses on SMMEs that are in Gauteng province. Gauteng province has many manufacturing SMMEs and the researchers' have worked with most of them. The researchers considered that in the interest of resources and time for data gathering, it is better to focus on Gauteng SMMEs only.

1.1 Research Objective

The objectives for the study were the following:

i. To establish a correlation between successful lean implementations and their impact on productivity metrics at Gauteng-based SMMMEs.
ii. To evaluate Lean implementation success rates among Gauteng-based SMMMEs.

iii. To investigate factors that impact SMMME Lean implementation in the Gauteng Province.

1.2 Research Questions

The major research question of this study is" How successful has Gauteng based SMMEs been in their lean manufacturing implementations?" The sub questions are:

- How do Gauteng-based SMMMEs measure lean manufacturing success?
- What are the pitfalls that characterise a Lean implementation outcome in an SMMME?
- How sustainable were lean implementation improvements in Gauteng-based SMMMEs?

1.3 Hypotheses

The following four hypotheses were tested (where perceptions of Lean implementation success and factors that influence the outcome are discussed by the respondents):

H_1: Lean implementation success rate among Gauteng-based SMMMEs is below 40%.

H_{01}: Lean implementation success rate among Gauteng-based SMMMEs is above 40%.

H_2: Lack of one or more of the following SMMME capability factors of management experience, Lean expertise, company culture, business needs, employee training, availability of financial and human resources will result in a failed Lean implementation.

H_{02}: Lack of one or more of the following SMMME capability factors of management experience, Lean expertise, company culture, geographical location cultural influence, business needs, employee training, availability of financial and human resources will not result in a failed Lean implementation.

2 LITERATURE REVIEW

This section covers literature review on SMMEs and lean manufacturing.

2.1 Definition of SMME

A single, uniformly accepted global definition for SMME doesn't exist, [7]. Different countries or economic regions tend to develop their own definitions based on a widely accepted practice that, a definition of SMME comprises some or all of the following three parameters namely: Number of employees; Annual turnover; and Asset value.

In South Africa, the National Small Enterprise Act , The SA Government Paper No. 102, (1996), [8], defines SMME categories as follows:

- Micro enterprises: 1 – 5 employees; turnover: <R200,000; Assets: R100,000
- Very small enterprises: 6 – 20 employees; turnover: <R6 million; Assets: R2 million
- Small enterprises: 21 – 49 employees; turnover: <R32 million; Assets: <R6 million
- Medium enterprises: 50 – 200 employees; turnover: <R64 million; Assets: <R23 million
- Large enterprises: 200 employees; turnover: >R64 million; Assets: >R23 million

This study adopted the South African SMME definition. Extensive international studies that include the works of the Muhammad et al. [9]; Yoshino and Taghizadeh-Hesary [10]; summarize the following key challenges facing SMMEs: Difficulty in accessing finance [11]; Low level of business Research & Development (R & D), Insufficient use of information technology, Low productivity, [3; 11], Government bureaucracy and regulations [3]; Access to market (both domestic and international markets [7;13]; Lack of managerial capability [3]. Literature suggests that there are some historical challenges faced by South African SMMEs [11, 14], such as: High levels of crime, onerous labour laws [2, 15], and poor Infrastructure and service provision [3].

2.2 Lean Manufacturing

The term lean manufacturing was coined by WAYMO CEO, John Krafcik (1988) to describe the Toyota Production System (TPS). The term was popularised by Womack et al., [17] in their watershed book called "The machine that changed the world", (Womack, 1990). Lean manufacturing can be described as a business philosophy that is concerned with maximising value for customers through the reduction of muda (waste). Shingo defined TPS/Lean as being 80% waste elimination, 15% production system and only 5% Kanban, [18]. It is underpinned by Industrial Engineering Techniques. The terms TPS and Lean Manufacturing are used interchangeably in this research document due to the background already provided above.

There are five steps to implementing Lean, namely: identify value; map the value stream; create flow; establish pull; and seek perfection, [17]..

There are two primary pillars to TPS and subsequently Lean, namely JIDOKA and Just-in-Time (JIT) [19]. Figure 2 illustrates how the TPS/Lean pillars interface with Toyota philosophies and desired outcomes.

Figure 2: TPS/Lean Model [20].

The oldest part of TPS/Lean is the concept of Jidoka that was developed in the 1920s by Toyoda founder, Sakichi Toyoda, at his weaving and looming plant (Smalley, 2002). Jidoka is concerned with building in quality at the production process as well as enabling the separation of man and machine for multi-process handling. There are two parts to Jidoka: 1) Building in quality at the process, and 2) Enabling the separation of man from machine in work environments.

The second pillar of TPS/Lean is the JIT pillar of the production system. Kiichiro Toyoda coined the phrase Just-in-Time in 1937 after the start of Toyota Motor Corporation, [21]. The company was poor and could not afford to waste money on excess equipment or materials in production. Everything was expected to be procured just in time and not too early or too late. The JIT concept aims to produce and deliver the right parts, in the right amount, at the right time using the minimum necessary resources.

The original Toyota model of Lean Manufacturing, from which various hybrids were developed, comprised eight tools and approaches, [18; 20; 22].

- **Total Productive Maintenance (TPM)** – An approach to asset care or equipment maintenance that aims to improve productivity through equipment reliability. Overall Equipment Effectiveness (OEE) is a key metric in TPM.
- **Visual Workplace (5S)** – 5S consists of 5 pillars that start with an "S" (Hirano, 1995). The 5 pillars are defined as Sort, Set in order, Shine, Standardise and Sustain. The objective of the 5S' is to expose defects visually to allow for the elimination of waste.
- **Just in Time (JIT)** – JIT generally precludes large batch production; instead, items are made in batches of one, referred to as one-piece flow. One-piece flow's ultimate goal is to expose quality and cost
- **Single minute exchange of dies (SMED)** – Achieving JIT requires using small-lot production employing SMED and dramatic reductions in lead times.
- **Jidoka or Autonomation** – Jidoka is anchored around the notion of building in quality at the production process as well as enabling the separation of man and machine for multi-process handling
- **Production work cells** – A production logic that brings together people, equipment and processes into a single location.
- **Kanban** – Kanban means "tag" or "ticket" (Shingo, 1988). The Kanban system is used as a means of control and coordination.
- **Poka-Yoke (mistake-proofing)** – Poka-yoke refers to a source inspection system that strives to achieve 100% inspection through mechanical or physical control (Shingo, 1986).

Common techniques found in Lean manufacturing today include: Just-in-time, SMED, Visual Management, 5S, PDCA cycle, 5-Why problem-solving (and the other 6 quality control tools), Value-stream mapping, Standardised work, Eight wastes, Hoshin Kanri (policy deployment), Total productive maintenance and Poka-Yoke. These techniques will all be considered as elements of Lean and companies will be measured against these techniques.

Lean is widely recognised as a productivity improvement technique because of proven and sustained results that Toyota has achieved over decades. Typical key performance areas that measure the success of Lean are Safety, Quality, Delivery, Cost and Morale, [23]. Companies implementing Lean tend to measure the five (5) key performance areas and benchmark each other based on those KPAs.

A study by Moorthi [4], highlighted significant benefits to implementing Lean and Moorthi specifies the following benefits to implementing Lean:

- More than 10% increase in direct labour utilisation
- 50% reduction in inventory
- 70% decrease in manufacturing cycle time
- 50% increase in capacity on current machines
- 90% reduction in lead time
- 80% quality improvement
- 75% reduction in space utilisation

The benefits presented are primarily results from big companies. The researcher analysed other research looking at Lean implementations in SMMMEs and found similar benefits often found in bigger organisations. Pingyu and Yu [24], found in the study of Lean Manufacturing in Wenzhou (China), that in some cases (before and after), measurements have been performed and the following Lean benefits were realised:

- A decrease of work in progress (WIP) by 90% and finished goods inventory (FGI) by more than 50% through layout improvement and single minute exchange of dies (SMED) activities
- Welding/assembly capacity increase by 50%
- Forty-three per cent (43%) set-up time reduction through SMED
- Decreased inventory level by two thirds

Pingyu and Yu [24], studying the impact of Lean at 100 SMEs in Wenzhou, China, also found the following challenges linked with implementing Lean:

- Misunderstanding of Lean – Pingyu and Yu found the following misunderstandings:
- The implementation of Lean requires a large investment and is only suitable for large companies,
- Lean is only suitable for specific industries,
- Lean originated in Japan and is not suitable for other countries,
- Employees' resistance to Lean – Pingyu and Yu argue that as a major business reform, the implementation of Lean will face resistance from the natural habit of internal people in the company.
- Implementing Lean mechanically without revision according to the environment of the company implementing – Pingyu and Yu note that Lean has gradually developed based on Toyota's specific environment, such as socio-economic and cultural backgrounds. Many SMEs implemented Lean as a particular technology without understanding its true meaning.

Emiliani [25], argued that the biggest obstacle to Lean is executive resistance. He noted that it is widely acknowledged within the Lean community that there has been far less recognition and acceptance of Lean as a more effective system of management than was originally imagined. Emiliani [25], further argued that senior management typically has multiple business improvement approaches that can be deployed with ease and quicker when compared with Lean.

3 RESEARCH METHODOLOGY

In order to be able to compare results, a mixed methods research design that combined quantitative and qualitative research elements was used in this study. Individually, qualitative and quantitative research methods have over time been criticised for lacking objectivity and generalisability [26], and as a consequence, a need to structure the study around a method that was more robust was a key factor in determining the mixed method design structure.
The quantitative approach of this research study was conducted using a survey questionnaire while the qualitative approach was conducted through interviews, [6].

Respondents were asked to reflect on the outcomes of a Lean implementation in their organisations, and to examine the success rate and factors influencing those Lean implementation outcomes. The questionnaire was distributed via email to 120 potential respondents in 80 SMMEs companies based in Gauteng Province of South Africa. Of the 120 identified respondents, 32 responded.

Respondents were asked to reflect and elaborate on the outcomes of a Lean implementation in their organisations. These reflections were structured around personal interviews that were conducted with identified representatives of five different companies based in Gauteng Province of South Africa. Qualitative data was analysed through themes found in lean management.
The quantitative data that was gathered was analysed with the help of SPSS Version 25, a statistical software package. The following statistical tests were performed: Descriptive statistics and frequencies to describe the group profile and Hypothesis testing was done through: Shapiro-Wilk tests, Mann-Whitney U tests, Chi-square and p-values.

4 RESULTS

The results were divided into two sections. Section 4.1 reported on the quantitative results and Section 4.2 reported on the qualitative results.

4.1 Quantitative Results

The quantitative results came from respondents who were employed by small and medium-manufacturing enterprises based in the Gauteng Province of South Africa. The study was unable to gather data from micro-manufacturing enterprises; further research needs to be done to ascertain Lean success rate in micro-manufacturing enterprises. Companies that responded were into a variety of sectors that include furniture, plastics, metal fabrication, packaging, textile and chemical. 23 companies had implemented lean for 2 years or less while 9 companies had implemented lean for 3 years or more.

Table 1 shows how long has the researched companies been in existence.

Table 1: Years organisation has been in existence

How long has the organisation been in existence		
Years	Frequency	Percent
Up to 14 years	15	46.9
14 years or more	17	53.1
Total	32	100.0

Table 2 shows the number of employees in the researched companies.

Table 2: Number of employees

Number of employees		
Employees	Frequency	Percent
10 to 49	18	56.3
50 to 249	14	43.8
Total	32	100.0

Table 3 shows positions of respondents in their respective organisations.

Table 3: Your position at the organisation

Your position at your organisation		
Position	Frequency	Percent
Production Manager	8	25.0
Operations Manager	8	25.0
Quality Manager	4	12.5
HR Manager	3	9.4
Director	7	21.9
Other (Factory Manager/ Foreman	2	6.3
Total	32	100

Table 4 shows the roles of the respondents during lean implementation in their respective organisations. Majority of the respondents were either project leaders or project sponsors.

Table 4: Your role during lean implementation process?

Your role during lean implementation process		
Role	Frequency	Percent
Steering committee leader	1	3.1
Steering committee member	1	3.1
Project leader	20	62.5
Project sponsor	9	28.1
Senior manager	1	3.1
Total	32	100

Table 5 shows lean manufacturing approach used by the researched companies.

Table 5: Lean manufacturing approach used by your company.

Lean manufacturing approach used by your company		
Lean approach	Frequency	Percent
Workplace challenge	7	21.9
Mission Directed Work Teams	22	68.8
20 Keys	2	6.3
TRACC	1	3.1
Total	32	100

Figure 3 shows what were the aims of implementing lean in the researched companies. It is clear that the aims of lean implementation were well understood by all the companies as shown by the high values received on all aspects. Understanding aims of lean implementation helps companies to focus and commit the necessary resources, [4, 7]

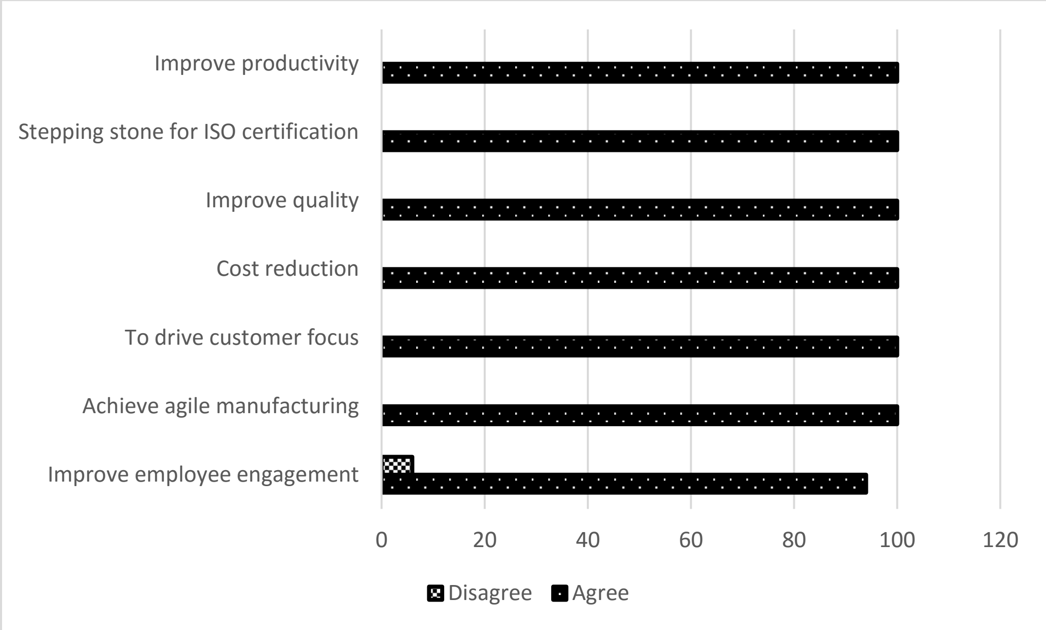

Figure 3: Aims of lean implementation.

Figure 4 shows lean implementation approach that was used by the companies under study. It shows that employee ownership was emphasised during lean implementation. Involving employees and encouraging employees to own processes normally results in better results [5; 7]. Most companies used a reward system. However the lean approach was not designed to suit the individual companies' resources, time and expertise. Implementing lean for the entire organisation without pilot phases might deliver poor results due to constrained resources, [9; 10]

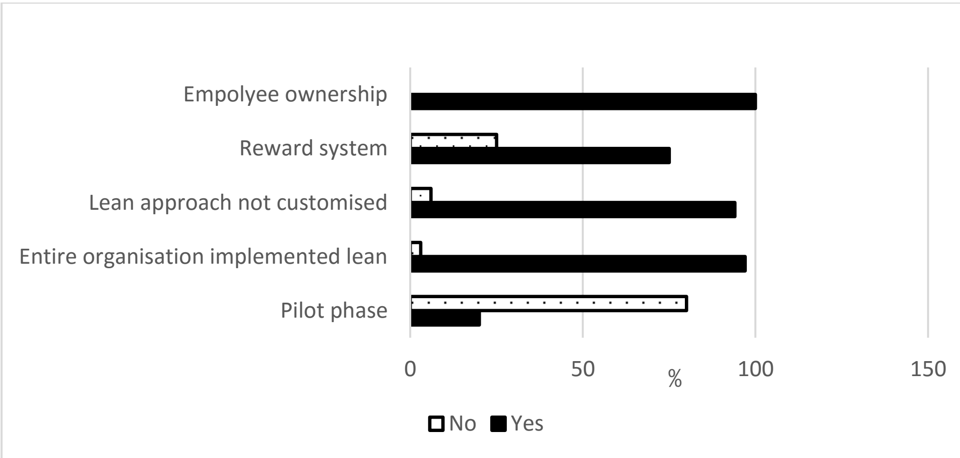

Figure 4: Lean implementation approach.

Figure 5 shows lean tools and techniques on which the researched organisations were trained on. Team work, Total productive maintenance, workplace orderliness, Quality Control tools, wastes and standard work were some of the tools that were given much attention followed by Kanban/JIT value stream mapping and Poka-yoke. Visual management, autonomous maintenance and SMED received very little training. Successful implementation of lean requires good training, [24].

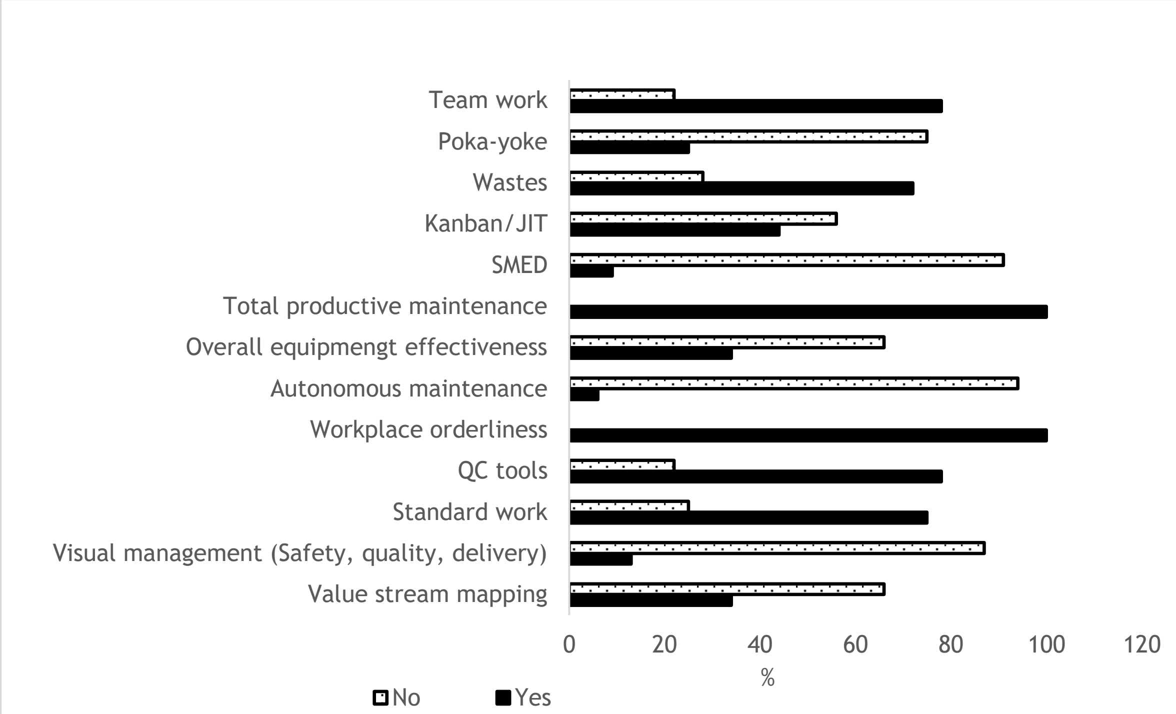

Figure 5: Lean tools and techniques on which organisation was trained on.

Figure 6 shows how the organisations followed the lean implementation approach and plan. Most of the companies used change management and steering committees to lead lean implementation and to a lesser extent structured implementation review. This was found to agree with the work of [4; 7; 21]

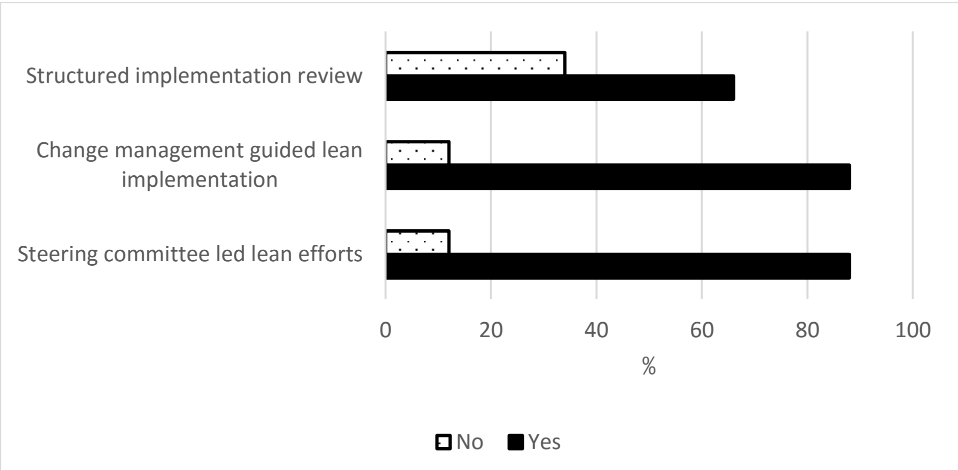

Figure 6: Lean implementation approach and plan.

Figure 7 shows what the organisations have achieved from their lean implementation efforts. Majority of these organisation, (about 70%), have managed to improve on their safety, quality, speed and cost reductions and about 65% of them linked lean tools to productivity improvement. About 57% indicated that lean aims were achieved and 50% agreed that change management improved lean implementation. However only 30% indicated that lean tools and techniques have been sustainable.

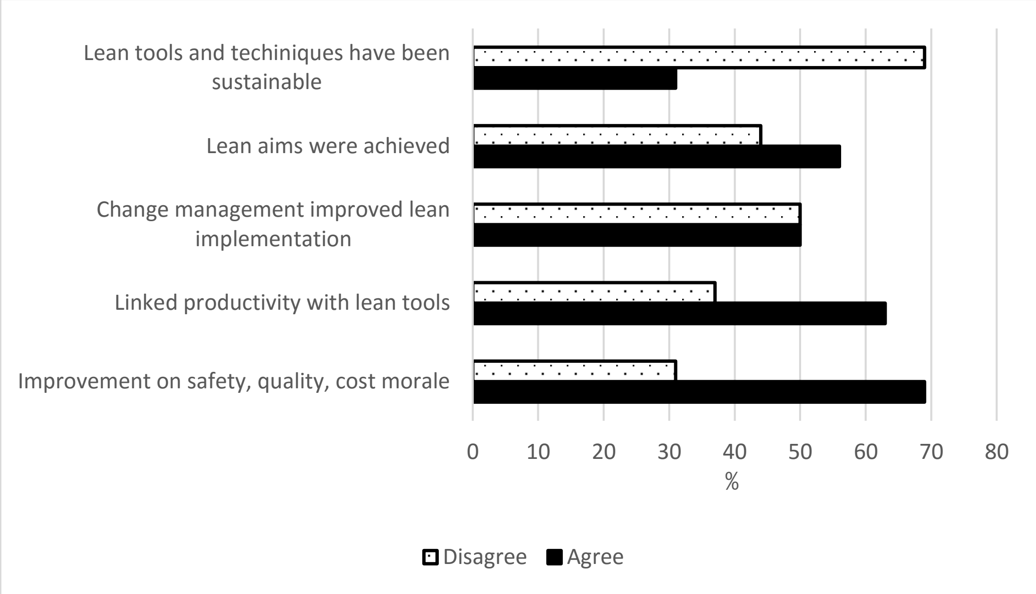

Figure 7: What organisations have achieved using lean approach.

4.2 Qualitative Results

When respondents were asked about the success rate of their implementation, 100% of the respondents in the qualitative study and 62.5% from the quantitative study agreed that their implementations had been successful. Rothenberg and Cost's (2004) findings also supported the results that there are immense benefits for most small enterprises in adopting Lean principles. When further comparison was conducted on the success of Lean implementations in relation to the size of the organisation, medium-sized manufacturing enterprises (those employing 50 to 249 employees) had a greater success rate when compared to small-sized manufacturing enterprises (those employing 10 to 49 employees), as can be seen on figures 8 and 9. Of the medium-sized manufacturing enterprises, 78.6% in the quantitative study and 80% in the qualitative study were successful in their implementation as opposed to a 50% success rate for small-sized manufacturing enterprises in the quantitative study and 20% in the qualitative study.

Figure 8 shows the responses from the quantitative data and Figure 9 shows the results from the qualitative study. Both graphs show that the size of an enterprise does matter when implementing lean. Large enterprises with workers between 50 and 249 exhibited the capacity to implement lean due to the availability of manpower. Interviews revealed that in large enterprises dedicated teams were formed to implement lean. In small enterprises the lean implementation team members were not necessarily focussed on lean, they had other day-today duties such as managing production and carrying out maintenance. This divided attention reduced their chances of successfully implementing lean.

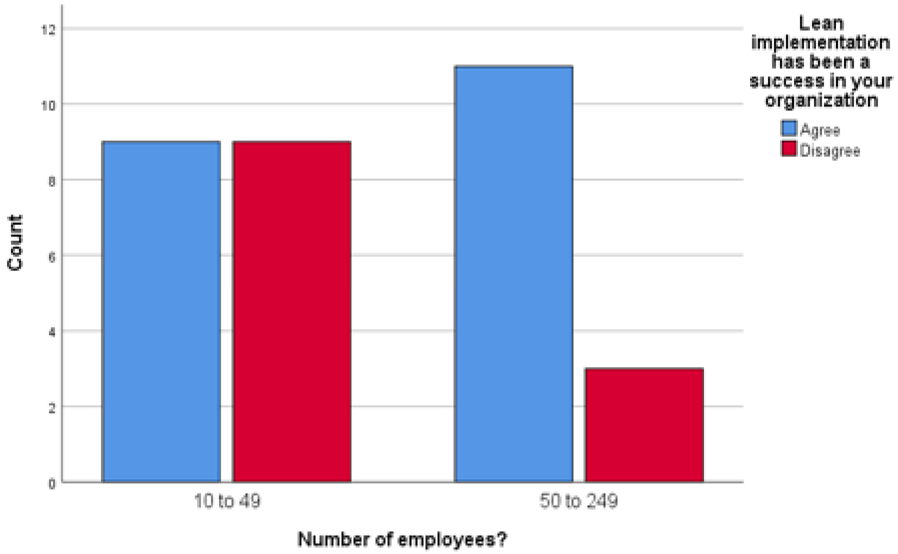

Figure 8: Lean success rate by enterprise size (quantitative study)

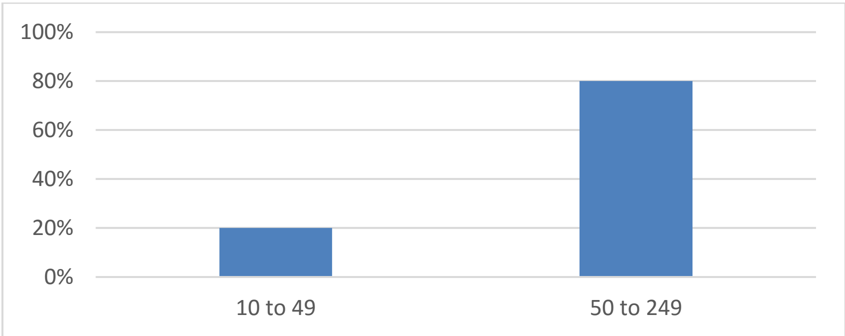

Figure 9: Lean success rate by enterprise size (qualitative study)

Table 6 shows that KPIs of quality, safety, absenteeism, cost were measured and analysed by the SMMEs that implemented lean. It is clear from the results that most of these SMMEs understood the key performance indicators of lean.

Table 6: Lean Implementation Success Metric - Qualitative Study

Questions	Interviewee #1	Interviewee #2	Interviewee #3	Interviewee #4	Interviewee #5
How did you measure the impact of each lean technique as you implemented?	Measured the impact of the Lean programme against Quality, Speed, Cost, Safety and People focus areas and these were measured monthly	Through the following KPIs: Absenteeism, Injury on Duty, Quality Faults and Sales Growth	Firstly, on understanding and articulation of Lean principles and secondly, it was measured on its impact on Quality, Speed, Cost, Safety and People focus areas	Customer quality audit outcomes and absenteeism	Measured the impact of the Lean programme against Quality, Speed, Cost, Safety and People focus areas and these were measured monthly

When a comparison was conducted between companies that used Safety, Quality, Delivery/Speed, Cost and Morale as a measure of productivity and those that realised the improvement of Safety, Quality, Delivery/Speed, Cost and Morale, 68.75% of the respondents in the quantitative study were successful in their Lean implementation while 60% of the respondents in the qualitative study realised improvement of Safety, Quality, Delivery/Speed, Cost and Morale. Figure 10 and Table 7 show the comparisons.

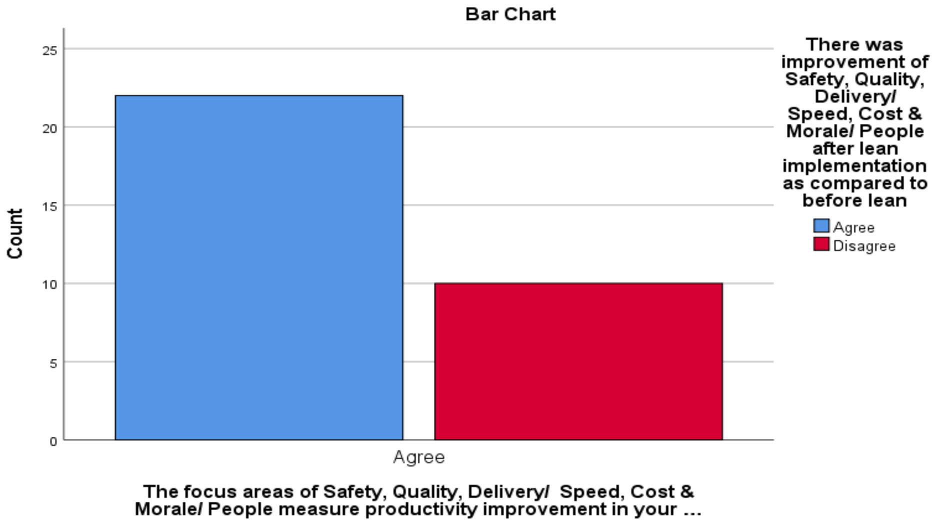

Figure 10: Productivity Improvement Comparison – Quantitative Study

During interviews respondents indicated that lean implementation was made possible through their managers' commitment, most workers saw the benefits of implementing lean and they supported the efforts of their companies. Further probing revealed that most companies used change management techniques and had sufficient budget which convinced the sho floor workers to buy into the idea. However some of the SMMEs suffered lack of internal skills and expertise and they relied on contracted lean experts.

Interview respondents also highlighted lean implementation barriers such as employee resistance, inadequate budget and lack of lean skills within some organisations.

Table 7: Productivity Improvement Comparison – Qualitative Study

Questions	Interviewee #1	Interviewee #2	Interviewee #3	Interviewee #4	Interviewee #5
How did the impact of each technique affect your business results?	Overall performance of Quality, Speed, Cost, Safety and People improved in the seven-year period of implementing the solution	3% improvement in absenteeism, injury on duty reduced by 4 incidents and quality faults per unit improved by 4.86	Overall performance improved across identified Quality, Speed, Cost, Safety and People KPIs through the strengthening of problem-solving using the 5 Why technique	Achieved green score for major customer (Woolworths) audit and 1% improvement in absenteeism	Realised positive benefits on Quality and Speed KPIs

4.3 Hypothesis Testing

Because of the small sample size that was analysed in this study, the data was tested using parametric statistics. SPSS Version 25 software was used to carry out the parametric analysis.

4.3.1 Testing of hypotheses 1

H_1 aims to understand if the success rate of Lean implementations will likely fall below 40%. The scores of the sub-questions in the questionnaire pertaining to hypotheses 1 were added together for each respondent, after which the average score was calculated for each question. The individual scores were then compared against each other and thereafter tested for normality. The outcome of the tests are outlined in Table 8.

Table 8: Normality Tests - Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	2.743[a]	1	0.098		
Continuity Correction[b]	1.659	1	0.198		
Likelihood Ration	2.839	1	0.092		
Fischer's Exact Test				0.147	0.098
Linear – by – Linear Association	2.657	1	0.103		
Nof Valid Cases	32				

a. 0 cells (0%) have expected count less than 5. The minimum expected count is 5.25.
b. Computed only for a 2 x 2 table

Based on the values of the Pearson and Fisher's Exact tests, the sample size does not affect the reliability of the results and as such, confirm that *H_{01}* is true in that the success rate for SMMME lean implementations in Gauteng Province of South Africa are greater than 40% and that Lean implementations are more likely to be successful than not.

4.3.2 Testing of hypotheses 2

H_2 aims to understand if the following factors of management experience, Lean expertise, company culture, business needs, employee training, availability of financial and human resources will result in a failed implementation. Similar to hypotheses 1 testing, the scores of the sub-questions in the questionnaire pertaining to hypotheses 1 were added together for each respondent, after which the average score was calculated for each question. The individual scores were then compared against each other and thereafter tested for normality. The outcome of the tests are outlined in Table 9.

Table 9 outlines the results and interpretations of the hypotheses testing, as well as the statistical measures that were used.

Table 9: Normality Tests - Shapiro-Wilk Test

		Statistic	df	Sig
Change Management	Agree	0.927	20	0.136
	Disagree	0.903	12	0.174
Internal Skills Cap	Agree	0.864	20	0.009
	Disagree	0.753	12	0.003
Adhering to Plan and Action	Agree	0.911	20	0.067
	Disagree	0.924	12	0.318

Based on the values of the Shapiro-Wilk test, the p value is greater than the chosen alpha level thus confirming that the data is from a normally distributed population and cannot be rejected and as such, confirm that H_{02} is true in that the following factors of management experience, Lean expertise, company culture, business needs, employee training, availability of financial and human resources will result in a failed implementation.

5 CONCLUSION

Data from both the qualitative and quantitative studies point out the following themes for sustainable lean implementation:

- Senior leadership commitment
- Shop floor buy-in
- Adequate budget
- Internal Lean skills/expertise
- Change management linked with company culture change understanding.

The aforementioned enablers came out strong in the qualitative study and there is need to ensure that the gaps are addressed as they are regarded as crucial steps in ensuring that lean implementation will be successful. Barriers to lean implementation that were identified in this study were found to be consistent with previous findings from [5; 24; 25]. Their findings included the following enablers:

- Employee resistance to Lean
- Customisation of principles such that they address the organisation’s specific needs
- Senior leadership resistance
- Lean expertise within the SMMEs.

When respondents were asked about the sustainability of the results they achieved, 60% of the respondents in the qualitative study agreed that their implementation had been sustainable compared to 31% that agreed in the quantitative study. When interviewees were probed further regarding factors influencing sustainability, the following themes were raised:

- Adherence to routines set-up during the initial implementation phase
- Senior leadership support
- The pace of implementation
- Internal Lean skills/expertise
- Adequate budget.

The above findings are consistent with the work of Leite [27], where the barriers and enablers were classified into two aspects, namely cultural and technical aspects. The cultural aspects were found to have a major impact on the success and sustainability of Lean deployments, constituting 64% of the barriers while the technical aspects constituted 36%. Leite [27], superimposed the cultural and technical aspects on Hines' Lean iceberg model to illustrate the difficulty of seeing and addressing the cultural aspects of a Lean deployment, arguing that the technical aspects were easier to address than the cultural aspects. Although Leite's findings were not specific to SMMEs, those barriers and enablers agreed with outcomes of this study. However these results cannot be generalised because the study received fewer responses and it only focussed on Gauteng province.

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AN INVESTIGATION INTO KEY ENABLING FACTORS FOR THE SUCCESSFUL IMPLEMENTATION OF KANBAN SYSTEMS IN SOUTH AFRICA: A CASE STUDY

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ABSTRACT

The manufacturing sector, considered to be a significant industry in any country, is often plagued with delivering measurable benefits in terms of efficiency and quality in manufacturing and the degree of competition has greatly increased due to global marketing. In order to cope with this challenge, organisations attempt to improve their manufacturing operations by using different tools and techniques to reduce costs while remaining profitable. This study investigated the existing applications of Kanban systems of two different manufacturing organisations in South Africa. The objective of the study was to identify the strengths and weaknesses of the Kanban system in an attempt to improve quality and productivity. An empirical study was conducted using quantitative methodology. A survey questionnaire was distributed to the shop floor workers and engineers of two chosen organisations. The results of the study showed that in both organisations there are similar and contributing factors that enable effective application of Kanban systems.

Keywords

Industrial engineering applications, Kanban systems, quality, productivity

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1 INTRODUCTION AND BACKGROUND

The success of the Toyota Production System (TPS) enabled Japanese manufacturers to improve productivity and reduce costs three decades ago. With manufacturing costs escalating on a regular basis due to various reasons, manufacturing organisations that are unable to compete eventually file for bankruptcy. An integral feature of just –in-time (JIT) systems is the use of pull shop floor control systems which is commonly known as Kanban. The kanban system was introduced by the Japanese to complement the JIT system. This system was introduced to do away with the push system which was and is still used by many industries, the concept initially originated from US supermarkets where customers get (a) what is needed, (b) at the time it is needed, and (3) at the correct amount needed [1] The idea of tangible and touchable food items in a supermarket was applied by Taiichi Ohno in Toyota around 1952 to: (a) reduce inventory and production time, (b) Increase the speed of information exchange, and (c) improve efficiencies[1]. After the gains demonstrated by Kanban, many industries adopted the system. The Kanban Concept was introduced by the Japanese through the Toyota Production System Concept. The Kanban system was introduced to work hand in hand with the Just-in- Time concept and the practise of standardised work. This system was later recognised by a number of manufacturing industries worldwide due to the impact it had in the Toyota manufacturing plants. Kanban Systems efficiently control repetitive manufacturing environments and offer simplicity. However, they are not suitable for non-repetitive manufacturing systems.

2 METHODOLOGY

[2] define methodology as the study of procedures or methods used in research to create new knowledge. On further examination, [3] and[4] advocate that qualitative and quantitative techniques are commonly used to conduct research. In most cases, qualitative research is focused on understanding and interpreting data while providing a detailed description of events, situations and interaction between people and things, thus providing depth and detail. The views of [2] and [5] concur with [4] in that qualitative research aims to study human interaction from the insider's perspective as they identify, examine and reflect on perceptions. In summary, qualitative techniques are used to study phenomena that do not fit into particular theories.

[4] articulate that quantitative research is often used for testing a theory and focuses on describing, explaining and predicting data with the use of statistical and mathematical methods. In essence, quantitative research is most commonly encountered as part of formal or conclusive research and the aim of this technique is to determine the relationship between an independent variable and a dependent or outcome variable in a population. Principally quantitative approach was adopted as it enables the researcher to focus in a particular area and gather information through various means. In this case study, data was collected through the review of existing literature and triangulated with face to face discussions and telephonic discussions using shop floor workers and supervisors as primary participants.

3 LITERATURE REVIEW

The famous inventor of the cotton gin, Eli Whitney, perfected the concept of interchangeable parts in 1799. For the next 100 years, manufacturers concerned themselves primarily with developing systems of engineering drawings, perfecting modern machine tools and developing large scale processes [6]. The works of early industrial engineers such as Frederick Taylor, Frank Gilbert and Lillian Gilbert in the late 1890's, introduced the era of scientific management [7]. They developed concepts such as "time study", "standardised work", "motion study", "process charting" and workplace pyschology. Following the aforementioned information, it can be suggested that these specialists originally introduced the concept of what is today referred to as "waste elimination".

3.1 The toyota production system

Early in the 1940's, Taichi Ohno and Shigeo Shingo began to incorporate Ford production, Statistical Process Control and other techniques into the TPS. They recognised the central role of inventory and the importance of respect to employees from the contradictions and shortcomings they identified in the Ford system [6]. Ohno visualised an ideal production system in terms of a sequential workflow that produced goods Just In Time (JIT) with little or no inventory between workstations [8]. This prompted a shift from the traditional "batch and queue" mass production philosophy to "one piece flow" pull production. In order to maintain the sequential workflow and keep inventory to a minimum, Shingo worked on reducing machine set- up times by developing the Single Minute Exchange of Dies (SMED) system [8].

It was during the 1950's that Ohno developed the concept of "one piece flow" by merging the knowledge and skill of master craftsmen [9]. During this era, many other concepts such as JIT, Kanban, Quality Circles, Kaizen and Cell Manufacturing emerged within the TPS. When the popularity of productivity and quality gains in the TPS became known globally, American executives travelled to Japan to study these concepts. The American executives adopted mainly the superficial concepts like JIT, Kanban and Quality Circles which proved to be successful over time [10].

3.2 Lean manufacturing

Toyota captured the world's attention in the 1980's, when it was perceived that their vehicles were lasting longer and required much less repairs than American vehicles. The most remarkable aspect was that the vehicles were designed much faster, with more reliability, and at a more competitive cost than the Americans. According to [11] it was a mystery for a number of years that the Japanese were able to produce automobiles at such high quality and low cost. This, however, lead to the largest and most thorough study ever undertaken in any industry. A research group at the Massachusetts Institute of Technology took five years in the late 1980's to explore the difference between American mass production and the TPS in the automotive industry [12].

In 1990, James Womack's book titled "The machine that changed the world" provided an account of the history of automobile manufacturing combined with a study of Japanese, American, and European automotive assembly plants. His objective was to demonstrate to organisations, managers, employees and investors that there was a better way to organise and manage customer relations, the supply chain, product development and production operations. This approach, which was pioneered by Toyota and named the TPS after World War 2, was labelled Lean Manufacturing [13].

The term "lean manufacturing" focuses on producing value-added features while identifying and eliminating non-value-added activities in the production environment. In essence, lean manufacturing aims to reduce wasteful practices while providing increased customer value. The central focus of value, according to [13], should be on providing products with specific capabilities, offered at predetermined prices, through a dialogue with predefined customers. To understand how this concept applies to industry, [14] distinguishes "value-added" as an activity that makes a product more complete from "non-value-added" as an activity which does not advance the product to a finished state.

In order to focus on all activities that create value, [15] propose that it is essential to have an alignment between strategic goals and operational activities. From a more specific point of view, [16] contends that traditional organisations grow both value-added and non-value-added operations in order to increase production and profits. However, lean organisations should focus on reducing non-value-added activities by transferring efforts to those operations which add value, thus growing both production and profits without added resources. Therefore, to demonstrate this idea, Mekong [17]) cites the following key implications of Lean manufacturing compared to traditional batch manufacturing.

The main principles for the implementation of Kanban systems are as follows:

- Level production (balance the schedule) in order to achieve low variability of the number of parts from one-time period to the next.
- Avoid complex information and hierarchical control systems on a factory floor.
- Do not withdraw parts without a Kanban.
- Withdraw only the parts needed at each stage.
- Do not send defective parts to the succeeding stages.
- Produce the exact quantity of parts withdrawn.

The Kanban system is a means to control just-in-time supply and "autonomation" (automation with a human touch). The Kanban system works hand-in-hand with the "order-point method."

The order-point method is a control technique used to carry out optimum ordering in repetitive production processes. It is a technique/formula used to lower inventories using smaller and smaller lots, thereby increasing the frequency of delivery of materials. Because materials are delivered more often, new strategies are needed to deal with the amount of increased transport, in order to ensure that excessive transport waste is not created

Kanban is a means of visual control, used to keep the supply system going. The theory behind Kanban is that only what is used is replenished. By only creating what was taken, it creates a "pull" of inventory through the system, rather than "pushing" material through that was created without need.

The key objective of a Kanban system was to deliver the material just-in-time to the manufacturing workstations, and to pass information to the preceding stage regarding what and how much to produce.

A Kanban full fills the following functions:

- Visibility function

The information and material flow are combined together as Kanban's move with their parts (WIP- work-in progress).

- Production function

The Kanban detached from the succeeding stage full fills a production control function which indicates the time, quantity, and the part types to be produced.

- Inventory function

The number of Kanban's actually measures the amount of inventory. Hence, controlling the number of Kanban's is equivalent to controlling the amount of inventory; i.e. increasing (decreasing) the number of Kanban's corresponds to increasing (decreasing) the amount of inventory. Controlling the number of Kanban's is much simpler than controlling the amount of inventory itself [18][19].

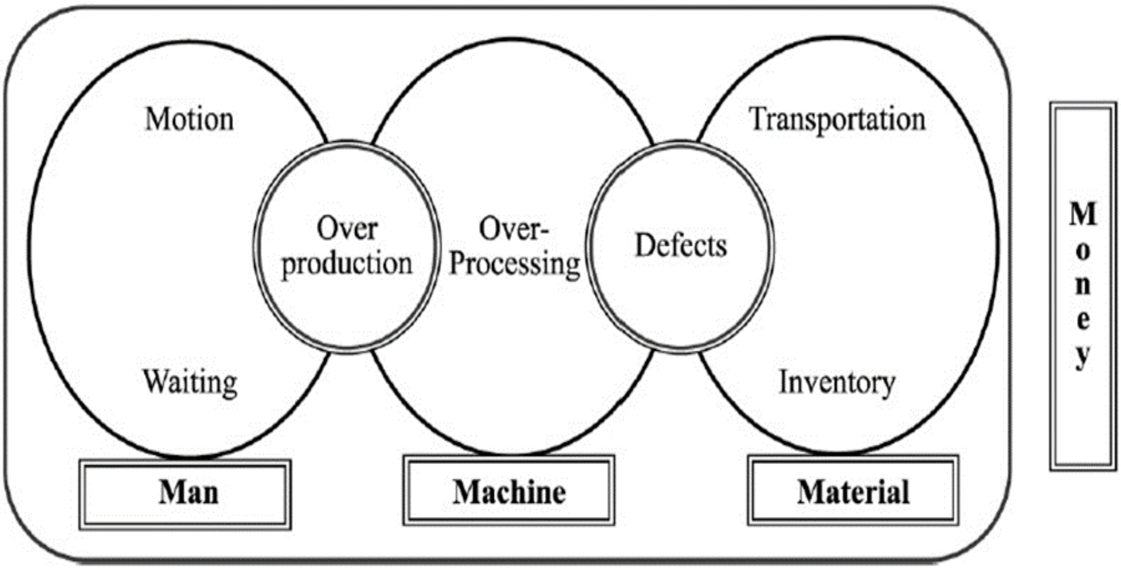

Figure 1: The three main categories of waste (man, machine, materials) and its effect on money [19]

According to Figure 1, the “man” group indicates unnecessary motions during operations, employees waiting for preceding processes and over-production; the “machine” group represents inappropriate processing of products and the “material” group identifies waste resulting from transportation, excess inventory and defects. On closer examination, [19] maintains that over-production overlaps man and machine while defects overlap machine and material. The figure reveals that the main sources of waste overlap each other. Indeed, by removing one source of waste it can lead to the reduction or elimination of others.

It is evident that lean manufacturing aims to lower product costs through the constant elimination of waste. Identifying waste is not easy due to the large number of parameters and overlap between different processes that may cause waste activities to be concealed between other activities. Therefore, in order to accomplish the methodical classification of waste in production, this study explores the different sources of lean manufacturing waste in existing and past literature.

4 RESULTS AND DISCUSSION

Critical success factors were identified and the aim was to compare the two organisations and identify key enabling factors for an effective Kanban system and if they share those five common critical factors. The sections are as follows: cultural transformation, creating a visual workplace, focus on WIP- inventory, to focus on good housekeeping and elimination of waste (Muda).

4.1 Cultural transformation

An extensive amount of time was spent with employees particularly shop floor employees who are the day to day operators of the Kanban system in both organisations Time was also set aside with management to see if employees shared the same sentiments with management. Kanban systems involves a complete cultural change of doing things. It was evident that there are common and contributing factors of effective application of Kanban systems at both organisations.

- Training and education is facilitated to all levels of management and employees
- Employee involvement ‘ownership’ and innovation is encouraged in both organisations

- The strategic level revolves around the customer while the techniques and tools apply to the operational level
- The importance of management support and communication
- The Goal is satisfying customer requirements
- Employee involvement 'ownership' and innovation is encouraged in both organisations.

4.2 Visual workplace

Upon investigation of the two workplaces which was part of the research it was found that:

- A place for everything and everything in its place
- Demarcation of work areas and work benches
- Visual Kanban cards were visible
- Labelling of equipment and tools is evident
- Clean working environment
- 15 minutes before close of business, employees clean their work areas
- Identify defects and errors by visual control

Visual controls give the ability to see abnormalities at a glance. This in turns comprise a series of activities for eliminating waste that contribute to errors, defects and safety related issues in the workplace.

4.3 WIP - inventory

The purpose of inventory management is to be able to manage the operation's inventory in order to satisfy customer demand; that is actual demand in the market regarding products and services, without exposing the organisation to unnecessary costs and risks. Effective inventory management in can be one of the toughest tasks in business because the achievement of organisational objectives is linked to the relationship between its functional goals. All organisations should be concerned with inventory management and a particular emphasis should always be put on it. A sound inventory management involves the coordination of an organisation's strategic functions (production, finance, marketing) in order to achieve organisational objectives. The more inventory a company has, the less likely they will have what they need - Taiichi Ohno [11].

Decades ago Toyota started thinking in terms of pulling inventories based on immediate customer demand. In the Toyota Way "pull" means the ideal state of Just-In-Time manufacturing thereby giving the internal customer (next stage in production line) what they want when they want and in the amount they want [11]. It is 100% on demand and has zero inventories. Toyota tries to keep it this way, but there is always little bit of buffer and when it is used then it will be replenished.

By implementing the 'pull' system instead of the 'push' system both organisations are carefully monitoring and co-ordinating to replenish thousands of parts and tools internally.

4.4 Housekeeping - 5s

The 5s principles play a major role in both organisations (Seiri, Seiton, Seiso, Seiketsu and Shitsuke) [11] As a part of housekeeping, a senior person regularly evaluates all areas to ensure that all employees adhere to a clean and safe working environment by allocating the person a grade from 1 to 5 (1 very good – 5 very bad). The Toyota way recognizes that visual management complements humans as humans are visually, tactilely and audibly oriented.

4.5 Elimination of waste

The organisation found it can create the leanest possible operation and eventually give better service and production quality by leveling out (Heijunka) its production schedule and not always building to order. There are a total of eight wastes (Muda) but we will discuss here the three M's which fit together as a system to make an effective Kanban at Toyota. They are; Muda, Muri and Mura (in Japanese terms).

It was also evident for the study that XYZ Plastics endorses the elimination of 8 wastes which was explained in detail in the previous sections.

Below is a representation of the 3M's that effective Kanban systems try to eliminate by all means

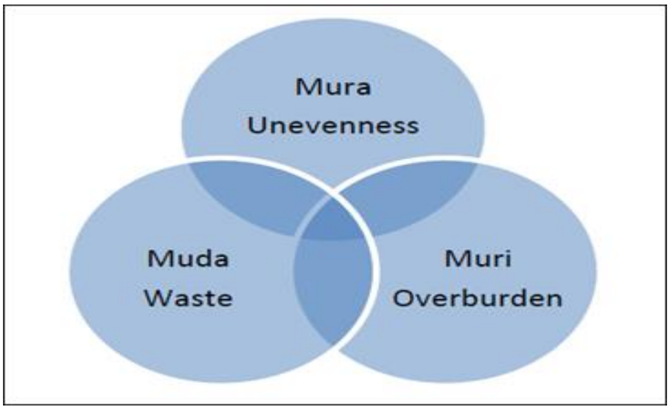

Figure 2: 3M's that effective Kanban systems try to eliminate

Muda: Non-value added; all the wasteful activities in making the final product that lengthen the lead times, such as extra movement to get parts or tools, excess inventory, or in any type of waiting. Everything other than the actual cutting is considering Muda according to this analysis.

Muri: Overburdening People or equipment; this means pushing people and machines beyond their natural limits. Overburdening causes safety and quality problems and in machinery it causes breakdowns and defects.

Mura: Unevenness; this means unevenness due to irregular production schedule or fluctuating production volumes due to internal problems, such as down time or missing parts or defects. Muda will be a result of Mura[11].

Eliminating Muda is only one third of achieving continuous flow, but to achieve complete flow, eliminating Muri and smoothing Mura are equally important.

Results of the study revealed that there are common enabling factors between Toyota and XYZ Plastic for the effective application and implementation of Kanban systems. Study also revealed that both organisations share and live on five critical factors that enable effective Kanban system.

In Conclusion from above were the results of the study, Kanban systems has been broadly embraced to eliminate waste and to improve quality and productivity and these benefits can be affirmed by the employees. Based on the analysis and presentation of the results obtained, the following chapter will present the conclusion and recommendations for the project.

5 RECOMMENDATION AND CONCLUSION

Based on literature review and assessment of XYZ Plastics operations, the conclusions reached are summarized as follows:

The literature presents an in-depth analysis of lean manufacturing which includes Kanban System and details its constituents including its origins

The paper assesses XYZ Plastics operations with regard to its Kanban system

XYZ Plastics Kanban System is comparable with that of Toyota Production System

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A TECHNOLOGY BASED SUPPLY CHAIN MANAGEMENT

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ABSTRACT

The evolution of purchasing resulted into the concept of Supply Chain management. Supply chain management links all the supply activities and organizations in an integrated two-way communication system. The increase in global interconnectedness and inter-dependency, demands a dynamic technological innovation process for Supply Chain Management. Technology brings a new evolution that requires a different type of analysis and a management process. The new paradigm is technology driven and integrates supply chain management activities. The paradigm comprise of the original two-way communication between the original three tenants of a supply chain (Suppliers, manufacturing and Customers). The advent of technology brings with additions to the original Supply Chain Management components, these additional components include the external environment (PESTE) impact, big data, Internet of Things (IoT) and technology enhanced manufacturing. This qualitative research paper will present a new model of Supply Chain Management that will highlight the impact of technology on supply chain.

Keywords: SCM; Purchasing; Technology; Procurement; manufacturing

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1 INTRODUCTION

Supply chain management can be defined as an integration of two or more independent firms working together to align their supply chain process so as to create value to end customers and stakeholders which is greater than when they work alone Togar et al.[22]. Firms in a supply chain establish and share the responsibilities and benefits by instating a degree of cooperation with their upstream and downstream partners in order to create competitive advantage Togar et al. [22]. Through this collaboration, all members in the chain integrate and act as a homogenous entity. Performance is enhance through the chain as the matching of supply and demand improves profit Radjou [17]. Profit is improved because supply chain collaboration amongst independent firms often provides larger benefits from effectively satisfying end customer needs than working in isolation.

Although the main trust in a supply chain collaboration is to achieve a win-win solution for all participating members of the chain, there is often, a large disparity between potentials and the actual results manifested Togar et al.[22]. The main cause of this dilemma is the lack of awareness about the existence of constraints along and in between the supply chain activities that prevents the benefits of collaboration from being fully realized. In order to remedy this dilemma, the supply chain is viewed as a system that is established for the purpose of accomplishing a system's goal. In order to ascertain whether or not the supply chain is accomplishing its system goal, i.e. making money, the dilemma of supply chain collaboration must be resolved through ensuring that the supply chain members identify and focus their decisions on managing the constraint(s) that prevent them from making more profit as a whole.

Therefore, tenants of a supply chain are integrated, and technology is applied in the management of the supply chain process. Literature indicate an increasing dependence of manufacturers on information technology (IT) , to increase the benefits brought by technology, i.e. to improve supply chain agility, reduce cycle time, achieve higher efficiency, and deliver products to customers in a timely manner Radjou [17] in Togar et al.[22]. Thus the question: How can technology create a sustained competitive advantage for a firm, is central to this research. However, various authors have published research output that clearly postulates that technology, in particular IT investment in supply chain does not guarantee a stronger organizational performance Togar et al. [22]. Thus, it confirmed that the use of technology, in particular IT, on the supply chain process is not a panacea to the supply chain dilemma.

In this era of focused information and data analysis, technology aided supply chain (SC) processes can be a real asset from which enterprises can benefit greatly. In support of this notion, the research objective of this paper is to provide some new perspective in explaining how technology can create a sustainable competitive advantage through its application in the supply chain management process. The research objective is achieved by answering the main question: How does technology create sustainable competitive advantage for the firm through its impact on the supply chain process? The research proposes that technology based supply chain capabilities serve as a catalyst in transforming the supply chain through the integration of technology in its vertical and horizontal process tenants. It is also proposed that this integration of technology remedies the supply chain dilemma in the firm.

The value of technology in a particular firm can be enhanced when information management strategies are embedded through the supply chain process. For example, the implementation of technology in the SC can enable a firm to develop and accumulate comprehensive data about the tenants of a particular supply chain, and therefore, management can be aided in making sound decisions that will influence the performance of the firm Togar [22]. It is apparent that past literature has a tendency of treating Technology (in particular IT) as standalone resource without considering the interrelationship established, when integrated in the firms supply chain. Authors Clemons & Row [8]; Tippins & Sohi [23] and Togar et al. [22] declares that the interrelationships between IT, the firms strategic emphasis and the overall business process creates value and thus it serves as prove that it cannot be treated as a standalone resource.

This research paper proposes a system approach to supply chain management and explores the extent to which a firm can apply technology to augment its supply chain capabilities, therefore, reflect on a particular firm's strategic emphasis in integrating and coordinating IT embedded within its supply chain. The research will also establish a conceptualization process for supply chain capabilities, as a higher order construct, consisting of an activity integration dimension, an information exchange dimension, coordination dimension and, supply chain responsiveness dimension. It is perceptible in past literature that the four dimensions of supply chain have been discussed, as seen in Frohlich [22] and Togar et al. [22]. However, there is no evidence of a discussion of the conceptualization of SC capabilities as a transformation of the SC process and its tenants, resulting from the impact of technology changes evident in the history of industrial revolutions.

2 LITERATURE REVIEW

The world is at an inflection point where the impact of digital technology will manifest through automation and development unprecedented inventions (McAfee & Brynjolfsson [13]. Literature is pregnant with the revolution's historical events and a prediction of what is to come. The main thrust of this revolution is its contribution to the fusion of technologies that are blurring the lines between physical and digital worlds (Bonnes [3]. Due to the impact of this revolution, there is a concomitant transformation of the supply chain environment from purchasing to the digital supply chain management. This transformation is further enhanced by emerging progress of technology such as machine learning, robotics, IoT, AI, etc. (Laudante [11].

The fusion of technologies, which is characteristic of the changing environment, manifests in the vertical and horizontal integration of the supply chain activities, both internally and across the channel partners Wise et al. [26]. The horizontal integration is an inter-firm technology and activity integration, which is a two dimensional process. It is noted that in current literature, technology integration is reflected at the level of technology alignment with channel partners and activity integration is conceptualized as the extent to which a firm coordinates its strategic channel activities with its supply chain partners (Wise et al. [26]. Thus, Clark & Stoddard [7] declare that channel members need to shift from discrete transaction to continuous and consistent transactions with their channel partners. Clark & Stoddard [7] assertions highlights the importance of differentiating the strategic activities of Technology integration and Activity integration.

There is a trace of discussions of one or a few aspects of the above capabilities, individually, in current supply chain literature and an apparent lack of studies that provide a conceptualization of the supply chain capabilities that encompasses both dimensions. Literature tends to discuss IT as a separate and stand-alone resource and ignore its interrelationship with the strategic emphasis embedded in the firms supply chain system. This status, according to Wise et al. [26] leads to less sound evaluations of the potential of technology influence on the supply chain performance. Therefore, technology as resource can provide sustained competitive advantage, when embedded in the firm's supply chain process (Srivastava et al. [18]. Then the technology advantage achieved through embedding IT into the supply chain process, results in a synergistic supply chain processes manifesting as an integrated supply chain system.

This research puts forward a proposition that IT alignment provides the basis for an integrative capability, that is tacit and complex , and for functional adequacy of a supply chain, IT alignment between supply chain partner is indispensable but complex (Taylor [24]. Integration between the trading partners is one of the biggest challenges in supply chain management and failure to achieve this system integration across the supply chain has been a complex supply-chain system issue, as depicted in literature from Taylor [24]. Massimo et al. [14] elaborates further and declares that for functional adequacy a sophisticated complex information and communication technology plays a central and critical role in the distribution service design of a firm in the supply chain process.

Therefore, when technology alignment throughout the supply chain is achieved (as espoused by Taylor [24] and Wise et al. [26], supply chain members would be able to identify improve initiatives that focus on supply chain constraints that prohibit the achievement of the supply chain system goal (profitability). This efficiency of the supply chain manifests through the ability for channel partners to match supply and demand at different points of the supply chain. This is a supply chain capability achieved through embedding and integration complex information and communication technology into the supply chain system Taylor [24]. When supply and demand is matched and synchronization among channel partners is achieved, variability magnification, as transactions move between the channel partners (the Bullwhip effect, see Figure.1) is eliminated.

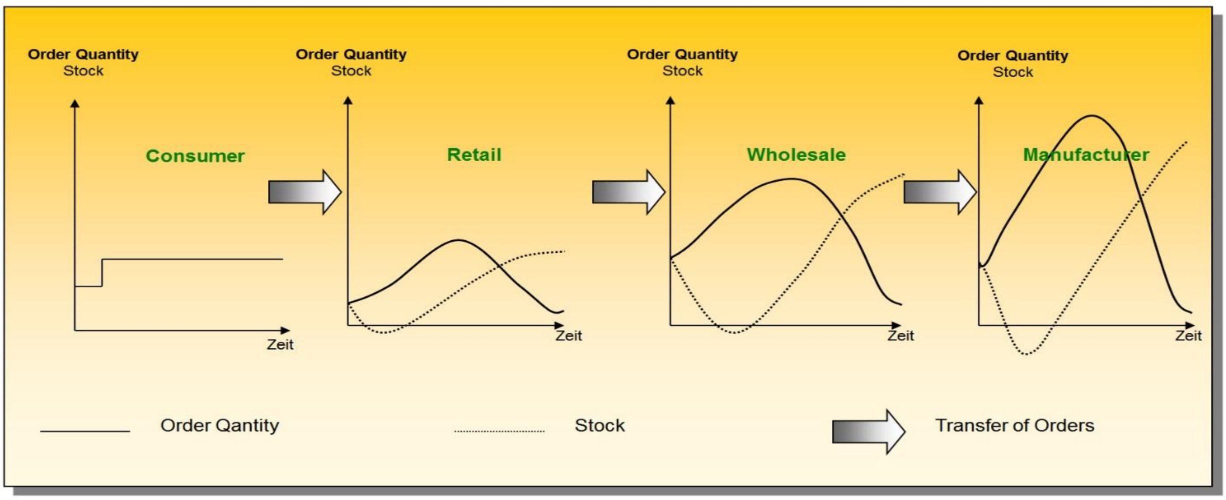


Figure.1: Variability Magnification throughout the channel partners - Bullwhip effect (adapted from Chase et al. (2002)

Massimo et al. [14] postulates that success depends on the accuracy of demand forecast data. However, current literature indicate that supply chain systems suffer from the effects of uncertainty which results in the Bullwhip effect. As indicated earlier, it is a phenomenon that describes the upstream amplification in demand variability Vlosky et al. [26] therefore, to eliminate this effect, the research puts forward a remedial proposition. A technology based supply chain model that employs predictive and big data analytics for the supply chain processes and enables a vertical and horizontal integration throughout the system, must be adopted in the service design of supply chain systems. The supply chain will have IT embedded in the supply chain's activity integration process through the 4IR system tools integration that includes ICT, IoT, smart technology, real time monitoring, etc.

3 RESEARCH METHODOLOGY

Qualitative case study methodology affords researchers opportunities to explore and explain a phenomenon within its context using a variety of data sources (Baxter & Jack [1]. This approach ensures that the phenomenon under study is explored through a variety of lenses that allows an in-depth understanding and allows multi facets of the case under study to be revealed and understood (Baxter & Jack [1]. A case study approach aligns to the goals of this research in that the focus of the study is to explore and explain with the aid of a comprehensive research in that it illustrates whether and how the application of technology impact, aligns and integrate supply chain processes systematically.

The unit of analyses (the case) in this study is the impact of technology, throughout the vertical and horizontal activity integration, on the supply chain process. The attributes of this research satisfy the definition of a case as stipulated by Patton [16], and they are in line with Yin [25] and Stake [21] stipulations concerning setting boundaries for cases in a case study research approach (Baxter & Jack [1]. The research also appeals to boundaries stipulated by Creswell, those of time and place (Baxter & Jack [1]. In line with the boundaries of the definition and context, and the research question (What is the impact of technology on the supply chain processes?), the type of case study research adopted, aligns with explanatory and exploratory or descriptive case study as categorized by Yin (Baxter & Jack [1].

Yin [25] and Patton [16] stipulate that a hallmark for case study research is the use of multiple data sources. A strategy that enhances data credibility (Baxter & Jack [1]. This case study will apply a triangulation of the following data sources i) document analysis and archival records and; ii) field notes; and iii) service system design methodology analysis. It is rational to apply document analysis in this research since it is often used in combination with other qualitative research methods as a means of triangulation. The combination of data collection methods in the study of the one and the same phenomenon enables researchers to draw upon multiple sources of evidence and, to seek convergence and corroboration with different data sources (Baxter &Jack [1]. This approach ensures improved data and decision credibility and eliminates researcher bias in recommendations and conclusion.

Sogunro (1997) provided an exemplary clarity concerning the use of document analysis. The researcher reported that the use of document analysis provided information on history, goals, objectives and substantive content of the phenomenon under study. Stake [21] and Yin [25] found that document analysis is particularly applicable in qualitative research for intensive studies producing rich descriptions of a single phenomenon (Patton [16]. Based on the theoretical framework established by various authors indicated above, the research adopted a qualitative case study approach in which a desktop research approach is engaged.

The research applies data collection and analysis method of i) document analysis and archival records, to establish literature reviews and current status of supply chain systems. Then, ii) field notes of previous researchers are examined to capture the reality and the essence of supply chain process management in action. This method is applied in order to gain understanding of the cold phase with regards to supply chain activities, so as to enable superior activity integration in the technology based supply chain service design. The last data collection method is iii) the service system design analysis method. This method is applied to collect data required in the design of the supply chain as a system and to identify all the required process steps in the systemology of supply chain processes.

4 SYSTEMOLOGY OF THE SUPPLY CHAIN PROCESS

There are many categories of human-made systems, and there are many applications where the concepts and principles of system engineering can be effectively implemented. Every opportunity that arise in which there is a newly identified need to accomplish some function, a new system requirement is established. Therefore, viewing a supply chain process as a system denotes that there is at least three components in that system, these are Input, transformation and output. In each instance, there is a new design and development opportunity that must be accomplished at a system level. This leads to a variety of approaches at the subsystem level and below, at design and development level and, at software level. In each step of a new requirement in the supply chain process, there is a required service design effort for the system overall. Figure.2 below depicts a normal supply chain system as is currently viewed in supply chain analysis.

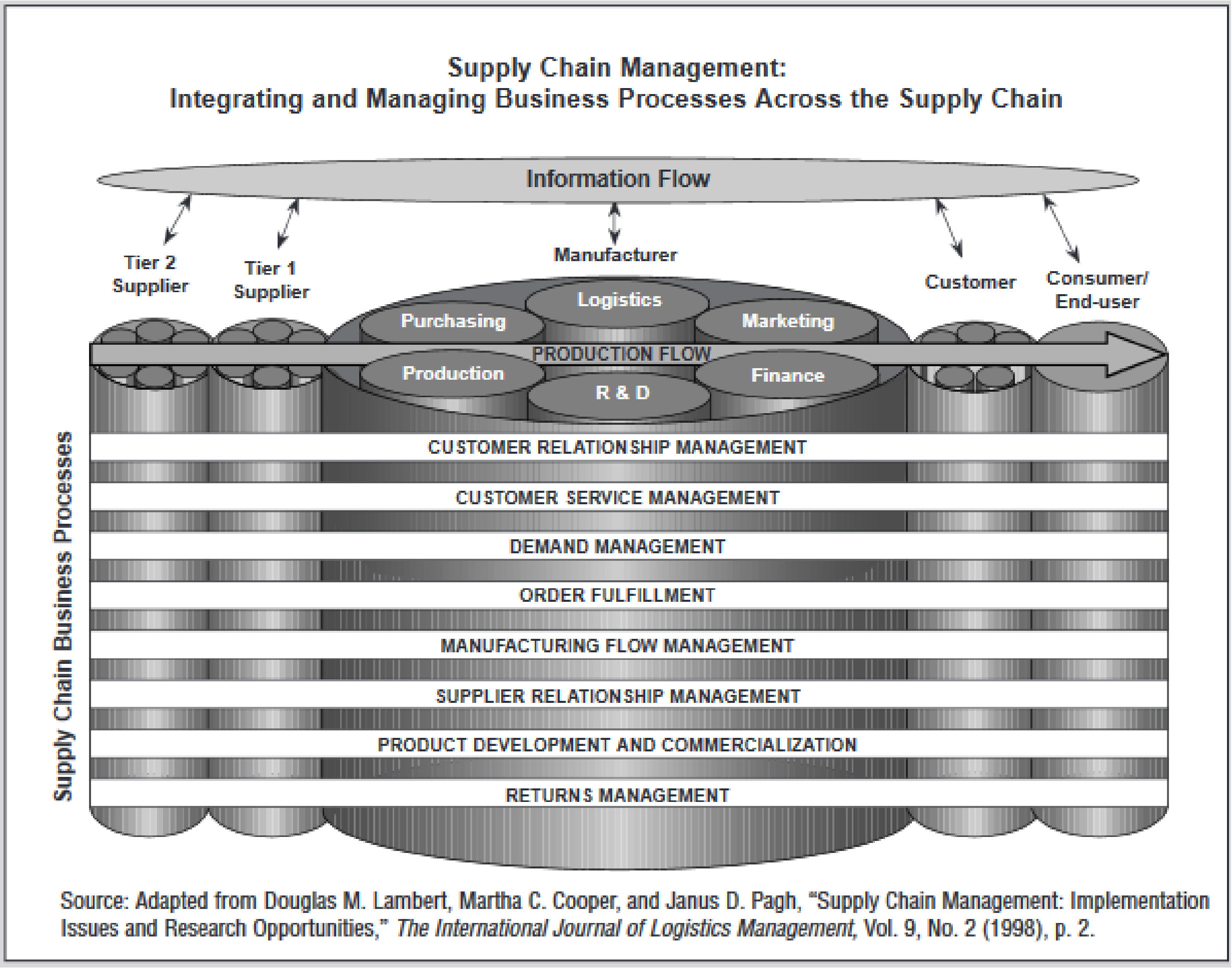


Figure 2: Current "as is view" of supply chain process

The supply chain process depicted above contain the main components of a system but it is not functionally adequate to ensure that the supply chain system goals are achieved and the system constraint, that leads to a magnification of the variation in the process (Bullwhip effect), is eliminated. Therefore the ideal and new future supply chain system will have IT embedded in it to enable activity integration an information integration, that transform the supply chain process into an integrated system with supply chain capabilities required to for a functionally adequate supply chain process. The new supply chain process is still composed of the input, transformation and output components of a traditional supply chain system, with added predictive and data analytics integrated into the supply chain process through the embedded information and communication technology capabilities.

Current trends in supply chain management indicate that the complexity of systems is increasing, and many of the currently in-use supply chain systems are not meeting the needs of the customer in terms of functional adequacy, self-regulation, feedback and, performance effectiveness. Thus, new technology capabilities are being introduced to the supply chain processes on a continuous basis. The new technologies introduced into the supply chain process are driven by the advent of the fourth industrial revolution, and specifically ICT embedded capabilities, that are brought into the supply chain to improve supply chain agility, efficiency and reduce cycle time. This transformation of the supply chain process leads to the establishment of an IT-enabled supply chain system that serve as a catalyst in the achievement of the supply chain system goals (i.e. efficiency and profitability.

The supply chain transformation process, from the "as is" current process to a new IT-enabled supply chain system is dome through the system engineering's system architecture role known as Heuristics. The use of Heuristics as described in the book of Rechtin [19], the art of systems architecture, is a method of applying system engineering tasks throughout the SE process. Heuristics is a functional architecture process that is especially useful when there is a lack of information, which might be normally be required when using normal SE methods or techniques (Martin [15]. Heuristics are usually used at a higher level of abstraction during the SE process than non-heuristic techniques, and there are very few tools that support heuristics (Martin [15]. Therefore, this methodology is appropriate for the supply chain transformation into an IT-enabled system, since the architectural process (see Figure.2,3,4 and 5) has not being fully engaged before and there are few, if any, support tools available in the system engineering environment.

4.1 The system architectural process leading to the new IT-enable supply chain system is as follows:

First, a Vee system process model is adopted. There are two distinct approaches in this approach, i.e. the decomposition and definition sequence, followed by integration and verification sequence. This model starts with the user needs and ends up with the user-validation systems. The outcome of the approach is system task clarity and the new system purpose establishment (see Figure.2).

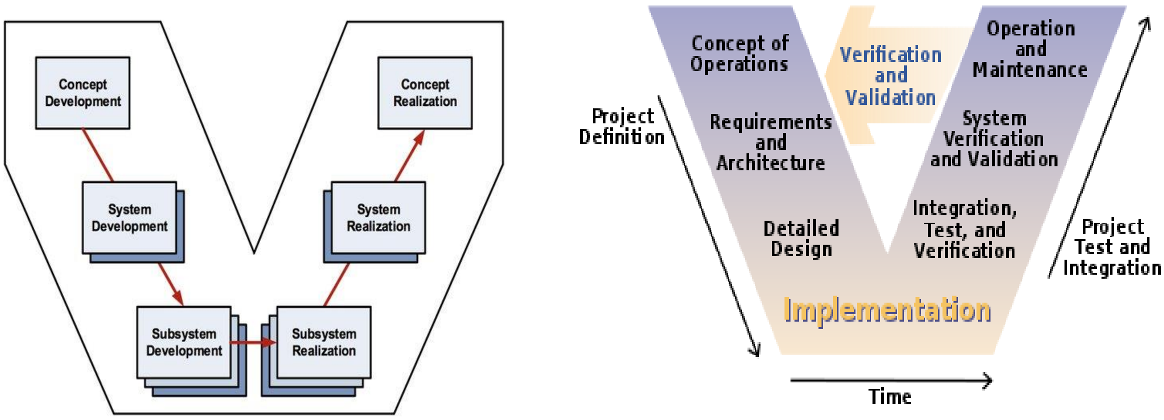


Figure 3: The "Vee" Process Model

Second is the adoption of the system life-cycle process. Supply chain system design within the life-cycle system context is different from design in the ordinary sense, because life-cycle focused design is simultaneously responsive to customer needs (i.e. the requirements expressed in functional terms) and life-cycle outcomes. The design model transforms a supply chain into a system configuration and ensures the design's compatibility with related and stated physical and functional requirements. Further, the design model ensures operational outcomes and performance effectiveness (see Figure 3).

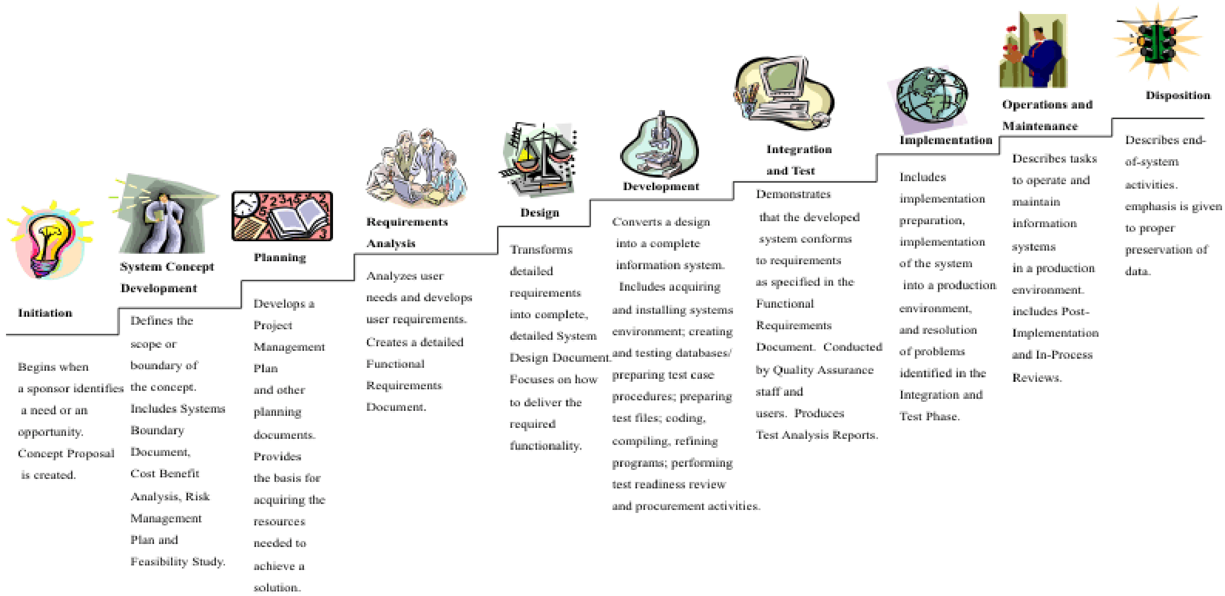


Figure 3: The system life cycle process

Third is the embedding of a feedback in the supply chain system engineering process. Feedback is embedded in the supply chain process through a process of system engineering which begins with an input identification and concludes with the development of a physical supply chain system (see Figure 4). Traditional supply chain process is transformed into a system by the application of an engineering design method that starts with a bottom up approach. The design process starts with the known elements and then creates a system by synthesizing a combination of system elements. Then the system elements and their combinations are altered into an effective and efficiently performing system, with feedback embedded in it.

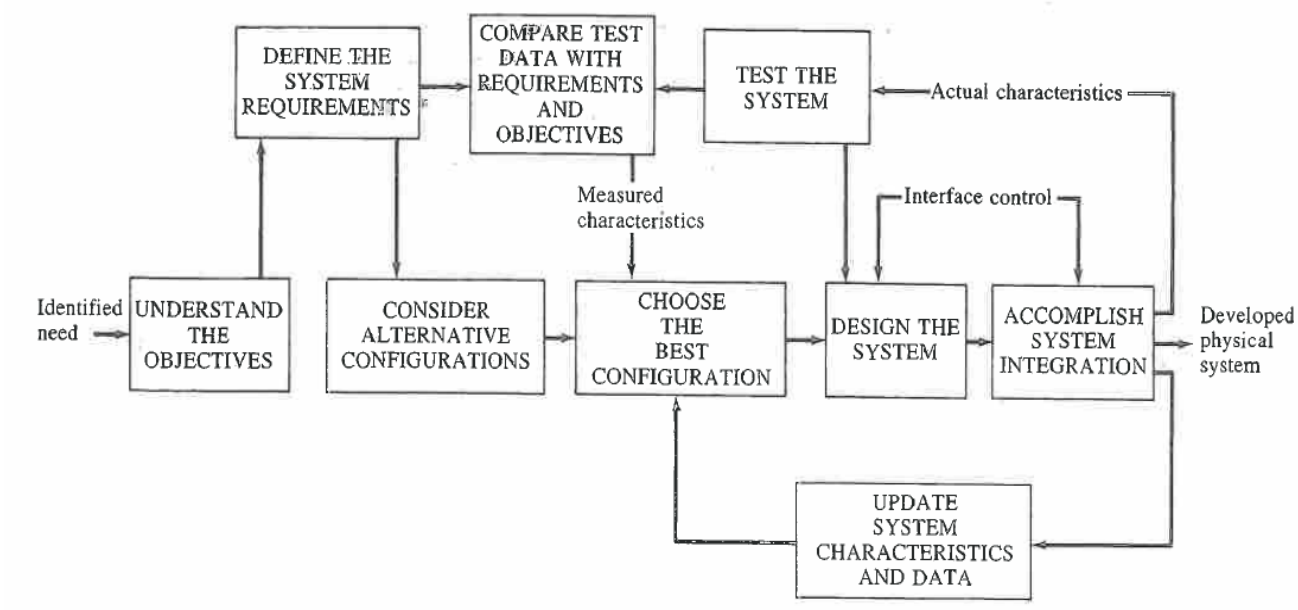
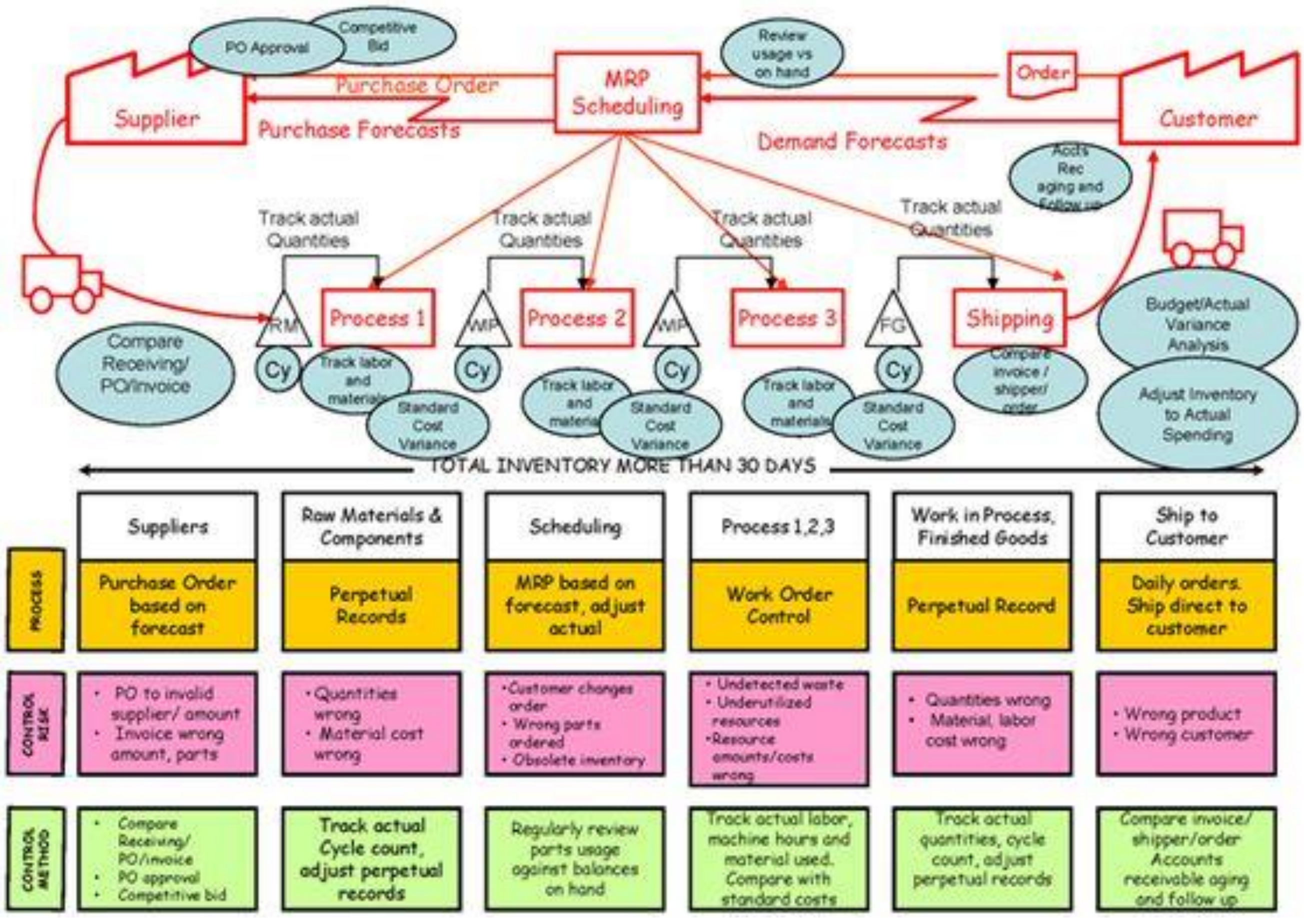
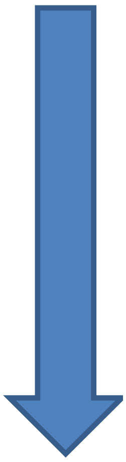


Figure 4: Feedback in the system engineering process

Then last, a continuous system improvement is launched in the supply chain process transformation process. The system improvement is iterative, with the number of iterations in design efficiency, determined by the creativity of the designer as well as the complexity of the new supply chain system. System improvement methodology is evoked in system engineering based on a top-down approach to design. Starting with the requirements about external behavior of any part of the system, that behavior is analyzed to identify its functional characteristics. Then, these characteristics are described in more detail and, they are made more specific through repetitive refinement (Blanchard & Fabrycky [4]. In conclusion, the appropriateness of the system's functional components is verified through synthesizing the original system's parts (see Figure 5).





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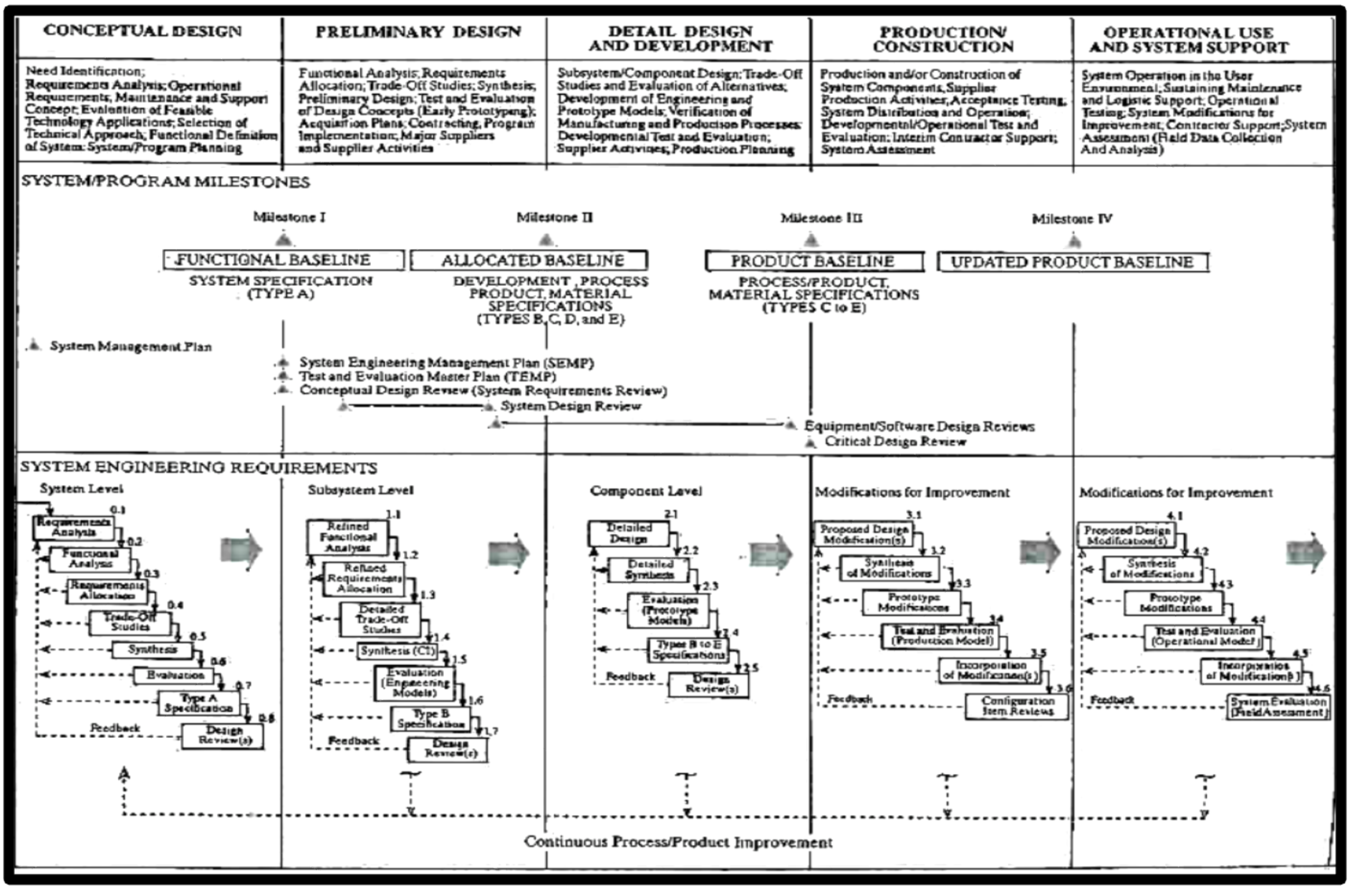


Figure 5: Continuous process improvement models

5 TECHNOLOGY BASED SUPPLY CHAIN

Current supply chain network models are composed of three components, the input, transformation and output (see Figure 2 and 6).

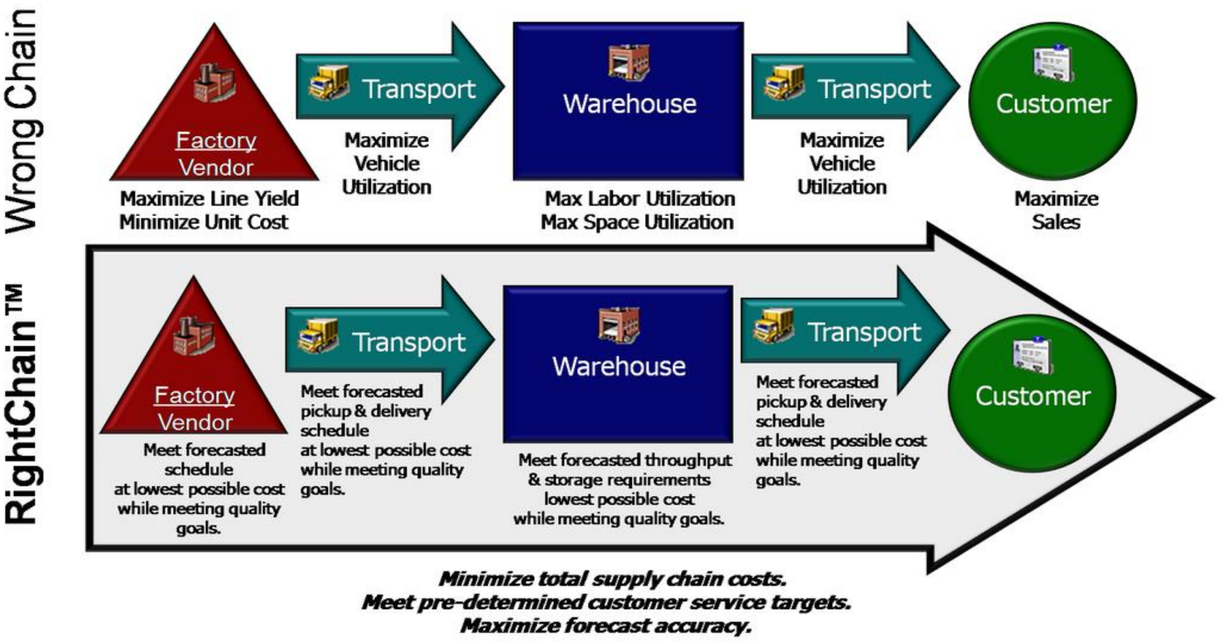
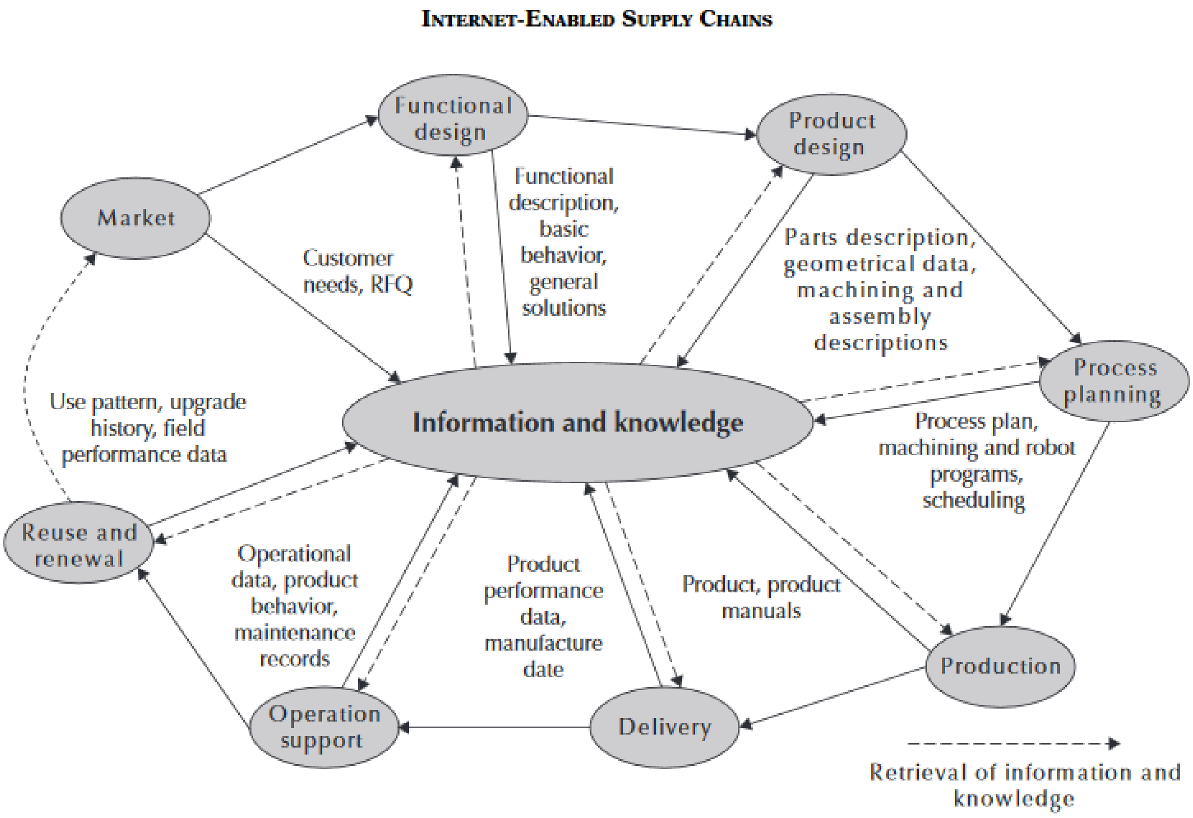


Figure 6: Supply chain system model.

Current trends in supply chain management indicate that the complexity of systems is increasing, and many of the currently in-use supply chain systems are not meeting the needs of the customer in terms of functional adequacy, self-regulation, feedback and, performance effectiveness. Thus, new technology capabilities are being introduced to the supply chain processes on a continuous basis (see Figure7: The new IT-enabled supply chain system model).



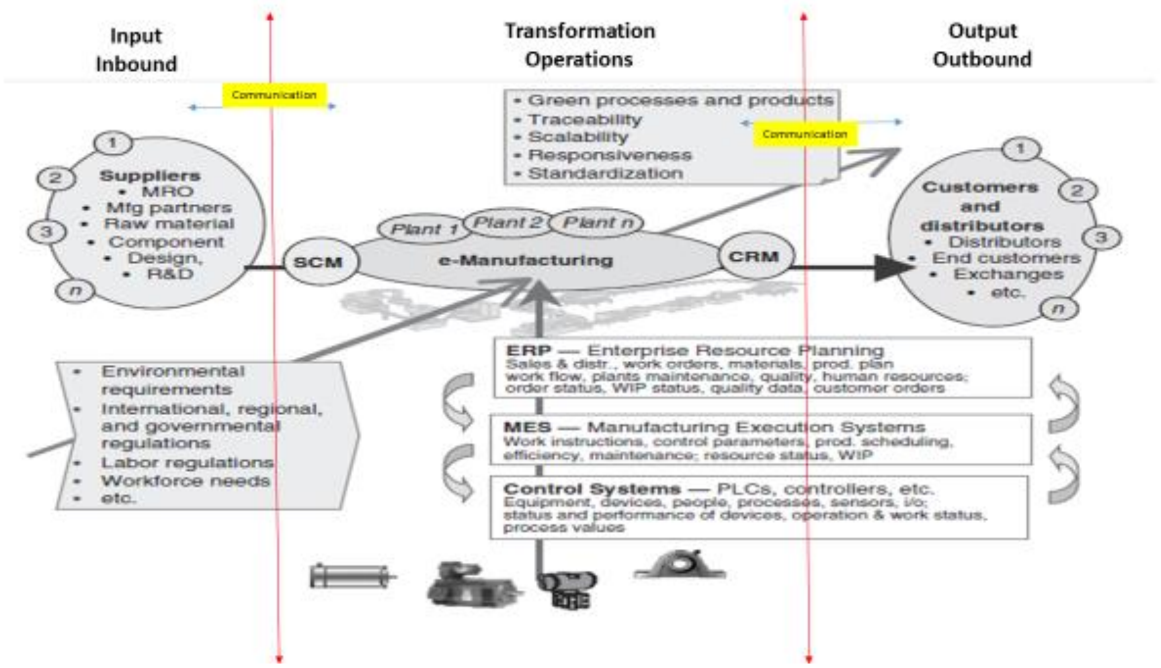


Figure 7: The new IT-enabled supply chain system model

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The new supply chain process is still composed of the input, transformation and output components of a traditional supply chain system, with added predictive and data analytics integrated into the supply chain process through the embedded information and communication technology capabilities.

6 DISCUSSION

Through embedding IT into a firm's supply chain system, the firm is able to enhance channel specific assets through effective information exchange and better coordination with supply chain partners. A higher level of supply chain capabilities bestows the firm an information advantage over competitors through gaining access to and even integrating knowledge from multiple sources that are not available when acting alone. The improvement in supply chain capabilities through IT allows the firm to learn and respond to market changes better and quicker than competitors. In addition, a firm possessing these capabilities can shield itself from immediate competitive imitation since such capabilities are developed over time and are deeply embedded in organizational routines. This provides the basis of sustained competitive advantage (e.g., Barney [3]; Bharadwaj, [6]).

The mediation effect of supply chain capabilities also implies that incorporating proper mediators may help better explain the impact of IT on firm performance. The present study provides some explanations regarding the inconsistent effects of IT on firm productivity (Brynjolfsson [5]. The findings suggest that examining the impact of IT in a specific setting, such as a firm's supply chain system, can help better gauge the effect of IT on firm performance (Barney et al. [3]. The results also provide some implications for managing the supply chain system. In particular, managers need to recognize the role of supply chain capabilities in realizing the value of IT resources. As the resource-based view argues, IT resources offer benefits when they are embedded in specific organizational processes (Barney et al. [3].

The study examines the impact of IT resources on firm performance in the context of SCM. Findings suggest that a proper deployment of IT resources in SC can help realize the benefits of IT through building higher supply chain capabilities in such areas as information exchange, coordination, activity integration, and supply chain responsiveness. The study also provides support for conceptualizing supply chain capability as a higher order construct. Managers need to realize that the different dimensions of supply chain capabilities are interrelated. The investment in the supply chain system needs to be coordinated throughout the channel partners in order to realize the full potential of technology investment in the supply chain system. Moreover, a firm's supply chain capabilities are likely to contribute more to firm performance when stemming from well-balanced supply chain activities rather than from fragmented and imbalanced activities.

7 CONCLUSION

Despite the crucial role of IT in realizing the value of supply chain capabilities on the firm performance, achieving such capabilities is not an easy task. Supply chain capabilities, as higher-order organizational capabilities represent a firm's abilities to effectively combine resources using information based organizational processes to serve customers. A higher level of knowledge integration from multiple sources and multiple partners throughout the supply chain is required to perform the tasks effectively and efficiently. The findings suggest that technology advancement and IT alignment are able to facilitate the development of supply chain capabilities. By deploying the newest technology for SC, especially before it is diffused widely, firms are expected to achieve higher efficiency than their competitors in channel activities, both within the firm and with partners.

The adoption of an advanced IT for supply chain processes can improve information sharing and coordination between channel partners. Due to the interconnectedness enabled by information technology, the once isolated decision making process from upstream suppliers to the downstream customers is becoming more intertwined. In fact, Van Hoek [28] indicates that the purpose of information sharing is to facilitate integrated and/or coordinated decision making in supply chain. In addition, sharing information across the supply chain network can help firms forecast market demands better, reduce inventory costs, and be more responsive to customer orders (Lin et al., 2002). The new IT-enabled model is functionally adequate and will enable the firm to achieve the supply chain system goal. The system goal of any supply chain system is profitability and eliminating variability magnification within the supply chain partners operations.

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INDUSTRIAL ENGINEERING TECHNIQUES AND SERVICE DELIVERY IN MUNICIPALITIES

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ABSTRACT

Industrial engineering techniques have been applied in the private sector in manufacturing and service industries with success. Industrial engineering techniques have also been applied in the public sector. This study aimed to investigate the application of industrial engineering techniques to optimise municipal services. In South Africa poor service delivery has been a continuous problem for inhabitants for more than a decade. Municipalities are under pressure to improve service delivery and reduce costs. Researchers approached the City of Johannesburg and the city of Ekurhuleni for access to their data pertaining to the study. The current state, of reaction times to complaints logged, were investigated at Ekurhuleni. At the City of Johannesburg a survey was completed to determine satisfaction of clients with general service delivery of the municipality. Industrial engineering tools were used in the analyses of the current state and it was established that industrial engineering techniques could be used to improve municipalities.

1 INTRODUCTION:

The unsatisfactory service delivery of municipalities in South Africa has been a continuous problem for inhabitants for more than a decade. It is regularly reported in the media that inhabitants have staged protest actions to complain about poor service delivery. It is the responsibility of municipalities to provide basic services such as refuse removal, sewage management, water, street surfaces, street and traffic lights and electricity. In many parts of South Africa residents do not pay for these municipal services as they can simply not afford to or choose not to pay for services.

Three students from the University of Johannesburg conducted a research project as partial fulfillment of the Bachelor in Engineering Technology requirements. The project chosen by these student were to establish in what way industrial engineering techniques could improve service delivery. These students approached the City of Johannesburg and the city of Ekurhuleni for access to their data pertaining to the study. The current state, of reaction times to complaints logged, was investigated at Ekurhuleni. Suggestions for improvements were made using industrial engineering techniques. At the City of Johannesburg a survey was completed to determine satisfaction of clients with general service delivery of the municipality.

The application of industrial engineering techniques to improve municipality services have been reported in a number of published articles and will be discussed below.

2 OBJECTIVE

The purpose of this research study was to investigate the application of industrial engineering techniques to optimise municipal services.

3 LITERATURE REVIEW

3.1 South African Municipalities

The establishment, power and the functions of South African municipalities are outlined in the Constitution of 1996, sections 155 and 156. According to the Constitution it is the municipality's responsibility to manage the local communities' affairs [1]. Municipalities cooperate with the national and the provincial government. Certain functional areas are the responsibility of the municipality.

In South Africa there are several unique challenges for municipalities. Corruption has negatively affected South African society as a whole. Pillay [2] wrote in 2004 that corruption specifically inhibited good governance and negatively affected economic development in South Africa. Unfortunately this is still the case in 2019. Corruption charges are frequently reported on in the popular press with regard to municipalities. Corruption Watch was established in 2012 and according to them the working definition of corruption is "the abuse of public resources and public power for private gain" [3]. The majority of reports received in 2017 by Corruption Watch were from the larger cities in Gauteng with City of Johannesburg accounting for 19.5% of reports and Ekurhuleni with 5.6%. Reporting corruption is one way to fight corruption, as is transparent operations.

3.1.1 Open governments and information and communication technology

Open Government is an approach that encourages transparency, accountability, open data, access to information, new technologies, democracy, citizen collaboration and participation [4]. The concept of an Open Government has been expanding internationally. Internationally governments are working towards open government while providing services as required. In order to achieve a successful Open Government system data needs to be shared and there are certain requirements to achieving sharing of data. Software and processes need to be designed in such a way that having open information is integrated into everything that is done in the public sector [5]. Open Government might assist with the reduction of corruption.

To ensure that citizens have access to open data, Information and Communications Technology (ICT) is very important. These systems should also help to improve the standard of service. ICT has the potential to help people overcome previous disadvantages and strengthen democratic institutions. However, to achieve this, these systems need to be implemented and used effectively [6]. South Africa is implementing e-government and other poverty alleviation programs. Government has started to provide wireless broadband to certain schools, clinics, libraries, multipurpose community centers and post offices. These multipurpose community centers are public places where people can use computers, the internet and other digital technologies to gather information, create, learn and communicate with others [6].

Major cities in South Africa have invested in public-private initiatives to build their own broadband networks. Many of these cities have created wireless user groups to provide many residents with free connectivity. The reasons for adopting municipal wireless networks have been cited as: engaging citizens in government [7] economic development [8], alleviating the digital divide [9] and to aid municipal workers in their work. Various business models exist to create these municipal wireless networks [10].

3.1.2 Financial constraints

In South Africa municipalities obtain income from two main sources, fees and subsidies. Income can be generated by the municipality through property rates, service fees for water, electricity, sanitation and refuse removal, and fines. Income can also originate from grants and subsidies which is transferred from other spheres of government. The majority of income is generated by service charges [11]. Some municipalities are almost completely dependent on grants and subsidies as it is not always possible to source their own income. This is caused by the poor income base of the residents of the municipality as well as non-payment of services by residents [12].

The City of Johannesburg Metropolitan Municipality includes the following cities Alexandra, Diepkloof, Diepsloot, Ennerdale, Johannesburg, Johannesburg South, Lawley, Lenasia, Lenasia South, Meadowlands East, Meadowlands West, Midrand, Orange Farm, Pimville, Randburg, Roodepoort, Sandton and Soweto. Many of these cities have very poor residents who cannot pay for municipal services and then there are other areas where residents are wealthy and generally pay for municipal service [13].

3.2 Industrial engineering techniques in municipalities

Municipalities have been under pressure to improve service delivery and reduce costs. Industrial engineering is concerned with improving quality, reducing cost and improving productivity [14]. Modern Industrial Engineering is concerned with the integration of resources and processes into cohesive strategies, structures and systems for the effective and efficient production of quality goods and services [15]. Industrial engineering techniques have been making a significant impact in the private sector but is often not applied in the public sector [16]. Van Heerden and van Heerden [16] matched the governmental needs with the industrial engineering supply.

Table 1. Matching needs with industrial engineering [16]

Governmental need	Industrial Engineering supply	Industrial engineering tools, techniques & methodologies
Bulk infrastructure investment decision making	Decision support	Simulation modelling and analysis

Programme management	Project management, monitoring and evaluation	PMP, PRINCE2©, DMAIC, PDSA, analytics, systems thinking
Optimal placement of social facilities	Optimisation	Operations research
Risk management	Risk mitigation and minimisation	Monte Carlo methods modelling, operations research and risk analysis
Professionalise the public service	Skills transfer and training	Multiple
Densification of cities	Modelling and decision support	Transport modelling, urban growth modelling, geospatial analysis
Transport improvements	Modelling and decision support	Transport modelling, operations research
Better job location	Optimisation	Operations research
Logistics corridor improvements	Supply chain management and logistics	Supply chain analysis and gap analysis
Revitalisation of value chains	Value chain improvement	Business process re-engineering, value chain mapping
Optimal use of budgets	Optimisation, prioritisation	Financial management, operations research
Monitoring and evaluation	Monitoring and evaluation	Requirements analysis and specification, database design, data collection and maintenance, key performance indicator development, business analytics and quality assurance

It would be possible to expand this table and add more detail of industrial engineering techniques that could be applied.

3.2.1 International examples of the application and benefits of industrial engineering in municipalities

Some of the techniques that have been used in municipalities elsewhere have been discussed in the literature [17]. Lean-Kaizen was applied in three local councils in Spain to improve their processes and their level of service provided to the public [18].

Lean is about adding value to the customer and reducing waste [19]. The Lean approach has three pillars, just in time flow, respect for people, and continuous improvement [18]. The five principles of lean are: Identify the value to the client; identify the value stream that provides that value and remove all waste from it; achieve continuous flow; introduce pull between steps and work towards perfection [19]. Waste is defined as anything that does not add value [20]. Originally seven wastes were identified but recently an eighth waste was added [21]:

- Defects
- Over processing
- Over production
- Waiting
- Inventory
- Unnecessary transportation
- Unnecessary motion of people or machines
- Unused talent

Kaizen refers to continuous improvement which is one of the pillars of Lean. Techniques identified as useful in public sector are value stream mapping, 5S, process mapping, kaizen and six sigma [22]. In all three of the councils studied by Suarez Barraza et al. in Spain the population was relatively small. The largest council had a population of approximately 227000. All three councils were able to achieve significant improvements in their processes and services delivered by using Lean-Kaizen.

Lean was also implemented in the Danish public sector [19]. The Danish public sector implemented lean for a variety of reasons often because of internal or external factors such as government expecting an institution to improve productivity with 25% [19]. Findings in this environment were the importance of a long term perspective on lean implementation and resources and abilities were important as lean often rivaled daily work. Some specific areas that suit lean well are waste disposal and maintaining parks [24]

Lean implementation in a UK government office led to double-digit productivity gains and improved customer service [24]. Implementation of lean is not a simple task, this is even more so in the public sector.

The City of Fort Wayne used six sigma to improve customer service and general service delivery [23]. Four cities in Florida implemented quality management and even though it was difficult it was possible to make improvements.

Quality Function Deployment was used in a process of municipal administration for support of family farming and backyard agriculture in the Moroleon City in Mexico. It was possible to clearly identify customer requirements. Quality Function Deployment was used to improve services according to the customers' expectations [24].

In Greece the measurement and assessment of performance became a major issue as decision making was decentralized. Efficiency performance was measured using different approaches [25].

4 METHODOLOGY

A research project was designed to investigate the use of industrial engineering techniques to optimise the functioning of two municipalities in South Africa. The research was conducted at the University of Johannesburg in partial fulfilment of the Bachelor of Engineering Technology: Industrial

One researcher identified and analysed complaints logged over a period of a month at the Ekurhuleni Municipality. There were only three technicians involved. The distribution and planning of technicians' tasks were specifically interrogated. The aim was to establish the current state of service delivery in Tembisa and to use industrial engineering techniques to analyse the current state. Pareto diagrams were used to determine the cause of the majority of complaints as well as reasons why these complaints were not addressed successfully.

At the City of Johannesburg the Municipal Manager was interviewed. Two students developed questionnaires to survey customer satisfaction with service delivery. Customers surveyed were from Randfontein, Soweto, Diepsloot and Ivory Park. The researchers used a sample of convenience. Participants were given a survey that used a three point Likert scale. The constructs covered in the survey were:

- Housing and shelter, specifically with reference to Government Subsidy Housing (also known as RDP houses),
- Law enforcement and traffic services,
- Rates and Accounts,
- Service experience,
- Parks and open spaces, and
- Halls and sports fields.

5 RESULTS

The Pareto analysis of complaints logged at the Ekurhuleni Municipality indicated that the most significant contributing factors to complaints were power failures and malfunctioning meter keypads see Figure 1.

Table 2. Pareto Analysis

Complaint type	No of complaints	Cumm %
No Power	410	58.405
Malfunctioning Meter Keypad	192	85.755
Call Center	31	90.171
Block off	21	93.590
High consumption	13	95.442
Cable Fault	11	97.009
Outstanding issues	11	98.575
Reconnection	6	99.430
Meter tamper	4	100
Illegal connections	2	100
Electric Trip	1	100
	702	

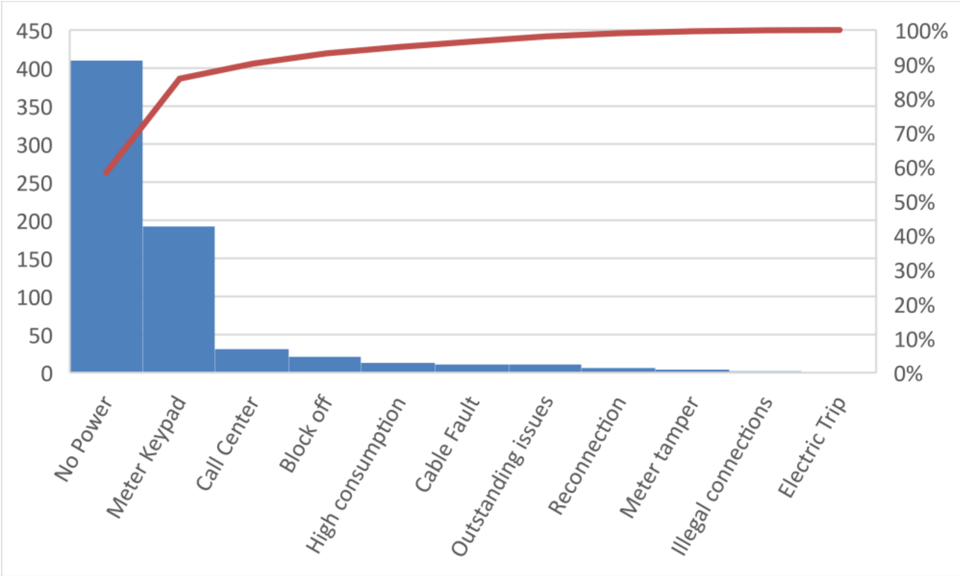

Figure 1: Pareto Diagram and Pareto Curve

Productivity was determined to be low as the percentage of work completed by the technicians was 48.29% for attended complaints over total complaints. Each technician had approximately 22 geographical areas to attend to. It appeared that additional technicians were required for this area. The current scheduling of technicians could also be improved on.

According to the survey results from the City of Johannesburg none of the residents of Soweto and Ivory Park indicated that they received excellent services, only 6% of residents from Diepsloot indicated that they received excellent services. Thirty percent of the residents in Randfontein rated their services as excellent. Residents indicated poor service delivery in Ivory Park (93%), in Diepsloot (73%), in Soweto (57%) and Randfontein (47%).

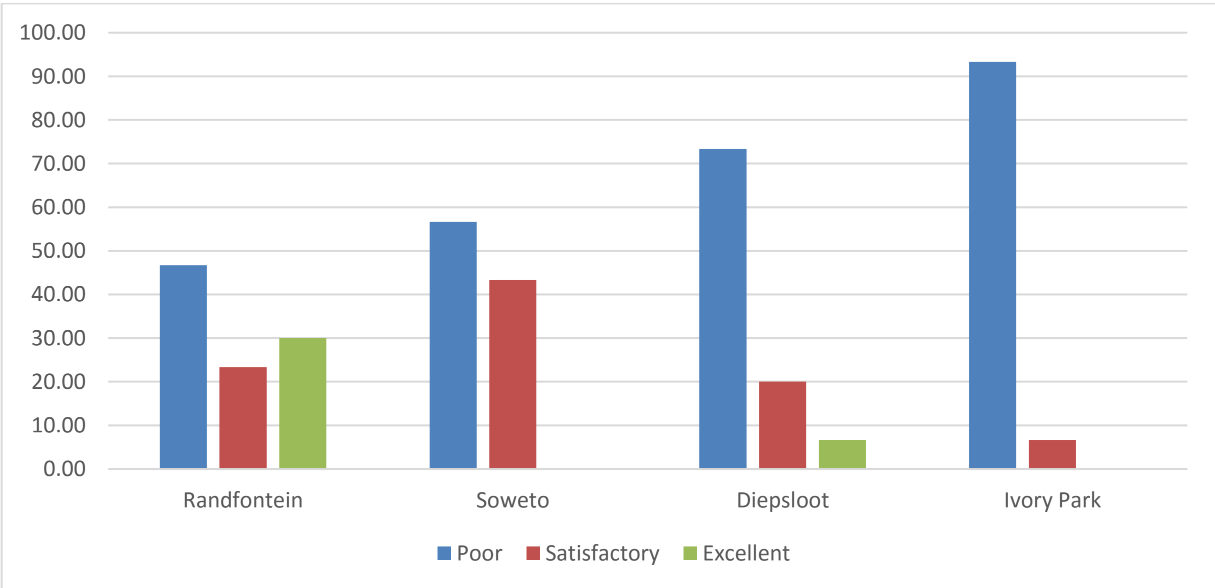

Figure 2: Participant level of satisfaction

Ensuring their safety, in parks and public spaces, was indicated by 93% of residents as a specific service that was problematic. The other specific areas of service delivery residents were negative about were road maintenance (77%) and refuse removal (70%). See figure 2

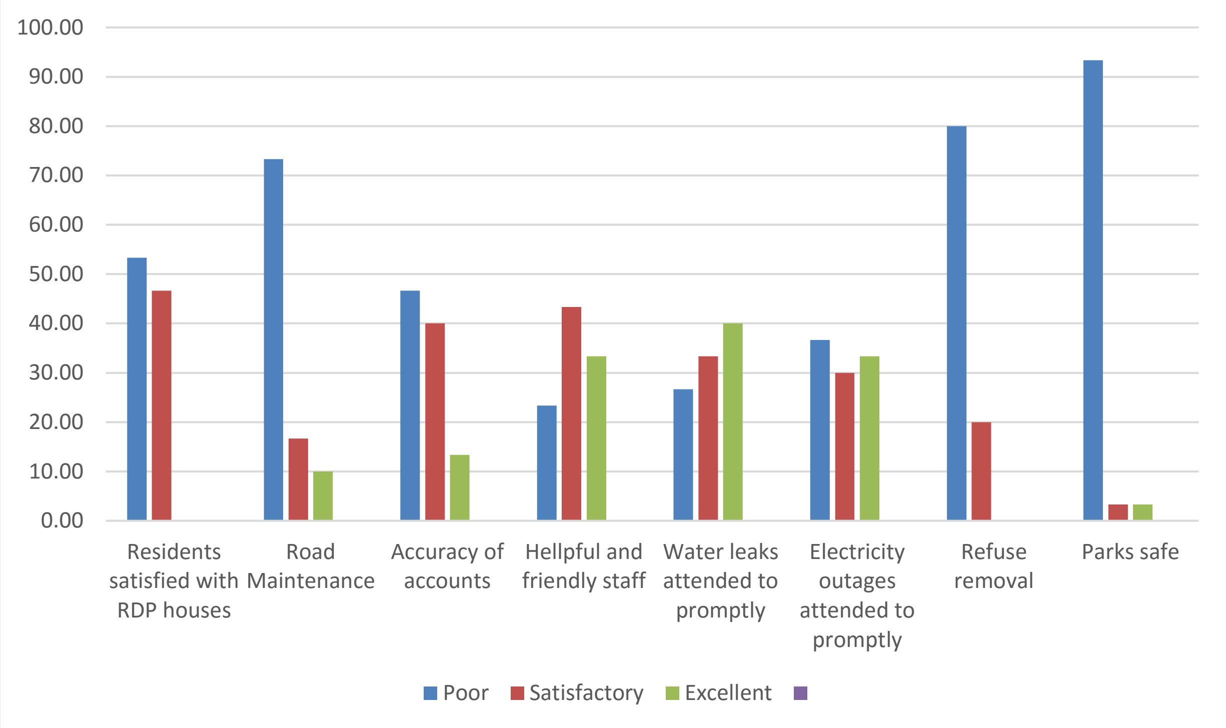

Figure 3: Level of satisfaction with specific services

According to the municipal manager of the City of Johannesburg two industrial engineering techniques, Lean diagnostics and Best Practice Benchmarking had been done, to ensure optimal service delivery. The municipality was aware of what good service delivery is however they blame limited resources for the poor performance. A culture of continuous improvement is required and in-house capability should be developed to achieve this goal. Employees need to be trained and motivated to be productive and continuously improve their performance.

6 CONCLUSION

At the Ekurhuleni municipality the current state of service delivery was established using industrial engineering tools. Further investigation is required to determine specific improvements to reduce power failures and malfunctioning meter keypads. Scheduling of technicians tasks has an important part to play and proper scheduling could improve the productivity of the technicians. There seems to be an indication for more technicians, but the extent needs to be determined by future research.

Even though Lean diagnostics and Best Practice Benchmarking were applied at the City of Johannesburg, the residents were still dissatisfied with services. A more rigorous implementation of Lean may lead to added value for the customers. Resources need to be considered as lean implementation can lead to significant benefits, it is however difficult for employees to implement lean while completing daily tasks [19]. As waste disposal and maintaining parks are identified as suitable to lean [24], and these are services residents are particularly dissatisfied with, lean could potentially improve customer satisfaction.

It is important to know the current state of service delivery, customers' dissatisfaction and to know what is required to deliver good services at the City of Johannesburg. However, the most important aspect is to come up with a plan of moving from the current state to the desired future state and implementing and maintaining that plan. Many industrial engineering techniques such as Kaizen, removing waste, business-process re-engineering and change management, could assist with achieving this goal.

Based on the literature and the information obtained from the two municipalities industrial engineering techniques may and are being used to improve service delivery in municipalities.

In South Africa there are unique challenges. Financial constraints remains a challenge to many of the municipalities. This supports the need for reducing costs as far as possible and improving productivity, which is central to industrial engineering. Annually there is a migration into the metropolitan areas of South Africa. Urban growth modelling and geospatial analysis could be used to better prepare for and manage this densification of the cities. Corruption is also a challenge that needs to be overcome. One possible way to address corruption is to ensure transparency possibly by implementing open government systems and to provide residents with wireless networks to improve involvement from residents' side. Open wireless networks have many other important benefits such as overcoming the digital divide. Free Wi-Fi has been made available to residents in many of the larger cities.

In the international examples mentioned many of the areas were smaller than those surveyed in this study and some also had financial constraints. There were clear benefits in these municipalities when using industrial engineering techniques to overcome some of the identified problems.

7 ACKNOWLEDGEMENT

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A FRAMEWORK FOR STANDARDISED INDUSTRIAL PROCESS DATA REPORT STRUCTURING

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ABSTRACT

Industrial processes generate vast amounts of data. If relevant data is captured and analysed, useful information can be extracted. Through reporting and dashboarding, this information can be used for informed decision-making.

Although business intelligence tools allowing effective reporting exist, spreadsheet software, like Microsoft Excel, is still widely used instead. This is despite the disadvantages of using a tool that is not specifically designed for reporting. One of the main disadvantages is that report set up is often non-standardised, making it difficult and time-inefficient for persons to maintain reports they are unfamiliar with.

This paper presents a framework with which reports can be structured. The framework is a method for defining all report data sources and content. It also defines how data and content are linked. The framework has been applied to a South African mining group. 36 report templates were generated adhering to the standard. With all report data sources and content being defined in a standardised and structured manner, the report generation, standardisation and approval process was expedited.

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1 INTRODUCTION

The past few years, with the Industry 4.0 paradigm, there has been a tremendous growth in the amount of data available [1]. However, relevant industrial process data is not always captured and utilised effectively [2]. Process data can be exploited to make data-driven decisions, rather than decisions based on opinion or intuition [3].

Reports and dashboards are ways to view and present data [4]. Reports contain static data whereas dashboards contain dynamic or live data [4]. Reporting and dashboarding facilitates data-driven decisions [4], [5]. Business intelligence (BI) software packages, like Sisense and QlikView, integrate data sources and provide a central point for decision-making. However, such BI tools are often not used. Reasons for this include financial constraints, and information and communication technology (ICT) infrastructure limitations [6]. Spreadsheet software is often used instead. In fact, Microsoft Excel is one of the tools most widely-used for BI [7]–[9].

Excel is a robust tool, but not specifically designed for reporting or dashboarding. This leads to problems when using it as the primary tool for creating dashboards or reports [7], [9]–[12]. What is especially noted from these references, is how using Excel for reporting can be time-consuming and difficult. Report set up can be difficult to analyse, especially if the spreadsheet has been developed by multiple people. Spreadsheets often become interlinked and data is hidden through this process. This can lead to difficulties when new persons need to maintain old reports. Despite these shortcomings, Excel is trusted, familiar and accessible to a large user base, and still used as a reporting or BI tool [8]–[10].

Some studies on dashboards have investigated topics such as their purpose, use, adoption; metric selection, experience/perceptions by users, and technical software design [13]–[15]. However, there are little to no scientific studies available that provide guidelines for the setup of dashboards [14]. Moreover, none focus on how exactly these dashboards should be set up in Excel (which provides complete freedom to the user). From this stem the disadvantages of using Excel for BI – there is no standard. There is no set way in which reports are set up in Excel; each person tackles this process in a way they see fit.

Since Excel remains widely used for BI, efforts can be made to address some of these disadvantages. As an alternative to the unstructured way reports in Excel are typically created, this paper proposes a framework that can be used for structuring reports within Excel. This framework sets a fixed standard, with which many types of reports can be created. This standardisation should improve the ease of setup and maintainability of reports.

As a case study, the proposed framework is applied to reporting on industrial process data. Daily reporting on process equipment and process variables' time series data has been shown to be advantageous [16]. Reporting within this context refers to the use of dashboard-like reports; reports that are concise and summary-like. With these reports designed to be monitored at a glance, it allows easy and effective process monitoring and aids in decision-making.

2 DEVELOPMENT OF SOLUTION

This section proposes a top-down framework for report structuring. It applies the framework on the sources of the data, as well as on the way data representations are defined. Two types of data representations are used in reports, namely: charts and tables. The data displayed in these originate from time-series measurements of process equipment or variables. From here on, the data representations are referred to as "content", and the data sources as "components".

2.1 Framework levels

The framework entails evaluating all report components and content. Their characteristics or setup are allocated into four levels (Figure 1). These levels serve as somewhat of an "instruction set" that allows the creation of a specified component or content to be replicated. The four levels can be used to describe all of the report's content.

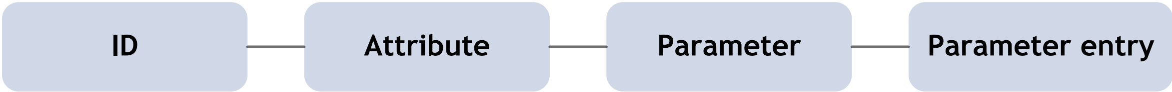

Figure 1: Report component and content structuring levels

The four framework levels specified in Figure 1 are described as follows:

- *ID*: unique identifiers used to refer to different components or content.
- *Attribute*: used to specify each attribute of the component/content being set up.
- *Parameter*: a modifier of the attribute, indicating which value is being specified.
- *Parameter entry*: the actual entry where the information is stored.

2.2 Structuring data sources into components

Charts and tables should contain data. Using the framework as a set of instructions, one needs a way of defining all data sources. As mentioned, the sources of process data are referred to as "components" within this framework. The following attributes are recommended to fully specify a component and store data within:

- Type: The type of the component, e.g. pump or compressor.
- Group: The group (if any) to which this component belongs. For example, location-based (e.g. surface or underground), or manufacturer-based (e.g. Sulzer compressors, Centac compressors, or GHH compressors).
- Any number of component-specific attributes and accompanying parameters, e.g. actual power consumption measurement and rated power consumption.

The framework for creating report components is visually summarised in Figure 2.

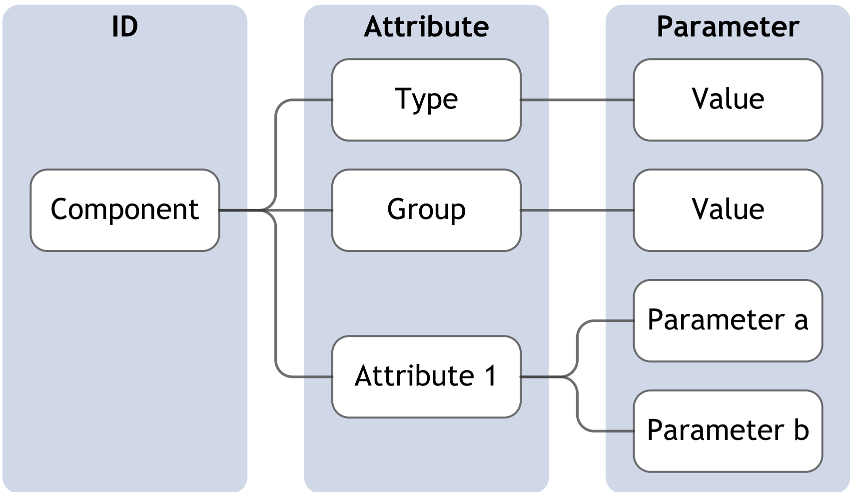

Figure 2: Report component framework

2.3 Creating report content

Report content, like charts and tables, are created by applying the framework. Specifying *which data* to use in this content is a significant step. This is discussed in Section 2.3.1. Furthermore, with the data originating as time-series data, one also needs a way of specifying exactly *how* this data needs to be prepared (discussed in Section 2.3.2).

The specification of "*which data*", and "*how*", are done via *Link*, *Grouping*, *Aggregation*, and *Data set*. Figure 3 is a visual summary of the framework for creating report content. *Link*, *Grouping*, *Aggregation*, and *Data set* are discussed afterward, and in reference to Figure 3.

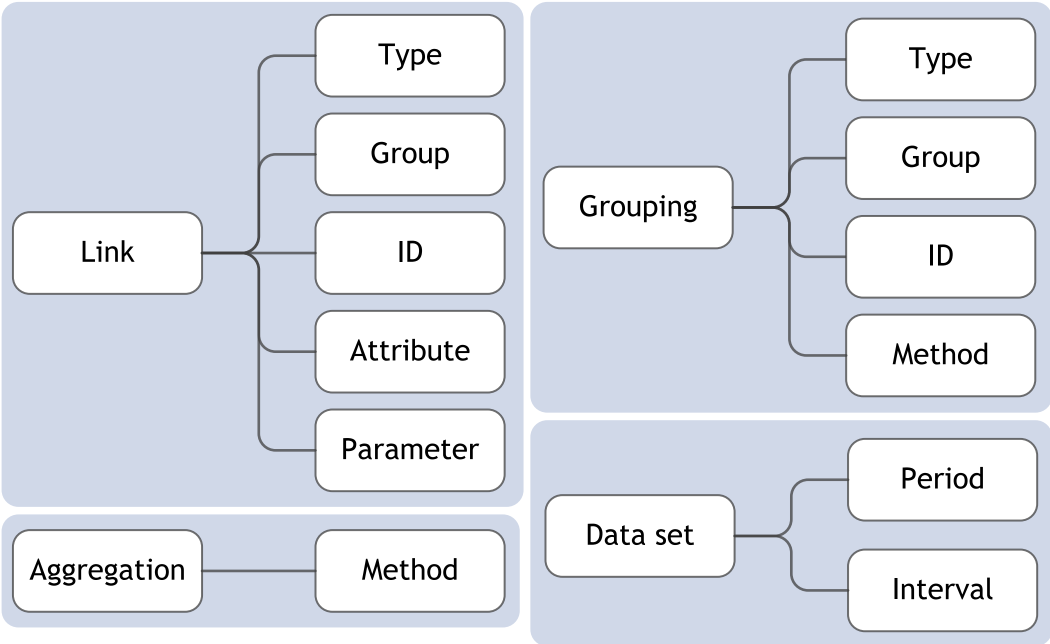

Figure 3: Report content framework

2.3.1 Linking data sources to content

The *Link* describes what data of which components are used in the content. *Linking* acts as a way to filter the list of components. One can specify a combination of component Type, Group, or ID to filter by. The list of components is narrowed down as more Link information is provided. The remaining components matching the Link criteria are those that are selected to be used in a chart or table.

Specifying a Type will filter all components that belong to this type. Specifying a Group will filter all components that belong to this Group. Specifying an ID is a way to link one component directly (since IDs are unique).

Link is also used to specify the components' Attribute and Parameters to be used in the report content.

2.3.2 Specifying how to use the components' data

After components have been selected by means of a Link, it is required to specify how their data should be prepared for use. Through Linking it is possible to select more than one component. Subsequently, one needs to decide if the selection needs to be grouped (e.g. calculating a total for all the components that belong to a certain Group). After grouping, one needs to specify how data should be aggregated for use in the report content. This section of this paper describes the specification of *Grouping*, *Data set* and *Aggregation*, used to perform the above-mentioned data preparations.

Grouping
Grouping describes how the linked components (or their data) should be grouped, and how the groups' totals should be calculated. Grouping can be performed based on components' Type, Group, or ID (i.e. components remain ungrouped). The method to be used for grouping is also specified (e.g. sum, average, minimum, maximum, etc.).

Data set
Data sets are used to specify the content's data range and resolution. These are referred to as *Period* and *Interval*, respectively, within the framework. Period refers to the range of data to use, for example one month's data. *Interval* refers to the required final data point interval or resolution, for example one value per day.

Aggregation

Grouped data is still in the original raw data resolution. *Aggregation* describes the resampling of the grouped data into the interval, as specified in the chart or table's data set interval, using a specified method (similar to Grouping).

3 RESULTS AND CASE STUDY

Reporting is required for project oversight and monitoring for a South African mining group. Daily reporting ("static dashboards") on the mining group's pumping, compressed air, and winder systems are required and imperative to the success of these projects. These reports are required for each of the group's six shafts, with a total of 36 reports required per day.

Since there is not a generally-accepted way in which reports should be set up, it is easy to image how these 36 reports can all be set up differently. Instead, the framework as described in Section 2 was applied in setting up all the required reports. This section presents the result of applying the framework on one of the charts and one of the tables required, as described in the above case study.

One of the required reports is on a pump station energy project. The pump station consists of four pumps. A total power consumption chart with hourly values for the previous day is included in the report. This gives an indication of how operations fall into the Eskom time-of-use tariff structure. The maximum demand for the previous 7 days is also indicated in a table, to monitor running within electrical infrastructure specifications.

3.1 Applying the framework to report components

The report contains four pump components, each of which is structured as in Figure 4:

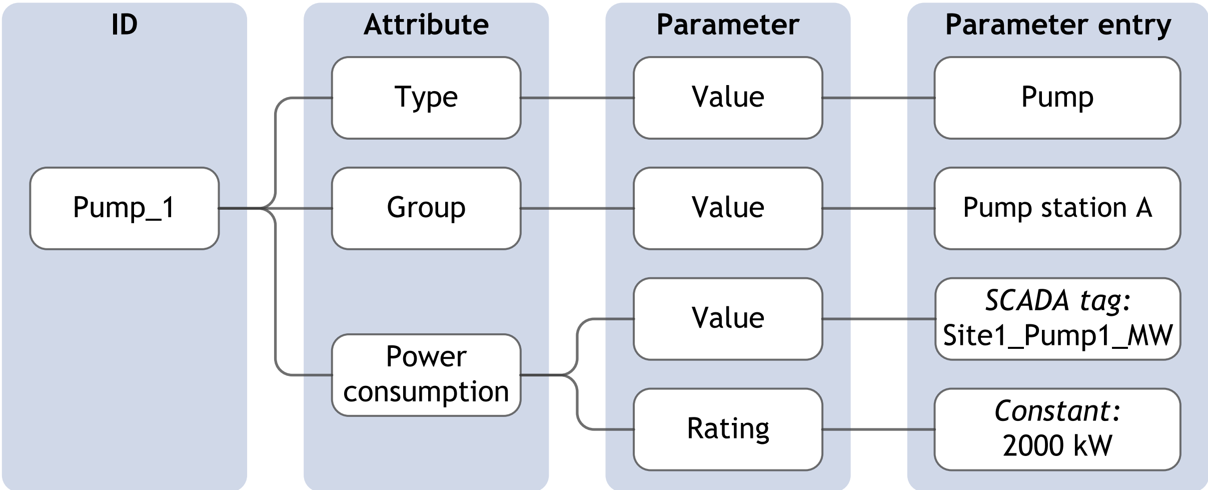

Figure 4: Report component specification example

3.2 Applying the framework to report content

3.2.1 Chart

A total power consumption chart with hourly values for the previous day needs to be created. This chart is structured as shown in Figure 5. Note how the accompanying series (in Figure 6) is linked to the chart in Figure 5.

Figure 5 also includes other chart-specific attributes and parameters. These attributes are: caption, height, width, legend, x-axis and y-axis. This illustrates how the framework levels are used for defining report content, as required for recreation.

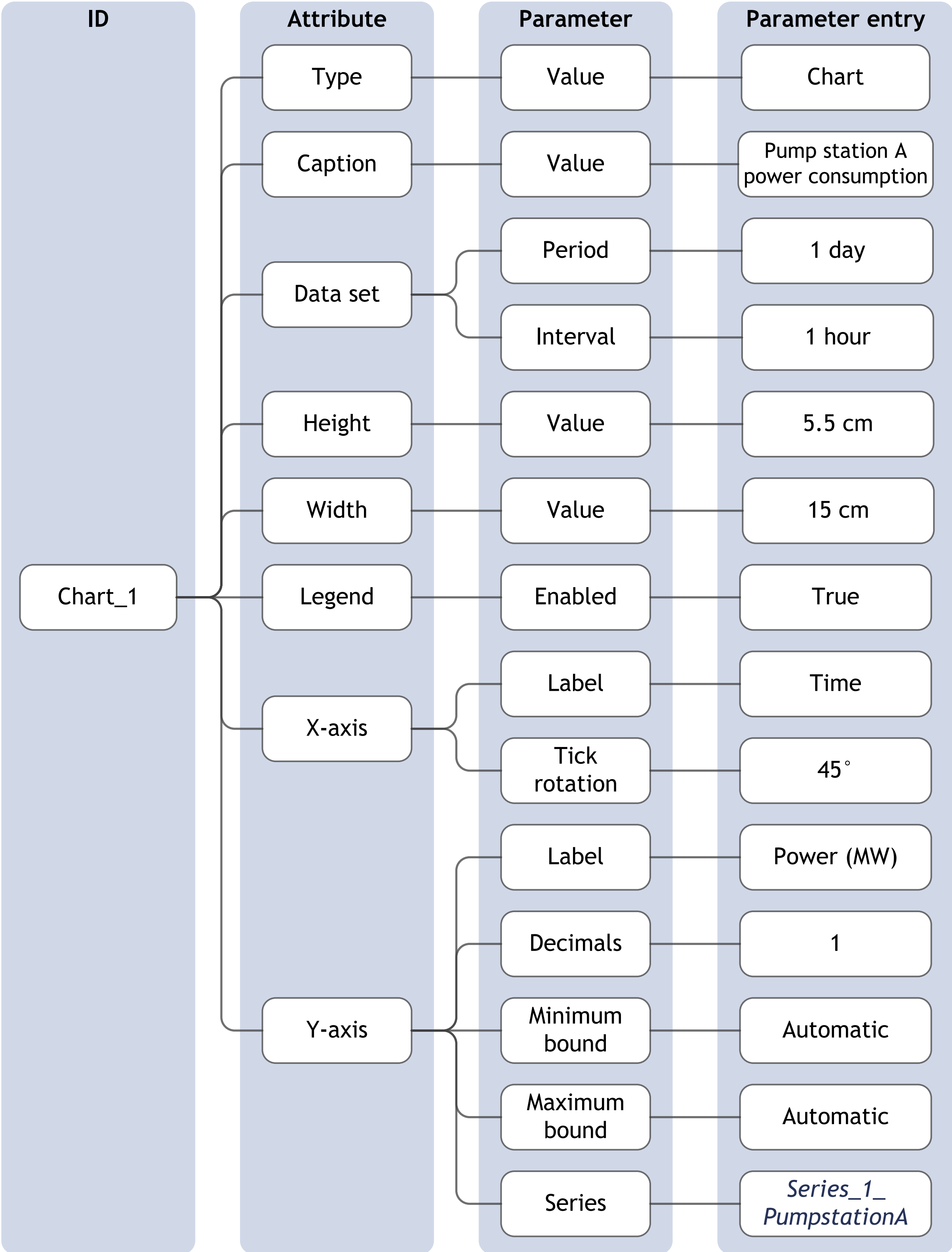

Figure 5: Chart specification example

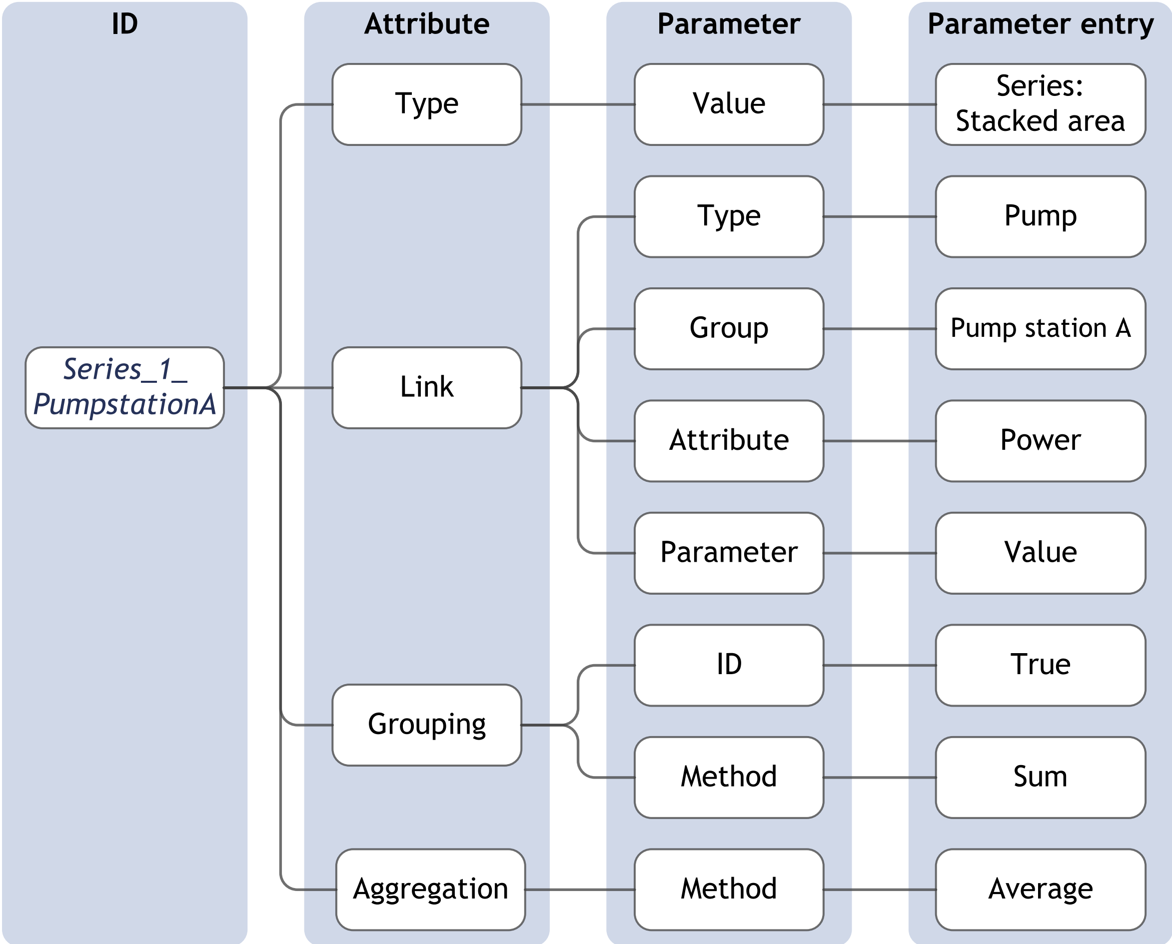

Figure 6: Chart series specification example

In the structuring of *Series_1_PumpstationA*, *Link*, *Grouping* and *Aggregation* were specified as follows (referring to Figure 6):

Link:
Firstly, find all components of type "Pump" from the list of components. From this subset, find all components with "Pump station A" as their group. For the components as selected, use the data stored in the "Value" parameter of the "Power" attribute. In performing the above-mentioned, all four pump components have been selected.

Grouping:
Group by ID – keep each of the four selected pump values separate. Do not group them into a total. (Since this is a stacked area chart, the values will stack to form the total value and no grouping is required.) Since no grouping is required, specifying the grouping method as "sum" means that each selected component's values will be used as-is (the sum of only one component's values).

Aggregation:
Resample the components' raw data to the interval of the data set using the method "average". The resulting data points will be in hourly resolution, where each new data point is the average of those in the raw data falling within each points' timespan.

Following the instructions set out in Figures 5 and 6, the chart as in Figure 7 will be created.

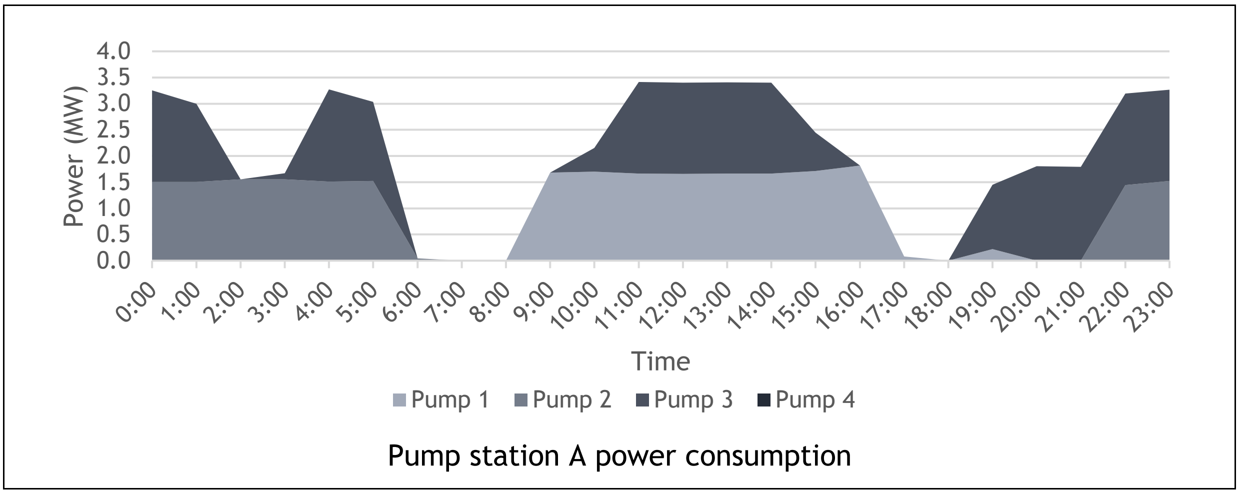

Figure 7: Resulting chart created by following the framework. The figure illustrates the power consumption of each pump during a 24-hour period.

3.2.2 Table

The pump station's maximum electrical demand for the previous 7 days needs to be indicated in a table. The structuring of this table is as in Figure 8. Note how the accompanying column (Figure 9) is linked to the table in Figure 8.

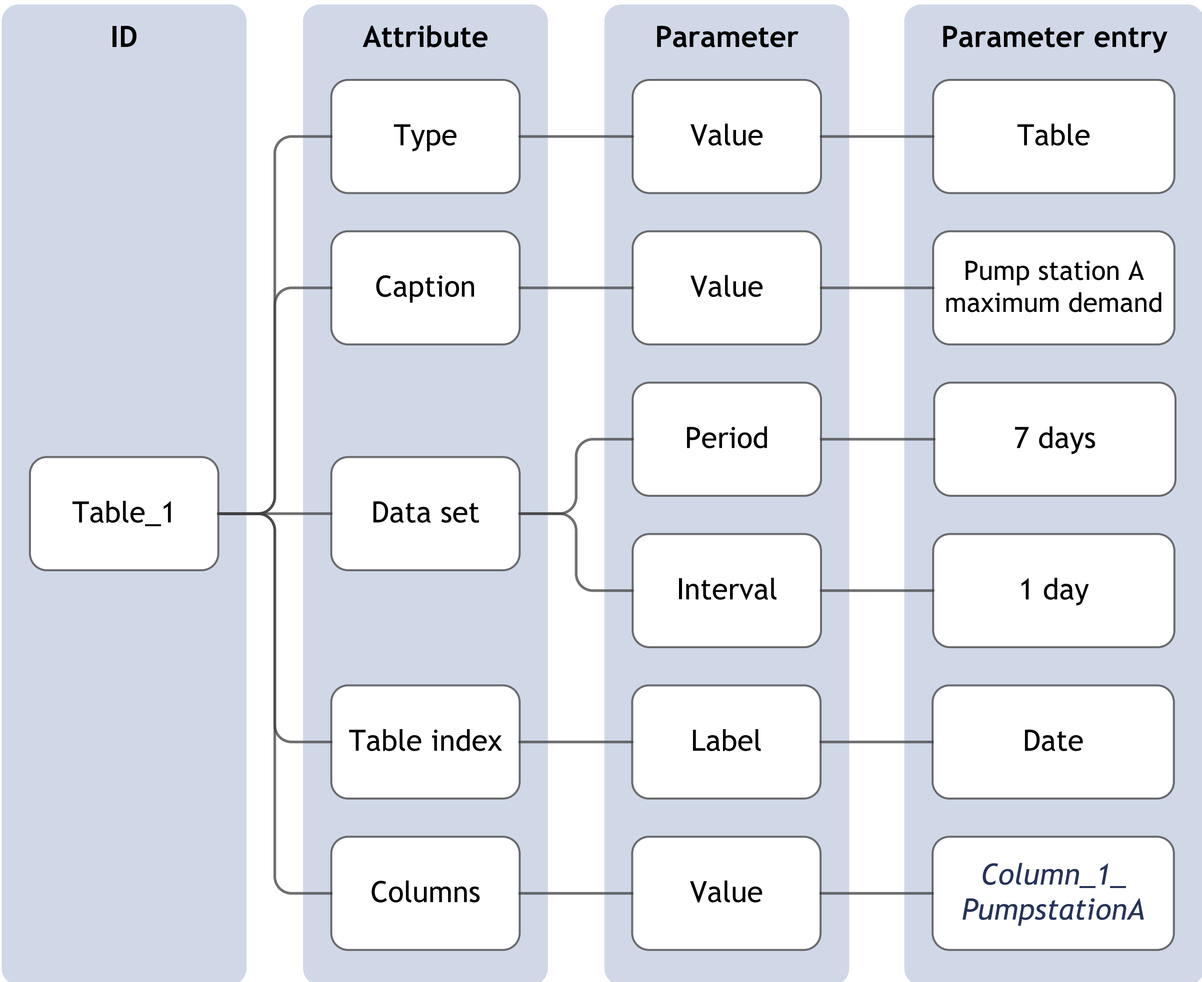

Figure 8: Table specification example

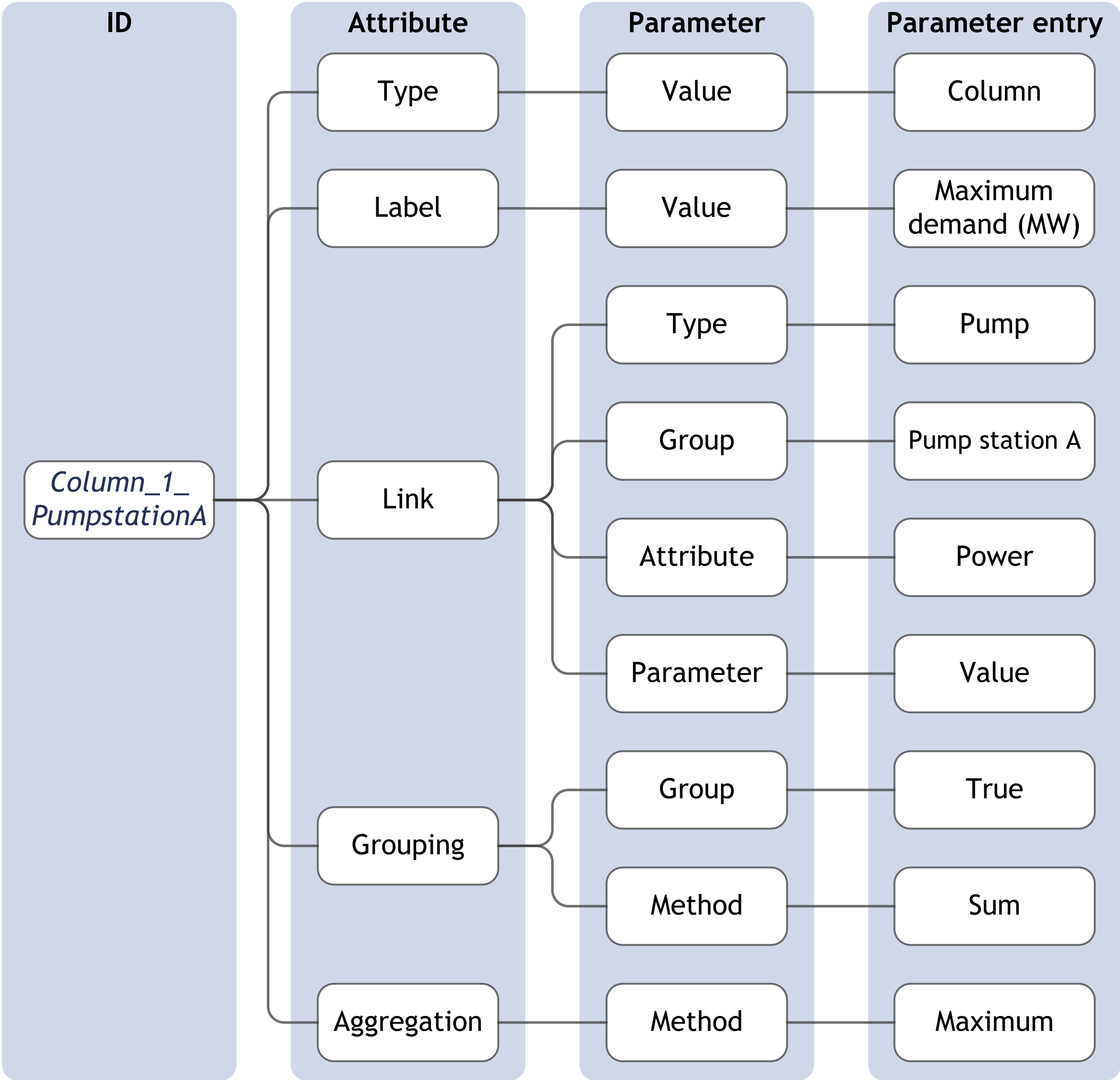

Figure 9: Table column specification example

Figures 8 and 9 also include other table-specific attributes and parameters. These attributes are: caption, index labels, and column labels. This illustrates how the framework levels are used for defining report content, as required for recreation.

In the structuring of *Column_1_PumpstationA*, *Link* was specified the same way as for *Series_1_PumpstationA*. *Grouping* and *Aggregation* were specified as follows (referring to Figure 9):

Grouping:
Calculate the total value for each group (group by Group). The total value is the sum of all selected components' values. This results in the total power for the four pumps in *Pump station A*.

Aggregation:
Resample the components' raw data to the interval of the data set using the method "maximum". The resulting data points will be in daily resolution, where each new data point is the maximum of those in the grouped data above, falling within each points' timespan.

Following the instructions set out in Figures 8 and 9, the table as shown in Figure 10 will be created:

Date	Maximum demand (MW)
24 May 2019	3.4
25 May 2019	3.8
26 May 2019	3.1
27 May 2019	3.1
28 May 2019	3.4
29 May 2019	3.8
30 May 2019	3.4

Pump station A maximum demand

Figure 10: Resulting table created by following the framework. The table illustrates the maximum demand for the pump station during a 7-day period.

4 DISCUSSION OF RESULTS

The framework, as discussed in Section 2, was proposed to structure the components and contents within a report. In Section 3 it is described how, as a case study, daily reporting of multiple systems of a South African mining group is required. Section 3 presents the structuring of one of the charts and one of the tables that are required in the reporting effort.

Specifically, the graph presented in Section 3 is used to monitor the operation of the pump station. Monitoring the pump station power consumption throughout the day shows operations fall into the Eskom time-of-use tariff structure. This information is then used to optimise the system in terms of energy cost. The table presented in Section 3 is used to monitor whether cost-optimising operation is within electrical infrastructure specifications.

The results presented in Section 3 are meant to illustrate how one would specify the "instruction set" for specifying components and building report contents. Although the results are presented as a specific example, these results are generalisable. It can easily be extended or adapted for use in other reports. The framework can be used to structure reports wherever graphical and tabular reporting on data is required.

In the authors' case, it has proved advantageous to follow the proposed framework. In the authors' everyday oversight and monitoring of mining-related projects, the framework was applied to 36 report templates. Applying the framework allowed for standardisation of the reports' structuring.

After designing the first of each kind of report, this standardisation allowed for easier and quicker creation, approval and roll-out of subsequent reports. Where typically it would take approximately two weeks or more to design and create a single client-ready report, applying the framework resulted in a more than double increase in time-efficiency. Four kinds of reports were successfully designed and created within the same timeframe.

The standardisation of the structuring also allowed for multiple users to easily work on reports and make required changes. There was less searching needed, as all reports are expected to be set up similarly. Users could refer to the structure and follow that as a "map" that provides the set of instructions of how the report is set up. This allowed persons unfamiliar with a specific report to be able to also maintain it, since all reports follow a structuring standard.

5 CONCLUSION & RECOMMENDATIONS

Although business intelligence tools allowing to effective reporting exist, spreadsheet software, like Microsoft Excel, is still widely used for reporting. This is despite the disadvantages of using a tool not specifically designed for reporting. One of the main disadvantages is how report set up is often non-standardised, making it difficult and time-inefficient for persons to maintain reports they are not familiar with.

This paper presents a framework with which reporting can be structured. Structuring report contents in the way proposed in this paper, has proven advantageous in the authors' case. It has decreased the amount of time needed for multiple reports' generation, standardisation and approval. The standardised structuring also made it easier for persons to maintain unfamiliar reports. The framework has contributed towards alleviating some of the disadvantages of using Excel as a reporting tool.

Still, Excel is not designed primarily as a reporting tool. Following this, a further step towards improving reporting would be to incorporate this structuring into a reporting-centred system. A system that enforces the structure in a user-friendly manner will be a step closer towards moving away from reporting that relies solely on the use of Excel.

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FIBRE NETWORK PLANNING WITH RETRACTABLE CABLE TECHNOLOGIES

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ABSTRACT

The passive optical network (PON) planning problem involves the computation of facility locations, such as splitters and central offices, and the placement of optical fibres in order to service demand points (optical network units). The objective of the PON planning problem is to minimise overall deployment cost. Traditional PON planning models assume the flexibility of single fibre configuration without having to take into account deployment-specific constraints. In this paper, a PON network planning model is proposed which specifically incorporates the use of retractable cable technologies for fibre deployment. The computational results presented in this paper demonstrate the restrictive effect that retractable cable technologies may have on PON network configurations as well as the expected cost implications. Furthermore, initial results also suggest that a significant increase in computing times may be expected when computing solutions for PON planning problems that incorporate retractable cable technologies.

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1 INTRODUCTION

The use of automated passive optical network (PON) design tools is imperative for dealing with the complexities involved in PON deployment projects. Not only does it ensure effective use of network resources, but it also accelerates the planning process such that the total project time from conceptual design to final deployment is minimised. These design tools are typically based on some underlying mathematical model that provides as output a network topology describing the placement of splitters, the required trenching and duct installment, as well as the fibre layout which will ensure all demand points are connected to a central office via a splitter (see e.g. [1]–[3]).

Various algorithmic approaches exist for computing solutions to the mathematical models that describe the PON planning problem. In general, these approaches may be classified as either being exact or heuristic. The latter is typically more computationally efficient without any solution quality guarantees, whereas the former has the attractive feature of providing proven optimal solutions, but typically to the expense of computing times and memory usage. In this paper, an exact approach is followed by modelling the PON planning problem as a mixed integer linear programming problem (MILP) and solving it to optimality through the application of a commercial off-the-shelf MILP solver.

The use of MILP is well suited for the purpose of modelling passive optical networks due to its ability to capture logical decision-making and its application in the modelling of generic network design problems. In [4]–[6], path-based MILP formulations are presented towards solving the PON planning problem and in [7]–[9] several planning considerations such as survivability, multi-level PONs and demand uncertainty are taken into consideration.

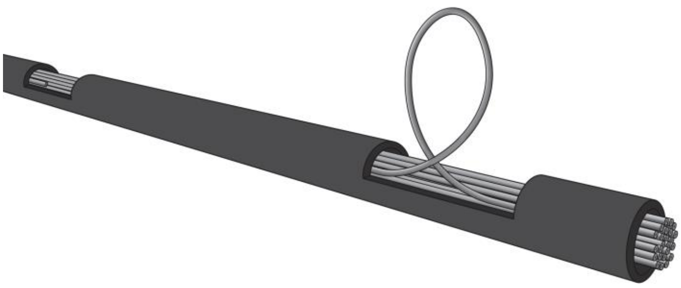

Figure 1: A schematic depiction of a retractable cable containing several fibres. Single fibres are retracted through an opening in the cable shell and then connected to either a splitter or an optical network unit (ONU).

The application of a MILP formulation to model the use of retractable cable technologies is of specific interest to this study. The current mathematical formulations of the PON planning problem found in the literature assume the flexibility of installing single fibres, without taking into consideration the restrictions imposed by the method of deployment. Figure 1 is a depiction of a retractable cable showing that a single fibre may be “retracted” from the cable in order to connect either a splitter or an optical network unit (ONU). Intuitively it makes sense that retractable cables be placed such that clients within the same geographic vicinity are served by the same cable. This will ensure that more economic value is derived by utilising as many of the fibres as possible within a single cable. From a planning perspective, however, the use of retractable cable technologies poses a challenge. Depending on the PON topology and the geographic distribution of the ONU's, it may turn out that a feasible solution requires connecting only some of the fibres in a single cable. The PON planning problem with retractable cable technologies, therefore, has to optimise fibre usage while satisfying all ONU demands.

In the remainder of this paper, details of a mathematical model that incorporates retractable cable technologies are provided. Computational results of a small problem instance are presented to demonstrate what the effect is on the final PON configuration and the total deployment cost when considering deployment-specific requirements. The paper is concluded with a summary and some concluding remarks.

2 MATHEMATICAL MODEL

A graph representation of the PON planning problem is used for the purpose of formulating the mathematical model. Figure 2 shows an example of an input graph $\mathcal{G}(\mathcal{N},\mathcal{E})$ with a set of nodes $\mathcal{N}$ and a set of edges $\mathcal{E}$. The edges represent all the permissible trenching that may be undertaken at a unit cost of c_e with $e \epsilon \mathcal{E}$. A node $n \in \mathcal{N}$ may represent either a central office (denoted by a square in Figure 2), a splitter (triangle), an ONU (circle), or a junction in the trenching network (an intersection of any pair of lines in the graph). Let $\mathcal{O} \subset \mathcal{N}$ be the index set of all central offices and let c_0 denote the cost associated with the installation of a central office $o \in \mathcal{O}$. The index set $\mathcal{S} \subset \mathcal{N}$ contains the set of potential optical splitter locations and the index set $\mathcal{T}$ denotes the set of different splitter types. The cost associated with installing a splitter of type $t \in \mathcal{T}$ is denoted by c_t.

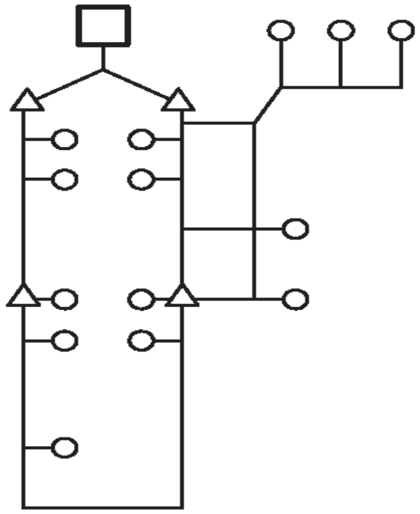

Figure 2: An example of a PON input topology showing the placement of potential cental offices (squares), splitters (triangles), ONUs (circles).

Let $\mathcal{U} \subset \mathcal{N}$ be the index set of all ONU's and let c_u denote the cost associated with the installation of an ONU $u \in \mathcal{U}$. The set of vertices $\mathcal{V} = \mathcal{N} \backslash \{\mathcal{O} \cup S \cup U\}$ is used for modelling junctions in the trenching network.

A distinction is made between the part of the network topology that includes fibres connecting the central offices to the splitters, and the part of the network where fibres connect splitters to the ONUs. The former is referred to as the *feeder network*, whereas the latter is referred to as the *distribution network*.

The index set R is used to describe the set of all potential retractable cables to be used. The unit cost c_w is assumed to be the same for all the retractable cables $r \in R$. The subset $R^F \subset R$ contains all the retractable cables that may be deployed in the feeder network and the subset $R^D \subset R$ contains all the retractable cables that may be deployed in the distribution network. For purposes of explanation, the subset R^F may be viewed as a set of auxiliary nodes within the feeder network. The process of deciding which fibre in which retractable cable to connect to a splitter is facilitated by the notion of a commodity pair (i,j), where $i \in R^F$ is a specific cable in the feeder network and $j \in S$ is a specific splitter. In order to simplify notation, a commodity pair (i,j) will be denoted by $k \in K$, with K the set of all commodities to be considered in the problem. The same logic is applied for the distribution network where a commodity pair $k = (i,j)$ facilitate the use of a fibre in retractable cable $i \in R^D$ to connect a splitter $j \in S$.

The subset $K(\mathcal{O}, R^F) \subset K$ contains all the commodities $k = (i,j)$ with $i \in \mathcal{O}$ and $j \in R^F$ and the subset $K(R^F, S) \subset K$ contains all the commodities $k = (i,j)$ with $i \in R^F$ and $j \in S$. The same logic holds for the distribution network where the subset $K(S, R^D) \subset K$ contains all the commodities $k = (i,j)$ with $i \in S$ and $j \in R^D$ and the subset $K(R^D, U) \subset K$ contains all the commodities $k = (i,j)$ with $i \in R^D$ and $j \in U$.

The solution of the proposed model specifies which central offices, splitters and retractable cables to use, as well as the layout of the required trenching. More specifically, let $\gamma_0 \in \{0,1\}$ indicate whether a central office $o \in \mathcal{O}$ will be used, let $z_r \in \{0,1\}$ indicate whether a retractable cable $r \in R$ is used, and let $\mathcal{Y}_{st} \in \{0,1\}$ indicate whether a splitter of type $t \in \mathcal{T}$ will be placed at location $s \in S$. The decision variable $x_e \in \{0,1\}$ is used to determine whether trenching will be undertaken for an edge $e \in \mathcal{E}$. Some auxiliary decision variables are required to complete the formulation. For instance, the variable $\psi \in \{0,1\}$ is is used to determine which commodity pair will be active in order to connect a splitter to a central office in the feeder network, or to connect a ONU to a splitter in the distribution network, $f_{ijk} \in \mathbb{R}$ is a variable indicating whether fibre for a commodity k will be running along an edge $(i,j) = e \in \mathcal{E}$, n_r captures the number of fibres used in a retractable cable $r \in R$ and m_r provides the maximum length of retractable cable that will be required for deployment.

The function $\mu(i)$ returns the adjacent nodes to node $i \in \mathcal{N}$, the function $\phi(r)$ returns the adjacent central offices $o \in \mathcal{O}$ to the retractable cable $r \in \mathcal{R}$, the function $\sigma(r)$ returns the adjacent optical splitters $s \in S$ to the retractable cable $r \in \mathcal{R}$ and the function $\pi(i)$ returns the adjacent retractable cables $r \in R$ to node $i \in \mathcal{N} \backslash R$.

The objective of the PON planning problem with retractable cable technology is to minimise

$$\sum_{o \in \mathcal{O}} \gamma_o c_o + |U| c_u + \sum_{s \in S} \sum_{t \in T} \mathcal{Y}_{st} C_t + \sum_{e \in \mathcal{E}} x_e c_e + c_w \sum_{r \in R} m_r \qquad (1)$$

subject to

$$\sum_{k \in K(R^D,u)} \psi_k = 1, \qquad \forall u \in U, \qquad (2)$$

$$\sum_{j \in \mu(i)} f_{ijk} = \psi_k, \ \forall k \in K(i,U), i \in \mathcal{R}^D, \qquad (3)$$

$$\sum_{j \in \mu(i)} (f_{ijk} - f_{jik}) = \psi_k, \ \forall k \in K(i,U), i \in \mathcal{R}^D, \qquad (4)$$

$$\sum_{k \in K(r,U)} \psi_k = n_r, \ \forall r \in \mathcal{R}^D, \qquad (5)$$

$$n_r \leq \mathcal{Z}_r K, \qquad \forall r \in \mathcal{R}^F \cup \mathcal{R}^D, \qquad (6)$$

$$\sum_{k \in K(\mathcal{R}^F,s)} \psi_k = \sum_{t \in T} \mathcal{Y}_{st}, \qquad \forall s \in S, \qquad (7)$$

$$\sum_{j \in \mathcal{R}^D} \mathcal{Z}_j K \leq \sum_{t \in T} \mathcal{Y}_{st} n_t, \qquad \forall s \in S, \qquad (8)$$

$$\sum_{j \in \mathcal{R}^F} \mathcal{Z}_j K \leq \gamma_o n_o, \qquad \forall o \in O, \qquad (9)$$

$$\sum_{k \in K(\mathcal{O},\mathcal{R}^F)} \Big(\sum_{j \in \phi(i)} f_{ijk} - f_{jik} \Big) = \mathcal{Z}_i K, \qquad \forall i \in \mathcal{R}^F, \qquad (10)$$

$$\sum_{k \in K(\mathcal{O},\mathcal{R}^F)} \Big(\sum_{j \in \pi(i)} f_{ijk} - f_{jik} \Big) = -\sum_{j \in \mathcal{R}^F} \mathcal{Z}_j K, \qquad \forall i \in \mathcal{R}^F, \qquad (11)$$

$$\sum_{k \in K(\mathcal{O},\mathcal{R}^F)} \Big(\sum_{j \in \mu(i)} f_{ijk} - f_{jik} \Big) = 0, \qquad \forall i \in \mathcal{R}^D \cup S \cup \mathcal{U} \cup \mathcal{V}, \qquad (12)$$

$$\sum_{j\in\mu(i)} f_{ijk} = \psi_k, \ \forall k \in K(i,S), i \in \mathcal{R}^F, \quad (13)$$

$$\sum_{k\in K(r,S)} \psi_k = \mathcal{N}_r, \ \forall r \in \mathcal{R}^F, \quad (14)$$

$$\sum_{j\in\mu(i)} (f_{ijk} - f_{jik}) = \psi_k, \ \forall k \in K(i,S), i \in \mathcal{R}^F, \quad (15)$$

$$\sum_{j\in\mu(i)} (f_{ijk} - f_{jik}) = 0, \ \forall k \in K(\mathcal{R}^F,S)\backslash K(\mathcal{R}^F,i), i \in S, \quad (16)$$

$$\sum_{j\in\mu(i)} (f_{ijk} - f_{jik}) = 0, \ \forall k \in K(\mathcal{R}^F,S), i \in \mathcal{R}^D \cup S \cup \mathcal{U} \cup \mathcal{V}, \quad (17)$$

$$\sum_{k\in K(S,\mathcal{R}^D)} (\sum_{j\in\sigma(i)} f_{ijk} - f_{jik}) = \mathcal{Z}_i K, \qquad \forall i \in \mathcal{R}^D, \quad (18)$$

$$\sum_{k\in K(S,\mathcal{R}^D)} (\sum_{j\in\pi(i)} f_{ijk} - f_{jik}) = -\sum_{j\in\mathcal{R}^D} \mathcal{Z}_j K, \qquad \forall i \in \mathcal{R}^D, \quad (19)$$

$$\sum_{k\in K(S,\mathcal{R}^D)} (\sum_{j\in\mu(i)} f_{ijk} - f_{jik}) = 0, \ \ \forall i \in \mathcal{R}^F \cup \mathcal{O} \cup S \cup \mathcal{V}, \quad (20)$$

$$\sum_{j\in\mu(i)} (f_{ijk} - f_{jik}) = 0, \ \forall k \in K(\mathcal{R}^D,\mathcal{U})\backslash K(\mathcal{R}^D,i), i \in \mathcal{U}, \quad (21)$$

$$\sum_{j\in\mu(i)} (f_{ijk} - f_{jik}) = 0, \qquad \forall k \in K(\mathcal{R}^D,\mathcal{U}), i \in \mathcal{R}^F \cup S \cup \mathcal{O} \cup \mathcal{V}, \quad (22)$$

$$\sum_{(i,j)\in\mathcal{A}} f_{ijk} d_{ij} \le m_r, \ \forall k \in K(r,u), r \in \mathcal{R}^D, u \in \mathcal{U} \quad (23)$$

$$\sum_{(i,j)\in\mathcal{A}} f_{ijk} d_{ij} \le m_r, \ \forall k \in K(r,s), r \in \mathcal{R}^F, s \in S \quad (24)$$

$$\sum_{k\in K} (f_{ijk} + f_{jik}) \le \Delta x_e, \ \forall (i,j) = e \in \mathcal{E}. \quad (25)$$

Constraint sets (2), (3) and (4) force each Optical Network Unit (ONU) to connect to exactly one fibre cable and ensure the correct flows of the corresponding commodity pairs. Constraint set (5) ensures that n_r captures the number of ONUs connected to retractable cable r. Constraint set (6) allows a maximum of κ fiber cables in each retractable cable r. Constraint set (7) enables optical splitters when used and constraint set (8) limits the number of fibres connected to an optical splitter to its capacity. Constraint set (9) limits the number of fibres to be connected to a Central Office (CO), to its capacity. Constraint sets (10), (11) and (12) connect necessary retractable cables to the CO. Constraint sets (13), (14) and (15) force a connection to the corresponding pair of retractable cables and splitters. In constraint sets (16) and (17), flow over the remaining vertices are set to zero.

Constraint sets (18), (19) and (20) connect necessary retractable cables to each optical splitter. In constraint set (21) and (22), flow over the remaining vertices are set to zero. Constraint sets (23) and (24) force m_r to be at least the maximum cable length for retractable a cable r. Constraint set (25) enables all the trenches used in the graph.

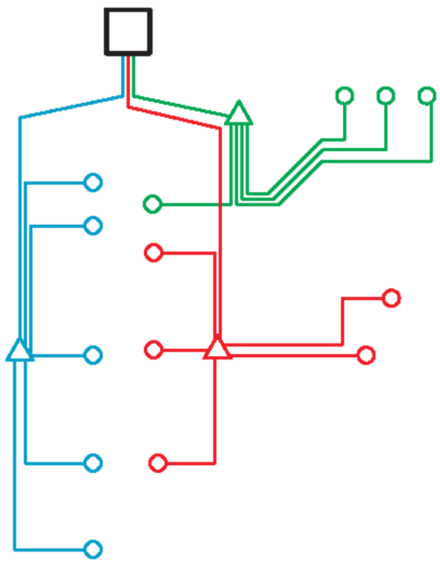

Figure 3: The solution obtained for the PON planning problem without deployment-specific constraints, based on the formulation in [10].

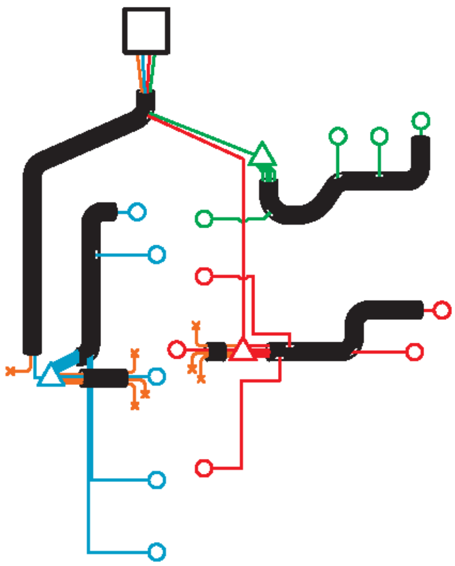

Figure 4: The solution obtained for the PON planning problem with retractable cable technologies, based on the formulation (1) - (25).

3 RESULTS

The model proposed above incorporates retractable cable technologies as a means of deploying PONs. The following computational results are used to demonstrate the added value when modelling deployment-specific technologies in the formulation of PON planning problems.

The example network in Figure 2 was used as input and two sets of solutions were generated. The first solution set was obtained by solving a PON planning problem that does not take deployment technologies into account. The problem formulation in [10] was used for this purpose. The resulting solution is depicted in Figure 3 and it shows the connections of individual fibres that allow each of the ONUs to be served by a central office. There are three splitters to be used, indicated by the blue, green and red triangles. The different fibres are colour-coded according to their connections to each of the splitters. The main observation is that there is no indication of how these fibres are grouped together representing a single cable. An additional post process is required to determine which of the fibres are grouped together such that a deployment plan of cables can be generated. This may, of course, lead to a heuristic solution that could be far from optimal.

The solution obtained by solving the PON planning problem that incorporates retractable cable technologies, is presented in Figure 4. Once again, three splitters are used, and the different fibres are colour-coded according to their connections to each of the splitters. The main advantage now is that additional information is provided by the solution indicating which fibres are grouped together in order to represent the use of a single retractable cable. An important observation is that fibres of the same colour do not necessarily come from the same cable. That is, the placement of the cables are optimised according to deployment cost, taking into account the potential topology and ONU distribution. It should be noted that since each cable comprises a fixed number of fibres, there may be redundant fibres not connected to any device. These fibres are displayed in Figure 4 as the orange lines that are terminated with the symbol 'x'.

The fact that there may be redundant fibres in the solution to the PON planning problem when incorporating retractable cable technologies, also suggests that additional costs might have been overlooked in traditional PON planning approaches. More specifically, by comparing the cost of the solution in Figure 3 with the cost of the solution in Figure 4, an increase of almost 8% is observed. That is, by following a PON planning approach that does not take deployment-specific information into account, such as the use of retractable cable technologies, total deployment cost may be underestimated with a sizable margin.

4 CONCLUSION

In this paper, a formulation of the PON planning problem with retractable cable technology, was provided. Computational results for a small problem instance were used to demonstrate how the additional information on cable configuration may assist in PON deployment planning. In addition, the solution obtained for the simple example in this paper also highlighted the risk of underestimating deployment cost if deployment-specific technologies are not included in the problem formulation of the PON planning problem.

Future research may focus on algorithmic improvements since the additional complexities introduced in the formulation of deployment-specific constraints may have a severe effect on computing times.

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ALTERNATIVE DATA STRUCTURES FOR IMPROVED ENERGY REPORTING AND BUDGETING ON GOLD MINING GROUP OPERATIONS

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ABSTRACT

Accurate internal energy-use reporting on large gold mining groups remain vital to ensure correct budgeting and adequate tracking of financial performance of operations and systems. Metering errors are unfortunately a reality of this monitoring process, affecting everything from single sub-systems on small operations, to the entire group's financial performance review. These types of errors also have an accumulating nature, becoming larger if left unaddressed.

The energy reporting structure of a gold mining group with a budgeted electricity bill of approximately R 3-billion was investigated for the purposes of this research. It was found that due to compounding errors in sub-system metering, average errors of up to 8% (R 236-million) were identified in relation to the total consumer electrical sub-station measurements (Eskom billing meters). This led to erroneous reporting of sub-systems' progressive electrical performance (daily resolution), as consumer sub-station measurements were only available once per billing cycle (monthly).

A methodology was developed to normalise sub-system metering data more regularly with check-metering data which was available on a daily basis. This daily normalisation was implemented on a division of the mining group using an automated daily reporting system and displayed on an online dashboard. The average daily sub-system error displayed on the online platform was reduced by 6.9%, paving the way for an alternative energy reporting system and improved budgeting. This error reduction equates to approximately R 55-million per annum, that can now be allocated under the correct low-level sub-system budgets.

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1 INTRODUCTION

1.1 Background

The gold mining industry of South Africa faces an uncertain future. Mines are aging, becoming deeper and more complex [1] and requiring more work than before to maintain profitable production levels [2]. This combined with the ever rising cost of electricity [3] and dwindling gold prices [4] has reduced profit margins to fine lines with mines being forced to look for alternative solutions to remain sustainable operations.

Due to this tough financial position, budgeting on gold mines has become an activity of great importance. Budgets are no longer used only for financial planning, but play a considerable role in performance evaluation [5]. Performance evaluation has a high priority in marginal operations and should ideally be done as often as possible. Budgets are available at a lower resolution (usually monthly), than what is desired for performance evaluation. For performance evaluation to be effective high-resolution budgets are required. Budgeting is also required on a systems level, as information could be lost in high level summaries [6].

Unfortunately, small errors on budgets can have significant financial consequences. Errors between budgets and actual usage are often given as percentages, misrepresenting the true financial impact of the error. A 3% error, for instance, might seem inconsequential, but on a total budget of R3-billion it equates to R90-million.

To simplify budgeting procedures on gold mines, actual measurements are used in conjunction with production outputs to compile high level budgets. Major sub-systems (compressed air, dewatering, refrigeration, hoisting and ventilation) will typically be benchmarked to past production and usage metrics. These benchmarked values are then used to determine the budget based on planned production figures. Performance of an operation or sub-system can then be evaluated through comparing the actual measurements to the goals set in the budget.

For budgets to be reliable, they need to be composed of high-quality data. Using high quality data has been proven to lead to better decision making [7], which will ultimately lead to more effective performance evaluation. While industries are collecting more data now than ever before [8], [9], the data tends to have quality issues [10]. These issues are especially apparent on mines, where production and cost take president, often to the detriment of other areas. Due to the nature of measurement and data capturing equipment, data can also not be assumed to be 100% correct [11], [12]. Careful analysis of data is thus required to determine data quality before data can be used.

Data quality assurance is especially difficult with complex systems such as gold mines. Their sites are immense, and limited monitoring of the systems take place [13], [14]. Figure 1 contains a section electrical grid layout on a South African gold mine. This is to show the reader the complexity of the systems this investigation deals with.

This figure represents the main consumer substation incomers, along with connections to various equipment (in this case electrical motors powering centrifugal equipment) located both above- and underground. The figure is not to scale, as some connections between equipment can reach over 10 km.

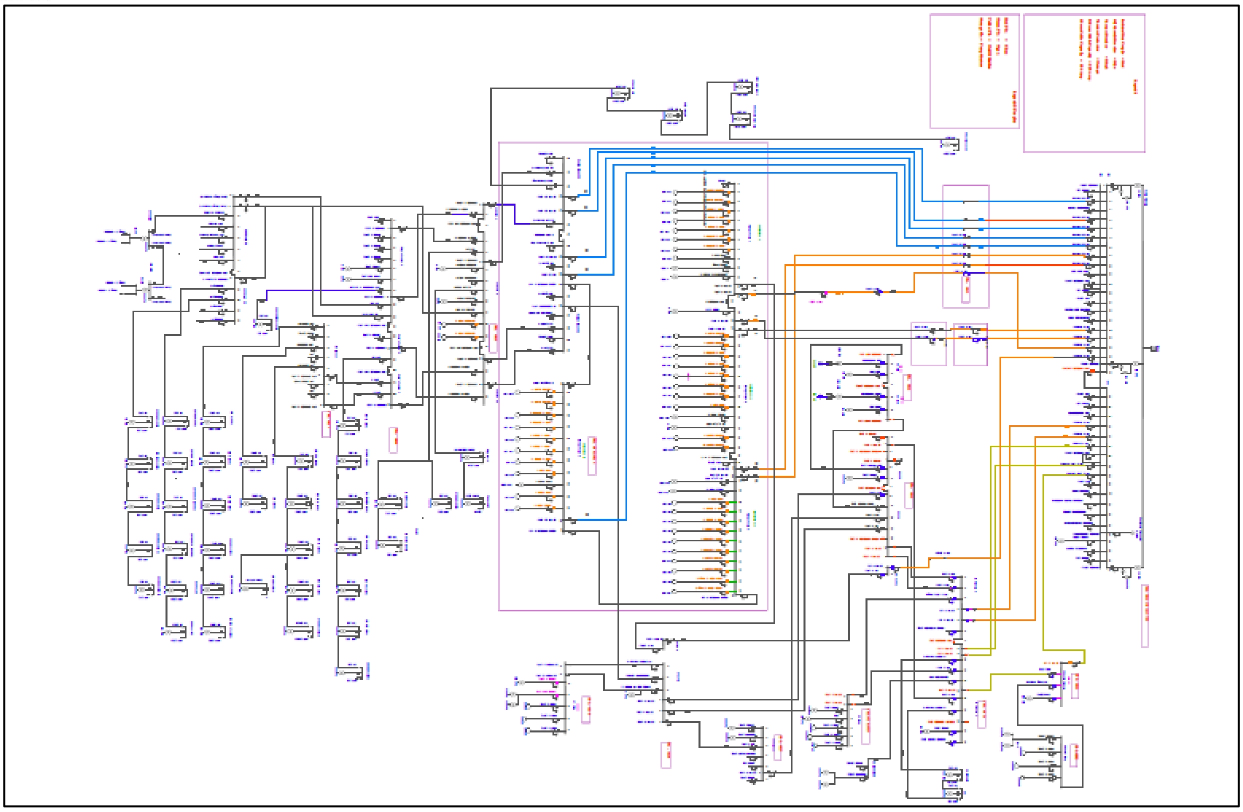

Figure 1: Mine operation – Complexity of electrical grid layout

Within the group relevant to this investigation, most measurement points do not have measurement current transformers (CTs) installed. Instead most points are monitored by retrieving measurements from protection relay devices (protection CTs). These devices mainly serve as a safeguard to prevent damage to equipment that could be caused by power surges. A dedicated measurement CT serves a single purpose: to provide a measurement. Protection relay CTs provide both measurements and protection to the circuit, making them considerably more cost effective to use.

The combination of the complexity of most mining systems along with the current financial positions of mines compel them to install only protection relay CTs, the least expensive of the options available. The third-party metering company employed by the mine group in question make use of protection relay CTs that allow for an approximate error of 2%. Other acceptable error allowances may be encountered in other industries based on the specification of equipment used.

Due to the complexity of the system layout and the requirement for daily budgets, manual quality checks would be neither feasible nor practical. Manual checks on data have also been shown to not be reliable [15]. For the composition of reliable budgets that can be used for effective performance evaluation, traceable calibrated data from a quality source is required.

Budgeting is required on a high resolution (daily), so as to ensure up to date budgets are available when required. This will allow for errors to be identified and amended soon after they occur. The knock-on effect of errors may therefore be eliminated by gaining awareness of the issue sooner, and having sufficient information to eliminate it. Accurate, daily, systems level budgets are thus required for effective mine performance evaluation.

1.2 Objective

From the background, it is clear that performance evaluation is needed for mines to assess their operation more frequently to ensure profitably. This study will focus on the following four points to improve performance evaluation of gold mine electrical systems:

- Accurate budgets,
- High quality data,
- Daily interval budgets, and
- Sub-system level budgets.

The goal of this study is to find a practical solution for data to provide these types of budgets. The system will need to be repeatable, easy to implement and cost effective. Ideally, no capital expenditure will be required from the mine.

1.3 Scope

This study focusses on determining accurate actual usages, as these values are the foundation for the development of a budget. A South African gold mining operation is used as a case study. Only data readily available from these mines are used in the solution.

2 METHODOLOGY

This methodology will focus on the acquisition, verification and reporting of actual meter values. The resulting values can be used to develop dependable, high resolution budgets to be used for performance evaluation. An analytical approach will be followed to do this, using only the values from meters already installed on the mine. The following flow chart shows the steps that will be taken in this methodology to obtain a dataset from which budgets can be developed.

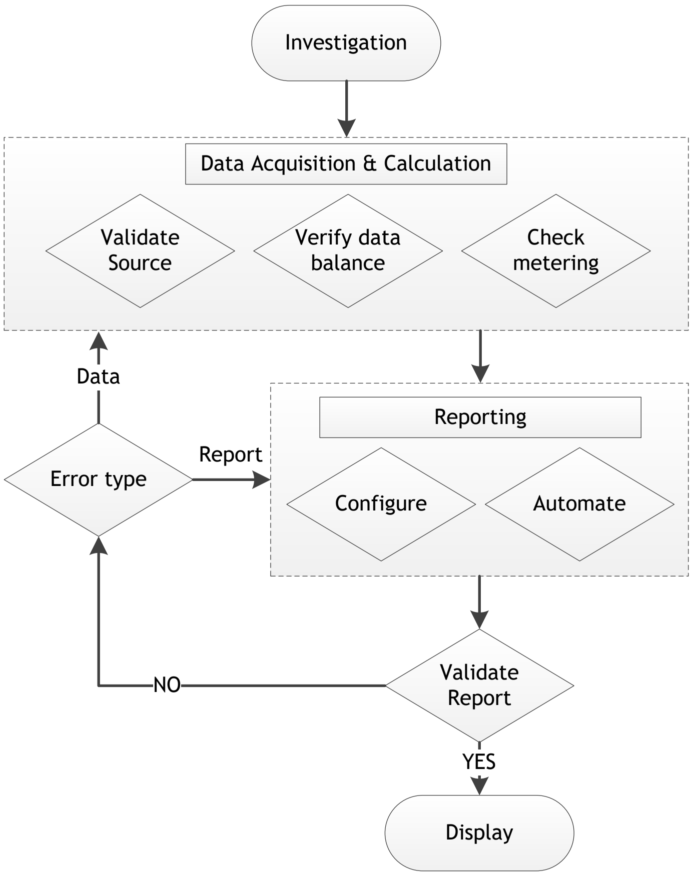

Figure 2: Methodology flow chart

This methodology is split into a data section and a reporting section and includes a two-step verification process. This process will be used to validate both the obtained data and how it is reported. This will be discussed further in section 2.4.

2.1 Investigation

The first step of the investigation is to determine the layout of the mine in question. This metering layout is intended to identify electrical feeders, and which systems and sub-systems are powered by the identified feeds. Gaining an understanding of the plant is crucial to accurate energy reporting and developing a dependable budget. To do this, the level of available data on the mine must be determined.

Full facility data should be easily attainable. The facility is made up of several major sub-systems. Each subsystem may have multiple individual systems, as well as some auxiliaries. Most mine budgets are on the level of major sub-systems.

For the purposes of this study, a metering layout to the level on which the mine wishes to budget required. A layout indicating all the available measurements for points of interest on the mine should be drawn. This will be used as a reference later in the study.

Although metering layouts might be available, they are often not. Once major sub-systems are known, some investigation will be required to compile a comprehensive metering layout. On mines, consultation of section supervisors, foremen and electricians should lead to an understanding of the metering systems and all its components.

2.2 Data acquisition and calculation

Once a metering layout of the mine is available, data from all the meters mentioned should be collected. This data will be the core of the investigation, as no additional meters can be installed due to cost constraints. This alternative approach aims to add value to a complex, yet limited metering system. The following section aims to improve upon the quality of this data.

This section is divided into three steps. They are source validation, data balance verification and check metering. Following these three steps should result in a set of accurate values which can be used for budgeting.

Figure 3: Data accusition and calculation steps

2.2.1 Source validation

Data for this investigation may come from several sources such as third parties, mine databases, meters on site or even from calculations done by the mine. On data like this quality checks are important. Several types of errors are prevalent on data originating on mines [16]-[18]. These errors include, but are not limited to, missing data, abrupt errors, out of bounds data and hanging data. Several analysis techniques are available to detect and amend these errors [16], [19], [20]. Data analysis tools can be utilised to determine the quality of the available data. Some meters may have calibration certificates, indicating that their data is of a certain quality.

Data analysis software is widely available and can be utilised within this investigation to verify and clean data [19]. Manual data quality determination might also suffice, depending on the complexity and frequency of the data that is to be analysed. At this stage the quality of each data source should be noted, as high-quality, verified sources will be used later on in the method.

2.2.2 Data balance verification

Once quality data sources have been established, the next step is to determine how the various data sources compare. High-quality data will often only be available on a systems level. Data from the sub-systems is available, but the quality thereof remains questionable.

All available information on the system and sub-systems can be utilised for this step. Examples of information that can be useful for balance verification include installed capacities, key performance indicators, maximum theoretical power draw and transformer overload ratings.

The available information can be used to perform logic checks on the systems. The following two examples are for illustration purposes only. The logic checks to be performed will depend entirely on what data is available and what is known about the system.

Example 1:

A pumping sub-system consists of 4 x 1 000 kW pumps connected to a feeder. It is known that one pump is no longer in operation, and that the mine only requires 2 pumps to run at any given time. Presume that this feeder reads 3 000 kW. This can mean two things:

1. The value from the feeder is wrong.
2. Unknown equipment is connected to the feeder.

Further investigation in-to the system will be required at this point. If no additional equipment is connected to the line, the feeder value must be assumed to be incorrect. A check meter must be identified to adjust the value from the feeder so that it can be used in budgeting.

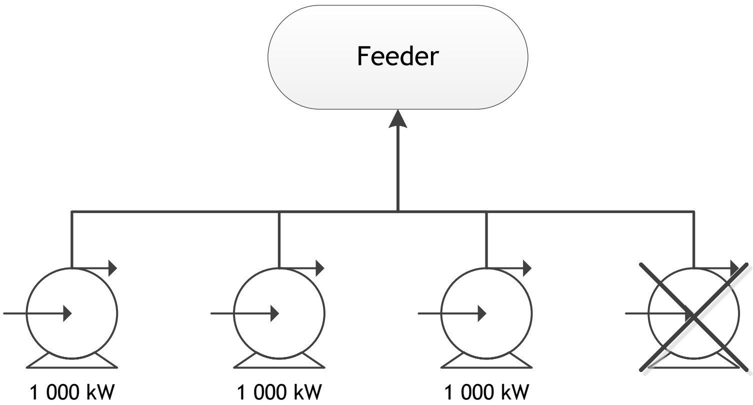

Figure 4: Data balancing - Example 1

Example 2:

Assume a system incomer with three sub-system feeders connected to it. The system incomer has a calibrated meter according to which the electricity used by the system is billed. The system incomer has a measurement of 10 000 kWh. Each sub-system feeder is measured, but the meters are not verified. The sum of the sub-system measurements is 10 800 kWh.

From this, the values of the individual sub-system feeders must be assumed to be incorrect. The meter on the incomer can be used as a “check meter” to determine realistic values for the sub-systems.

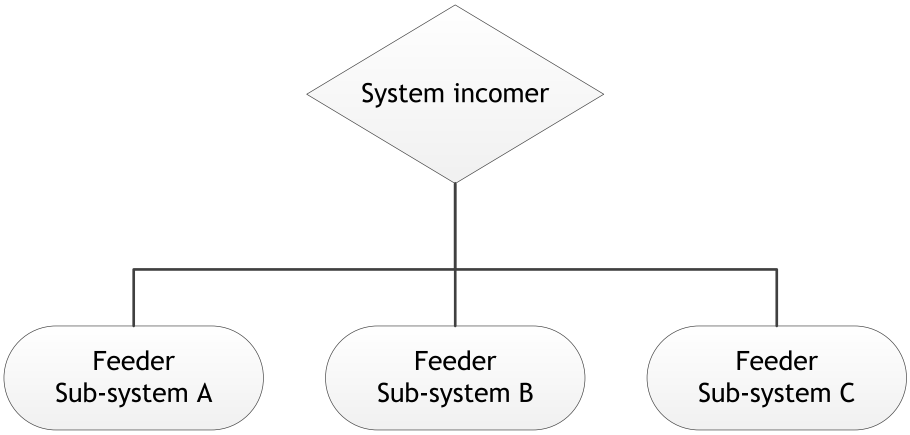

Figure 5: Data balancing - Example 2

2.2.3 Check metering

Calculation is the final step of this data utilisation process. Calculations are only necessary if the sub-system level measurements are not verified, or when their quality is questionable. If the system incomer cannot be verified, additional intervention will be required.

On calculations where the sub-systems do not add up to an incomer, as in example 2, the following steps can be followed:

1. Determine a check meter with verified data.
2. Verify the system incomer with the check meter.
3. Determine the weight of each sub-system.
4. Determine the difference between the sum of sub-systems and the system incomer.
5. Allocate the difference to the sub-systems according to their weight.
6. Check if calculated sub system values add up to the value of the verified check meter repeat steps 1-5 if they don't add up.

Once these steps are completed, reliable values will be available for every sub-system in the metering layout. This normalisation can be done on a daily basis as long as check meters are regularly verified. This allows daily availability of budgets, in place of monthly.

2.3 Report configuration

Reporting is an important step in any data processing endeavour. Data has to be well represented to ensure optimal user-end interaction [21], such as effective budgeting. After the calculations in the previous section are done, a report must be compiled with the various derived, calculated and verified values. This can be done according to the metering layout that was drawn in Section 2.1.

This report can be compiled manually, but automation of the calculation and reporting will be more efficient. Any internal data handling and reporting system available to the mine can be used to automate the calculation, thereby rewriting the erroneous data.

2.4 Validation

The information displayed in the report has to be verified before being sent out. As the calculation and reporting sections rely on human interaction, mistakes are possible and both steps must be checked.

A two-step error approach is suggested. If a problem arises in the report, it can be due to a problem in the automated reporting system, mistakes in the check metering calculation, or changes made to the system in question. Mines are dynamic; therefore, the system layout and metering layout must be revised regularly to keep the calculations up to date.

If the type of error in the report is clear, it can be addressed directly. The error might not always be forthcoming; therefore, the following two steps are suggested to verify the report:

1. Repeat the data source validation and data balancing steps.
2. Check that the calculation is done correctly in the reporting step.

If these two steps are followed, the result will be a report with accurate data that passes logic checks and contains information that is representative of the mining system.

2.5 Display

For effective interaction with data, data needs to be displayed to a user [21]. This is an integral but often overlooked aspect of data handling. How the data is displayed will determine how it is used. It is important that the data is available to users on their own terms. The maximum benefit of the information gained will only be achieved if a user is able to access and use the data in its entirety.

Most mines have internal data handling and display software. The values that were determined within this methodology can be integrated to the system of the users choosing. Once the correct information is displayed by the system, all that remains is to ensure that it is available to the relevant entities to be used for budgeting purposes.

3 RESULTS

A section of a gold mining group in South Africa was used as a case study to test the methodology developed for this study. A confidentiality agreement was undertaken with the group and therefore all sites in this study will be referred to generically and names hidden in actual results. For the sake of brevity, all results displayed will be for Mine A.

3.1 Investigation

The mining group in question budgets on a sub-system level. A thorough investigation was conducted on their site layouts and metering systems in order to gain an understanding of these systems. This was done for 12 of the 17 major operations within the mining group.

The following metering layout was constructed for Mine A. For the sake of simplicity, equipment feeding from each subsystem was not included in this layout.

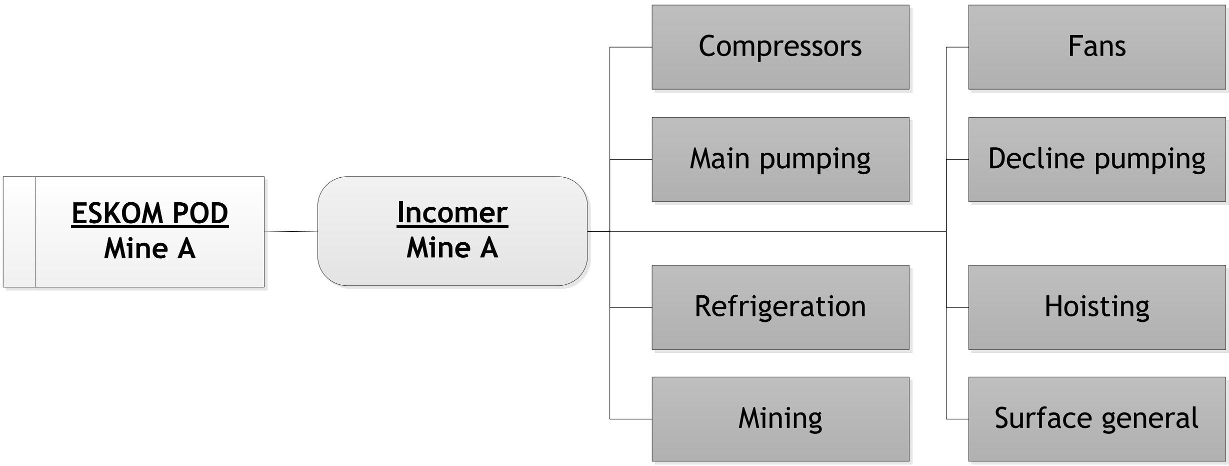

Figure 6: Metering layout - Mine A

This layout can now be used as a visual reference for the data processing steps that are to come.

3.2 Data acquisition and calculation

3.2.1 Data source validation

Data from all the available and relevant measurement points on the mines were collected. The collected datasets were free from discernible data errors. Sub-system level measurements were only available from protection CTs. Their accuracy could thus not be verified, and will have to be investigated in the data balancing step.

System incomers have two available measurements. One from a third party metering company, the consumer sub-incomer. The Eskom measurement, for billing purposes, is on this same line. The Eskom meters are regularly calibrated and can be used as check meters. Unfortunately, the only data available from the Eskom meters is a single value per month.

Half hourly, real-time data is available from the consumer sub-incomer. The measurement of the incomer can be compared to the monthly Eskom value, and therefore a level of certainty is attainable for these meters. They can then be used as check meters on a daily basis.

3.2.2 Data balance verification

Data balancing was done on each of the 12 sites included in this investigation. The sum of the sub-systems was compared to the measurement of the incomer, as that can be verified. The incomers were also regularly compared to the measurements from the Eskom meters. Table 1 was the result of the energy balance of monthly totals on Mine A.

From this data balance it is evident that the sub-system meters on this incomer are incorrect. The sub-systems add up to more than the monthly bill. There is a 0.54% residual error between the incomer and the Eskom measurement. Due to the constraints of this investigation, the residual error will remain, but the 1.08% error on the sub-systems can be addressed through check metering calculations.

Table 1: Data balance verification - Mine A

Data balance verification	
System	**Energy (kWh)**
Eskom POD - Mine A	**24 746 420**
Incomer - Mine A	**24 880 750**
Hoisting	1 672 737
Pumping	3 159 790
Decline pumping	1 334 306
Refrigeration	3 946 325
Mining	4 353 536
Fans	3 827 223
Surface general	458 762
Compressors	6 396 157

Sum of sub-systems	25 148 836
% Difference	-1.08%
Difference	-268 086

3.2.3 Check metering

The only true check meters available within this investigation are the meters used by Eskom for billing. The scope of this investigation is to provide accurate daily values for sub-systems, thus an alternative solution had to be implemented.

The Eskom check meters were used to verify the consumer sub-incomer meters. Once verified, these incomers could be used to amend the errors found in the data balancing step.

Data from the site incomers and sub-meters are available daily. An automatic calculation was set up that calculates the difference between the incomer and the sum of the sub-systems. This difference was then added to the sub-systems according to their weight. This calculation is performed for all 12 sites every day, with the resulting values uploaded to a database used by the reporting system.

3.3 Reporting

The mining group used as a case study employs a third party energy management company. As a part of their services they provide the group with a data reporting structure. The data from the calculations above was integrated into the system, and the system was set up to automatically perform the required calculations, effectively overriding the faulty data.

Reports that can be generated include performance summaries over any period of the users choosing, as well as visuals indicating whether budgets were met or missed. Included here is a monthly performance summary for Mine A (Figure 7), and visual representation of the performance of sub-systems on the same mine (Figure 8).

System	Budget energy	Actual energy	Over/under budget
Consumer sub-incomer	23 456 320 kWh	24 188 780 kWh	-732 460 kWh
Hoisting	1 878 376 kWh	1 334 261 kWh	544 115 kWh
Pumping	2 633 048 kWh	3 381 401 kWh	-748 353 kWh
Decline Mining & Pumping	1 110 490 kWh	1 484 104 kWh	-373 613 kWh
Refrigeration	3 568 040 kWh	3 384 023 kWh	184 017 kWh
Mining	3 632 391 kWh	4 465 061 kWh	-832 670 kWh
Fans	3 948 614 kWh	3 187 267 kWh	761 347 kWh
Surface General	486 218 kWh	461 908 kWh	24 310 kWh
Compressors	6 196 830 kWh	6 490 756 kWh	-293 926 kWh

Figure 7: Monthly performance summary - Mine A

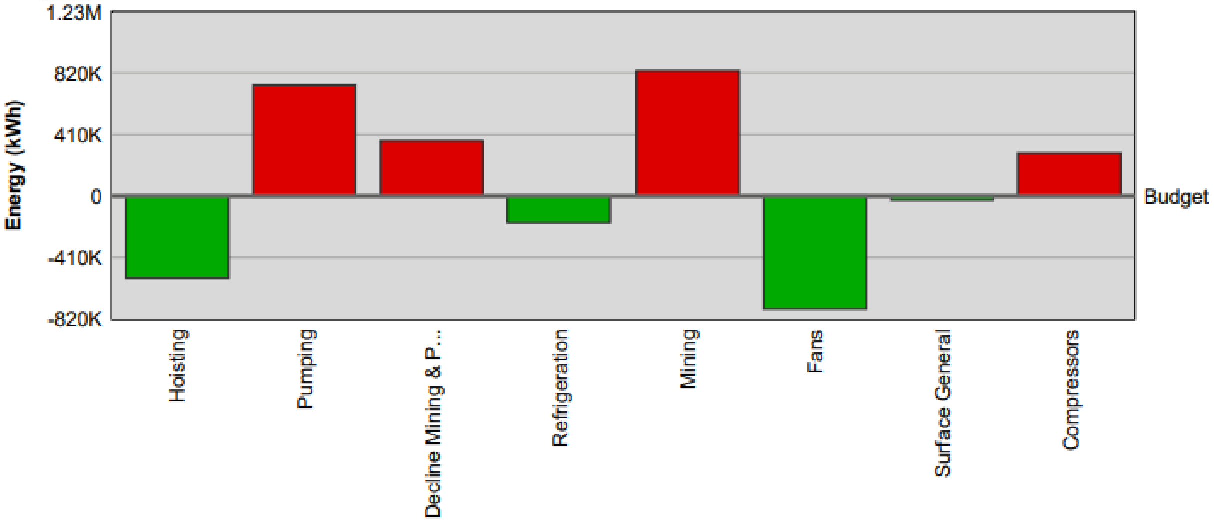

Figure 8: Sub-system performance visualisation - Mine A

3.4 Validation

The following table gives a summary of the results that were obtained during this case study. The error before normalisation is a sum of the absolute errors between the incomer and sum of sub-systems, and the incomer and Eskom meter. The residual error after normalisation represents the error between the incomer and the Eskom meter, which was not addressed within this study.

Table 2: Results summary

Operation	Error before normalisation	Residual error after normalisation	Cost implications (Before)		Cost implications (After)	
Mine A	1.70%	0.54%	R	4 544 170	R	1 445 658
Mine B	7.34%	1.49%	R	8 581 922	R	1 741 888
Mine C	4.04%	0.77%	R	4 694 622	R	894 408
Mine D	1.52%	0.15%	R	2 534 748	R	249 911
Mine E	26.75%	4.10%	R	5 525 229	R	846 732
Mine F	1.70%	0.03%	R	2 161 569	R	38 093
Mine G	2.84%	0.78%	R	781 863	R	214 460
Mine H	36.90%	0.24%	R	27 474 144	R	178 680
Mine I	4.27%	1.40%	R	5 284 901	R	1 732 710
Mine J	7.88%	3.46%	R	586 608	R	257 482
Mine K	1.15%	0.60%	R	555 910	R	290 058
Mine L	0.63%	0.27%	R	309 976	R	131 885
Averge error/Total cost	8.06%	1.15%	R	63 035 662	R	8 021 966
Budget allocation corrected		6.91%			R	55 013 696

Three errors became apparent once these results were reported. Each was addressed using the 2-step error verification method suggested in the methodology section.

On Mine E, the first error is larger than expected. After investigating the data, it was found that the check meter was faulty. As the sum of the sub-systems' total was much closer to the Eskom measurement, no normalisation was done on the daily values for this site. Instead the shaft total was replaced by the sum of the sub-systems. The residual error is still large, but the reduction in cost implications was significant.

The initial error present on Mine H, over one third of the total facility energy usage, was caused by the majority of the underground load not being measured. Upon investigation it was found that load was being fed through multiple back-up feeders, that were not part of business-as-usual operation. Subsequently, the load was not represented in the data received from the third-party metering company. This "missing" load was being allocated to remaining sub-systems by the mine to match with Eskom billing figures, which could only be done once a month.

This resulted in Mine H's sub-systems appearing to be constantly over budget at the end of each month, even though the daily tracking on individual systems showed the opposite. After this was realised, the back-up feeders' load was incorporated into the data balance verification. Each sub-systems' load was then correctly allocated throughout the month on a daily basis, leading to a residual error of only 0.24% being reported.

An investigation on the data of Mine J found significantly larger errors from the protection CTs than were expected. Upon further inspection it was discovered that the site had scaled down considerably since the meters were installed. The consumer sub-incomer meter was specified for the original operation, and subsequently now operate in conditions it was not designed for. The original CTs were designed for 2 000 A current, where the operation currently only operates at 200 A. The mine opted not to replace the meters and accepted the residual error of 3.46%. As Mine J accounts for less than 0.2% of the group's annual energy consumption, replacing this meter is simply not worth the money.

3.5 Display

Once the data was validated, it was added to an online dashboard used for data display purposes by the mining group. The data was made available to all the relevant entities. They are able to adjust the frequency of the data, and trigger it as needed. This allows them to monitor their performance closely and adjust their systems as needed.

Figure 9 was obtained from the daily calculated data of Mine A. This summary is intended for performance evaluation. A red date indicates that the daily usage was over budget, a green one that the day was under budget. This report is available daily and allows the mine personnel to take immediate action.

Figure 9: Daily performance summary - Mine A

The display in figure 10 enables the user to track the performance of individual sub-systems to a daily resolution. This visual allows the user to track the daily performance as well as view the cumulative/progressive performance with respect to the budget.

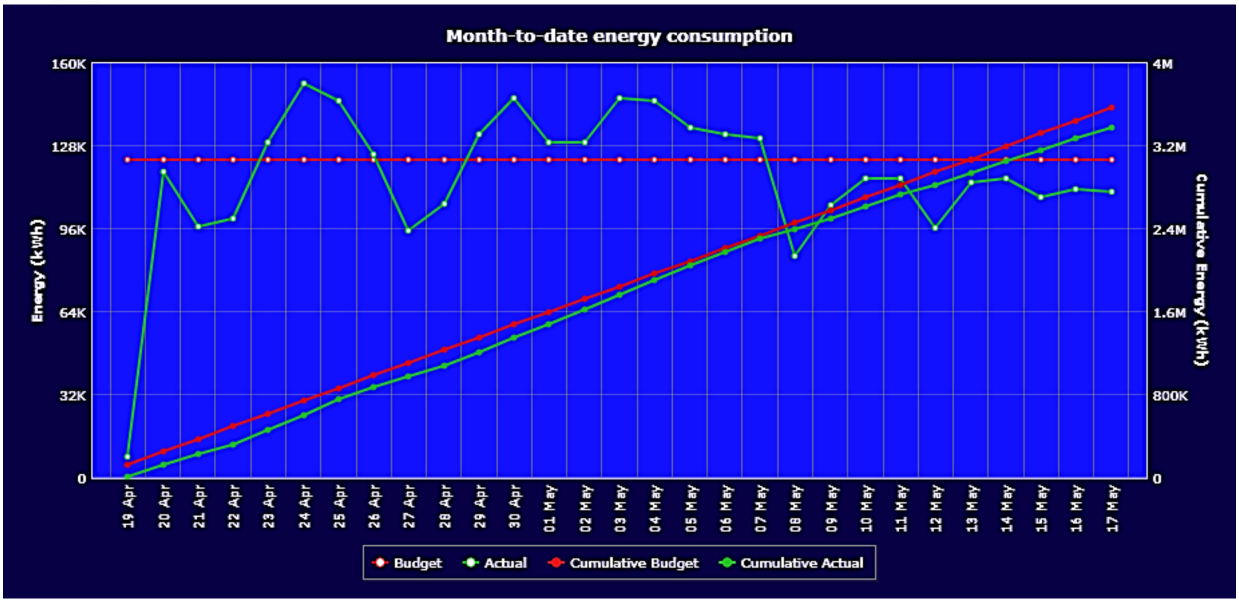

Figure 10: Energy consumption and budget - Mine A refrigeration

3.6 Application of alternative problem solving in the mining industry

If the financial situation of the mining industry in South Africa was different, a study like this wouldn't need to exist. The reality is that times are tough, and alternative solutions are needed to solve problems that could otherwise have been solved by other means, i.e. with money. Reducing the errors in budget from 8.06% to 1.15%, an 86% reduction, can mean a lot for mines in a challenging financial climate. For the $1.4-billion[4] mining industry of South Africa, this equates to a corrected allocation of $96.6-million. Correct budget allocations and credible information enable meaningful performance evaluation, allowing mines to operate optimally, despite this reality.

4 CONCLUSION

The nature of mining operations in South Africa has led to multiple challenges within this industry. The research contained within this article focused on an often overlooked area, namely the effect of budgeting accuracy on effective performance evaluation. Gone are the days where performance evaluation could be done on a monthly basis. Accurate daily monitoring has become crucial for marginal operations to keep their heads above water.

Due to financial constraints caused by the current socio-economic climate, most mines do not prioritise maintenance or upgrades on metering systems. This leads to the deterioration of intricate power metering systems over time. Unreliable metering systems pose a threat to South African mining operations as it impedes performance evaluation.

A methodology was developed to use the existing measurement infrastructure in alternative ways to address the need for quality sub-system data to be used in conjunction with high resolution budgets. This included data quality checks and normalisation to verified meters.

[4] Trading economics, "South Africa GDP From Mining | 2019 | Data | Chart | Calendar | Forecast." [Online]. Available: https://tradingeconomics.com/south-africa/gdp-from-mining. [Accessed: 13-Jun-2019].

The resulting information was integrated with automated reporting structures and validated before being displayed on an online dashboard to relevant parties.

Application of this method to a large section of a South African Gold mining group reduced errors from 8.06% to 1.15%. This resulted in R55-million being allocated to the correct sub-systems and budgets when conducting critical performance evaluation. This study found a real alternative solution for implementing cost-effective, repeatable and easy to use energy reporting for performance evaluation through improved data quality and budgeting. Correctly applied, this method can provide relief to the financial strain experienced by mines in South Africa.

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INTEGRATION OF CATENARY TRACER TO ASSESS TRAIN CATENARY CONDITIONS OF HIGH SPEED TRAINS

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ABSTRACT

A catenary is an overhead system used that supplies electrical power to trains. This overhead system consists of support structure (mast pole), catenary insulators, arching horns, earthing connection, parallel return wires, droppers, and a catenary wire above the live contact wire. Electric trains (electric multiple unit (EMU) or electric locomotive) receive power from the overhead wires to power electric motors of the trains, which are then transformed into electro - mechanical energy to drive their wheels and provide traction power or locomotion. The electricity is delivered via the pantograph to the high speed circuit breakers and thus distributed to the different required systems.

This study focusses on integrating a catenary tracer system. A catenary tracer is a system that assesses the condition of the catenary wire (overhead wire). This system is utilized by the EME's supplied by Gibela rail, in Johannesburg, South Africa for monitoring the conditions of the overhead system. The catenary tracer device measures the wear of the overhead contact wire, and provides continuous monitoring of the catenary. Integration of this system intends to reduce the overhead system maintenance costs, monitoring the condition of the overhead catenary system and prevents unforeseen service interruptions where a fault has been identified. At present it is labour intensive to inspect every meter of the high voltage 3 kV contact wire throughout the electrified system. The data of the catenary wire is collected by a laser scanner mounted in a housing bracket on the roof of the train. At the same time, the data acquisition box obtains the speed from the speed sensors, and the vibration signals from the accelerometer sensors, mounted on the bogies. The system is designed to continuously collect this data, synchronize it all through computation and store it until it can be downloaded for routinization or analysis. The collected raw data is analyzed and loaded to the depot server to determine if the required maintenance on the catenary. The analysis of the collected data is presented herein.

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1. INTRODUCTION

A catenary wire is an overhead system that supplies electrical power to trains. The catenary system is mounted in sections along the railway infrastructure line. A pantograph is an apparatus mounted on the roof of an electric train, to collect power through contact of the pantograph skate with an overhead catenary wire which is a common type of current collector. The train catenary tracer measures the wear of the overhead contact wire. This device is useful as it greatly reduces the overhead system maintenance and labour costs. At present a huge labor force is employed to continuously inspect every meter of the high voltage 3 kV contact wire throughout the electrified system. Visual checks are carried out almost continuously, while accurate spot checks are performed at six months intervals and this manual inspection may have inefficiencies due to human error.

2. METHODOLOGY ADOPTED

Equipment structure is subjected to a load during its working life. In this context, a comprehensive analysis must be performed to accurately evaluate the stiffness and the behavior of the structure under these loads. The results such as static stresses under proof loads are given to justify that the equipment structure is designed for sufficient static resistance. The finite element method is used to perform analysis on any structural behavior. The stresses are calculated according to linear elastic behavior of the material. The finite element calculations are performed with the commercial software called Hyper Works (version 14.0) for the structural modelling, meshing, solving and post-processing computations. The catenary tracer's frame is mounted on the roof of the train on the trailer car with 12 x M8 8.8 CPC2 bolts.

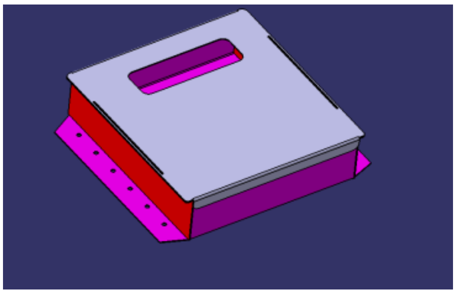


Figure 1: Cad view of the support structure

2.1 Modelling description of the base bracket

The model (Figure and Figure 2) is composed of 50.013 mm mesh with absolute sag of 8 mm for 12 clamping points (Table 1). Equipment's masses are modelled with lamped mass elements that are positioned at their Centre of Gravity (COG). Total model's weight is 56.83 kg with 30.95 kg of equipment and 25.88 kg of structure.

Table 1: Element types of catenary tracer support

Element type Table	Weight
Laser scanner More	20.385
DAQ box	18.324
Support structure	25.88
Total weight of Equipment	56.83

Static and fatigue load cases are performed according to EN12663 standard for a PII vehicle category. EN 12663 Railway applications standard is for structural requirements of railway vehicle bodies for Locomotives and passenger rolling stock.
Mechanical characteristics of steel RCS355 material are shown in table 2. This material was selected for the structure of the design because the roof of the train where it is to be

installed or mounted on is of the same material, eliminating the risk having rust due to materials that are not compatible.

Table 2: Mechanical characteristics of RCS355 steel material

Criteria		*Value*
	E	210 000 MPa
	N	0.3
	P	7.85 e-9 t/mm^3
Re	Base Metal	375 MPa
	Welded joint	350 MPa
Rm	Base Metal	430 MPa
	Welded joint	0A

2.2 Boundary conditions

Catenary support is clamped at its fixing points (interface with train roof Car Body Shell).

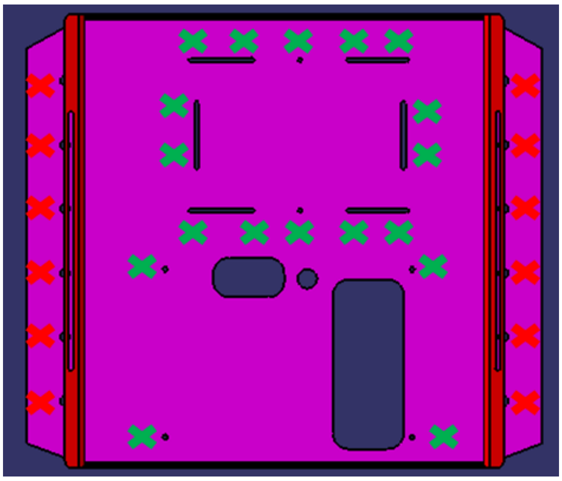


Figure 2: Clamping of the support structure

X - M12 x class 8.8 CPC2 x12

X – M8 x class 8.8 CPC2 x 18

Defined bolted assembly consists of M12 bolts, fixing the equipment on the roof of the train, see figure 4. M8 bolts fixing the system equipment on to the support structure, with a nut, and a washer to respect friction factor constraints, and possibly a second washer under the screw head.

2.3 Load Cases

Static and fatigue load cases are performed according to railway applications standard for a PII vehicle category.

2.3.1 Static loads:

- Longitudinal: ± 3g along X & -1g along Z
- Transversal: ± 1g along Y & -1g along Z
- Vertical: (-1 ± c)g along Z with c = 2

2.3.2 Fatigue load:

- Combined Longitudinal & vertical: ± 0,15g along X & 1 ± 0,15g along Z
- Combined Transversal & vertical: ± 0,15g along Y & 1 ± 0,15g along Z
- Vertical: (1 ± 0.15)g along Z

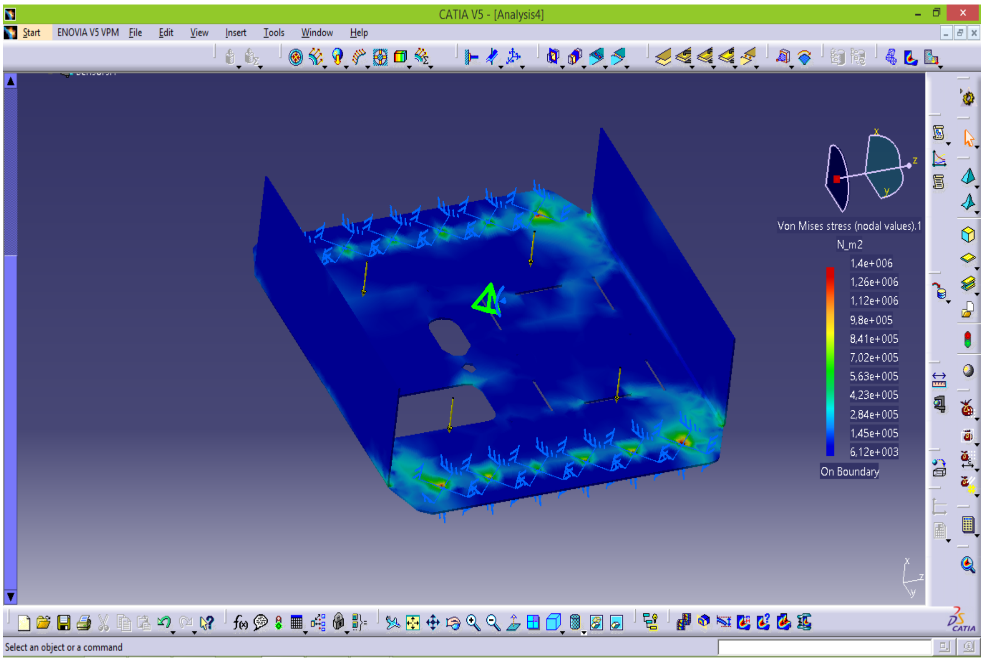


Figure 3: Clamping of the support structure

Figure 3 shows Static strength on the von Mises yield criterion that suggests that yielding of a ductile material begins when the second deviatoric stress invariant reaches a critical value. It is part of plasticity theory that applies best to ductile materials, for the base of the support structure. For static load cases, the maximal computed stress must be lower than the yield stress of the considered material in equation (1):

$$1.4^{*}\sigma_c \leq \sigma_e \qquad \textbf{(1)}$$

Note: according to EN 12663-1 standard if local stress concentration is encountered the computed stress may exceed the yield stress, but the local plastic deformation area associated with stress concentration should be small enough in order to not induce significant permanent deformations after the load is removed.

For fatigue strength the endurance limit method is used for the fatigue strength assessment of the structure. According to this method the calculated stress range of each individual fatigue loading should not exceed the endurance limit for the considered material (10 million cycles). The allowable stresses ranges are given in table 3 according to technical specifications (mechanical properties eng, 2014).

Table 3: Allowable limit for fatigue load cases

Material	Designation	Δσadm [MPa]
Steel	Base metal	118
	Fillet joint	54
	Double fillet joint	81

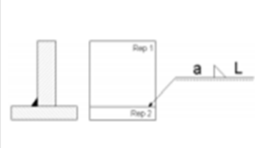
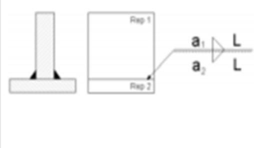
13a See also X3	Fillet joint	
13b	Double fillet joint	

Figure 4: Clamping of the support structure

2.4 Fasteners

See Table 6 for used acronyms.

Bolt failure - A bolt stressed at (N, T) level must stay in the green area of figure 5 in line with the failure criterion in equation (2), and if it overlaps outside the green area the bolt has failed.

$$sf\_failure = \frac{1}{\sqrt{\left(\frac{N}{Nu}\right)^2+\left(\frac{T}{Tu}\right)^2}} > 1 \qquad (2)$$

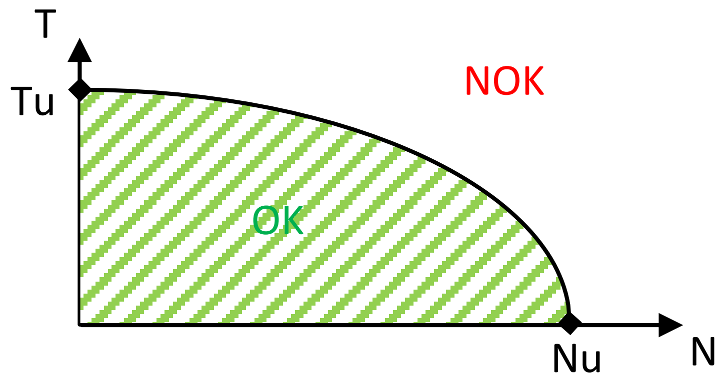


Figure 5: Failure criteria on the T-N curve

2.4.1 Sliding/separating

A bolt stressed at (N, T) level must stay in the green area as shown in figure 6 in line with the failure criterion in equation (3).

$$sf\_sliding/separating = \frac{F_{0\,min}*(1-0.0*R_{\%})}{(1-\lambda)N+\frac{T}{\Phi}} > 1 \qquad (3)$$

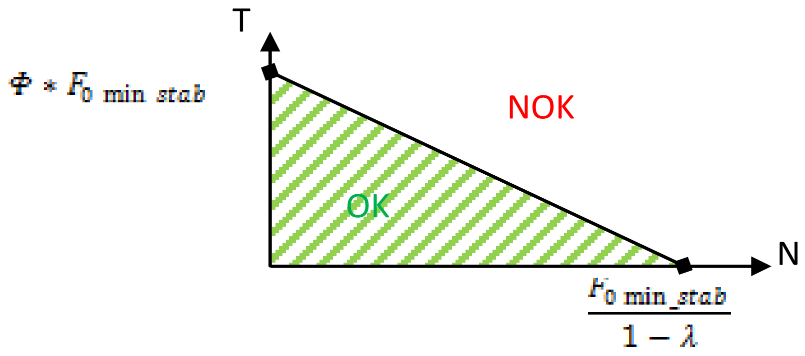


Figure 6: Failure criteria on the T-N curve

Table 4: Fasteners characteristics

Bolt	D (mm)	Tightening torque (N.m)	F0(min) N
M8 8.8 CPC2	8	17	7359
M10 8.8 CPC2	10	35	12 116
M12 8.8 CPC2	16	150	3354

Table 5: Fasteners characteristics

Bolt	F0(max) N	F0(nom) N	Friction factor
M8 8.8 CPC2	15 707	11 533	0.2
M10 8.8 CPC2	25 915	19 015	0.2
M12 8.8 CPC2	71 232	52 143	0.2

Λ = 0.05

Relaxation (R%) = 15

3 ANALYSIS OF RESULTS

The catenary tracer system is mounted on the roof of the train, with the laser scanner pointing or directed to the overhead catenary wire, the laser focusses and measures the height, stagger and wear of contact wire along the line. The measured parameters are recorded and stored in the data acquisition box. The speed sensors that are mounted on the underframe, next to the wheels, monitor the speed of the train, the measuring speed is between 50km/h and 120 km/h, and the location of the points along the route or line is updated by the antenna with GPRS and Wi-fi function, the antenna is already part of the train equipment that the drivers and operators use for communication and for traffic control on the rail network. It is mounted on the roof of the train. The data processing follows the procedure outline in figure 6. The sensor data is stored in the data acquisition box and forms the raw data input to the data processing stage. However, before the data can be processed it is first quality checked for the required standard. The processed data can then be subjected to further analysis such as statistical analysis, etc. Quality check and procession is done by the data acquisition box logic, using the set threshold to flag and indicate the action that must be implemented.

3.1 The system

The design consists of the following components;

- Data acquisition box
- Sensor box
- Antenna (Wi-Fi/GSM-3G/GPS)
- Power supply box (from vehicle)
- Laser scanner, LMS211 (measuring unit)

Table 6: Acronym for bolt formulas

Acronym	Description
F_0(min)	Minimum tightening tension in the bolt
F_0(nom)	Nominal tightening tension in the bolt
F_0(max)	Maximal tightening tension in the bolt
D	Diameter
d_{min}	Minimum hole diameter for rivet
d_{max}	Maximum hole diameter for rivet
A_{min}	Minimum Area
L_{nom}	Nominal diameter of rolled edge
N_u	Minimum tightening tensile tension in the rivet
T_u	Minimum tightening shear tension in the rivet
E_b	Young's modulus of the rivet
F_x	Computed axial force in the bolt : (+) traction (-) Compression
FS1	Computed shear force in direction 1
FS2	Computed shear force in direction 2
Ft	Normal force (if N<0 then N=0)
Fv	Tangential shear force
μ	Friction Ratio (steel/steel → 0.2)
γ	Stiffness ration of the assembly (5%)
R%	Relaxation effect (15%)
Tr	Required Tension
Sf	Safety Factor > 1

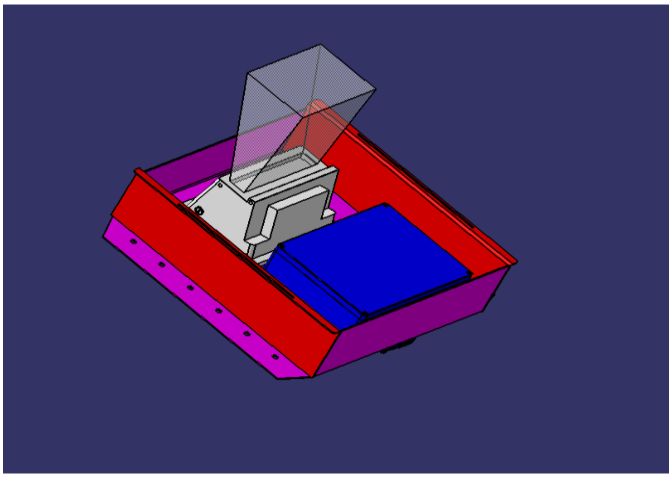


Figure 7: Assembled catenary tracer equipment

The equipment was installed on 4 lines to monitor the condition of the catenary wire, and the collected data was analyzed and compared. Below are the areas where the foresaid test was conducted:

- Wolmerton to Pretoria (XG_XF_XE_XB_XA_WD_WC_WB) – Length ~16,4 km
- Pretoria to Koedoespoort (WG1) – Length ~ 10,5 km
- Koedoespoort to Pretoria (WG2) – Length ~ 10,5 km
- Koedoespoort to Pienaarspoort (WH1) – Length ~ 16 km
- Pienaarspoort to Koedoespoort (WH2) – Length ~ 16 km.

3.2 Global architecture and processing methodologies

The raw data is uploaded automatically on to the storage hosted on the side server cloud, then processed and interpreted and sent to the relevant maintenance engineers for analysis.

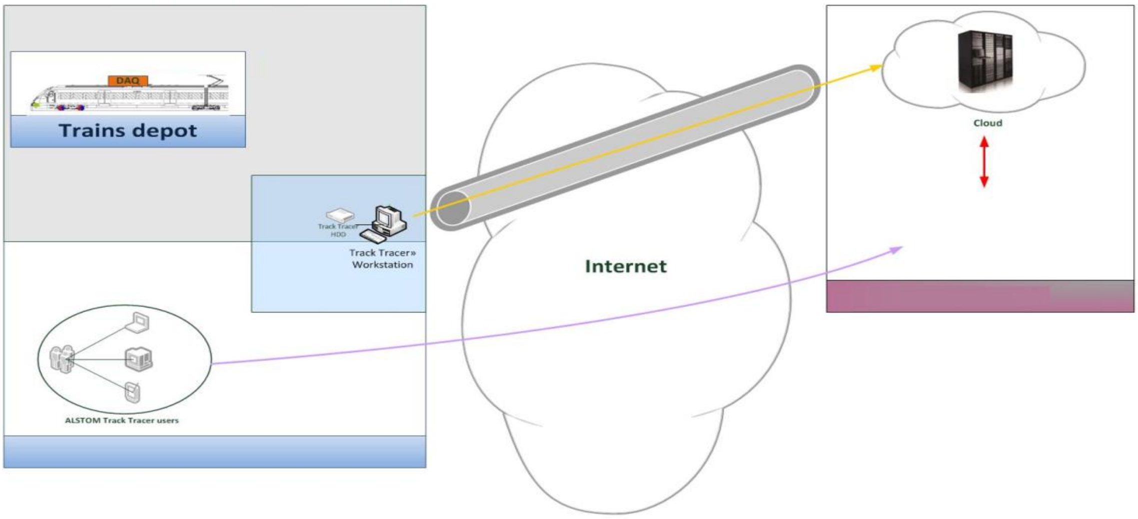


Figure 8: Data collection methodology

3.3 Statistical analysis – Wolmerton to Pretoria

Segmentation of each measured data was in sections, the data was collected per section for each area, at 20m intervals, as in figure 6. Static quantity is the difference between the true value of the quantity changing with time and the value indicated by the measurement system if no static error is assumed. It is also called measurement error as shown in figure 9.

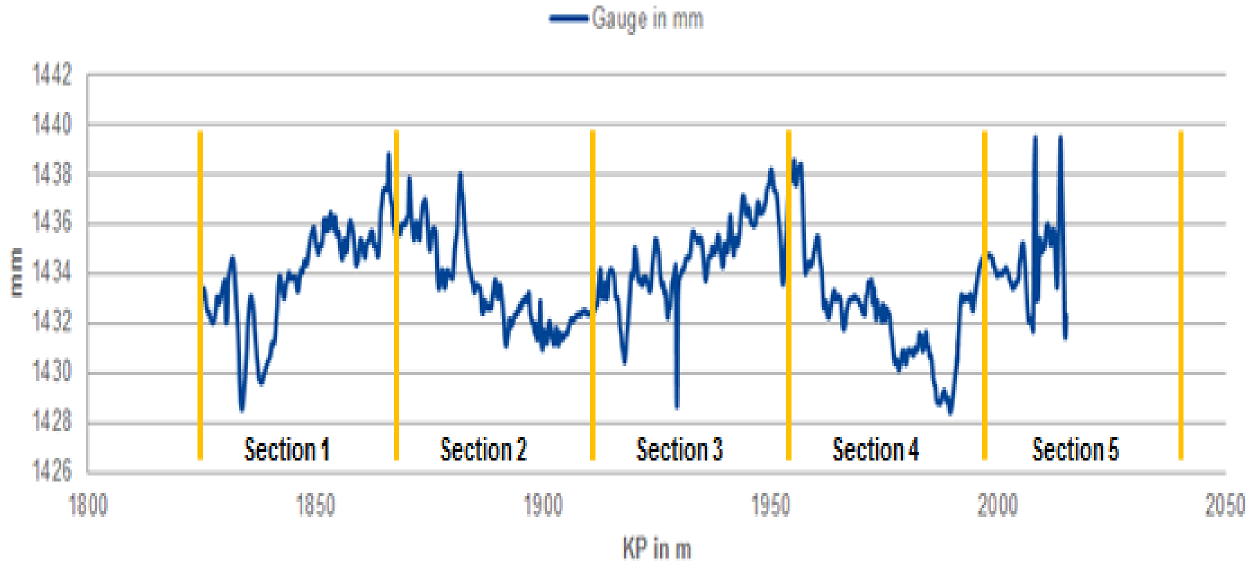


Figure 9: Segmentation of each measured data in sections

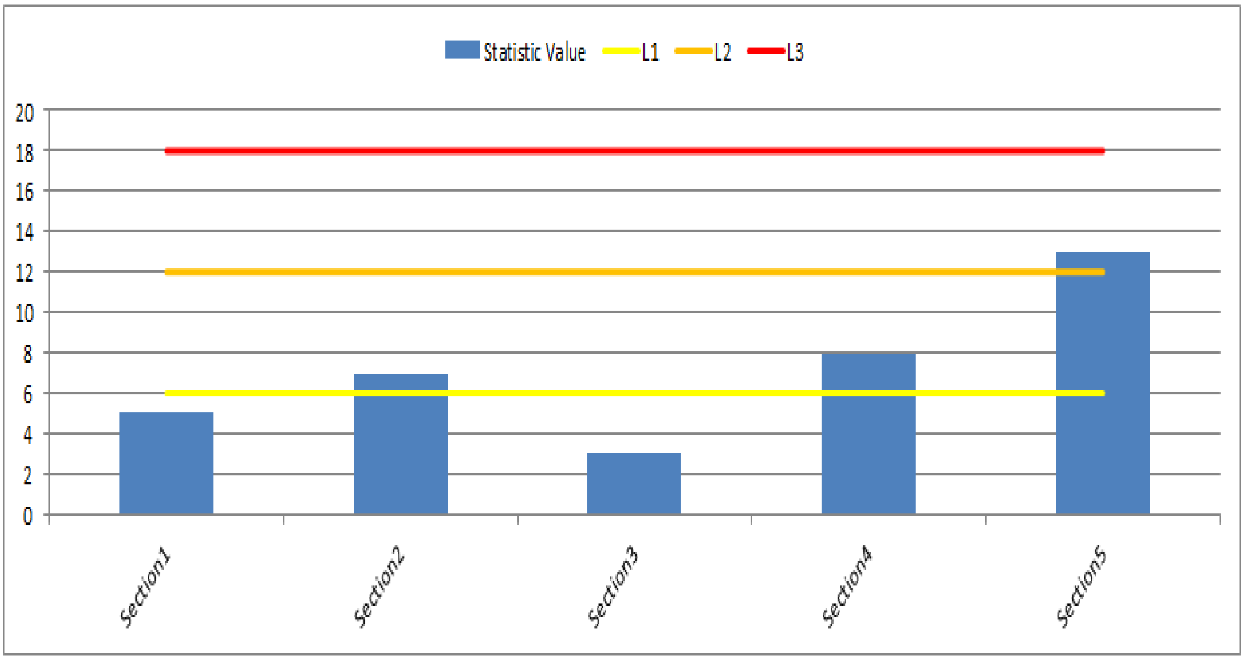


Figure 10: Computation of a statistic quantity over each section

Defects are classified in three different categories:

- L1 – Yellow class: to be corrected during routine/preventative maintenance or to be corrected during standard B maintenance in the vicinity.
- L2 – Orange class: Conduct maintenance not later than 6months.
- L3 – Red class: danger. Close section and attend immediately.

The thresholds from Table 7 are applied for the analysis to measure and categorize the defects classes. They were taken from NF EN 13848-5+A1 ENG for track quality. These values were used as baseline reference for the analysis of the catenary.

TABLE 7: The thresholds are applied for the analysis of results

CORRUGATION		YELLOW CLASS	ORANGE CLASS	RED CLASS
Corrugation	Longitudinal Corrugation	100 µm	300 µm	600 µm
	Lateral Corrugation	100 µm	300 µm	600 µm
Catenary Geometry	Longitudinal Level	-10/10 mm	-16/16 mm	-26/26 mm
	Alignment	-8/8 mm	-11/11 mm	-17/17 mm
	Twist	-2.5/2.5 mm/m	-3.5/3.5 mm/m	-5/5 mm/m

Figure 11: Location of Red class defect Wolmerton to Pretoria

4 CONCLUSION

Results from figure 11, indicate that the detected defect on Catenary Geometry for Wolmerton to Pretoria track line indicated a 1% of L3 defect respectively for 0.2km of 16.4 km, indicating that the line should be closed and attended to immediately for maintenance and repairs. And from that the results suggest that line should immediately be renewed / maintained and speed restrictions should also be implemented. A system of laser scanner mounted on the roof of the train, TC car, connected to data acquisition box was able to detect the irregularities on the parameter of the catenary wire, in the form of vibrations, in relation to the gauge and height of the catenary wire above the train. The data was then extracted from the data box, analyzed and computed accordingly over each section. The challenge today is that the infrastructure is very old, the lines and the tracks are rarely maintained, and since Prasa is investing in 500 newly designed trains, the same investment is slowly being done on the infrastructure. This newly integrated system detected a warning for 1.4 of 16.4km, for the section to be monitored regularly, 9% classified as orange class defect and no action required for the rest of the line. With this information maintenance schedules can be planned and executed according to avoid service interruptions, which in the main purpose of this system.

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ASSESSMENT OF THE CATENARY WIRE FOR MAINTENANCE DECISION MAKING

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ABSTRACT

A catenary is a system of overhead wires used to supply electricity to locomotives and electric trains equipped with a pantograph. The electricity is delivered via the pantograph to the high speed circuit breakers and thus distributed to the different required systems. This study focusses on integrating a catenary tracer system that assesses the condition of the catenary wire (overhead wire) for maintenance decision making. The system consists of a laser scanner and data acquisition box mounted on the roof of the train, and speed sensors mounted on the bogies. The system is designed to continuously collect data from the catenary wire, to assess and to detect defects on the catenary wire. The data is analyzed and classified in three different defect categories; Yellow class - to be corrected during routine/preventative maintenance or to be corrected during standard B maintenance in the vicinity, Orange class – Conduct maintenance not later than 6 months and Red class – indicating danger, and closure of section for immediate attendance. The collected data is then loaded to the depot server and compared to a reference to determine if maintenance on the catenary wire is required. The assessment of the catenary wire leading to various maintenance decisions forms the focus of this paper.

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1. INTRODUCTION

Overhead line equipment can be adversely affected by strong winds causing swinging wires. Power storms can knock the power out with lightning strikes on systems with overhead wires, stopping trains if there is a power surge which results in train delays, catenary and contact wire breakage which are expensive to replace, pose as a safety hazard if left unfixed. Many problems are associated with contact wire wear measurement. This is studied carefully before a decision is made regarding the best method of maintenance. For instance the presence of droppers makes the use of any type of mechanical sensor running along the top of the wire impossible. In fact, anything tall mounted on top of the pantograph is dangerous, since it will be struck by the cable at forks and at cross-overs. The method used must be affected neither by stagger nor by the varying height of the contact wire. It must be able to operate in the hostile environment of the overhead system among large electric and magnetic fields, obtain information from a point at a potential of 3kV and then transmit this down to ground where it can be recorded. It must also be robust enough to withstand the vibrations and shocks associated with pantograph motion, and must not be affected by grease, water, copper dust etc. Information regarding the extent of wear can be obtained by measuring one of three basic parameters. These are listed in table 1, together with some of the associated methods of maintenance.

Table 1: Parameters that influence wear, with the available types of methods.

Parameter Method	
Cross sectional area	a) Resistance measurement
	b) Deflection due to bending
Width of sliding surface	a) Closed circuit television
Vertical section	a) Ultra – sonic means
	b) Scanning of profile

The selected method for this study is Vertical section - Scanning of profile, these method is chosen because of the method of intergrating the equipment of the scanning profile. With the laser scanner equipment, the system can be easily assembled and disassemble from the roof with no challenges. The equipment is fixed securely on the roof, with laser pointing at the catenary without any physical contact with the catenary. The laser scanner type also referred to as reality capture or high definition surveying uses laser beams to measure and capture the parameters of the catenary wire, height, diameter (3.2mm), abrasion and twist. Also the method is of recent rapid advance in visual semi-conductor.

The data is transmitted and stored to the data acquisition box. The acquisition box is placed on the car body and enabled to acquire the speed from the speed sensors, and the vibration signals from the accelerometer sensors. The box collects data, synchronizes it all through computation and stores it until it can be downloaded to be scrutinized for maintenance decision making. The laser scanner is connected directly to the DAQ box, which is connected to 1 sensor boxes shown in figure 3, installed on the underframe of the train, on the bogies and 4 speed sensor on the underframe of the train is installed to measure the difference in the speed of the bogies. The DAQ box is also connected to the GPS receiver and wi-fi receiver (antenna) to indicate the location of the analysis on the catenary. The equipment is connected / powered by the battery which is installed on the underframe. The full system is shown in figure 2.

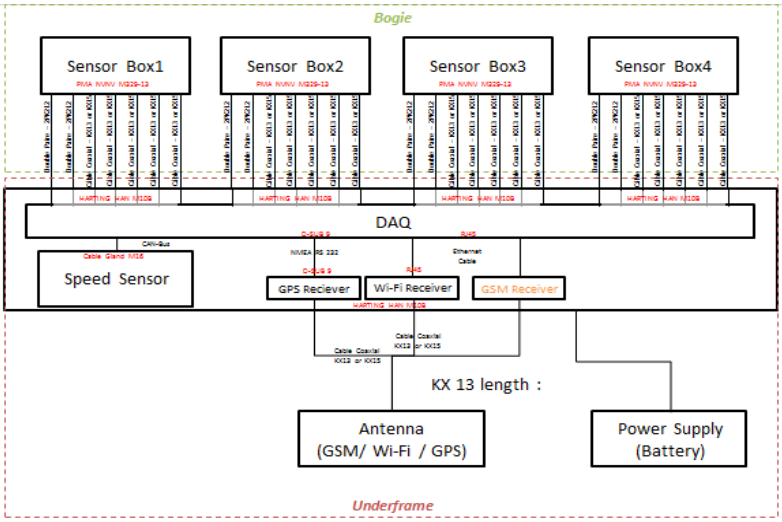

Figure 1: Electrical schematic of the catenary tracer system

1.1 Advantages of the Catenary monitoring system by laser scanner

The advantages specified are concluded form the individual components of the system, they were also identified as the requirements for the designing of the system;

- The equipment can be used on different trains at different locations/lines, since the equipment is not fixed at the station or depot.
- Easy, anytime offline maintenance of the system can be easily dismounted from the roof of the train.
- Raw data can be easily stored / retrieved from the data acquisition box and from the server and shared by memory stick if required.
- Detection and quantification of morphological changes, monitoring, quantitative interpretation, displacement rates measurements,
- High precision (centimeter and mm).
- Remote sensing, no contact with the overhead wires.

1.2 Installation of the system

The system is installed on the roof of the trailer car (TC), next to END 2 of the car. It is powered by the battery installed on the underframe of the car as shown in figure 2. The battery is powered with 110V, from the current collected by the pantograph from the catenary wire.

Figure 2: Position of the catenary tracer installation of the trailer car

1.2.1 The design consists of the following components,

- Data acquisition box
- Sensor box
- Antenna (Wi-Fi/GSM-3G/GPS)
- Power supply box (from vehicle)
- Laser scanner, LMS211 (measuring unit)

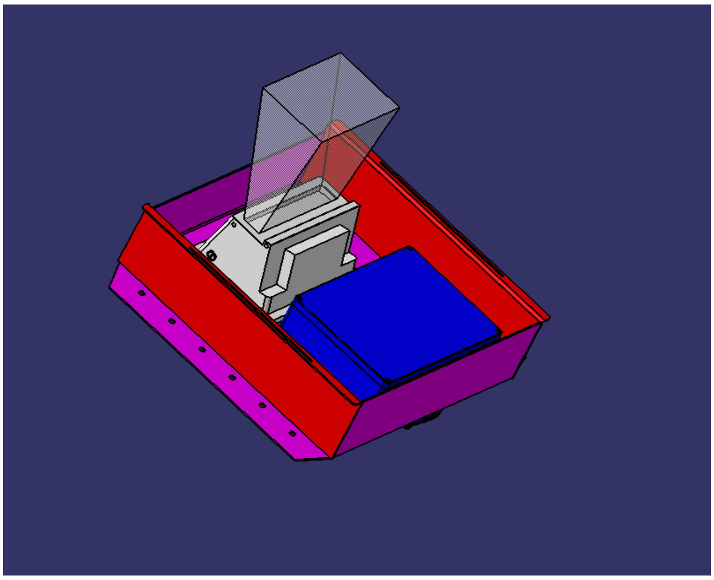

Figure 3. System equipment

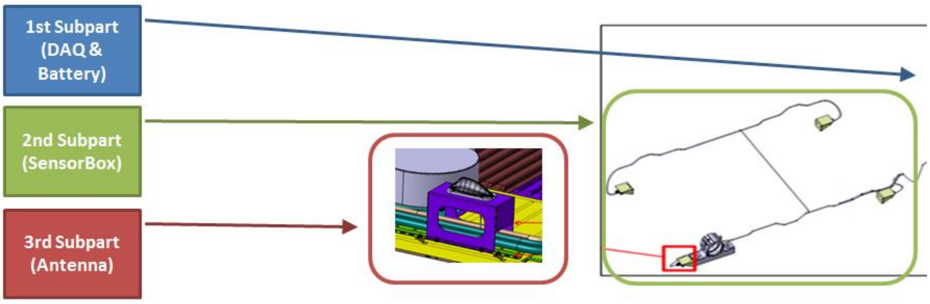

Figure 4: Placement of the speed sensors an Antenna for wi-fi

2. PURPOSE OF THE STUDY

This study will focus on the assessment of the catenary tracer for monitoring and detecting problems associated with the catenary system during normal service operation of trains in order to fix the problems when detected to avoid service interruptions. The catenary tracer system is designed by the author as a proposal to Gibela Rail Company to improve and extend the maintenance services that are already in place contractually. Prasa's main priority is to improve train service to the public of South Africa, as part of the PRASA's Fleet Renewal Programme, the new trains that were launched in May 2017, are expected to improve service by 18.2%, which is would be 7% higher than the previous year, and also reduce strikes leading to vandalism. The ageing rolling stock and infrastructure condition remains the biggest challenge in improving services, despite the operator's preventative maintenance and infrastructure rehabilitation efforts to sustain the capacity and performance of the commuter rail system. The reliability of the infrastructure has been affected by increasing speed restrictions on the network due to the quality of the railway and worsened by seasonal climate weather. Over 200 projects are managed within the PRASA Rail capital intervention program to rehabilitate the railway, overhead electrical structures, signaling & telecommunications system, drainage, fencing and replace critical components for rolling stock and signaling equipment.

This study will focus on monitoring and detecting problems associated with catenary system during normal service operation of trains in order to fix the problems when detected to avoid service interruptions.

After a steady increase in passenger numbers over recent years, Metrorail has experienced a decrease in support over the past financial year. As a result of unhappy customers who consider the trains as unreliable, the decrease in passenger numbers is attributed to decreased service capacity and quality of services offered to the public, the general decline in economic activity and passengers moving to competitive and alternative modes of transport such as taxi's and Bus Rapid Transit solutions being implemented. Figure 4 shows a declining customer satisfaction rating. As a result of passengers not being satisfied, a total of 588 asset related incidents were recorded in the year under review, including 133 incidents of cable theft, 64 incidents of railway and electrical equipment theft, more than 120 incidents of vandalism to rolling stock including arson. A total of more than 300 coaches were vandalized countrywide in yards and depots in the year under review, the majority of which were damaged by arson. Figure 5 shows the results if the customer satisfaction survey contacted yearly by Prasa. And from the graph, the rating drops from 79.1 to 72.1 between 2011 and 2015. With 120 incidents that are related to vandalism, which are mainly fuelled by service interruptions and service delays due to maintenance and repairs of the trains. The rating is based on customers answer service related questions, and also asked to give suggestions on how it can be improved as per the customers' expectations.

Figure 5: Service performance presented by Prasa, which is gradually declining.

3. METHODOLOGY

The laser scanner is mounted on the roof of the train, fixed with bolts, to measures the parameters of catenary, the thickness, difference in diameter across the line. The train is run at a slow speed, not more than 30km/h, to allow for accurate scanning of the catenary wire. This speed is an average that is used across the depot for the different tests and validations that are performed on the trains. The train is run to and from one station, Wolmerton to Pretoria and back to Worlmeton. Then the raw data stored on board by the DAQ box, data acquisition box, is downloaded from the box by a memory stick to a computer and saved as an excel file.

The raw data shown in table 2 and table 3, are compared and classified accordingly by the data acquisition box for identification. Data acquisition box stores data, in a form of vibrations and has a process of converting measurements, such as temperature, pressure, vibrations, into digital numeric values that are characterized by the thresholds values.

3.1 Processing Methodology

The data processing follows the procedure outline in figure 6. The sensor data is stored in the data acquisition box and forms the raw data input to the data processing stage. However, before the data can be processed it is first quality checked for the required standard. The processed data can then be subjected to further analysis such as statistical analysis, etc.

Quality check and procession is done by the data acquisition box logic, using the set threshold to flag and indicate the action that must be implemented.

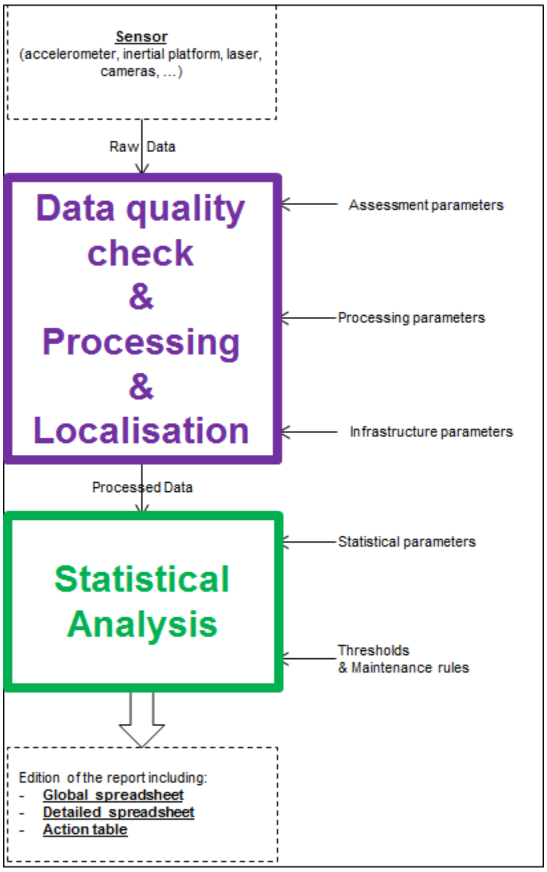

Figure 6: Processing methodology for the data collected from the catenary to be analysed for maintenace decision making.

4. ANALYSIS OF RESULTS

A total of 5 rail routes are currently being monitored as part of this study, but only 2 are focused on. The design is validated according to EN12663 STANDARD stress criteria and allowable limits (15% of safety factor according to EN12663). The standard is for Railway applications and structural requirements for all equipment designed for railway. The raw data is uploaded automatically on to the storage hosted on the side server, cloud, then processed and interpreted and sent to the relevant maintenance engineers for analysis and maintenance scheduling.

The focus of this paper is conducted along the 2 routes below;

- Wolmerton to Pretoria – Length, 16,4 km
- Pretoria to Koedoespoort – Length, 10,5 km

4.1 Collected raw data

The collected data is collected along the catenary wire at intervals of 20m sections. And also the collected data specifies an action on whether the catenary wire “on a specific area” along the route needs to be inspected, repaired or replaced. The highlighted routes are the areas of concentration for this study, and the catenary was monitored accordingly throughout.

Figure 7 shows Wolmerton to Pretoria route, which is 16.4 km. And figure 8 is for Pretoria to Koedoespoort route, 10.5 km long.

This paper focuses on the specified 2 routes because, Prasa's main depot for the new South African trains are stationed and maintained at Worlmeton in Pretoria. And also Gibela after service teams, Warranty and maintenance teams are based at the Prasa Worlmeton depot full time.

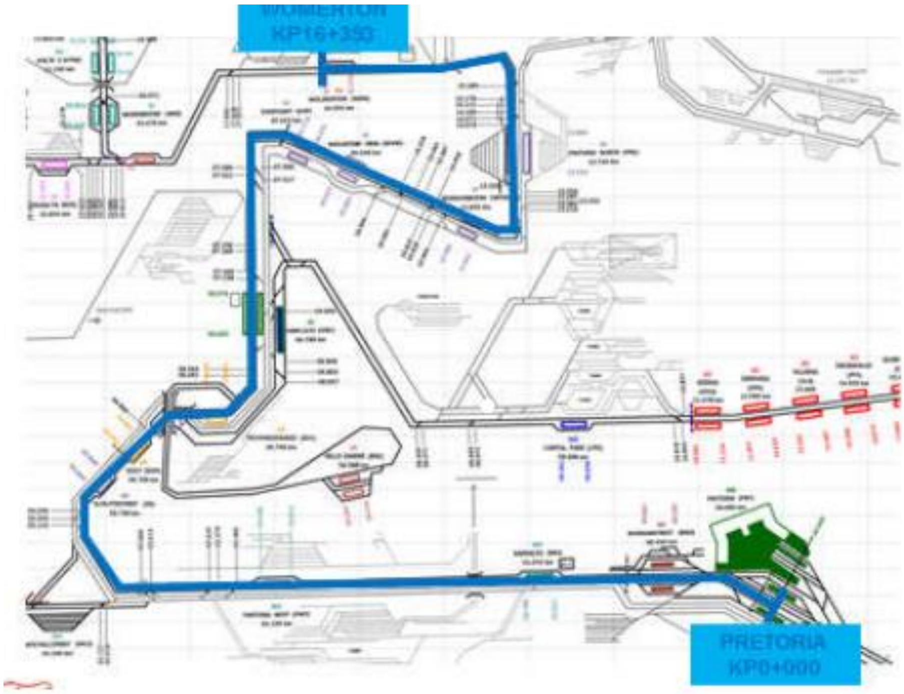

Figure 7: The train route map of Wolmerton to Pretoria – Length, 16,4 km

The results in Table 2 and Table 3 show the data that is collected along the Wolmerton to Pretoria route and Pretoria to Koedoespoort, channel indicates the route where the data is collected, red points indicated on figure 9 and figure 10 show the section on the catenary and action indicates what actions should be done to maintain the condition of the catenary.

- Ok – no defects detected on the catenary.
- Areas to Be Inspected Regularly – potential defect detected, indicating that the area should be monitored closely.
- Action – maitanance and repairs to be done immidiately.

Table 2: Collected raw data across the Wolmerton to Pretoria route.

Channel	Action	Location	Distance (m)
CorrZR30100	Areas to Be Inspected Regularly	7380-7400	1200
CorrZR30100	OK	7400-7420	1200
CorrZR30100	OK	7520-7540	1200
CorrZR30100	Areas to Be Inspected Regularly	7540-7560	1200
CorrZR30100	Areas to Be Inspected Regularly	7580-7600	1200

CorrZR30100	Areas to Be Inspected Regularly	7620-7640	1200
CorrZR30100	Action	13300-13320	1200
CorrZR30100	Areas to Be Inspected Regularly	13340-13360	1200
CorrZR30100	Areas to Be Inspected Regularly	14080-14100	1200
CorrZR30100	Areas to Be Inspected Regularly	14700-14720	1200
CorrZR30100	Areas to Be Inspected Regularly	15100-15120	1200
CorrZR30100	OK	15120-15140	1200
CorrZR30100	Areas to Be Inspected Regularly	15140-15160	1200
CorrZR30100	Areas to Be Inspected Regularly	15320-15340	1200
CorrZR30100	OK	15440-15460	1200

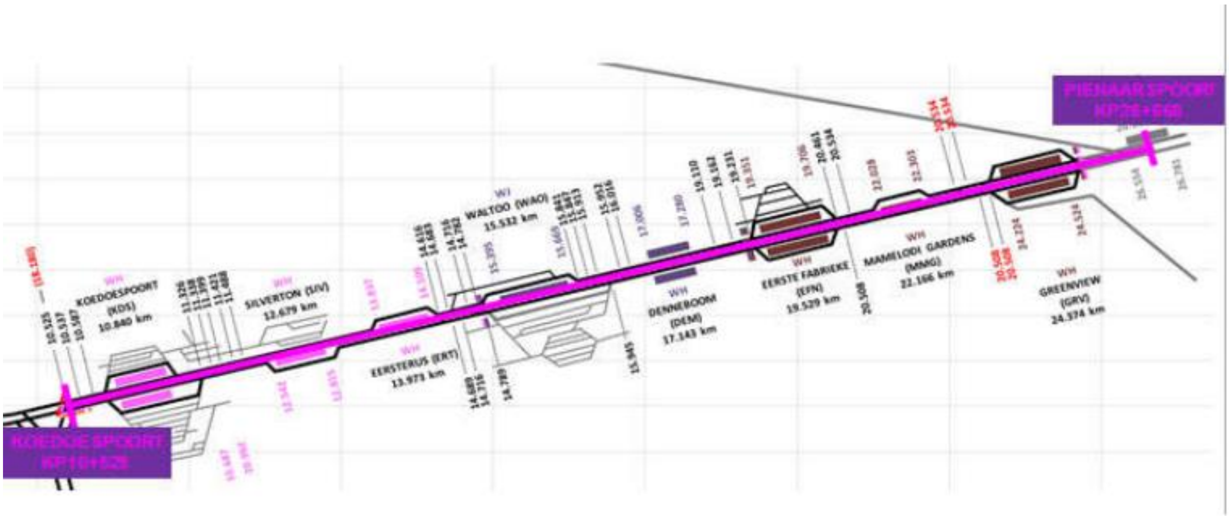

Figure 8: The train route map of Pretoria to Koedoespoort - Length, 10,5 km

Table 3: The train route map of Pretoria to Koedoespoort - Length, 10,5 km

Channel	Action	Location	Interval(m)	Distance(m)
CorrZL30100	OK	160-820	20	4460
CorrZL30100	Areas to Be Inspected Regularly	820-860	20	1220
CorrZL30100	OK	860-900	20	1220
CorrZL30100	Areas to Be Inspected Regularly	900-920	20	1220
CorrZL30100	Ok	920-940	20	1220
CorrZL30100	Areas to Be Inspected Regularly	940-960	20	1220

CorrZL30100	OK	960-980	20	1220
CorrZL30100	Areas to Be Inspected Regularly	980-1080	20	1220
CorrZL30100	OK	1080-2300	20	1220
CorrZL30100	Areas to Be Inspected Regularly	2300-2320	20	1220
CorrZL30100	OK	2320-2380	20	1220
CorrZL30100	Areas to Be Inspected Regularly	2380-2400	20	1220
CorrZL30100	Areas to Be Inspected Regularly	2400-2420	20	1220
CorrZL30100	Areas to Be Inspected Regularly	2420-2440	20	1220
CorrZL30100	Areas to Be Inspected Regularly	2840-2860	20	1220
CorrZL30100	Action	2860-2880	20	1220
CorrZL30100	Areas to Be Inspected Regularly	2880-3360	20	1220
CorrZL30100	Areas to Be Inspected Regularly	3040-3360	20	1220
CorrZL30100	OK	3360-6160	20	1220

4.1.1 Statistical analysis for Wolmerton to Pretoria Line and Pretoria to Koedoespoort

The laser scanner has a static meter that measuress the diameter of the catenary wire in relation to the height of the catenary system. The data collected is classified accordingly after analysis for maintanace decision making.

4.1.2 Defects are classified in three different categories:

a) L1 - YELLOW CLASS : To be corrected during routine/preventative maintenance or to be corrected during Standard B maintenance in the vicinity.

b) L2 - ORANGE CLASS : Conduct maintenance not later than 6 months.

c) L3 - RED CLASS: Danger, Close section and attend immediately.

The thresholds from Table 4 are applied for the analysis to measure and categorize the defects classes. They were taken from NF EN 13848-5+A1 ENG for track and line quality. These values were used as baseline reference for the analysis of the catenary.

Table 4: Thresholds applied to measure and categorize the defects.

Track Name`	Track Geometry Defect		
	YELLOW CLASS	*ORANGE CLASS*	*RED CLASS*
Wolmerton to Pretoria	23% (3,8km of 16,4km)	9% (1,4km of 16,4km)	1% (0,2km of 16,4km)

Pretoria to Koedoesport (10.5km total length)	8% (0,8km of 10,5km)	2% (0,2km of 10,5km)	-
Koedoesport to Pretoria (10.5km total length)	13% (1,4km of 10,5km)	8% (0,8km of 10,5km)	8% (1,2km of 16km)
Koedoesport to Pienaarsport (16km total length)	6% (1km of 16km)	1% (0,2km of 16km)	-
(Pienaarsport to Koedoespoort (16km total length)	21% *(3,4km of 16km)*	8% (1,2km of 16km)	-

4.2 Current Catenary Defects - Wolmerton to Pretoria

The results in table 5 were obtained from the recorded data for catenary tracer defect per area. The focus is on the area between Wolmerton to Pretoria. Location distance is the sum of the areas to be monitored regularly and the 1 area that is to me repaired immediately as according to Table 2. 10 areas are flagged as “to be monitored regularly” and 1 area is to be attended to immediately. And the average speed of the train when the data was collected was 30.4km/h. The allowable max speed specified for Metrorail trains in South Africa is 60km/h. Figure 9 shows the exact location of the re class defect detected.

Table 5. Parameters of the measured line defects (Wolmerton to Pretoria)

Defect Type	Alignment
Location	226-0.426Km (Pretoria)
Measured Value	-33.79mm
Average Speed	30.4km/h

Figure 9: RED class defect noted from Wolmerton to Pretoria

Table 6: Measured line defects (Wolmerton to Pretoria) per class

		YELLOW CLASS	ORANGE CLASS	RED CLASS
Track Geometry	Longitudinal Level	-10/10 mm	-16/16 mm	-26/26 mm
	Alignment	-8/8 mm	-11/11 mm	-17/17 mm
	Twis	-2.5/2.5 mm/m	-3.5/3.5 mm/m	-5/5 mm/m

Figure 10 show the location of the defects detected from Pretoria to Koedoespoort, simirlaly to Wolmerton to Pretoria route, one section on the indicates an alert for line replacement or repair.

Figure 10: RED class defect noted from Pretoria to Koedoespoort

From the collected data, the total number of defects from table 7 are summarized and assessed accordingly:

- L1 – 1753 detected yellow class defects, to be corrected during routine/preventative maintenance or to be corrected during Standard B maintenance in the vicinity.
- L2 – 221 detected orange class defects, maintenance to be conducted not later than 6 months
- L3 – 2 detected red class defects, to be attended immediately.

5. CONCLUSION

Results from table 4, indicate that the detected defect on Catenary Geometry for Wolmerton to Pretoria track line indicated a 1% of L3 defect. And from that the results suggest that line should immediately be renewed / maintained and speed restrictions should also be implemented. The results indicate that the catenary wire system should be replaced immediately/as soon as possible, and commuters be notified of service interruption due to the renewal of the line, in parallel alternative line or routes can be opened to compensate for normal train service.

Also 2% of the section on the Pretoria to Koedoespoort indicated L3 defect that should be payed attention to immidiately.

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META-MODELS OF MONTE CARLO SIMULATION MODELS

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ABSTRACT

Simulation is used extensively for the modelling of large, complex, dynamic and stochastic systems, but the approach tends to depend heavily on computer execution time and the availably of advanced simulation modelling software. The severity of these problems has been lessened by the increased execution speed and power of existing computer hardware and the availability of powerful simulation modelling software. However, the development of effective and easy to use simulation languages has resulted in the increasing development of large and complex simulation models. Furthermore, real time applications of simulation models, requiring a quick response, are becoming more common. The inclusion of a simulation model as part of a bigger model might require numerous replications of the simulation model. This is, for example, true in the case of an optimization model using a simulation model in conjunction with a search algorithm. These kinds of models might still require extensive execution times and an applicable simulation meta-model might prove to be useful.

This paper will discuss and illustrate the development of meta-models of Monte Carlo simulation models using multi-variable regression. Post simulation analysis applications, of the meta-models, for example optimization, will be discussed. Suggestions for further research, applicable to the meta-modelling approach, will be briefly mentioned.

1 INTRODUCTION AND BACKGROUND

…. the sciences do not try to explain,
they hardly even try to interpret,
they mainly make models

1.1 The art of modelling

The tendency to imitate, emulate, mimic, pretend, reproduce, make-believe and imagine has been part of human nature for a long time. These tendencies have had a major influence on the arts, language and culture but also contributed significantly to the sciences. Scientific modelling is a scientific activity, the aim of which is to make a particular part or feature of the world easier to understand, define, quantify, visualize, or simulate and is an essential and inseparable part of many scientific disciplines [1]. Computer simulation modelling and the use of random numbers were formalized and used by John von Neumann and Stanislaw Ulam in the 1940's as part of their research into nuclear physics and they coined the phrase "Monte Carlo simulation" since the technique resembles in some way a kind of gambling [2]. Since then simulation modelling, in all its various forms, has developed considerably to become one of the most widely used techniques in industrial engineering whenever stochastic modelling is required [3] [4]. The method of least squares, on which statistical regression is based, was developed by Carl Friedrich Gauss and Adrien-Marie Legendre and the name "regression" was coined by Francis Galton [5]. Statistical regression analysis is one of the best known and widely used data-dependent modelling techniques in mathematical statistics. The primary techniques used in this paper are Monte Carlo simulation modelling and regression analysis.

1.2 Meta-Models of simulation models

Industrial engineers use a simulation model as a surrogate of an aspect of the real world because it is often impractical and costly to construct and experiment with multiple prototype versions of the real system. However, these models themselves might become complex, and so simpler approximations are often constructed; models of the model, or ***meta-models*** (**meta-**, of a higher or second-order kind, transformation from one form to another [6]). This concept is illustrated in Figure1.

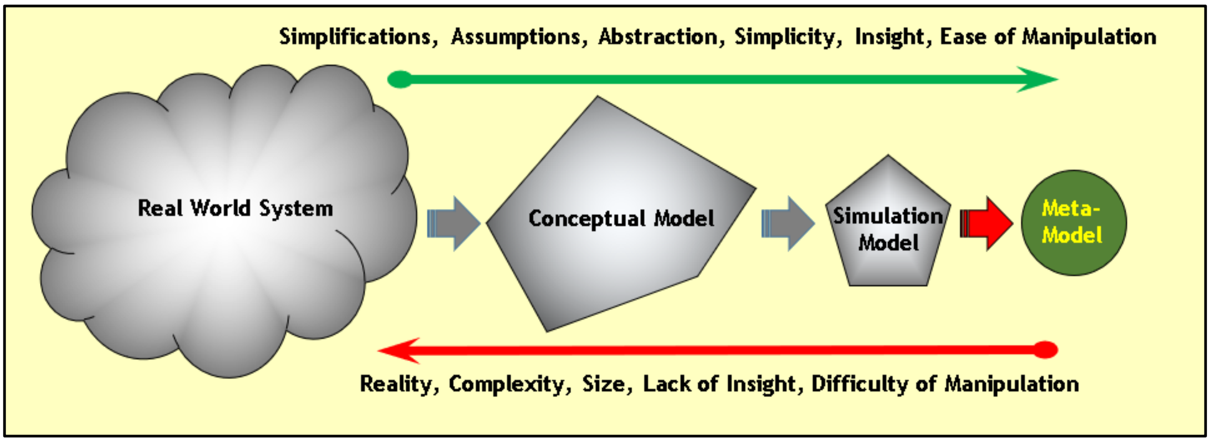


Figure 1. A simulation modelling framework and the concept of a meta-model

The concept of meta-models is not new and has been used extensively for the construction of simple models of simulation models [4] [7] [8]. The major traditional problem associated with simulation modelling used to be the excessive computing time often required. This problem has been partially alleviated because of the increased power and execution speed of available computer hardware. However, the power and availability of simulation modelling software have also increased significantly, making it easier to build and execute large simulation models. The possible advantages associated with meta-models of simulation models might be summarized as follows [4] [9] [10] [11]:

a. The need for simulation models, that might be used in a real-time decision-making environment and automation applications, has increased significantly.
b. Meta-models might be used as a surrogate sub-model or building block in larger mathematical or simulation models. Similarly, meta-models might be embedded in computer hardware and is an important part of artificial intelligence applications.
c. Meta-models might provide additional insight into the characteristics of the system since the resultant simple mathematical model might be easier to understand and analyse than the relevant simulation model of the system being modelled.
d. Traditionally meta-models were constructed using regression methodology, but other approaches have become available, for example, neural networks, which might be successfully applied to the fitting of meta-models.
e. Post simulation analysis and computations, for example, exploratory analysis, evaluation of alternative decisions and rapid adaptive calculations might benefit from the use of meta-models.
f. The ease of optimization, using, for example an evolutionary search algorithm, might be enhanced by using meta-models.
g. A meta-model of a simulation model is in many ways like the "smoothing" operation affected by regression when applied to a data set subjected to variation. The output of a simulation model is stochastic in nature and represents only an estimate. Therefore, it might be argued that, a meta-model might be better for prediction purposes, or at least more convenient, than using a single estimate from the relevant simulation model.

2 MONTE CARLO SIMULATION MODELLING

Anyone who considers arithmetical methods of
producing random digits is, of course, in a state of sin
John von Neumann

2.1 A basic budget model

The effective demonstration of the meta-model concept requires the definition of a relatively simple system and the associated Monte Carlo simulation model. For this purpose, consider the simple budget of a small retail business as shown in Table 1.

Table 1. A budget of a small retail business

Expected sales per day	500	Stochastic Variable
Variable cost per item	0.5	Constant
Fixed cost per day	100	Parameter
Selling price per item	1	Input
Marketing expenditure per day	50	Input
Expected profit per day	100	Output

The budget might be considered as a spreadsheet model, but is subjected to a few non-realistic assumptions. Firstly, the assumption that the daily sales will stay constant from day to day is not credible. Modelling the sales per day as a random or stochastic variable and constructing a Monte Carlo model might resolve this problem. The structure and characteristics of the basic budget model are shown in Figure 2 emphasising the multiple inputs and only one output. Therefore, a typical multi-regression approach might be an appropriate technique for the development of meta-models in this situation. Regression analysis might handle multiple input variables with relative ease but is not particularly suited to the handling of multiple output variables. For this purpose, an approach such as neural networks might be better suited.

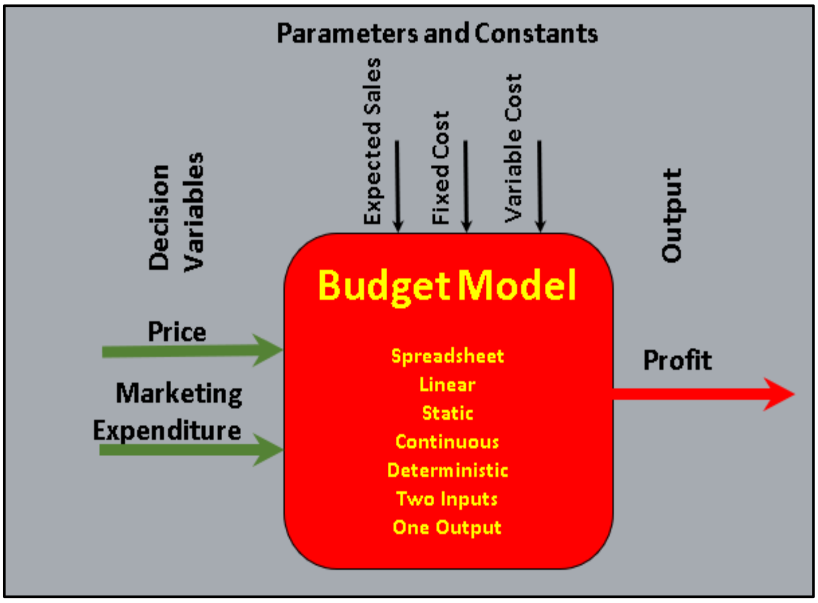


Figure 2. The structure and characteristics of the basic budget model

The basic budget model might be used to introduce the concept of a meta-model. A traditional “what-if” analysis might be performed on the budget model and the results might be displayed as a three-dimensional graph as shown in Figure 3. A meta-model fitted to this data using a multi-regression approach is shown in Figure 4. Since the basic budget model is deterministic and linear this two-variable first order polynomial is as close to a perfect fit of the simulation data as one can wish for with a coefficient of multiple determination, R^2, equals to one. This meta-model might not be very useful, but the concept could still assist in making repetitive “what-if” analysis of large and complex spreadsheet models easier.

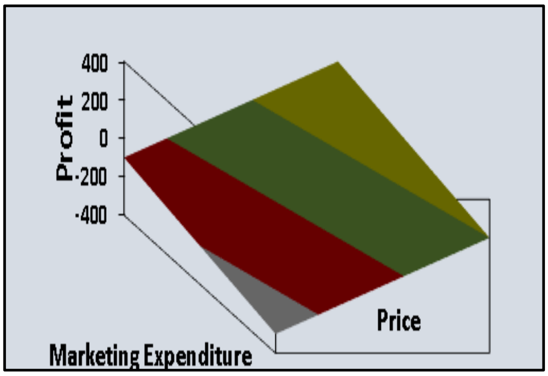


Figure 3. Budget model ”what-if” experiments

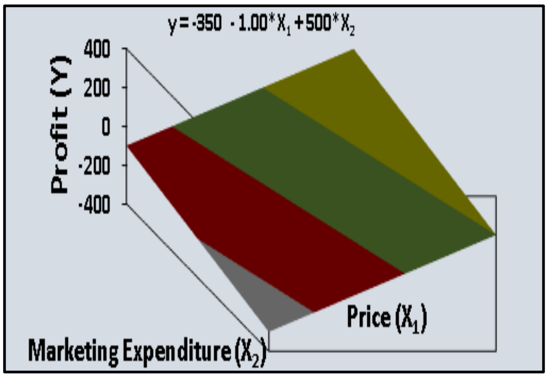


Figure 4. Meta-model of the budget model using a first-degree polynomial

2.2 A basic Monte Carlo model

The concept of computer generated pseudo-random numbers and statistical distributions to model stochastic processes is well known and an inherent part of any stochastic simulation model. In this way, Monte Carlo simulation might be seen as one of the basic building blocks of all the simulation modelling paradigms. Monte Carlo simulation is used widely in, for example, risk analysis, reliability engineering and measuring the effect of the "flaw-of-averages" [12] [13].

The basic budget model has some important limitations, for example, the assumption that the daily sales will stay constant is not realistic. The daily sales should be modelled as a stochastic variable by using an appropriate statistical distribution, as shown in Figure 5, and a Monte Carlo simulation model. Table 2 shows the results obtained from the basic budget model and replications of the basic Monte Carlo simulation model for specific values of the input variables.

Table 2. Typical results from the models for specific values of the price and the marketing expenditure

Model output for: Price = 1 and Marketing expenditure = 50			
	Mean profit	**Mean sales**	**Mean profit flaw-of-averages percentage**
Basic budget model	100	500	N/A
Basic Monte Carlo simulation model	98.59	502.38	-1.41%

Given the output of the simulation model several important characteristics of the system might be estimated. Figure 5 shows a histogram for the mean profit and a Gamma distribution fitted to it. The histogram for the mean profit and the Normal distribution fitted to it is shown in Figure 6 and might be used to construct the risk profile as shown in Figure 7. For any given value of the expected profit, the risk profile provides an estimate of the probability (risk) of achieving a profit less than the stated profit. Therefore, it provides estimates of the risk of making a loss and the downside risk. The downside risk is the probability of achieving a profit less than expected and is often used as a metric in risk analysis.

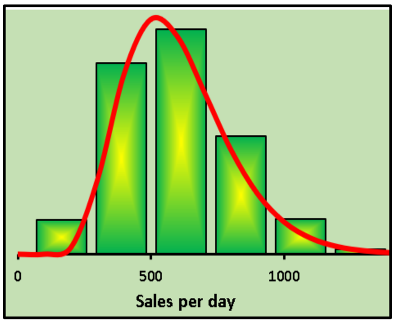


Figure 5. A histogram of the estimated sales per day and the fitted Gamma distribution

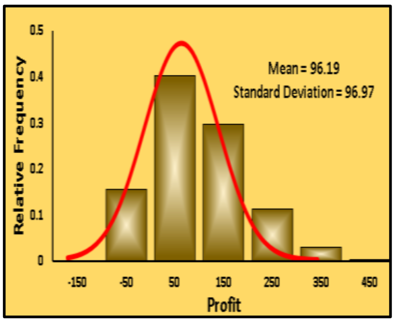


Figure 6. The histogram of the mean profit and the fitted Normal distribution

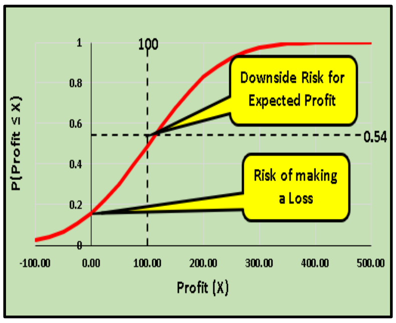


Figure 7. The risk profile from the fitted Normal distribution

[4245]-5

2.3 An enhanced Monte Carlo model

The basic Monte Carlo simulation model has some other limitations. The possible influence of one variable on another is not considered. For example, it is assumed that the price and the marketing expenditure have no influence on the expected sales which is not likely.

These aspects might be modelled and included in the simulation model by using sub-models. The sub-models developed for this purpose are summarized in Figures 8, 9, 10 and 11.

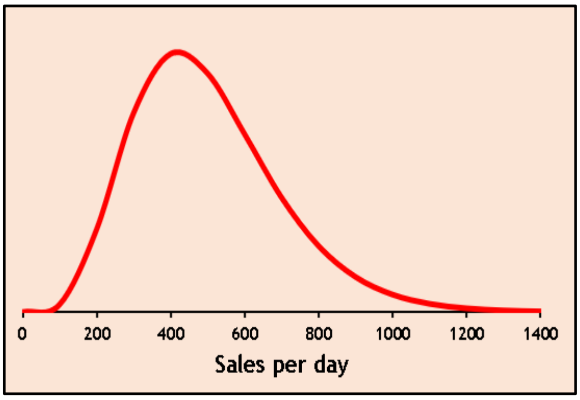


Figure 8. The Gamma distribution used for the generation of the daily sales

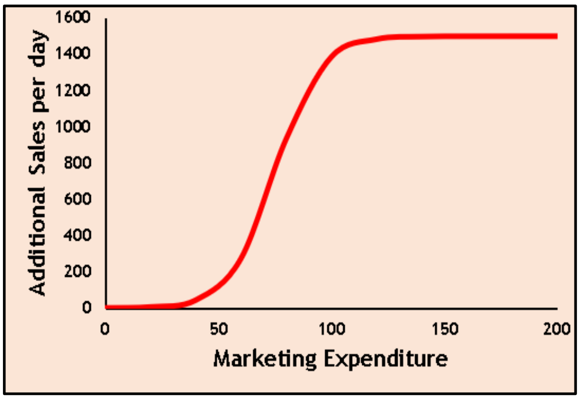


Figure 9. The logistics function used to model the influence of the price on the expected sales

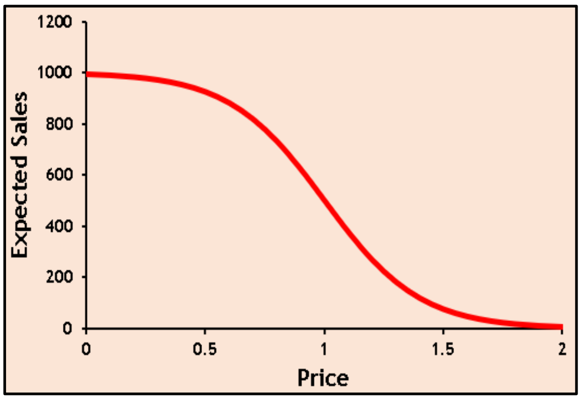


Figure 10. The logistic function used to model the influence of the marketing expenditure on the additional sales

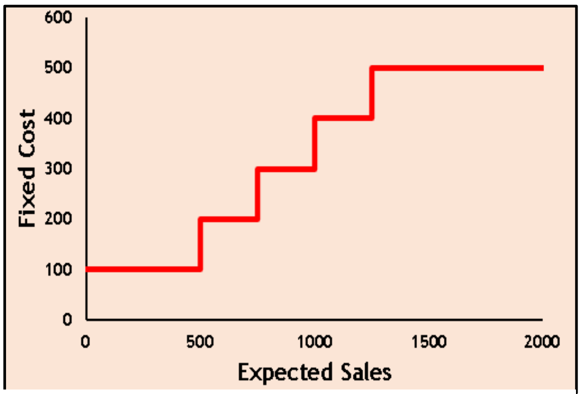


Figure 11. The step function used to model the influence of the expected sales on the fixed cost

Figure 12 illustrates the structure and interactions of the enhanced Monte Carlo simulation model. The necessary validation and verification of the simulation model was performed, and the model was used to conduct several experiments.

Figures 13, 14, 15 and 16 show three dimensional graphs of the meta-models developed for the mean profit and the downside risk associated with the budget model. Both these models were obtained by using multi-regression to fit a two variable second order polynomial to the data generated with the simulation model.

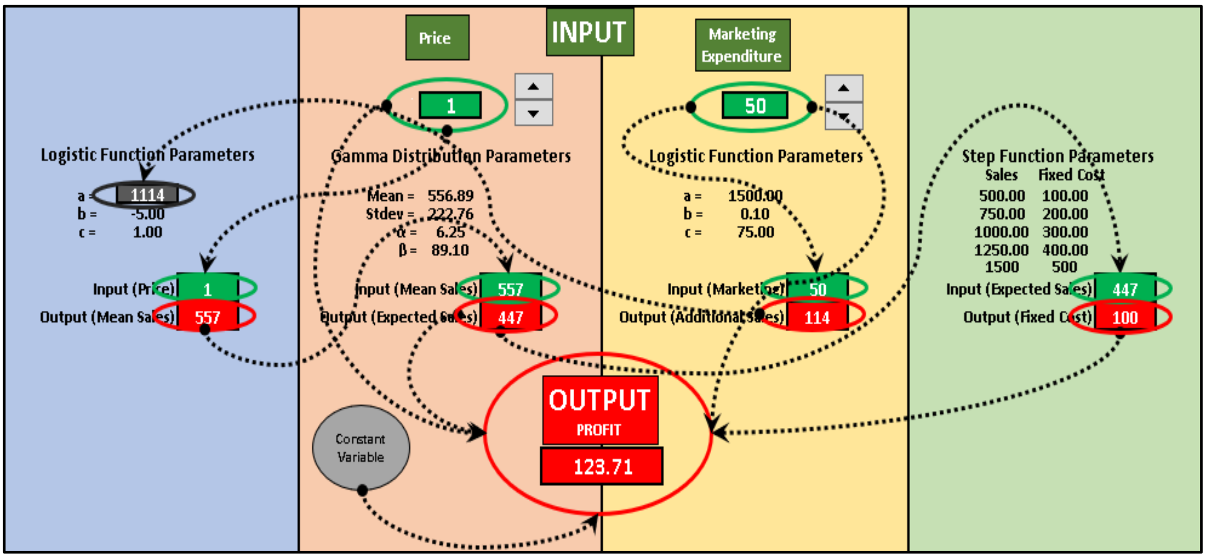


Figure 12. Structure and characteristics of the enhance Monte Carlo model

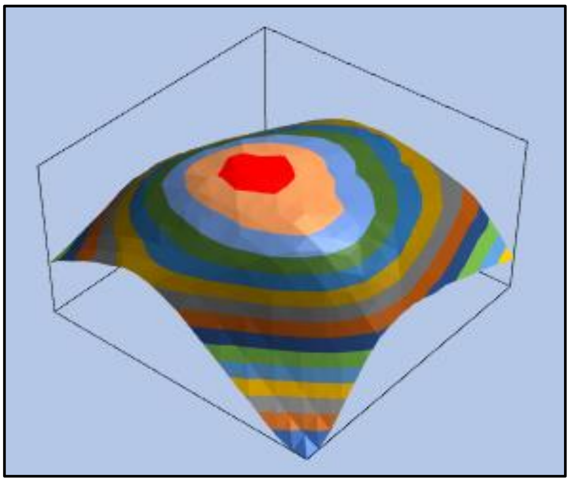


Figure 13 Results for the mean profit obtained from the Monte Carlo simulation model

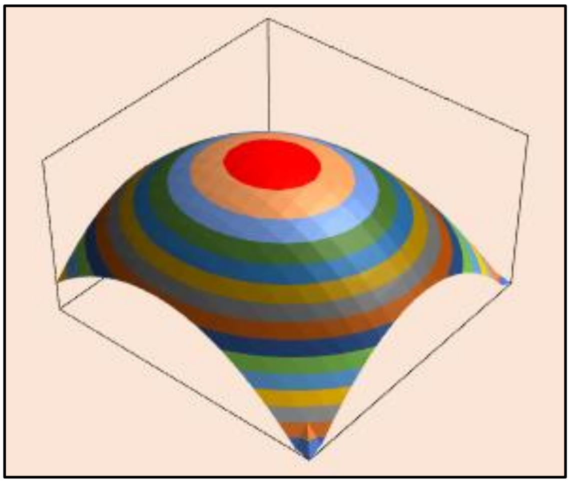


Figure 14. Results for the mean profit obtained from the meta-model

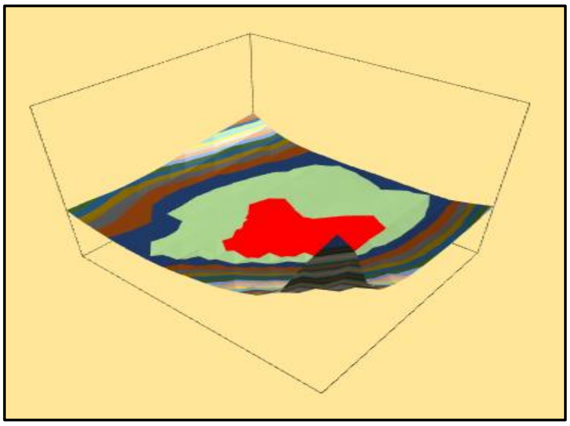


Figure 15. Results for the downside risk obtained from the Monte Carlo simulation model

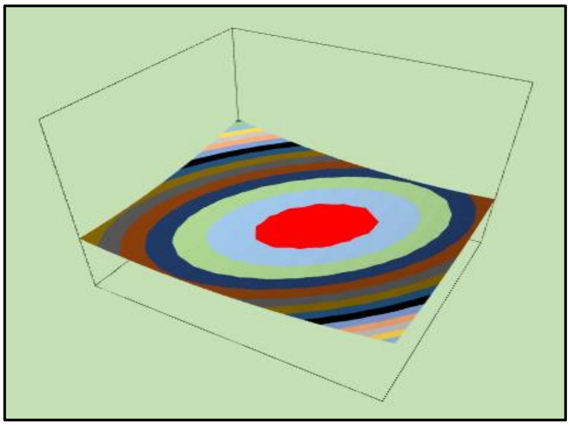


Figure 16. Results for the downside risk obtained from the meta-model

2.4 Meta-model adequacy and prediction accuracy

A meta-model is a model like any other one [14] and should be subjected to tests of adequacy. Figure 17 illustrates the goodness-of-fit by showing the results from the simulation model, in wire-frame format, superimposed on the results from the meta-models. The meta-models seem to be adequate.

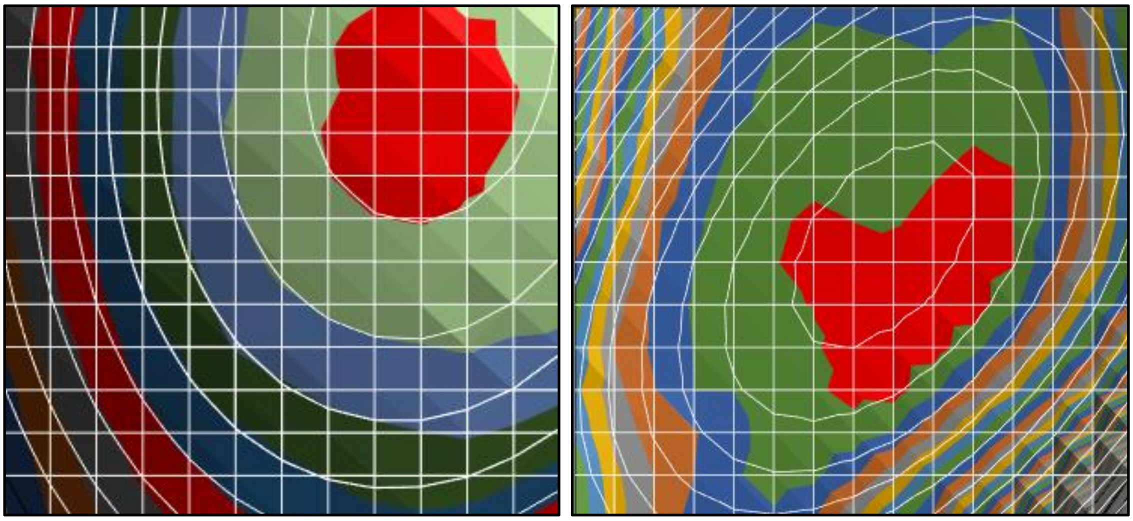


Figure 17. A visual comparison of the meta-model contour maps (in wire-frame format), superimposed on the simulation model contour maps

Table 3 shows a summary of the fitted meta-models and the statistical tests performed. These results indicate that the meta-models might be considered as adequate representations of the simulation models.

Table 3. Meta-models and model adequacy

Fitted meta-models		
Regression model: **A two variable second order polynomial**	$Y = Constant + a*X_1 + b*X_2 + c*X_1^2 + d*X_2^2 + e*X_1X_2$ Y = Mean Profit X_1 = Price X_2 = Marketing Expenditure	$Y = Constant + a*X_1 + b*X_2 + c*X_1^2 + d*X_2^2 + e*X_1X_2$ Y = Downside Risk X_1 = Price X_2 = Marketing Expenditure
Regression model adequacy		
Coefficient of determination	R-Square = 0.9690	R-Square = 0.8070
Analysis of variance (ANOVA)	F-Statistic = 2466.99 P-Value < 0.05	F-Statistic = 136.33 P-Value < 0.05
Regression coefficients	P-Value < 0.05	P-Value < 0.05
Constant	Yes	Yes
a	Yes	Yes

b	Yes	Yes
c	Yes	Yes
d	Yes	Yes
e	Yes	Yes
Chi-square goodness-of-fit test	Test statistic $x^2_0 = 12.35$ Critical value, $x^2_{0.05,397}$ = 354.64	Test statistic $x^2_0 = 32.42$ Critical value, $x^2_{0.05,397}$ = 96.36
Since the critical value > test statistic and all the P-values indicate significance the null hypothesis might be rejected, and the conclusion is that there is no significant difference between the simulation models and the meta-models		

Determining the accuracy of any estimate usually requires some specified, known and accurate reference value. In the case of meta -models of simulation models this estimate is not available, and the output of the simulation model is the only reference, even though such output is only an estimate and subjected to variation. Figures 18 and 19 show the results of a comparison of the output of the simulation models and the output of the meta-models. The absolute percentage errors are also shown indicating high accuracy in the middle of the experimental range and close to the optimum values. However, when the limits of the experimental range are reached the accuracy becomes much worse. The dangers associated with extrapolating the meta-models beyond the experimental range is clearly shown.

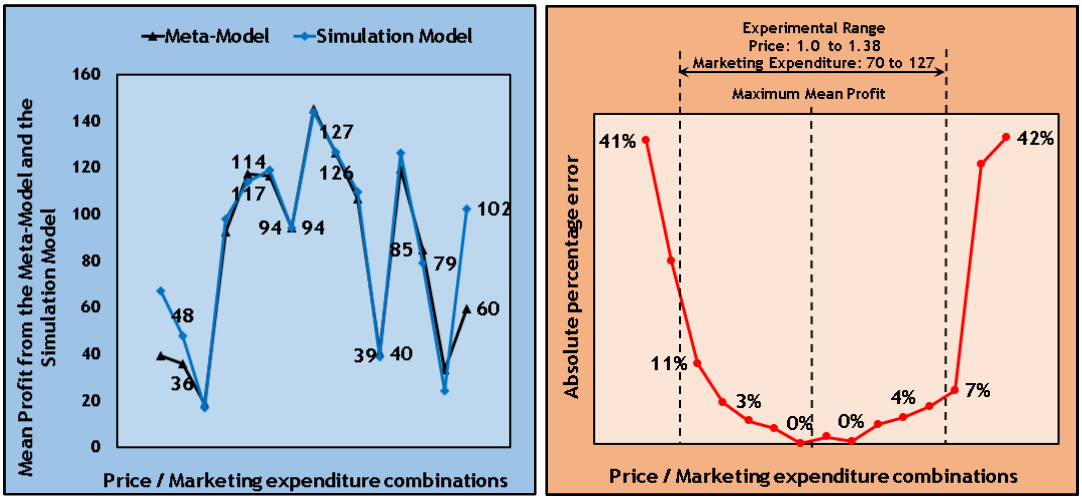


Figure 18. The prediction accuracy and absolute percentage error of the mean profit meta-model relative to the simulation model

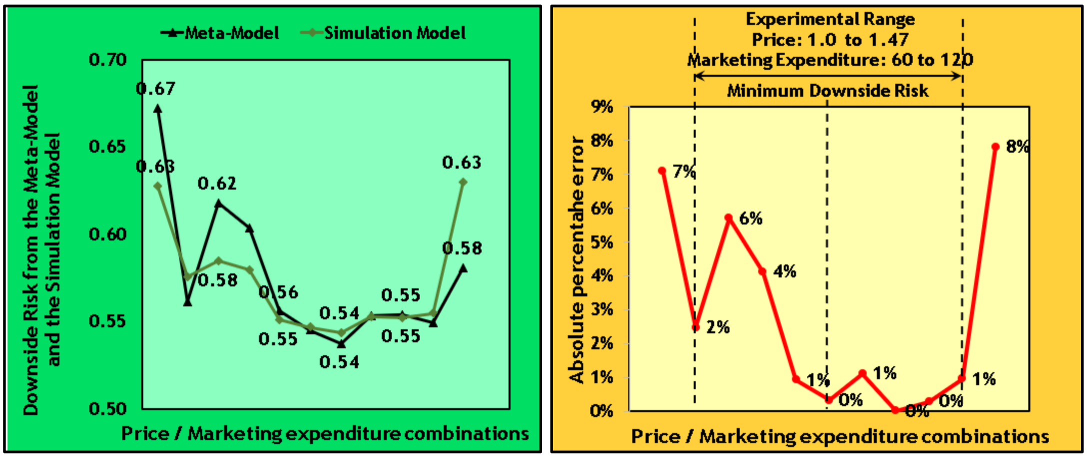


Figure 19. The prediction accuracy and the absolute percentage error of the downside risk meta-model relative to the simulation

3 POST SIMULATION ANALYSIS

It ain't over till it's over

Yogi Berra

The major advantage of meta-models is the increased ease by which they might be used in post simulation analysis relative to the simulation models. Three such applications, optimization, sensitivity analysis and utility theory, will be illustrated in the next paragraphs.

3.1 Optimization

It is often required to obtain optimum solutions using simulation models of complex systems. Performing optimization analysis, based on a simulation model, might be hampered by the inevitable variation present in the output of simulation models and the required sample size and thus the simulation model execution time. Using a non-linear optimization algorithm in conjunction with a simulation model might be difficult. Optimization of simulation models might be the most valuable contribution of meta-models. Figures 20, 21, 22 and 23 show the optimum values for the mean profit and downside risk obtained from the simulation models and meta-models respectively. Given the meta-models, the optimum values for the mean profit and downside risk might be obtained in several ways. The graphs shown in Figures 20, 21, 22 and 23 might be visually inspected to obtain rough estimates of the optimum values. Since the meta-model are mathematical in nature, the calculus might be used to determine the optimums. However, if it is not possible to mathematically differentiate the meta-models, a non-linear optimization search algorithm might be used, for example, the generalized reduced gradient (GRG) algorithm. These results are summarized in Table 4.

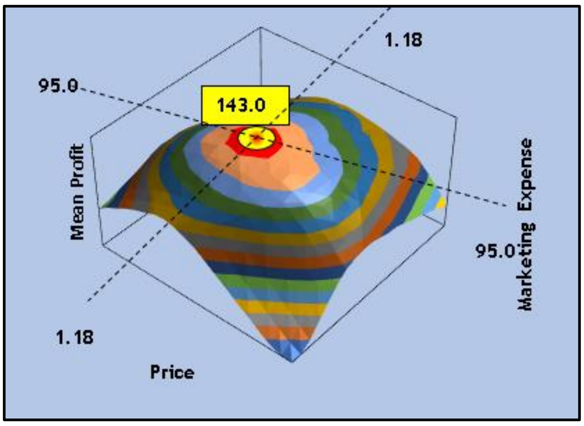


Figure 20. Optimum values for the mean profit obtained from the simulation model

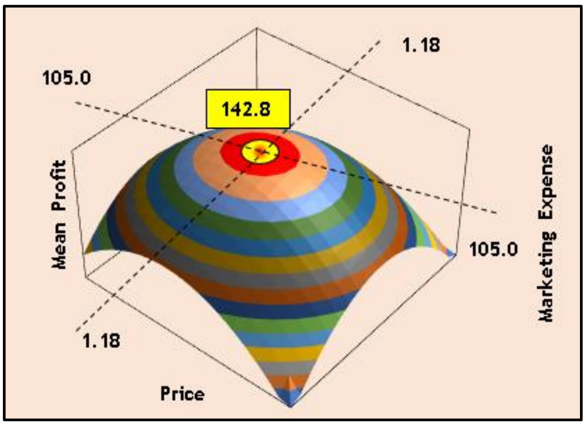


Figure 21. Optimum values for the mean profit obtained from the meta-model

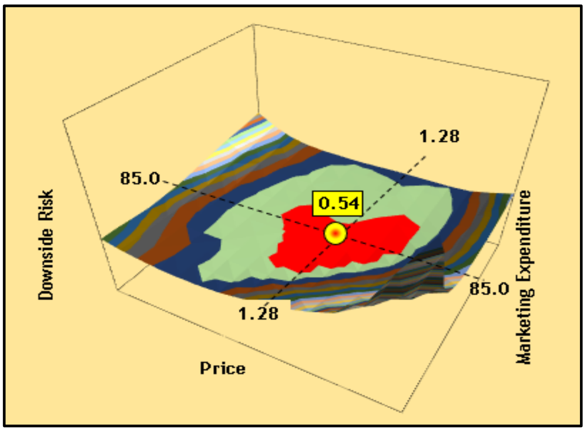


Figure 22. Optimum values for the downside risk obtained from the simulation model

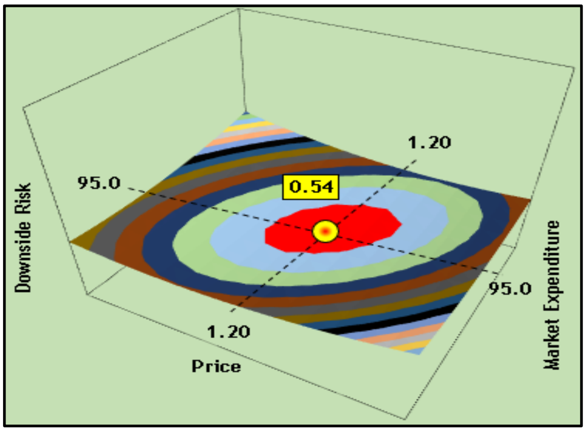


Figure 23. Optimum values for the downside risk obtained from the meta-model

Table 4. Optimum results

Obtained by:	Maximum mean profit	Price	Marke-ting expen-diture	Minimum downside risk	Price	Marke-ting expen-diture
Inspection of the relevant simulation model data	143.30	1.18	95.00	0.54	1.18	95.00
Inspection of the relevant meta-model data	142.20	1.18	103.20	0.54	1.20	95.00
Using the meta-model and the calculus	143.1570	1.1844	103.1007	0.5376	1.1988	95.6643

Using the meta-model and a GRG search algorithm	143.1636	1.1864	103.1636	0.5373	1.1931	92.0865

3.2 Sensitivity analysis

A proper sensitivity analysis is an important and necessary part of any modelling exercise. Such a sensitivity analysis might contribute to the model verification and validation activity, provide support for the decision-making processes and offer some additional insight into the characteristics of the system being modelled. However, a proper sensitivity analysis might require several experiments with the simulation model.

If a regression approach is used to develop the meta-model the data might be first normalized, i.e. scaled to values between zero and one, before applying the regression methodology. By normalization of the data the regression coefficients might be used as relative indicators of the sensitivity of the output value for the various input values. Figures 24 and 25 are showing the sensitivity of the mean profit and downside risk for the various regression components.

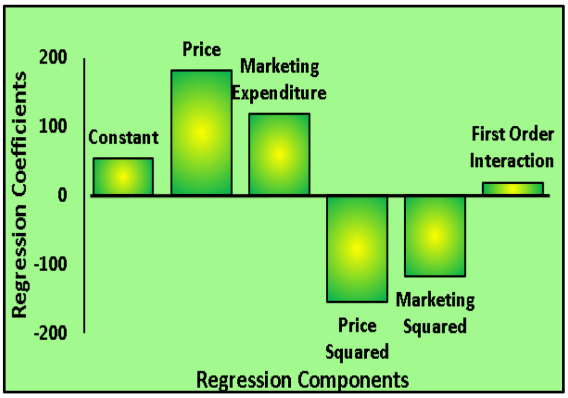


Figure 24. Sensitivity of the mean profit for the various regression components

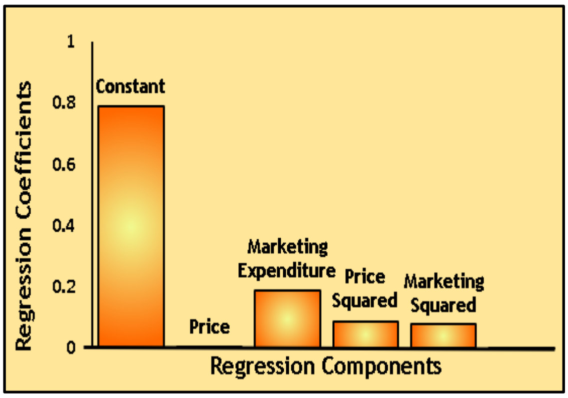


Figure 25. Sensitivity of the downside risk for the various regression components

3.3 Price and risk trade-off

Utility theory assumes that any decision is based on the utility maximization principle, according to which the best choice is the one that provides the highest utility (wealth, value or satisfaction) to the decision maker [15]. Figure 26 demonstrates the concept of utility and of risk preference [15]. Decision makers are often confronted by two conflicting decisions in which case the concepts of utility and risk preference might be useful. The same is true for the budget model. The maximum mean profit might only be achieved at a higher downside risk and the minimum downside risk at a lower mean profit as illustrated in Figure 27. These results might be used to perform a trade-of between high profit / high risk and low risk / low profit alternatives.

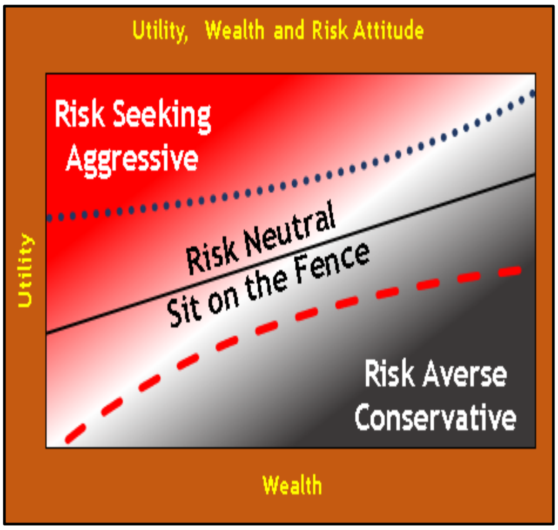


Figure 26. Utility theory and risk preference

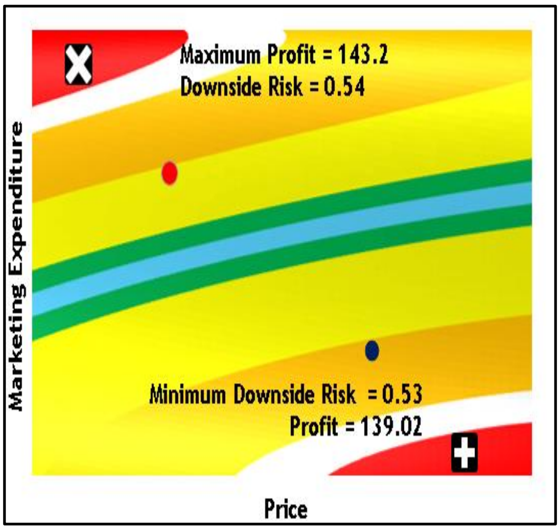
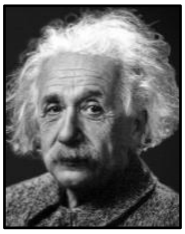


Figure 27. Mean profit and downside risk trade-off

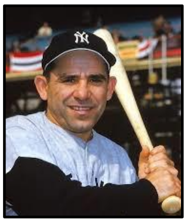
4 SUGGESTIONS FOR FURTHER RESEARCH

If we knew what it was, we were doing,
it would not be called research,
would it?
Albert Einstein



This paper focussed on the Monte Carlo simulation modelling paradigm and the multi-regression meta-model construction approach. However, several other simulation paradigms are in existence, for example, agent-based, discrete or next event simulation. Similarly, several alternative data dependent meta-model construction approaches are available, for example, Neural networks, ARMA/VARMA models and multi-target or multi-response non-linear regression. However, the techniques which will be the focus of the next research effort will probably be discrete simulation, specifically queuing network systems, transient behaviour of queuing systems, neural networks and Box-Jenkins models. Some exploratory research has been conducted into the application of these techniques for the development of meta-models and the preliminary results are promising.

5. REMARKS AND CONCLUSIONS



It's like déjà vu all over again.
Yogi Berra

By its very nature and application base, simulation models are often large, complex, multi-variate, dynamic and non-linear. Meta-models of simulation models have several advantages and might contribute significantly to the simulation modelling process. However, the development of meta-models might be time consuming and arduous, requiring adequate knowledge of the relevant mathematics, statistics and modelling principles. Furthermore, the inevitable stochastic character of simulation models might require large sample sizes and numerous replications might be necessary to generate the appropriate amount of data. But, the execution of a simulation model is under the complete control of the experimenter resulting in the effective application of suitable experimental design techniques. This might reduce the computational burden without necessarily having too large an effect on the adequacy and accuracy of the meta-model.

The results of this paper indicate that it is possible to develop adequate and accurate meta-models of Monte Carlo simulation models which might be used as valid surrogates of the relevant simulation models. These models were based on regression analysis using two-variable second-order polynomials.

The meta-models might be used to perform post simulation analysis for example optimization, sensitivity analysis and profit/risk trade-off.

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Whatever is worth saying,

can be stated in fifty words or less

Stanislaw Ulam

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MEDICINES STOCK VISIBILITY SUPPORT TOOL USING DEMAND-DRIVEN SUPPLY CHAIN MANAGEMENT PRINCIPLES

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ABSTRACT

Healthcare supply chain management is of paramount importance when it comes to the provision of timely and quality healthcare services. However, the prevalence of drug stockouts in healthcare institutions across South Africa ascertains that there is a need for concrete, collaborative and proactive frameworks and tools to guide performance improvement and enhance service delivery. This paper outlines the conceptualisation of a drug stock visibility support tool that utilizes Demand-Driven Supply Chain Management (DDSCM) principles. The design process for the medicine stock visibility support tool is based on a conceptual framework that unifies the DDSCM concepts and aspects of standardised logistics management indicators in the public sector. The design process is informed by the Technology Life Cycle (TLC) approach and Frazelle's Logistics Scoreboard Framework. The proposed tool is intended as a step towards promoting collaboration for the implementation of DDSCM between Private and Public healthcare supply chain actors in South Africa.

*Corresponding author

1 INTRODUCTION

Supply chain management (SCM) is one of the most pressing issues when it comes to effective healthcare service delivery in developing countries [1].These concerns encompass inefficient cold chain technologies, lack of support staff for logistics management, complex procurement, payment and lack of technology that enables real time data visibility across the entire supply chain. The supply chain affects how value is created for patients. These inefficiencies act as barriers to effective service delivery, medication access and health systems strengthening. Positive healthcare outcomes rely heavily on the effectiveness of the health delivery system [2]. Improving the performance of the supply chain is a fundamental aspect in health systems strengthening that is achieved by understanding the current performance, by identifying systemic inefficiencies through assessments and by subsequently determining an improvement plan based on relevant indicators [2].

In the South African healthcare sector, stakeholders have become aware of the importance of implementing SCM tools and processes to optimise and improve healthcare service delivery. Despite spending more than a quarter of the healthcare budget expenditure on supply chain operations, the National Department of Health (NDoH) is still experiencing weak responsiveness in the effective and integrated procurement of health commodities [3]. Many of the concerns in healthcare delivery lie in the anomalies within procurement and the costs of medical supplies (leading to drug stockouts or wastage), equipment and waste management. These problems stem from a lack of understanding of the supply chain and supply chain management concepts. This can be seen in the current supply chain efforts that are mainly focusing on procurement and contract management [3]. However, positive strides are being taken, such as the Procurement Transformation Initiative (PTI) — a memorandum of understanding between the NDoH and the National Treasury that is aimed at improvement of healthcare logistics [3]. The development of supply chain tools and the coordination of people within the supply chain to work towards a unified system enable continuous improvement within the public healthcare sector, which can assist role-players to function at a higher level [3], [4].

This has seen the implementation of state-of-the-art supply chain infrastructure and systems that assist with the healthcare supply chain. An example of this is the Stock Visibility Solution (SVS) developed by Vodacom and Mezzanine in South Africa, that has been implemented in over 3200 clinics around South Africa by the NDoH [5]. The SVS is a system that assists with monitoring the drug levels in clinics, and that allows for tracking and tracing of drug expiration and usage. This is a novel solution that has received commendations; however, it is primarily designed for the public sector, and the extended ecosystem within the private sector does not have visibility of the public-sector supply chain. Yet, both the public and private sector should work collectively to address healthcare challenges.

In order to achieve supply chain excellence, it is paramount for hospitals to establish and adhere to documented operating standards with established specific performance metrics and benchmarks. These should be quantitative and multidimensional, and should facilitate trust amongst healthcare actors [1]–[3]. Determining standardised measures is therefore necessary to improve supply chain performance and to gain more accurate feedback from the system. The development and application of supply chain measures and indicators is integral to the development of the visibility tool that was developed in this study, as the tool needs to inform users on important supply chain aspects and identify weaknesses that can be improved upon.

2 PURPOSE OF THE PAPER

The main purpose of this paper is to present a concept demonstrator that can be utilised in private healthcare supply chain management and that can integrate with the public healthcare sector. This is done in two ways: first, by outlining how the core principles of Demand-Driven Supply Management (DDSCM) frame the development of SCM tools; and, second, by outlining the design process of the drug monitoring tool that was developed, based on those principles. The tool was developed using Tableau, which is business intelligence software that is also utilised in the public healthcare sector.

3 A BRIEF LITERATURE REVIEW

3.1 South African Healthcare Supply Chain

The South African Health System is a two-tiered system that is divided along socioeconomic lines, with subdivisions into primary, secondary, and tertiary levels [3], [6]. South Africa utilises a tendering procurement system in the public healthcare supply chain, where contracts are offered to manufacturers and producers of medical drugs or devices. This requires some high-level proactive planning with consideration of buffer levels to ensure that unforeseen circumstances are covered [7]. The interconnectedness of the planning processes is shown in Figure 1.

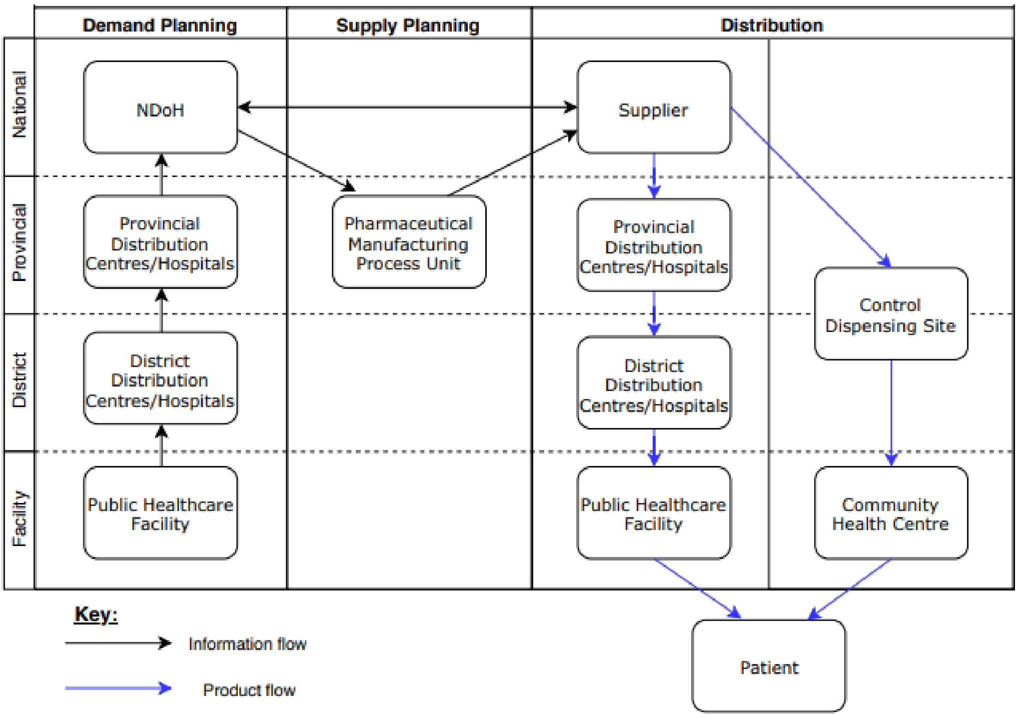

Figure 1: Current supply chain flow in South African public healthcare (Source: Adapted from Herbers & Viramontes [8])

3.2 Aspects of Demand-Driven Supply Chain Management in Healthcare

Hopp & Spearman [9] defined a demand-driven supply chain (DDSC) as a system of coordinated technologies and processes that senses and reacts to real-time demand signals across a network of customers, suppliers, and employees. The concept of demand-driven supply chain management was generated by coupling the supply chain (push) concept and the demand chain (pull) [10]. DDSCM is a set of practices aimed at managing and co-ordinating the whole supply and demand chain, starting from the end customer to raw material suppliers [11], [12]. It is a system that uses real-time information to allow participants within the chain to react quickly and effectively when unpredicted changes or situations occur.

With both supply chain visibility and DDSCM, healthcare supply chains can experience an improvement of supply chain performance and excellence, which complement other benefits such as reduced supply chain operating costs, a significant improvement in terms of inventory management, and enhanced supply chain responsiveness. The DDSCM approach is supported by technologies that facilitate information exchange about activities at different healthcare supply chain nodes [13]. Bvuchete et al. [13] illustrated in Figure 2 how DDSCM could be applied within a healthcare context. Activity at each node is preceded by the flow of information back from the next node along the supply chain, indicating a “pull” rather than a “push” supply chain strategy, in which producers produce in response to forecast demand.

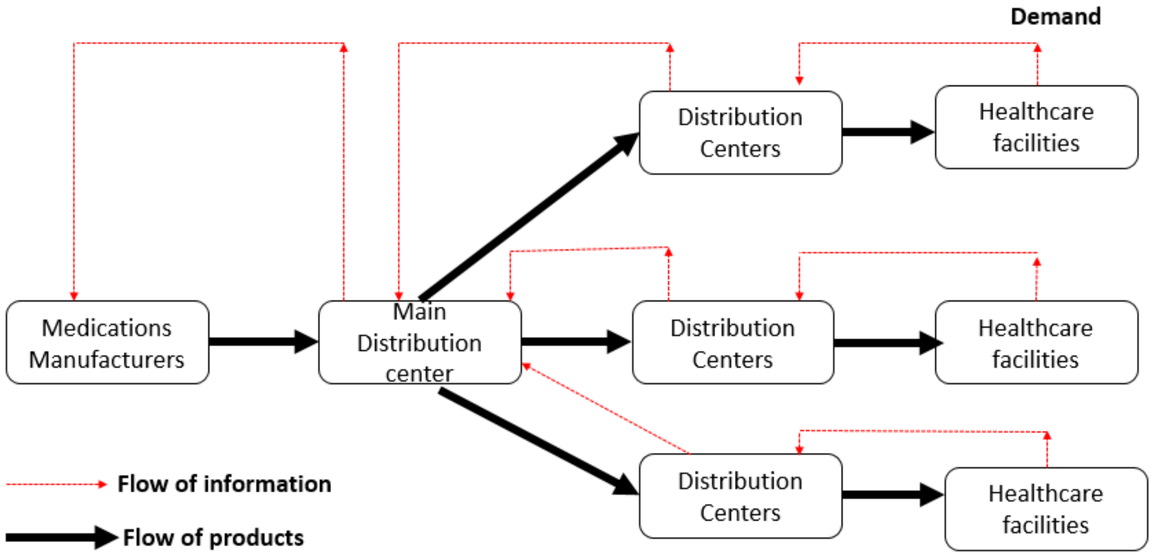

Figure 2: A healthcare demand-driven supply chain (Source: [13])

Supply and demand are easily matched if demand is steady over time with no change in volume or mix. However, as soon as demand changes, an organisation or facility must adjust the supply levels accordingly at each step of the supply chain [14].

3.3 Enablers of DDSCM

Organisational and supply chain enablers of DDSCM include customer orientation, product classification, information communication technologies (ICTs), collaboration, integration, cross docking and optimisation of distribution, lead-time and lead-time gap, organisational responsiveness and flexibility, visibilityand coordination [14]. Through a systematic literature review, Bvuchete et al. [7] classified the enablers under distinct categories, namely: visibility, technology, collaboration, human resources, change management/leadership, distribution management, and performance management (see Table 1).

Table 1: Enablers of DDSCM (Source: Adapted from [7])

Concept	*Description*	*Concept Classification*
Real time information sharing	Timeliness access of information from all supply chain actors	**Visibility**
Information quality	Information availability, accessibility, and usability from all actors on appropriately aggregated levels at the right time at the right place	
Demand visibility	Real time information of end-customer demand	
Inventory visibility	Real time information of end-customer inventory levels	
Information technology architecture	Supply chain dashboard that has the capabilities of data collection, data processing, modelling, communicating, and visualization of relevant information for the purposes decision making and development of alternative supply scenarios	**Technology**
Radio frequency identification	Enabler of real time information	
Vendor managed inventory	Inter-organisational interfaces for flow of products and information. Outlines clearly who is responsible for the replenishment process	
Collaborative planning forecasting replenishment	Orchestrating supply chain activities	
Relationships	Management of upstream and downstream relationships with suppliers and customers for the purpose of creating value	**Collaboration**
Trust	The element that influences the quality of information shared and partnerships in the supply chain	
Commitment	The element that is needed for the successful implementation of supply chain methods	
Joint planning and decision making	Activities that determine the operations of supply chain collaboration	
Mutual interdependence	High levels of interdependency result in successful partnerships	
Customer relationship management	The development and leveraging of market intelligence for the purpose of building and maintaining customer relationships	
Supply chain partners coordination	Management of complex subsystems and processes of numerous organisations in the supply chain. Integration of demand and supply processes.	
Customer orientation	Understanding the nature of demand	
Talent development	Training of supply chain staff	**Human Resources**
Skills	Staff have good supply chain planning capabilities and are able to use the available information for informed planning processes	

Innovation	Support of ideas by the supply chain staff to improve the supply chain	
Management support	Support of demand and supply strategies by management, and inclusion of all of this in the organisational agenda	**Change Management/ Leadership**
Organisational vision	Common vision and collective goals for all actors	
Strategic decoupling points positioning	Position of the decoupling point that separates push and pull approaches. It is also defined by optimised buffer levels	
Customer segmentation	Customised response to volatile demand	
Cross docking and direct deliveries	Deliveries of products made directly from the factory to the ultimate customer	
Product classification		
Cost management	Planning and managing supply chain costs	
Roles and responsibilities	Clear roles and responsibilities for supply chain staff	
Distribution planning	Scheduling shipment and transportation of products between warehouses in response to a supply plan	**Distribution Management**
Demand planning	The integration of statistical forecasting techniques, experience, and judgement of planners and consumption patterns to construct a demand plan	
Supply planning	Coordinating inventory and orders to optimize the delivery of products to fulfil the demand plan	
Warehouse management and automation	Activities related to the management and control of inventory of products. It also involves the process of receiving products, products sorting and storage, quality management, dispatching, and debriefing.	
Customer order management	Automated replenishment based on real time information on consumption, inventory levels, and transport status	
Lead-time gap reduction	Demand-driven supply chains are possible for supply chains with a small lead-time gap	
Transportation flexibility	Tailoring transportation to match customer segmentation needs. It also involves having the possibility to make changes to delivery routes and content, if needed	
Incentives	Motivational mechanism to encourage enhanced performance	**Performance Management**
Performance metrics	Use of indicators for performance monitoring for the purpose of operational process optimisation	

3.4 Supply Chain Frameworks Review

To address the dynamics aligned with Supply Chain Management, four supply chain frameworks were reviewed to determine the best fit for the tool. These were the Supply Chain Operations Reference (SCOR) model [15], the SCM framework [16], the Managing for Supply Chain Performance (M4SC) model [17], and Edward Frazelle's Logistics Scoreboard Framework [18].

The SCOR Model was originally developed by the Supply Chain Council (SCC) in 1996 [15]. SCOR is used as a way of explaining and analysing supply chain practices through use of six main components, which are: Plan, Source, Make, Deliver, Return, and Enable. The components represent the main inter-related business processes during the life-cycle of a product [19]. There are many benefits to using the SCOR model as a supply chain framework, some of which include: enabling the use of a common language across platforms, thus allowing for transparency and understanding from customers to service providers. Another benefit is the performance attributes and metrics that help to measure supply chain efficiency and inform the correct choice of supply chain strategy [20]. The SCOR framework is a sound option that could be applied for the purposes of this study. However, the performance metrics — which are calculated in-depth within the supply chain — are too detailed for a conceptual analysis.

The Supply Chain Management Framework consists of key supply chain processes, which are aligned with customer relationship management, customer service management, demand management, customer order fulfilment, manufacturing flow, procurement, product development and commercialisation, and the returns process [16]. Change management is touted as the leading factor that determines the success of SCM, meaning the transition from individual or separate functions to an integrated supply chain [16], [21]. The SCM framework identifies key supply chain processes and allows for cross-functional involvement, but is also limited therein that it is more aligned with change management than with the development of indicators that can assist with supply chain operations — which are particularly important for this project.

Managing for Supply Chain Performance is a SCM framework that allows managers and leaders to translate business strategies and tactics into supply chain execution plans and policies [17]. The application of the M4SC model enables users to easily translate overall business strategies to the resource level. M4SC provides communication levels throughout an organisation, allowing performance management and improvement, as well as response to environmental changes [22]. The applications of this model to the overall project objectives would be to create a scalable supply chain strategy that would inform management within the private sector, as well as to inform the development phase of the tool design process. However, when it comes to outlining indicators for the tool, a proper guideline or standard is lacking.

Edward Frazelle developed a framework of activities performed in SCM, as well as a scoreboard model for measuring supply chain performance that is holistic and consists of categorising supply chain indicators around the aspects of quality, time, finances, and productivity [18]. The four indicator aspects developed by Frazelle are used to determine the type of indicators that are needed across aspects of the supply chain. The Logistics Scoreboard framework allows for quantitative and qualitative assessment and improvement identification within the supply chain [18]. Each of the five areas of SCM shown in Figure 4 are used to separate the indicators into categories, namely: customer response, inventory planning & management, supply, transportation, and warehousing. These were categorised into four types of indicators, namely: quality, time, financial, and productivity [18]. Frazelle developed the framework that is shown in Figure 3 to summarize the world's definition of logistics and its related activities. Edward Frazelle's framework has been applied internationally, and has been used for the assessment of supply chains in Morocco and more countries around the world [23]. The USAID uses Frazelle's model as a referral model when it comes to building tools for logistics management such as the LMIS tools [2].

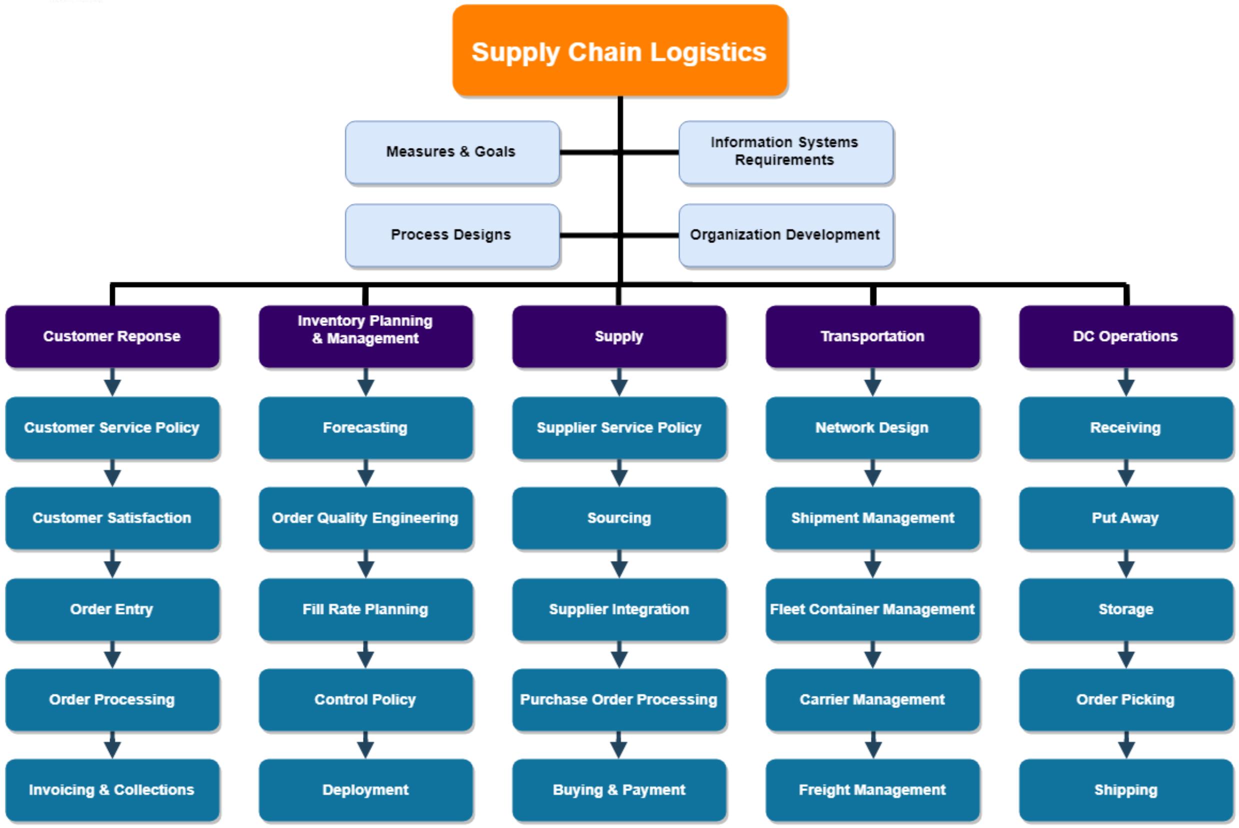

Figure 3: Edward Frazelle's logistics framework of activities (source [24])

It was concluded that the most appropriate framework for developing a stock visibility tool would be Edward Frazelle's Logistics Scoreboard framework [18]. The model can be used in complex environments, it is adjustable to suit the purpose of this project, it can be used to perform qualitative research, the framework applies directly to supply chain management – including healthcare supply chain management, and it is internationally recognised through the USAID as a base supply chain model.

4 METHODOLOGY AND CONCEPTUALISATION

Various techniques and processes are available when it comes to the formulation and development of a SCM tool. As this is a technological tool, the Technology Life Cycle (TLC) was selected as the foundation on which the various stages of tool development were undertaken [25]. The TLC is broken down into various phases, namely, the identification phase, the solution phase, the development or acquisition phase, the implementation phase, the exploitation phase, and the decommission phase, as shown in Figure 4. The usage of the TLC was done with emphasis on the DDSCM tool that is being developed in this article, incorporating the first three stages.

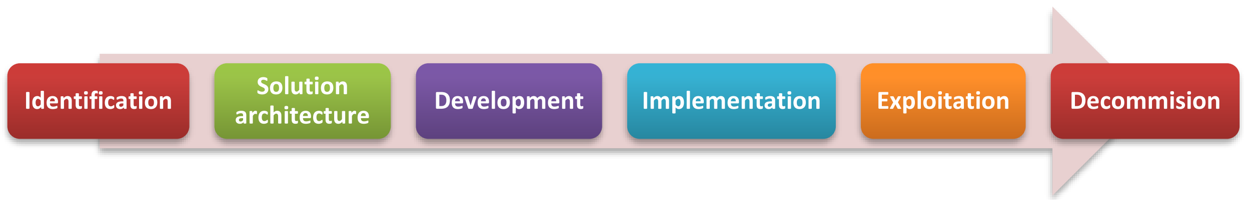

Figure 4: The Technology Life Cycle Source: Du Preez et al., [15]

5 TOWARDS A DDSCM-BASED PHARMACEUTICAL SUPPLY CHAIN MANAGEMENT TOOL

This section unpacks the supply chain frameworks and indicator structures that were used to develop the DDSCM-based design framework for the tool. It outlines the three sequential phases that were followed in the development of the concept demonstrator. The *identification phase* consists of mapping the process and listing all potential frameworks and tools. This is where all considerations were made for the scope and objectives of the project, and the aspects that were essential to successfully meet them. The *solution architecture phase* looks at selecting the appropriate framework and tools. Since this is a concept demonstrator, software selection is also important, as software that integrates into the public healthcare sector would be ideal. The *development phase* for this concept demonstrator includes the development of indicators that were deemed as being important to the solution tool.

The TLC was selected as an overall guideline for the development of the DDSCM concept demonstrator, integrating the enablers outlined by [7] on DDSCM with the Edward Frazelle Logistics Scoreboard framework. The indicators were populated in Microsoft Excel, the feedback from experts over the relevance and usefulness of the tool was gathered and, finally, the actual formulation and simulation of the tool was done in Tableau. The stages are show in Figure 5.

5.1 Phase 1 – Identification

During the identification phase of the TLC, the problem was identified as the need for a stock visibility tool within the private healthcare sector in South Africa that can inform users on specific indicators related to the visibility throughout the supply chain, by assessing tools that are already in use in the public sector and that align with supply chain management principles.

5.2 Phase 2 – Solution Architecture (Selection and Integration)

The second phase of the TLC involves the selection of solution architecture and software development platform guidelines that will guide the project to the best solution, through informed development.

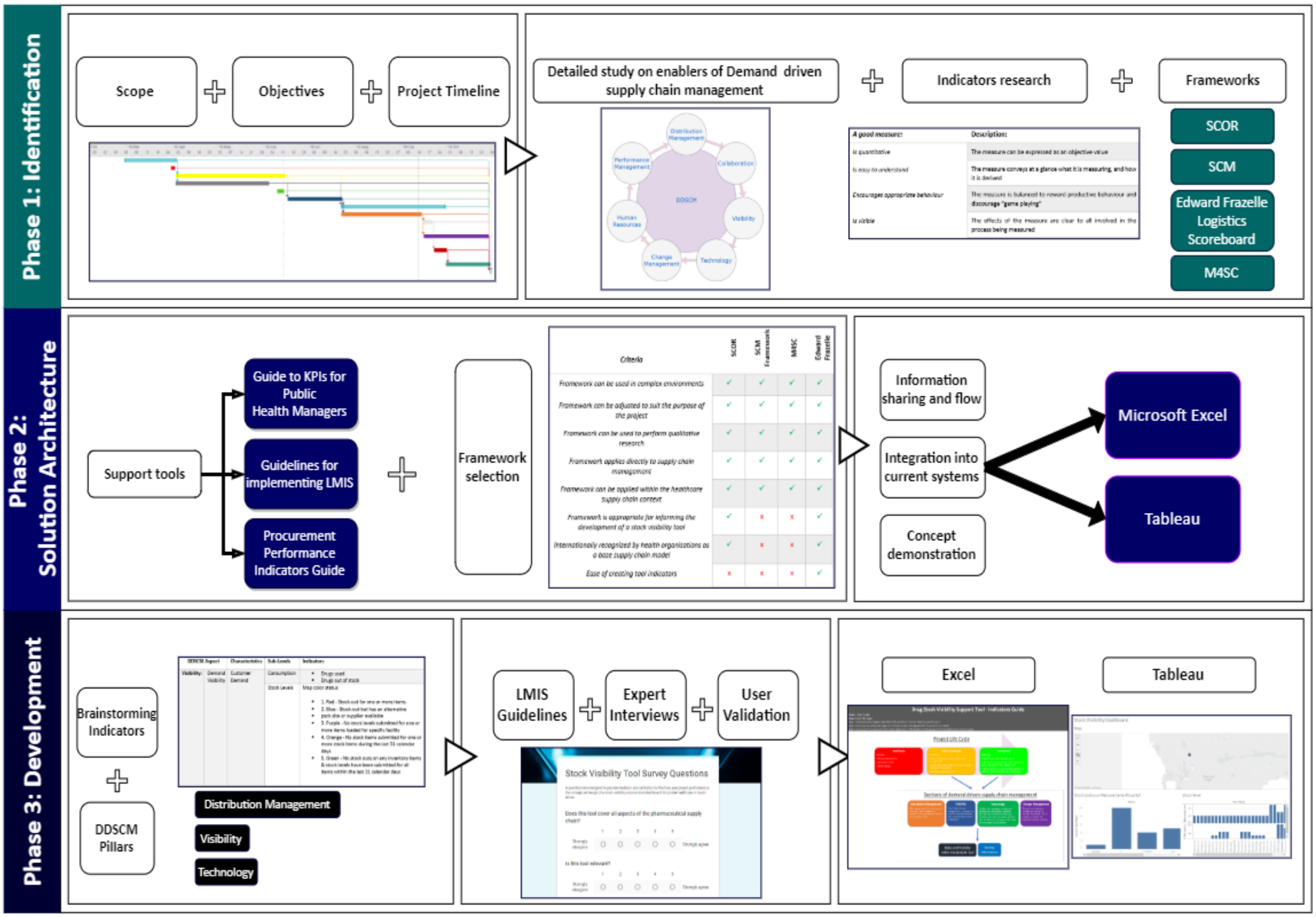

Figure 5: DDSCM Tool Design Process

5.2.1 Selection of suitable software for the tool

For the sake of this project, the criteria for the selection of the software for the solution tool were:

a) <u>Information sharing and flow</u>:

- The necessary information required by private healthcare users for the tool to provide value can be included in the tool. This could include information on product flow, roles and employees, lead-times, and stock attributes.

b) <u>Integration into current systems</u>:

- The tool can be easily integrated into current South African healthcare information systems and is versatile in terms of being multi-platform (desktops, tablets, cell phones etc.) and being an enabler for real-time information sharing
- The NDoH currently uses Tableau within their system, and use Microsoft Excel as a means of storing and capturing data. This allows for easy integration into the private sector, as much of the information that will be used is obtained in parallel with the public healthcare sector in South Africa. Microsoft Excel is also able to integrate with Tableau, as comma-separated value files can be accessed by the program. This allows for easy integration of data that are obtained from statistical websites such as Stats South Africa [26].

c) Concept demonstration:

- The ability to successfully and adequately provide a concept demonstrator for the stock visibility tool.
- Tableau is used worldwide as business intelligence software to visualise data in a way that is readable and valuable to users. Concept demonstration of the SVS tool, using a combination of Tableau as the visualization software and Microsoft Excel as the background storage software, allowed for a strong concept demonstrator that can be developed into a marketable tool in future. It is an integrated dashboard that allows for easy visualisation of tools and graphics.

Using these criteria, it was decided that the business intelligence software Tableau in combination with Microsoft Excel would be used to develop a concept demonstrator for the SVS tool.

5.2.2 Framework conceptualisation

This section provides a brief overview of the methodologies that were utilised as guidelines during the phases of the TLC.

a) Pillars of DDSCM: As mentioned in the literature overview, DDSCM is governed by seven pillars or best practices that are used to outline actions and activities that need to be performed for organisations to become demand driven, namely: distribution management, collaboration, visibility, technology, change management, human resources, and performance management [11]. The pillars were applied and filtered to suit the development of this tool in this project.

b) Edward Frazelle's Logistics Scoreboard framework: The framework by Edward Frazelle provides a good basis for the design and implementation of supply chain performance management. The framework was used as a means of informing indicator creation while building the tool, which in turn allows for important information to be gathered and utilised by users of the SVS tool.

c) Indicator reference guides: The guide to key performance indicators (KPIs), guidelines for implementing logistics management information systems (LMIS) [27], and the procurement performance indicators guide [28] were used to inform the indicator creation process. These indicator guides and examples provided a basis for healthcare supply chain indicators, and were used in combination to determine the best collection of indicators for the specified problem.

5.3 Phase 3 – Development

This stage of the TLC was necessary to develop and approve the design and implementation of the stock visibility tool. Development of the indicator listing was done through several brainstorming sessions in order to map and align the indicators and associated outputs for the LMIS.

a) Brainstorming of the applicable DDSCM pillars and their specific indicators

The design process started with a brainstorming process that was used to determine applicable pillars of DDSCM that could be used in the SVS tool. An example of this brainstorming process, as applied to the DDSCM demand visibility pillar, is shown in Table 2. The results indicated that the following pillars of DDSCM were applicable for implementation: visibility, technology, and distribution management. The outputs of the tool inform change management and highlight the performance management aspects of DDSCM.

Table 2: Brainstorming process for the visibility DDSCM pillar and indicator generation

DDSCM Aspect		Characteristics	Sub-Levels	Indicators
Visibility	Demand Visibility	Customer Demand	Consumption	Drugs used Drugs out of stock
			Stock Levels	**Map colour status:** 1. Red - Stock-out for one or more items. 2. Blue - Stock-out, but has an alternative pack size or supplier available. 3. Purple - No stock levels submitted for one or more items loaded for specific facility. 4. Orange - No stock items submitted for one or more stock items during the last 31 calendar days. 5. Green - No stock outs on any inventory items, and stock levels have been submitted for all items within the last 31 calendar days.

b) Merging DDSCM with the Edward Frazelle Logistics Scoreboard framework

The next step in the development phase of the TLC was to use the Edward Frazelle Logistics Scoreboard framework to develop pertinent indicators and the subsequent reports that are needed by users of the SVS tool. The pillars in Figure 4 were realigned with DDSCM concepts to cover the logistics activities outlined by Edward Frazelle (customer response, inventory planning & management, supply, transportation, warehousing). This expansion is shown in Figure 6, and allowed for more specific and applicable indicator creation. Since the aim of this project was not to assess the financial feasibility of a new tool for the private sector, but rather to develop a concept demonstrator for an SVS tool, the financial/cost indicator section of the Logistics Scoreboard framework was removed from the indicator creation process.

Figure 6: Expansion of DDSCM pillars chosen for tool development (Source: Adapted from [13])

An excel tool was developed that would enable users to view information for each applicable pillar of DDSCM, as well as to see the expected reports that could be used to implement change, and the roles and visibilities within the supply chain. The guide was used as a launching page with clickable links that would take users to the applicable pages. The following pages were included in the tool: Home – User Guide, Distribution Management, Visibility, Technology, Change Management, Roles, and Surveys (which were used during validation). This matrix was used as a template for the creation of indicators that could be used within a DDSCM-based SVS tool.

c) Development of expected reports

The final stage within the development phase of the TLC is the generation of applicable reports, using the indicators discussed above. A key factor to consider when generating a visibility tool is to consider the role players within the supply chain. The reports depicted in Figure 7 are examples of the output that would be required from the stock visibility tool. Role players within the supply chain were separated into role players with and without direct involvement within the pharmaceutical supply chain. As a result, the manufacturing aspects that are not related to pharmaceuticals were removed.

	Producers	Purchasers			Providers			
	Drug manufacturers	Wholesalers	Distributors	Group purchasing orgs	Hospitals	Clinics	Doctors	Pharmacists
Geospacial StockOut Map	X	X	X	X	X	X	X	X
Inventory Levels Report		X			X	X	X	X
Resupply Report	X							
Stock Status Report	X	X	X	X			X	X
National Stock Reports							X	X
Stock Availability Report		X	X	X	X	X	X	X
Average Stock-out Duration (Number of Days)	X				X	X	X	X
Stock-Out Reasons Report	X	X	X	X	X	X	X	X
Facility Stock Replenishment Report	X							
Warning /Alerts Low and Over Stock Report					X	X	X	X
Forecasting reports	X				X	X	X	X

Figure 7: Expected reports from the DDSCM tool

6 PRELIMINARY FRAMEWORK EVALUATION

The resultant tool framework and tool development was evaluated through a three-part process. Considerations were to discern the adherence of the tool to healthcare supply chain logistics standards, relevance and significance of the tool, as summarised in Table 3.

Table 3: Evaluation of the study

Type of Evaluation	Purpose of Evaluation	Method of Evaluation
Standard Adherence	Ensure the tool meets recommended internationally approved set of guidelines	LMIS guidelines [27] Procurement guidelines [28]
Context Validation	To ascertain DDSCM aspects are covered in the tool development	Interviews of DDSCM experts
Tool Validation	To assess practicality of developed tool in terms of relevance, ease of use, integration and correlation to current assessment tools	Validation with pharmacist, tool perception survey and ratings

6.1 Standard adherence: Validation Using the LMIS Guidelines

For standardisation, this was done using the Logistics Management Information Systems guidelines outlined by the USAID [27]. The LMIS guideline questions were then used as a form of validation for the concept demonstrator, and ensured that the tool development process was followed according to an internationally approved set of guidelines. These guidelines, shown in Table 4, outline aspects such as the types of reports that are needed, facility administration, and frequency by which the logistics data are reported.

Table 4: LMIS guideline validation of DDSCM tool (Source: [27])

LMIS Question	Solution from Concept Demonstrator
What data are needed for commodity management?	Indicators and reports to improve supply chain visibility
What records and reports are needed for commodity management?	Reports detailing stock status, stock levels, and demand levels
What unit of measure should be used?	Dependent on the packaging for each product
How will consumption data be collected?	Consumption data would initially be forecast, then obtained through consistent facility reporting
Who at the facility will be responsible for reporting the data?	Administration staff
At what frequency should logistics data be reported to the higher levels?	At least once every three months
How will the report/order get to the higher level(s)?	Using the stock visibility tool
Where should reports and requisition forms be sent? What department, division, or unit needs to receive the report or requisition? What will they do with the reports and/or requisitions that they receive?	Reports should be sent to supply chain managers at the various nodes, depending on the allowed/required visibility
What approvals, if any, are required for the resupply process?	The necessary approvals from admin/management staff would need to be acquired
Should some or all the commodity names be printed on LMIS forms?	Detail varies between reports
Can any elements of the LMIS be automated? If so, which ones? If using automation, how will information be transmitted from one level to the next?	Yes, depending on the level of integration throughout the system. It would potentially be more feasible in the private sector as higher resource pool to draw from

6.2 Context Validation: Expert Interview Evaluation

In order to ascertain that the DDSCM aspects covered in the tool development were relevant, an interview was conducted with a DDSCM expert to qualify the integration of the indicators from the Edward Frazelle framework, as well as the reports that would be an output of the tool. The DDSCM expert ascertained that the usage of the DDSCM aspects in the tool were valid.

6.3 Tool Validation: Survey Overview

Additionally, there was expert feedback from a pharmacist about the relevance and ease of use of the tool. The inclusion of pharmacists was key, as they have experience in both the private and public sector; they assisted in evaluation, and suggested improvements to the tool that integrated with the systems that they are exposed to. The feedback was collected through a survey, that included two separate types of questions: one had a rating system based on a one to five rating, with: 1 – strong disagreement, 2 – disagree, 3 – neutral, 4 – agree, 5 – agree strongly; the other comprised longer questions that were related to the tool.

Results from the short questions in the survey are found in Figure 8.

Question	1 - Strongly disagree	2 - Disagree	3 - Neutral	4 - Agree	5 - Strongly Agree
	Rating				
Does this tool cover all aspects of the pharmaceutical supply chain?					✓
Is this tool relevant?					✓
How likely are you to use the reports that come out of the tool for your planning purposes?					✓
Would you use this tool?					✓
Would you recommend usage of such tools across the private sector?					✓
Are most aspects of the pharmaceutical supply chain covered by this tool?					✓
Would this software be easily integrated into the current system?					✓
Would you purchase this software?					✓
Are the roles assigned to the private healthcare supply chain accurate in the context of South Africa?					✓

Figure 8: Results from the short questions asked in the survey

Recommendations for improvement were that a mobile messaging feature should be included into the tool to allow for user communication. It was also emphasised that accurate recording should be adhered to, so that accurate stock levels are maintained, and accuracy is thus ensured. Positive and important identified aspects were the notion of interconnectivity amongst different facilities, as well as the amount of waste at a facility and the inventory that is about to expire.

7 CONCLUSIONS AND FURTHER WORK

This tool serves as a step towards practically conceptualising and implementing DDSCM in healthcare. Notably, it is still at the developmental stages. The authors therefore suggest that further work should include more widespread testing of the tool to a wider set of respondents, and obtaining the perception and opinion of public service healthcare professionals so as to have a more rounded developmental process that includes all players in the healthcare service delivery ecosystem. The inclusion of all players is a starting point to easily integrating and usage of aspects such as data analytics in healthcare that can be used in conserving resources or proactive disease and drug management.

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CORRELATION BETWEEN MICROHARDNESS AND NANOHARDNESS IN AN ALLOY

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ABSTRACT

Measurement of mechanical properties plays a vital role in the quality control to ensure that the manufactured components conform to set material and design specifications. Hardness of the materials is one such properties to be tested during quality control of the components manufactured. In today's technological age of miniaturisation, the size of components is becoming increasingly smaller in electronic and other industrial products. As such, the challenge is to measure the properties of these minute structures or to predict their mechanical behaviour. The important question being whether microhardness properties can predict the material's nano-mechanical properties. In an industrial practice, it is relatively easy and quick to determine the micro-hardness of a component in a production line, rather than measurement of nano-hardness. Therefore, in the present investigation, it is proposed to establish a relation between micro and nano-harness of an alloy. With a nanoindentation hardness tester and a microhardness tester, nanoindentation hardness and microhardness values were measured in a wide range of loads for an alloy. The microhardness of the bulk alloy was compared with the nano hardness of the material. The correlation between the micro and nano-hardness is then established.

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1 INTRODUCTION

In order to achieve cost effectiveness while manufacturing any product, the design team must consider techno-economic feasibility by taking into account all possible materials that are functionally suitable for the purpose [1]. Selection of a suitable material after investigating the required properties gives insight into the materials mechanical performance under specific operating conditions [2]. Such material properties include tensile strength, yield strength, compressive strength, shear strength, stiffness, hardness, thermal conductivity, and thermal expansion [2]. Material hardness is measured by either macro, micro or nano-indentation. This paper focus on the investigation of hardness of Chromalloy material by measuring micro and nano hardness. Measurement of hardness of material through nano-indentation is relatively very expensive. The objective of this paper is to establish a simple relation between the micro and nano hardness so that the nano-hardness can be estimated through the measurement of micro-hardness without the need for nano-indentation experiments.

2 LITERATURE REVIEW

2.1 Material hardness

Hardness is a property specifically applied to solid material [2]. It is a measure of the material's resistance to indentation or penetration by another material [3]. It is also a measure of material's resistance to scratch [2]. In metals and alloys, hardness gives a measure of the resistance to plastic deformation and in ceramics; it is a measure of resistance to elastic-plastic deformation while in polymers it measures resistance to elastic deformation imposed by the load [3]. Hardness testing involves the use of a loaded indenter, which is applied to the particular material sample, at a predetermined loading rate, then held in place for a set amount of time and unloaded from the sample at a set rate [4]. In principle, hardness is expressed as a ratio of the applied indenting load (P) to the indentation area (A) shown mathematically as;

$$H = \frac{P}{A} \tag{1}$$

A is the projected contact area between the indenter and the specimen [4]. Thus, the projected contact area (A), is established by evaluating an empirically determined indenter shape function at the contact depth [5]. Contact area depends on the indenter tip shape and geometry and the indentation depth (h) [6]. There are various tip geometries that are used in hardness testing which gives various area functions A (μm2) [7]. The area function (A) differs for three indenters, is given as for;

Berkovich is a three-sided pyramid: $A=24.5h^2+0.562h+0.003216$ (2)

Vickers is a four-sided pyramid: $A=24.561\ (h+0.008)^2 +0.206(h+0.008)$ (3)

Conical is an inverted cone: $A=24.561(h+0.011427)^2$ (4)

The difference between the tip shapes in the Vickers tip and the Berkovich tip is that the Berkovich tip can have an apex that is much sharper than the Vickers tip. Usually the tip radius for a Berkovich tip is < 20nm [6]. Both tip shapes produce approximately 8% strain in the material during indentation allowing the hardness results obtained from these tests using different tip geometries to be directly compared [6].

2.2 Indentation depth

Another important parameter in the hardness experiment is the total indentation depth h, which shows two parts: (h_e) displacement outside the area of contact and hi displacements of the sample surface inside the sample as illustrated below in Figure 1.

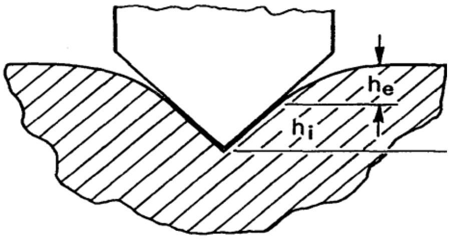


Figure 1 Total indentation depth [5]

Thus, total displacement depth is expressed as:

$$h=h_i + h_e \tag{5}$$

2.3 Load indentation curve

During the indentation test on an instrumented indentation tester, the load applied on the indenter is simultaneously measured with the indentation depth. The two values are then plotted on load-indentation depth (P-h) curve. A typical P-h curve for an indentation test is shown below in the figure 2, together with important values for calculating material hardness. [5].

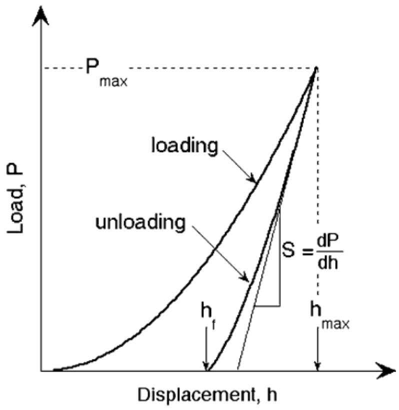


Figure 2. Load-indentation depth curve from an instrumented indentation [8].

A power law curve can be fitted to the unload data points and the curve is extrapolated to the fully unload final indentation depth [5]. Three important quantities that must be measured from the P–h curves: the maximum load, (P_{max}), the maximum displacement, (h_{max}), and the elastic unloading stiffness, S = dP/dh. The slope (S) at the maximum load data point is used to calculate the elastic modulus [5].

Analysis of indentation behaviour of elastic material shows that for several types of rigid punches (cone, flat punch, parabola of revolution and sphere) pressed into a flat surface, the stiffness of the contact [10], *S*, which is s given by

$$S = \frac{dP}{dh} \quad [6]$$

Relationships between indentation depth (h), load (P) and stiffness (S) are derived from a purely elastic contact solution and from Sneddon's relationships [10]. It can also be shown that the elastic displacement outside the indenter h_e, is related to the stiffness, *S*, and the load, *P*, as

$$he = c\frac{P}{S} \quad [7]$$

Where “c” is a constant that depends on the indenter geometry and has a value of 1 for a flat punch, a value of 0.68 for a conical punch, and 0.75 for a parabola of revolution [10]. The contact depth h_c between the indenter and the specimen can be estimated using:

$$h_c = h_{max} = \varepsilon\frac{P_{max}}{S} \quad [8]$$

where, P_{max} is the peak load and ε is a constant related to the indenter, which is less than 1.0 [10].

2.4 Derivation of modulus of elasticity from load displacement curve

The method starts from the fit of the unloading curve to the power–law relation [11]. A power law curve is fitted to the data points of unloading and is extrapolated to the fully unload final indentation depth [5]. The slope S at the maximum load data point is used to calculate the elastic modulus [5]. Oliver and Pharr method is used to determine the hardness and elastic modulus [9].The composite modulus $E_{eff,}$ modulus of the specimen can be extracted from the effective modulus using

$$\frac{1}{E_{eff}} = \frac{1-v^2}{E} + \frac{1-v_i^2}{E_I} \quad [9]$$

where E and E_i is moduli of the specimen material and indenter while v and v_i are Poisson's ratios for the specimen and the indenter, respectively [11]. This is due to the fact that elastic displacements occur in both the specimen and the indenter [9].

In order to evaluate the elastic modulus, hardness is based on the contact area achieved under load and thus, the reduced modulus E_r, for materials with a low E/H ratio taking into account elastic displacement in both the specimen and indenter, is evaluated from

$$E_r = \frac{1}{\beta}\frac{\sqrt{\pi}}{2}\frac{S}{\sqrt{A_C}} \quad [10]$$

where β is a constant with a value of 1.034 for a Berkovich indenter, *S* is contact stiffness [8]. A_C is contact area can be deduced from an empirically determined shape function Sakharova, et al.[7].

2.5 Microhardness and nanohardness testing

Typical samples for testing vary in size from large to small and measurements may be required on a micro to a nanoscale in the case of miniature components [6]. During micro hardness testing, the samples are prone to cracking if the test specimens are small and thin in size or when the test regions are small composite sample or plating where it can consists of information on surface features of materials with fine microstructure, or multi-phase, non-homogeneous [12]. In Vickers hardness testing for micro-indentation, the contact area is the surface area of the tip-faces that are in contact with the sample [6]. Vickers hardness value can be expresses in MPa using the expression;

$$VH = 2P/d^2 \sin\left(\frac{136^0}{2}\right) \quad [11]$$

Where P is peak load in kgf and d is diameter of the impression in mm. Nano indentation hardness testing is used on a very small scale to the order of nanometres including very thin films and microelectronic and micro-mechanical systems [13]. The Berkovich indenter is the most commonly used tip for Nano indentation experiments and it is recommended for materials that have elastic moduli over 0.5 GPa. In nanoindentation, the area is defined as the projected area of contact between the sample and tip [6].

The indentation area at nano-scale is difficult to measure with the traditional optical microscopy because of a too low resolution. Therefore the depth-sensing indentation technique with the use of imaging of the residual indent is employed [6].

3 EXPERIMENTAL PROCEDURE

3.1 Sample preparation

A prepared sample cut from a boilerplate made of Chromalloy steel was tested for micro-hardness and nano-hardness. The samples were tested using a scanning electron microscope (SEM) to ascertain elemental composition. First, the sample was prepared through cutting,

grinding and manual polishing using a Impetech Grinder polisher. The following reagents were used for polishing the test samples on a grinding machine using Aka Piatto diamond grinding disc with 200 grit size. Water is used as lubricant with Aka Allegra 3, Diama 6µm Poly. During polishing a force of 25N was applied for a duration of 2 to 4 minutes. Etching was done with Nital solution to reveal the grains and grain boundaries for the examination of microstructure under the optical microscope.

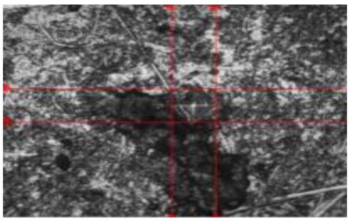
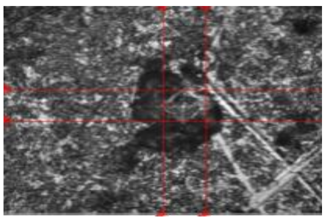
3.2 Microhardness testing

Micro-hardness test was carried out on the polished Chromalloy boilerplate sample. Testing was carried using Innovatest Falcon 507 micro hardness tester. A load of 20kg was used with a dwell time of 10 seconds. The indentation was measured by optical microscope incorporated in the microhardness tester. Two Indentations were made on various phases to determine diagonals of the indentation. Two distinct phases in the microstructure were observed under the optical microscope with a magnification of X100. One phase appeared bright in coloured while the other one as dark.

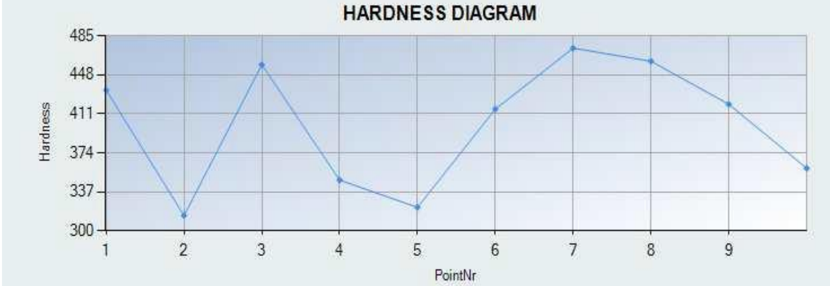
Two sets of ten indentations each were taken over the polished surface of the sample including a micrograph, which is shown figure 3. Under the microscope, two distinct phases were observed. Values of hardness were recorded for both phases appearing dark and bright.

3.2.1 Hardness testing of dark microstructural phases

It is observed that the dark microstructural phase is distributed throughout the microstructure of the sample surface when examined under the microscope. The dark micro structural regions are possibly due to the existence of carbide phases of the alloy. The dark carbide phase was tested for microhardness. The micrographs and results of the tests are shown below in Figure 3.

(a)



(b)

(c)

Measurements	10	Dwell time	10 sec
Max HV	473.45	Average HV	400.62
Min HV	314.58	Std deviation HV	56.45

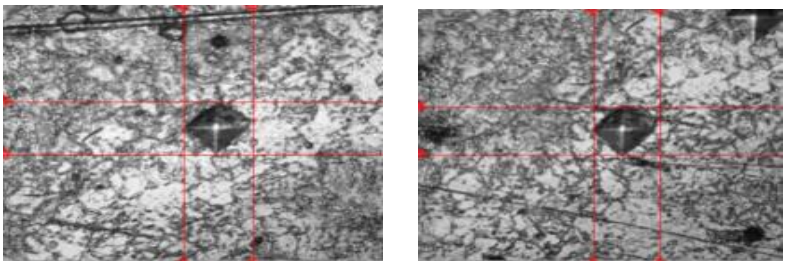
Figure 3. Results of the tests for the dark phases (a) micrographs of two indentations, (b) graph of indentations (c) summary of results.

An average hardness of this phase was 400.62 Vickers with a maximum value of 473.45 and a minimum value of 314.15.

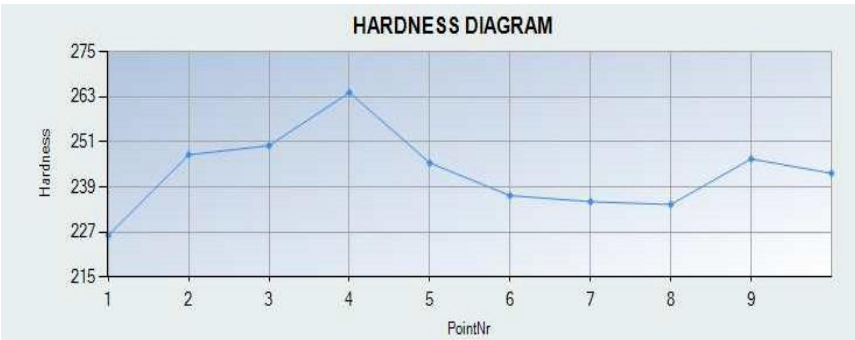
3.2.2 Hardness testing of bright microstructural phases

There are several regions, in the micrograph, that appeared bright under the microscope. These bright regions can be attributed to the presence of ferrite phases in the alloy. Ten micro-hardness measurements were taken on the alloy specimen on these bright phases. Images of indentation, micro-hardness variations are presented in figure 4(a) and 4(b). Maximum, minimum and average value of hardness along with standard deviation is furnished in figure 4(c).

(a)



(b)



(c)

Nr of measurements	10	Dwell time	10 sec
Max	264.18	Average	242.88
Min	226.12	Std deviation	9.99

Figure 4. Results of the tests for the dark phases (a) micrographs of two indentations (b) graph of indentations (c) summary of results

The average hardness of the ferrite phases was found to be 242.88 HV, with a maximum of 264.18HV and minimum of 226.12 HV respectively. The average microhardness of the Chromalloy is 321.75 HV considering the two phases (dark and bright).

3.3 Nanohardness measurement

Nanohardness measurements were taken on an Anton Paar Nanoindenter. The process parameters used during the test are shown below in Table 1. The nanohardness testing method used by the instrument is Oliver –Pharr method.

Table 1: Process parameters for nanoindentation experiment

Maximum load : 50.00 MN	Approach distance : 3000 nm
Linear loading retract speed : 2000 nm/min	Acquisition rate :10.0 Hz
Load in large range Unloading rate : 30.00 mN/min	Approach speed : 40000 nm/min
Pause time : 50.0 s	Stiffness threshold : 150 µN/µm
Poisson ratio: 0.21	indenter tip: Berkovich diamond B-T 40

Six hardness measurement tests were carried out over the sample surface. Micrographic images were taken on the surface on which indentations were made. Two such micrographic images are shown below in figure 5.

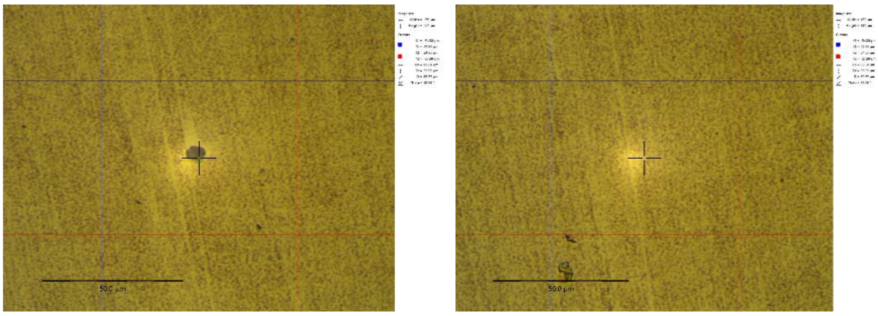


Figure 5. Images of two nanoindentations

From the indentation depth versus force curves, measurements of stiffness (S), maximum force (Fmax), depths Hc, Hr and Hmax, epsilon (ε) and the nanohardness were recorded from the instrument. The results are presented in the Table 2 (a) and the maximum, minimum and average nanohardness values in Table 2(b) below.

Table 2. (a) Measurements recorded for nanohardness test results (b) Average, maximum and minimum values

(a)

Indentation	1	2	3	4	5	6
S (mN/nm)	0.4090	0.4370	0.433	0.4289	0.3787	0.3173
Fmax (mN)	50.01	49.99	50.04	50.05	50.02	49.97
Hc (nm)	882.18	828.12	1355.71	893.49	889.5	91.46
hr(nm)	882.18	804.20	1329.45	867.53	860.75	881.49
hmax(nm)	1004.45	918.59	1444.94	984.21	992.83	1038.99
Epsilon (ε)	1.00	0.79	0.77	0.78	0.78	0.77
Hardness nanoVickers	263.65	306.64	109.67	226.54	263.65	246.45

(b)

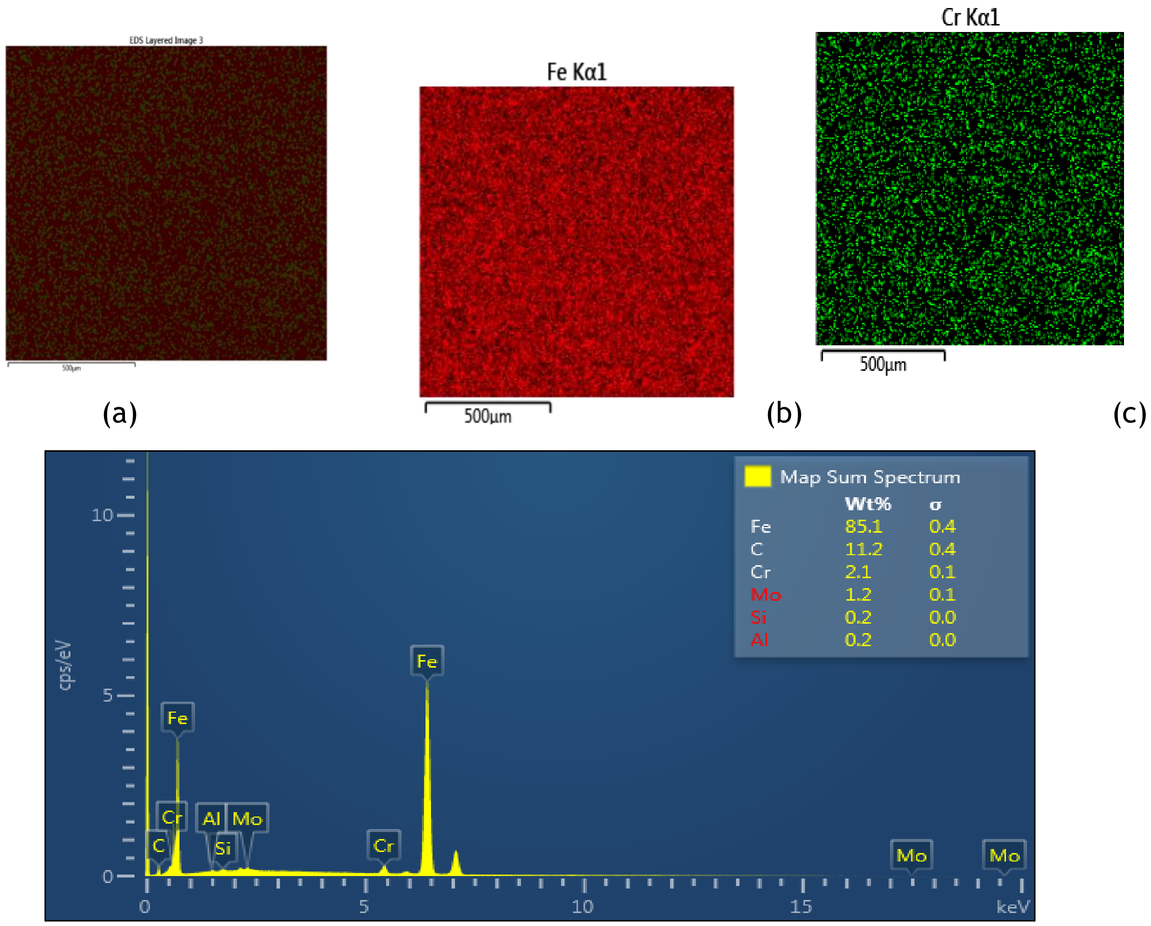
Max nanohardness	306.64	Average	241.93
Min nanohardness	109.67	Average excluding point 3	261.35

Two average values are computed with six values and another one where point 3 appears to be an outlier possibly due to a defect, and thus will not be considered in the computation of the average.

The maximum nanoVickers hardness value recorded was 306.64, while the minimum was 109.67 with an average being 241.93. The variation in the hardness values recorder over the surface can be attributed to microstructural variation. Thus further tests were carried out to establish these variations and their causes using scanning electron microscopy.

3.4 Characterisation of alloy composition

An Electron Diffraction Spectroscopy (EDS) elemental analysis was done to establish the constituent elements in the alloy using an Oxford Instruments scanning electron microscope and the micrograph shown below in Figure 6.e EDS analysis was done image shows the elemental distribution showing iron (b) and chromium (c) which are the dominant elements in the alloy.



(a) (b) (c)

(d)

Figure 6. Scanning electron microscope surface image and EDS analysis of Chromalloy

There are areas in the microstructure, which have high concentration of iron, chromium, while carbon exists as carbides. Molybdenum aluminium and silicon also exist in the alloy.

4 ANAYSIS

The results of the microhardness of the sample showed the following:

- dark phases on the sample surface tested by my microhardness which were presented in Figure 3 shows higher hardness values on the surface of maximum of 473.45, minimum of 314.58HV and an average hardness value of this phase of 400.62 HV.

- Bright coloured phases on the alloy presented in Figure 4 shows a maximum hardness value of 264.18 HV, minimum of 226.88 HV and an average hardness of 242.88HV.
- The average macro hardness of the bulk sample is thus the average of the light and dark phases equal to (400.62 + 242.88)/2 = 321.75 HV.

The results of the nanohardness of the sample showed the following

- Maximum nanohardness of 306.64 HV and a minimum of 109 HV, the minimum hardness becomes 226.54HV and an average of 241.93 HV.
- If the value of 109.67 is considered an outlier and is not considered the average of the other five nanohardness values becomes 261.35HV.

Comparison of the maximum and average micro and nanohardness hardness values in the alloy are shown below in Table 3 and Table 4.

Table 3: Comparison of maximum values of microhardness and nanohardness values of bright phases

	Average
Microhardness	264.18
Nanohardness	306.64
Percentage of microhardness to nanoharness	86.15%

Table 4: Comparison of average microhardness and nanohardness values of bright phases

	Average
Microhardness	242.88
Nanohardness	261.35
Percentage of microhardness to nanoharness	92.9%

5 DISCUSSION

The variation in hardness between the various measurements over the sample surface is attributed to the individual phases present owing to the distribution of constituent elements Cr, Fe, C, Mo and Si. These affect the stability of phases present. The distribution of Cr and Fe phases is evenly distributed in the microstructure (a). Phases dominated by chromium (c) can results in in the higher hardness values while those of high iron distribution (b) record lower values of both nano and microhardness. These elements form carbides through reaction with carbon. However molybdenum strengthen and stabilises the phase. Martensitic phases favoured by chromium tend to be higher in hardness compared to the ferrite phases. Variation in the microstructure on the surface of the sample is attributed to the variation in the hardness values recorded. Defects and other imperfections on the surface also play a role in these variations.

The value of the average of microhardness of bulk sample of the Chromalloy was 242.8 HV Vickers while the average nano hardness considering the low nanohardness value was 261.35. The value of a hardness of 109 Nano Vickers can be attributed to a point defect like a pore or an inclusion.

Thus, nanohardness can also can also qualitatively characterise the material's ability against deformation even in small parts given the challenge of measuring hardness of the small volume parts, where the residual projected area of the nano-indent is difficult to measure. This work supports the work of other researchers on other materials which included copper, stainless steel and nickel titanium alloys where they reported that the measured nanohardness values were 10 -30% higher than the microhardness [13].

6 CONCLUSION

It is possible to deduce microhardness of the Chromalloy steel given the nano-hardness values. In this particular experimental work, it was deduced that the average microhardness is about 92.9% of the average nanohardness. Maximum microhardness is about 86.1% of the maximum nanohardness value. Generally, microhardness values are lower than the nanohardness values. Microhardness gives the general hardness of the sample surface while nano-hardness measures the grain hardness.

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THE IMPACT OF DESIGN, MANUFACTURING AND END OF LIFE LOGISTICS ON SUSTAINABILITY OF CONSUMERS PRODUCTS

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ABSTRACT

In today's competitive environment, the survival of business enterprises depends on how they can adapt and overcome external forces they face, both local and global. They have to develop and implement strategies that are superior to those their competitors, adapt to change, ensure regulatory compliance, as well as meet current and future customer demands and preferences. The consumer goods industry as opposed to industrial industry is one such dynamic industry where adaptability and compliance is strictly required. In order to achieve these objectives a logistics and a systems approach to management of resources, technology, the product and its life cycle can be implemented. Best practices in design, manufacturing, transportation, use and disposal are required to ensure sustainable profitability and benefit to customers, shareholders and other stakeholders while minimizing impact on the environment. In the consumer market, activities and processes in the various stages of the product's life must ensure that the product minimizes damage to the environment ecosystems while meeting customer requirements. This paper discusses how best practices in design, manufacture, transportation and disposal of consumer products can be done in such a way as to minimize environmental impact and achieve sustainability of the product, business, society and the environment.

1 INTRODUCTION AND BACKGROUND

Any business organisation must be able to manage the creation and delivery of its products and services to the marketplace in a way that meets minimum standards set by such market if it is to survive in the long term. The management process entails the design of product, acquisition of technology, sourcing of raw materials, management and planning of production, the production process itself, storage and transportation [1, 2]. These collection of these complex processes are referred to as logistics processes and are aimed at achieving effective and success execution of the process [3]. Product life cycle logistics is increasingly important in organizations [4]. The nature of the product determine competitive pressures, environmental, governmental laws and economic factors its supply chain players face, hence impact on sustainability issues [5]. Sustainability, which is a concept of meeting present and future needs of business profitability, customer satisfaction, environmental and regulatory compliance, and public safety is becoming a key success factor for any business area from manufacturing to distribution [6]. A manufacturer and its ssupply chain partners must deliver during the design, manufacturing, transportation and end of life phases of the product life sustainably [4, 7]. This paper explores the impact design, manufacturing, supply chain and end of life logistics activities on the ability of business organisations to deliver competitiveness and sustainability of consumer products.

2 LITERATURE REVIEW

2.1 Waste problem: Environmental impact of consumer goods

Design of a product has an impact on its performance in the market in terms sales, performance in service and its defects and length of life span [8]. A well-designed product is one that it user friendly, fit for purpose and not give mediocre performance or whose styling be short lived [8]. Poorly designed products end up in landfills. For example according to the e-Waste Association of South Africa (eWasa), each individual in South Africa generates about 6.2kg of e-waste, while the South African Department of Environmental Affairs estimates an annual national tally of 360 000 tonnes consisting of broken phones, TVs, computers and other electronic products [9]. In 2006, the United Nations estimated annual global e-waste to be already about 50 million metric tons [8]. Changes in consumer tastes due to changes in technology has changed the demand patterns for the latest electronic devices contributes to the large amount of e-waste from obsolete products, with cell phones are the biggest problem [8,9]. The increase in waste is due to shortening product life cycles and poor design leading to disposal [9]. In addition to good designs, consumers today are increasingly conscious and prefer green-labelled, eco-labelled or environmental labelled products with information on environmental aspects of the product and its production process such as, energy use, greenhouses gases and pesticides used [10]. Consumption of eco-labeled products in the US is set to double from 2009-2019 [10]. Excess products that do not make it on the market are usually scrapped and end up being discarded, adding to the waste stream. This creates waste form these unwanted products and the consumption of energy during the processes of extraction raw materials, production of ingredients, components or subassemblies, processing of products and transportation when producing these products [11]. Vehicles used for transportation of raw materials and finished products produces emissions [11]. For example, in South Africa heavy vehicles contribute to 4% of the vehicles on the road fleet, they account for 14% of energy security and 14% of congestion [11]. In the United Kingdom, in 2014, 23% of carbon emissions which came from transportation of goods [11]. The less goods and materials are transported the less emissions.

Therefore, selection of quantity and size of materials affect loads to be carried and number of heavy vehicles on the road and thus energy consumption and carbon emissions.

Manufacturing processes also produce process wastes may or may not have economic value [5]. This waste together with products that have end of their useful lives, are disposed of to landfills [12]. With increase in populations and increase in populations, the impact of waste on the environment, ecosystems and the economy is a profound problem today [12]. Cities are enduring the most of waste. For example, consider the city of Cape Town in 2009. About 2 million tonnes of waste were transported to dumpsites, which induced huge amounts of disposal and transportation costs [12]. Although some waste ending up in landfills is recyclable, most of it is not, thus presenting challenges for space and environmental and health hazard [13]. Oceans and other water bodies face similar threats from micro plastics, abandoned fishing gear and other plastic pollution [14]. For example in 2014, it was estimated that 15 to 51 trillion micro plastic particles were floating in the world's oceans, weighing between 93,000 and 236,000 tonnes [14]. Plastic waste including containers and ghost gear causes littering of oceans and present physical harm and health hazard to marine life through poisoning, entangling, maiming and killing creatures [14].

Plastic bags and containers are viewed as an important part of many consumer products providing convenient packaging due to aesthetics [20]. However, they are now causing serious to urban pollution. For example, such an environmental problem was cited in Kenya where polythene bags are causing a solid waste management problem in urban areas [15]. The country consumes about 24 million polythene bags, which after use end of in landfills [9]. Landfill waste is a breeding ground for disease caring pests including malaria-carrying mosquitoes [15].

Research has shown that, globally about 80 percent of consumer goods, excluding packaging, are disposed after a single use with no plan or ability to be reused, recycled, or biodegraded [16].

2.2 Concurrent approach to waste minimisation at design stage

In order to develop a product that satisfies the sustainability criteria, sustainability requirements must be considered together with other requirements on the conceptual design stage. At this stage, the material selection, manufacturing processes, material handling, storage, product use and disposal after use to minimise environmental impact is taken into account [17]. First, in order to produce products which customers need, customer, regulatory and stakeholder requirements have to be compiled. [18]. The product development team can use tools like Voice of Customer and Quality Function Deployment to collect customer requirements. Customer and translated into product attributes and convert them to design [17]. A simple flow chart for the Quality Function Deployment process is shown below.

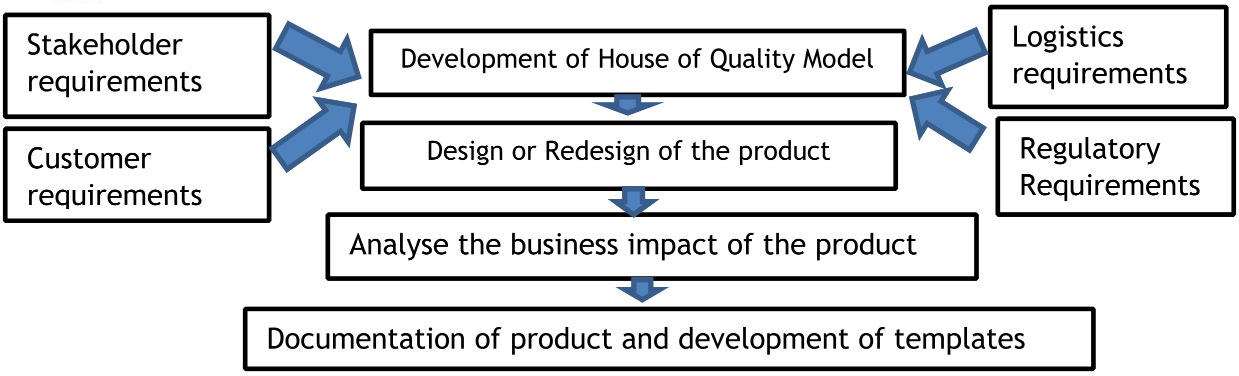

Figure 1: Schematic diagram of the QFD methodology [18]

Customer requirements include the price they are willing to pay, product features and performance. Logistics requirements include, weight size durability, space requirements of the product and its spares, ease of installation and storage [18]. Regulatory requirements include compliance to codes and standards, laws and bylaws. Stakeholder requirements look at impact on environment and impact on society. The design team can use tools like ABC analysis to classify and prioritize the most important requirements by considering the vital few (those causing 80% of costs or impact) and the important many (those causing 20% of costs or impact). The Quality Function Deployment model identifies requirements, which complement of conflict with each other. The output of the process will guide the design team to conceptualize material selection, quality of such materials, number of parts, size of parts, ease of assembly, and conformance to standards design.

Design for logistics is concurrently carried out with product design process. Logistics aspects considered include design for economic packaging and transportation, and parallel processing, and standardization [19]. These considerations will assist to control logistics costs during manufacturing, storage and delivery, use and disposal and increase customer service [20]. Design of packaging ensures packaging ensure the product can withstand demands it is exposed to during the course transportation and handling [18].

2.2.1 Environmentally conscious design

In order to achieve environmentally sustainable products it is important for a company to pursue environmentally sustainable design as a business strategy. This approach to product design is also called environmentally conscious design or eco design and involves designing physical objects and structures that comply with principles of ecological sustainability [20]. Its principles guide the design team to understand that natural resources are limited. This thinking consequently guides both investment and resource use priorities. It aims to reduce pollution, over exploitation of scarce resources, and elimination of processes that generate waste and pollution. Eco-design principles include the following [20]:

- Committing to waste prevention practices targeting activities that generate waste.
- Eliminating the source of the pollution problem.
- Using low impact, nontoxic sustainably produced materials.
- Use recyclable raw materials material.
- Design durable products which users can get emotionally invested in and keep them for longer
- be responsive to present and future as well as changing customer demands and preferences

In practice, one eco-design practice involves material substitution. In applications where petroleum based plastics are used for components or packaging disposal of such products leads to pollution, since they are non-biodegradable and last for years in the environment. However, biodegradable plastics materials such as those made of cornstarch and other plant-based materials, which take three to six months to decompose fully, can be a sustainable alternative [21].

2.2.2 Minimising waste through managing manufacturing logistics

Manufacturing processes play a role in the life cycle of a product [21]. The temporal scope of manufacturing logistics begins from the point where end-item customer demands are determined and extends to the point where the demands are fulfilled [21]. Its aim is to reduce overall product costs, improve efficiency in the delivery of products and services in an environment faced with instability

and complexity [22]. Manufacturing logistics function handled by a product manager. Activities of this function include managing of

- production process from concept, to design,
- sample production, testing,
- forecast, and costing,
- mass production
- product promotion and support,
- product end of life.[23]

The manufacturing logistics role often has to deal with manufacturing complexity arising from information requirements, and the amount of data needed for accurate decision-making [22]. Today, manufacturing logistics is faced with several challenges including product proliferation, shortening life cycles and product development times, which complicate the product development and retirement process [22]. After-sales support must be adequately available in the form of availability of spare inventory and technical staff and product information. Phase-in and phase-out procedures and aligned performance measures at various stages for products and processes are important aspects in order to achieve efficient flexible manufacturing and inventory management systems [22]. A concurrent engineering approach to design of product, manufacturing processes and support systems will lead to improved sales, product safety and sustainability through reduction of resource and energy consumption in processes and integrated management of information [23].

2.2.3 Role of collaboration in sustainable waste reduction

In order to achieve increasing sustainability, businesses are adopting a wide range of sustainable management practices on the demand and supply side of the supply chain [23]. Competencies in the external and internal supply chain have an impact a manufacturer's performance. Supply chain partners benefit from resources and knowledge, generated from outside the firm, from suppliers who are supplying raw materials components and technology [24]. Partners can help sustainability through optimizing processes, waste minimization, and pollution prevention and, recycling practices among [25]. Sustainability through collaboration in supply chain arises from knowledge exchange and inter-organizational learning, pooling complementary resources and capabilities, creating, integrating and transferring of knowledge across the supply chain. [24].

2.3 End of life logistics

A well-designed product must fulfil the purpose, which it was meant for as well as operate optimally throughout its lifetime [26]. Upon completion of useful life, there must be proper practices and procedures in place to safely retire the product. This is referred to as end of life logistics [27]. End of life logistics involves reverse logistics, disposal, recycling, and reuse [27].

2.3.1 Managing reverse logistics processes

Reverse logistics involves the return of a product from the consume to the supplier for various reasons [28]. Management of the reverse logistics process is important in its relationship with policies, environmental hazards and customer satisfaction and costs [28]. In regulated industries such as chemical, food and pharmaceuticals there are several constraints due to risks of toxicity and contamination, which result in the need for appropriate transportation, handling and disposal methods [29]. These industries face challenges such as limited opportunities for recycling or reuse. However, electronics and automotive industries have more developed reverse logistics systems in the form of efficient and economically feasible buy-back schemes, component reuse and recycling [4].

2.3.2 End of use

End of use (EOU) logistics concept, which means those situations where the user has an opportunity to return a product at a certain life stage of it [4]. The reuse in instances of unused products, which can be sold to second-hand markets such as clothing, bottles and components [30]. This is an alternative to disposal in cases where a product is still perceived to have some useful economic value by customers [30]. A management system of point of sale reverse logistics for returned items in the case of business-to-business or business to customer transactions is required for it to be mutually beneficial to both parties [4]. In order to have an effective reverse logistics system, there is need to value adequate inventory information using accurate technologies such as bar coding and radio frequency identification devices (RFID) technology [24].

3 DISCUSSION

An important objective of logistics form the design of a product its manufacture, delivery use and disposal is not just the role of the manufacturer itself but spans the entire supply chain and within an organisation is a multifunctional activity [31]. The number and competencies of the supply chain players determine how the supply chain processes from product development, manufacturing use and disposal are managed [31]. A company is supply chain with fewer and competent suppliers can achieve better profitability and sustainability even in a complex environment. Sustainability must be adopted as a long-term business strategy across the entire enterprise focusing on finance, people, the community, and the environment, through coordination the relationship between business activities and their impact on present and future economic, social and environmental issues [33]. Key success factors for sustainability includes being responsive to future customer demands using innovative staff, flexible technology and at the same time be able to redesign business models and practices. It can identify and implement sustainability best practices in design, partnering, collaboration, manufacturing, transportation, use and disposal of products. Material selection, product life cycle issues, production and transportation are key factors in business sustainability. Regulatory compliance allows access to markets, brand loyalty and responsiveness to requirements in an ever-changing market ensures competitiveness. It is important to integrate strategies and activities at product, process and system levels if sustainable value creation is going to be realised by the business for both shareholders and other stakeholders.

It is also important for a manufacturer and supply chain partners to be conversant with other sustainability management practices have emerged recently [5]. Green supply chain management and sustainable supply chain management aiming to minimize the carbon footprint of operations across the supply chain [32]. Corporate social responsibility (CSR) views the business as a citizen responsible for the wellbeing of society and the environment and must achieve profitability at minimum costs. It is important to note that integration of sustainability into the product and process development requires development of new models, frameworks, metrics, and techniques Moldavska & Welo [5]. Through pursuing CSR a business can deliver competitive, safe, reliable and cost-effective goods and services there by increasing is market share and developing a culture of continuous monitoring and improvement of the business processes.

Another benefit of CSR and adopting sustainable practices is that, it builds customer loyalty and customers today are willing to pay a premium for a sustainable delivered product if the business is able to prove that it is participating in a sustainable supply chain [31].

4 CONCLUSION

Sustainability is the key to business survival in a world where most resources are non-renewable and technology and customer demands are changing. Therefore, products must be manufactured, transported, used and disposed of, in ways that minimize harm to the environment. It is important to develop learning manufacturing companies understand the role that design, manufacturing, distribution and disposal plays on sustainability. Consumers also need products with a longer life span and information on how to dispose of them safely at the end of their life, while manufacturers need to develop technologies that can turn products into secondary raw materials for manufacturing new products.

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THE RELEVANCE OF TRADITIONAL INDUSTRIAL ENGINEERING DATA COLLECTION TOOLS & METHODS IN THE MODERN TECHNOLOGICAL AGE: A SURVEY ON THE PERCEPTION OF INDUSTRIAL ENGINEERS

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ABSTRACT

The effect of a fast-paced technological inclined world is that industry is constantly advancing. This wave leads to some trends such as the increase in environmentally friendly solutions and development of a paperless society. Industrial engineering is focused on continuous improvement, optimisation and cost saving. There may be new technologically aided tools available for use however due to the fast pace nature of industrial engineering the individuals may not have the time to source these software's and/ experiment with it. Hence, the study aims to investigate the perceptions of IEs regarding traditional methods of industrial engineering versus new technologically advanced software developed to assist them. The significance of the study is to determine the relevance of traditional methods and to determine if there are easier, more concise and faster methods to conduct data collection and analysis in the field of industrial engineering. A detailed survey will be used to collect the relevant data and the data will be analysed accordingly to determine the relevance of traditional methods in the technological age. IE's are not aware of the new solutions available and therefore tend to stick to traditional methods. The modern techniques are more efficient and accurate than traditional methods. Traditional methods are relevant as baselines for the development of modern IE solutions which are more efficient and less manual. IE's are not actively aware of advances within the field and therefore tend to stick to traditional methods even though it is inefficient.

1 INTRODUCTION

In the fast-paced technological world there is always an update or advancement in industry. With organisations shifting to more environmentally friendly solutions and evolving into a paperless society, the entire engineering approaches have changed completely to suit this trend.

To demonstrate this shift towards technologically advanced systems is the well-known Industrial Revolutions. The 4th Industrial Revolution of *Cyber Physical Systems*, which involves the shift towards a paperless system using programming of system specialised software to record and store data, is currently in motion yet the world has already begun shifting towards the development of *Artificial Intelligence*.

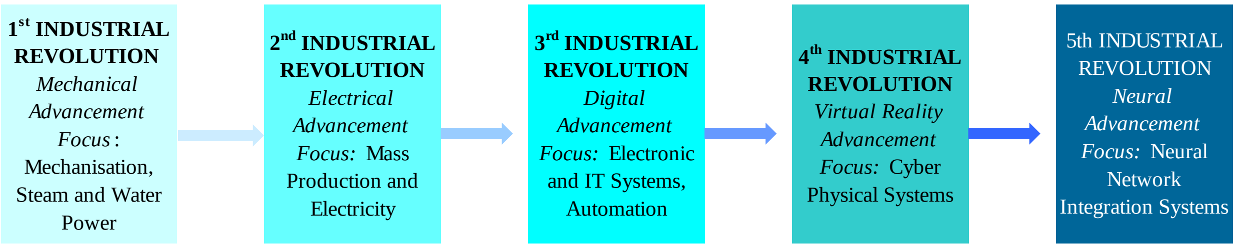

Figure 1: Industrial Revolution

A more focused engineering example to demonstrate the shift of industry is the move from paper and pencil technical drawings in the 16th and 17th century to the development of Computer-Aided Design (CAD) and Computer-Aided Manufacturing (CAM) which allowed digital drawings from the 1800's and onwards [1].

Industrial engineering is focused on continuous improvement, optimisation and cost saving. IE's are tasked to optimize various vast continuously evolving systems, yet the methods in which this optimization is applied, is outdated, inefficient and not of optimal standards. Work-study techniques, like time studies which is a time-consuming process, from the early 1900's is still used in this technological age. Can the related data not be collected in a way that does not require the IE to stand and monitor a process for extensive periods of time? Although there are new advanced methods available for use, the academic structure of IE has not been adapted accordingly.

This is what lead to the research question:
Is traditional industrial engineering techniques still relevant in the modern age?

- "Traditional" meaning an old deep-rooted, habitual methods that is usually manually intensive.
- "Modern" meaning the more recent development and technologically advanced methods.

2 PROBLEM STATEMENT

In the modern age which is in a rapid state of continuously improving in terms of technologically advanced methods, IE's, the specialist in the methods of continuous improvement, seem to be a world, or two, behind due to the traditional approaches used and maintained in industry.

Possible research questions that are stimulated in relation to the problem: -

- Are the traditional methods still relevant?
    - Traditional methods require intensively detailed data collection methods and is time consuming. Also, in many cases to increase the accuracy and reliability of the data, samples need to be taken. The data is yet to be analysed. Once the

study is finally complete, will the results still be valid? Alluding to the fact that the system that was studied may have already evolved and changed creating new problems that are prioritised over the reasons that initiated the original study.

- Are there established industrial engineering techniques that use technology?
    - There may be new methods that are available or even in the process of development. In fact, there have been software's developed which can be used by IE's to aid projects. Just as Technical draughters have CAD, IE's can use simulation software's to run trial and error tests. This will help improve the efficiency of IE's in industry as work related situations can be simulated and improved without affecting real time production.
- Are Industrial Engineers aware of new methods (if any)?
    - New methods are available but is not popularly commercialised. Therefore, IE's may tend to stick to the tried and tested traditional methods.

3 AIM AND OBJECTIVES

The study aims to reveal the relevance of industrial engineering techniques and is based on the opinions of IE's in industry towards the topic.

The objectives of the research project : -

- To determine the opinions of IE's towards the relevance of traditional techniques.
- To determine why the IE's feel that traditional techniques are relevant or not.
- To determine approximately how long industrial engineering improvement projects take, from data collection to the actual improvement implementation, when using traditional methods (i.e. Stop watch – Time studies).
- To determine how many IE's in the field are aware of and use new technologies that are available.

4 LITERATURE REVIEW

4.1 A Brief History of Industrial Engineering

Industrial engineering was initiated by a mechanical engineer, Frederick Taylor during the mid to late 1920's, who laid the foundation for industrial engineering by introducing work process standardisation methods [2]. Therefore, industrial engineering has been in existence, in South Africa, for close to 100 years. Due to the growth in industry after World War II, IE's, better known as production and manufacturing engineers during the period, were focused on productivity and output improvements.

The field of industrial engineering lacked the respect and recognition in industry as a more "intangible" field of engineering as IE's are more concerned with the design, integration and improvement of systems rather than a more hands-on approach to fixing a visible problem. In other words, Industrial engineering is more focused on manufacturing methods, techniques and systems other than the physical manufacturing of items.

The first industrial engineering qualification course in South Africa was introduced in 1961 at the University of Pretoria. Which shows that the first IE's entered the South African working environment 54 years ago.

4.2 Developments in Industrial Engineering

According to a study by J.W. Uys [3], which was conducted to determine which field of industrial engineering was being developed in terms of published research articles in the South African Journal of Industrial Engineering (SAJIE). Uys's study revealed that the research in the following fields rapidly changed in the 20th century: -

- *Supply Chain Management* research increased by 8.7% from the 1990's to the 2000's, yet *Production Management* research decreased by 5.9% from the 1990's to the 2000's.
  - This shows the shift of industry into integrate the supply chain as a key element in organisations. Therefore, the research into supply chains increased while the research into production decreased.
- *Intelligent systems and Methods* research increased by 8.3% from the 1990's to the 2000's yet *Advance Production Systems and Technology* research decreased by 5.9% from the 1990's to the 2000's.
  - This shows that there was an increase in intelligent systems as industry shifted towards automation and robotics while production systems and technology research declined allowing the focus shift.

The above data clearly indicates a shift in research topics that are on par with industry advancements and movements, yet, IE's are currently using techniques that were developed approximately 100 years ago. Should it not be that IE's in the working environment use the new improved methods that are in line with technological advances to carry out tasks to achieve the necessary results faster and more efficiently?

Industrial engineering research is incredibly advanced and innovative; however, the problem arises with the actual industry application. As mentioned previously, it is beneficial to conduct intensive research on topics and develop new methods or techniques. However, is it usually not useful if is not applicable or too costly to apply in real life.

It was predicted that industrial engineering research would substantially increase intelligent systems. It was also highlighted that industrial engineering techniques are becoming increasingly integrated in management and engineering departments and therefore, the field needs to be developed accordingly. Industrial engineering has evolved into more than just the traditional idea of work study officers. Dastkhan [4]

4.3 Awareness around new advancements in the field

A typical example of a traditional method is time and method studies which are done using a stopwatch and a time sheet which is manually filled in by the IE conducting the study. This process is time consuming and labour intensive. In industry, IE's are often busy with multiple projects simultaneously and therefore do not have the privilege of conducting a complete, detailed and accurate time and method study. Due to this, the IE draws conclusions from incomplete data. In many cases the system itself has evolved such that the data collected is considered irrelevant by the time it analysed.

There are technologically aided methods which have been developed to assist in data collection, yet it is not pushed and brought to the attention of IE's. Computer-Mediated Videos (CMV) programmes can be used to conduct time studies [5]. There are software's that can be programmed to recognise specific elements in a process and record the cycle times accordingly, this in turn eliminates the data collection and statistical analysis tasks involves in a time and method study. This then allows the IE to concentrate on sourcing new solutions and implementing improvement actions.

The major gap in research is the actual industrial awareness of new methods, which questions the relevance of traditional methods as these new methods are available. In industry, time equates to money, therefore, the focus of IE's needs to shift improving the methods used to improve the systems they are working with.

5 RESEARCH METHODOLOGY

A quantitative research approach was chosen as it is a systematic, formal and objective process to collect the necessary data required. A detailed survey was used to collect the relevant data. A survey was used as it is a descriptive, exploratory and explanatory research method.

This topic required a sample of IE's from different fields in industry who were questioned to determine the outcome. Therefore, the survey was best suited as it was consistent and allowed for different characteristics to be accounted for, like opinions, beliefs, behaviour, knowledge backgrounds, etc., and were analysed accordingly. However, a questionnaire was developed to pilot the study. A sample of 5 IE's in industry were approached to complete the questionnaire as part of a pilot test which was conducted to determine if the questionnaire was correctly structured to collect the necessary results. It was also used to determine if the questioning structure of the survey was correctly focussed.

6 ANALYSIS TECHNIQUES

The survey questions were scored to allow the data to be analysed. The scoring will convert the data into statistical data from which conclusions and results can be drawn.

The questionnaire was pilot tested and using the suggestions and advice received, it was improved accordingly to accommodate more information regarding the participant. Thus, conclusions could be made in accordance to the participant's: -

- Main field of study
- Level of experience in industry
- Suggestions related to improving the field of Industrial Engineering.

The questions were restricted to "Yes or No" answerable questions for ease of analysis. Thus, saving time for the participant to complete and is therefore more convenient.

The survey was created and shared using "Google Forms" which is an open source survey site. It was sent to various companies in different industries that have an industrial engineering position open or a job function related to industrial engineering. It was also shared via LinkedIn.

7 RESULTS

The results below are expressed as a percentage based on a total of 45 responses received.

Table 1: Survey Results

	No.	Question	Answers	Number	Percentage
Classification of Participant	1	Do you have an Industrial Engineering related qualification?	Yes	41	91%
			No	4	9%
	2	What is your Qualification Level?	ND*	21	47%
			B-tech	12	27%
			Degree	6	13%
			Other	6	13%
	3	How many years of experience do you have in the field related to Industrial Engineering? (Years)	0-2	25	56%
			3-5	10	22%
			5-10	6	13%
			> 15	4	9%
	4	Do you often work simultaneously on several projects of a high priority?	Yes	40	89%
			No	5	11%
	5	How many projects are you handling simultaneously? (Projects)	1 - 2	7	18%
			3 - 4	27	68%
			5 - 6	3	8%
			> 6	3	8%
	No.	Question	Answers	Number	Percentage
Traditional Methods	6	Did you complete a detailed industrial engineering task that required extensive data collection?	Yes	43	96%
			No	2	4%
	7	If yes, approximately how long did it take for you to complete the study from start to end? (Days)	0-5	12	28%
			5-10	12	28%
			10-15	15	35%
			> 15	4	9%
	8	Have you ever had to redo the study causing a delay in the projected project completion time?	Yes	31	69%
			No	14	31%
	9	If yes, approximately how long did it take for you to complete the study from start to end? (Days)	0-5	10	32%
			5-10	13	42%
			10-15	8	26%
			> 15		0%
	10	Is there sufficient time and resources available to complete the study?	Yes	31	69%
			No	14	31%
	11	Have you ever been in a situation where problem has subsided before solution implementation?	Yes	26	58%
			No	19	42%
Technology Aided Methods	12	Are you aware of any technological software/method that can be used as a tool in Industrial Engineering?	Yes	19	42%
			No	26	58%
	13	Have you used or plan on using any form of software that is designed to perform/aid industrial engineering tasks?	Yes	27	60%
			No	18	40%
	14	Did you find the software more efficient to use?	Yes	23	88%
			No	3	12%

	15	Were you able to complete the task faster?	Yes	20	87%
			No	3	13%
	16	In your opinion, Were the results achieved more accurate than if the task was to be manually done?	Yes	15	65%
			No	8	35%
Overall	17	Do you believe that traditional Industrial Engineering techniques are still relevant in the modern age?	Yes	31	69%
			No	14	31%
	18	Would you prefer to work using manual techniques or Tech-Aided methods?	Modern	32	86%
			Manual	5	14%
	19	Do you feel like there is room for improvement in the field of Industrial Engineering?	Yes	41	91%
			No	4	9%

ND* National Diploma

Table 2: Reasons why traditional methods are relevant or irrelevant?

	No.	Reason	Number	Percentage
Is Not Relevant	1	Traditional techniques are outdated	7	16%
	2	Do not Provide real time, accurate results	4	9%
	3	Are Manually intensive	3	7%
Is Relevant	1	Are the core methods of IE, the basis for any improved methods	14	31%
	2	It is the only way to collect data and complete project	13	29%
	3	Organisations lack the finances to implement newer methods	4	9%

Table 3: Area's for improvement within IE based on the opinions of participants

No.	Area of improvement	Number	Percentage
1	Development of new technologically based methods to complete IE tasks	18	44%
2	The integration of existing software with IE, Expanding the scope of IE to work together with other fields in industry	11	27%
3	IE is a continuously improving field and therefore naturally improves in its own stride	7	17%
4	Improve and increase the awareness of IE's on new methods, increase networking between IE's to share experiences	5	12%

8 DISCUSSION

The results revealed that new technological software's available are more efficient and accurate than the traditional Industrial Engineering methods.

Most of the participants (68%) work on 3-4 projects simultaneously in industry. This confirms that IE's are often multitasking between projects. Although 69% of participants indicated that they had enough resources to complete the projects, 69% of participants admitted to having to redo the initial study due to inefficiencies. A study, using traditional methods, usually takes 10-15 days to complete, however, redoing a study, due to initial study inaccuracies, adds approximately 5-10 days to the initial project schedule. Also 58% of participants indicated that by the time a solution is reached and implemented using traditional methods the actual problem has subsided. This clearly indicates that traditional methods are inefficient.

Only 42% of participants are aware of new technological software's that can be used by IE's. Yet, 60% of participants intend on using the available software. Overall, most of participants expressed that the new software's are more efficient; accurate and faster than traditional IE methods. Since the accuracy and efficiency is increased it will decrease the need to redo studies and semi-automate the IE process.

Of the participants, 86% would prefer modern technologically aided techniques over the traditional methods. However, it can be said that the traditional techniques are still relevant as it provides the baseline for the development of newer modern tech-aided solutions.

9 CONCLUSION

Based on the survey results, it can be concluded that IE techniques are in need pf improvement. There are technologically advanced software's available for use but IE's in the field are not aware of such and, therefore, tend to use the traditional manual techniques.

In relation to the opinions received from the survey, traditional techniques are still relevant as it provides the basis for any study. However, modern techniques can substantially improve the work of IE's, by reducing the project time and increasing the project accuracy. Thus, to create these technologically aided tools the traditional methodologies are used as baselines.

It is recommended that increased quantitative research needs to be conducted to quantify and qualify the efficiency of the technologically advanced tools available. Research also needs to be conducted on the cost factors that regarding modern versus traditional methods.

The survey revealed a gap in research with regards to the experience and qualification level of the survey participants. This may have skewed the data accordingly and therefore should be refined to

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EVALUATION OF THE EVAPORATOR SYSTEM OF AN ATMOSPHERIC WATER GENERATOR DESIGNED FOR RURAL KWAZULU NATAL

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ABSTRACT

Atmospheric Water Generators (AWGs) are a rapidly growing technology used to condense water vapour from air and produce drinking water. This study reviews the evaporator unit of a cooling condensation type AWG design and investigates the rate of water condensation across the evaporator at three climate conditions of the east coastal region of KwaZulu-Natal (the case study region) using first principal steady state calculations and Computational Fluid Dynamics (CFD) methods. The study findings illustrate the high dependence of AWG technology on climate conditions and suggest that operating an AWG system at temperatures of 15°C and below with 40% relative humidity can be considered to be beyond the effective operational limits of a cooling condensation type AWG. The study findings also suggest that AWGs can be effective at the high temperature climate condition of the case study region and could be an effective solution for high temperature drought relief of rural communities in the region.

Keywords: Atmospheric Water Generator, Heat Transfer, Computational Fluid Dynamics

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1 INTRODUCTION

The concept of condensing water vapour from the atmosphere for human consumption can be traced back to the sixth century BC when the ancient Greeks built large dew condenser to harvested water vapour to supply the city of Theodosia, present day Feodosia, Ukraine [1, 2, 3]. Today the concept of water harvesting from atmospheric air using Atmospheric Water Generator (AWG) technology has developed into one of the fastest growing commercialised solutions to meet the growing water demand globally [4]. The cooling condensation type AWG is the most widely available water vapour extraction method on the global market [4, 5] due to its effectiveness, compactness, simplicity and reliability [6, 7].

A cooling condensation type AWG uses refrigerant technology under the vapour compression cycle to cool humid air to below its dew point temperature resulting in the precipitation of water vapour [7]. The major components of this AWG system are the refrigerant compressor, evaporator, condenser and the throttle valve. The compressor pressurises refrigerant liquid-vapour causing it to superheat and discharge to the condenser. The condenser is a heat exchanger (HEX) with cool air blown over it resulting in sub-cooling of the superheated refrigerant gas. The sub-cooled liquid refrigerant is then passed through an expansion valve which reduces the refrigerant pressure and subsequently causing flashing of the liquid refrigerant to a low temperature liquid-vapour mixture. The cold liquid-vapour refrigerant is then discharged to an evaporator HEX. Warm humid air is blown over the evaporator HEX and is cooled to below its dew point temperature causing the water vapour to condense. The refrigerant is superheated in the process and discharged to the compressor where the process is repeated. Figure 1 illustrates the working principal described for a cooling condensation type AWG. In 2015 South Africa experienced servere water shortages due to the worst drought the country has faced in over 23 years in the driest and the warmest year ever record in the country [8,9]. There is a strong relationship between temperature increase and rainfall decrease in South Africa with temperatures increasing by 2% from 1997 to 2006 while annual rainfall has decreased by 6% over the same period [10]. It has been projected that by 2050 the country's internal temperature will rise by a further 2 to 3°C [8]. The effects of the rising temperatures and growing water shortages in the country are devistating to its economic growth potential. South Africa'a major production sectors which include manufacturing, aggriculture and mining utilise large volumes of water and often produce harmful effluent waste which can further risk the availability of fresh water resources for human consumption when untreated. Nearby rivers and rain water storage tanks are the main sources of water for remote rural communities of the country. The livelihood of these communities has been greatly endangered with the recent droughts. An ecofriendly water supply solution is required to service the water needs of the country's rural communities with the potential to be upscaled to service the growing water needs of the country's production sectors.

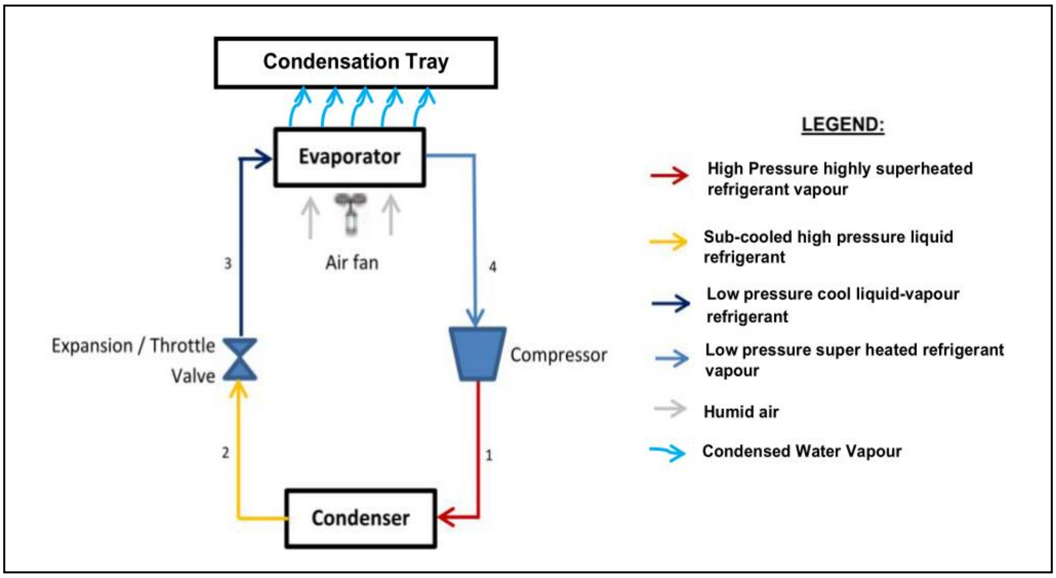

Figure 1: Cooling condensation type AWG working principal [7]

The east coastal region of South Africa, mainly comprising of eastern KwaZulu-Natal, is humid with warm temperatures due to the warm Mozambiquean current along the Indian Ocean [11,12]. This region's climate conditions are favourable for the implementation of AWG technology and for this reason it was selected as the case study location for this review. Three climate conditions were selected based on the low, mean and high temperatures experienced in the region with their respective relative humidity percentages. The high temperature condition can be readily exceeded during droughts. The rate of water vapour precipitation across the evaporator unit was analysed against these three conditions to determine the suitability of using an AWG system in this region for drought relief of surrounding rural communities.

2 RESEARCH METHODOLOGY AND A.W.G. DESIGN

Heat transfer calculations were conducted on an evaporator HEX design to predict the water vapour precipitated by the unit at the three climate conditions with the same amount of cooling energy (Q) transferred across the HEX at each climate condition. A computational model of the HEX unit was developed using Autodesk Inventor 2017 and the performance of the unit was computationally simulated using Autodesk CFD 2017 to predict the water precipitation at the three climate conditions. The results of the first principal method and CFD simulation were evaluated and the findings on the predicted performance of the evaporator discussed. The evaporator design is based on a C-shaped cooling condensation type AWG concept developed by Thisani [7] and illustrated in Figure 2. The CFD mesh specifications for the analysis conducted in this paper are as shown in Table 1.

Table 1: CFD Mesh Specifications

Number of Nodes	2287898
Number of Elements	7268032
Number of layers	3
Layer factor	0.45
Layer gradation	1.05

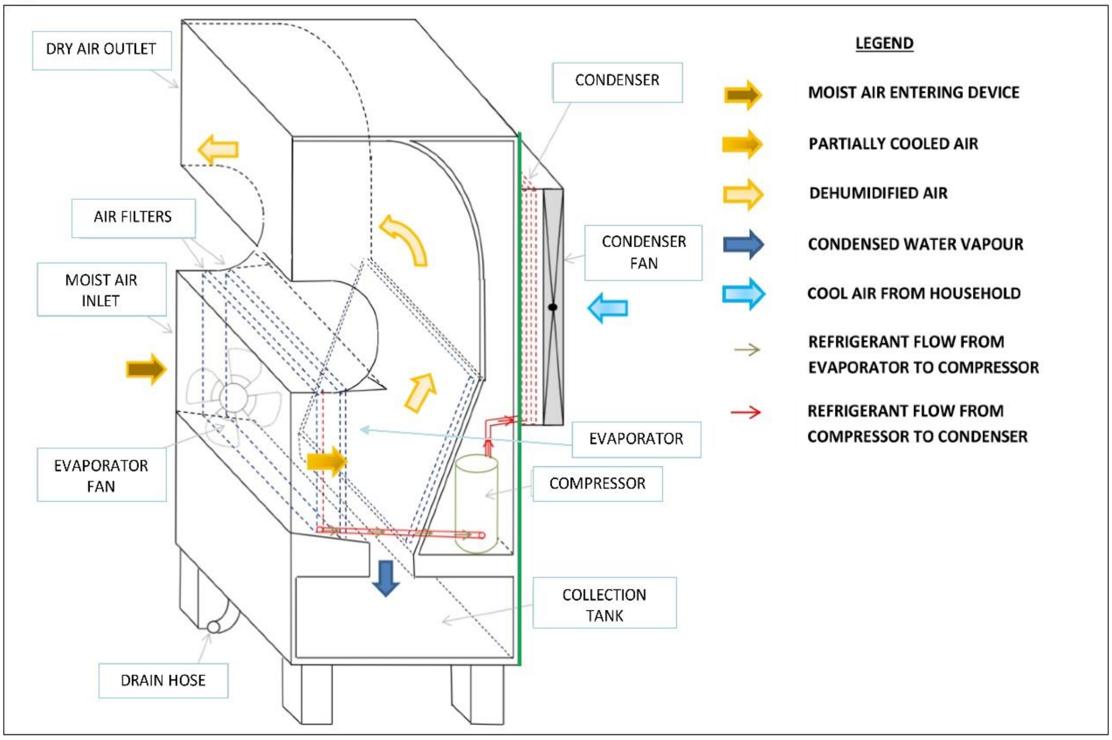

Figure 2: AWG Design [7]

In the AWG design illustrated in Figure 2, a fan blows ambient air across a fin and tube type evaporator HEX. The air is cooled to below its dew point temperature resulting in condensation. The condensed water vapour is collected in a sump while the dried air is vented out through the top exit duct. Ambient air is blow across the condenser HEX on the opposite end of the AWG unit to cool the superheated refrigerant vapour to sub-cooled liquid phase. The sub-cooled liquid is flashed to a chilled liquid-vapour mixture by a throttle valve before being introduced to the evaporator where it is superheated. The superheated vapour is pressurised by a compressor and discharged to the condenser where the cycle is repeated.

2.1 Evaporator Design

The evaporator unit is a finned tube type HEX made of copper tubes with aluminium fins for optimum heat transfer. The unit was designed by Thisani [7] to achieve water condensation over the AWG's air intakes surface area. The overall dimensional and material design specifications of the HEX are defined in Table 2. The geometry and dimensions of the HEX are illustrated in Figure 3.

Table 2: Evaporator HEX Design Specifications

Description	Design Parameter	
Evaporator type	Finned tube type	
Tube specifications	L_T = 5 m Material = copper K_{Cu} = 386 W/m·K [13, 14]	D_O = 12 mm D_i = 10.9 mm r_O = 6 mm r_i = 5.45 mm
Fin specifications	L_C = 18.9 mm K_{Al} = 170 W/ m·K [13, 14] Material = aluminium 6061 Number of fins = 222	P = 8.1mm A_C = 2 x 10^{-5} m^2 thickness = 0.5 mm, Fin spacing = 1.7 mm

Description	Design Parameter	
Refrigerant specifications	Type = R-134a h_{tp} = 7000 W/ m^2K [7]	$\dot{m}_{R134a}$ = 0.02611kg/s
Air specifications	$\dot{m}_{AIR}$ = 0.107 kg/s	h_{AIR} = 100 W/m^2K [13, 14]

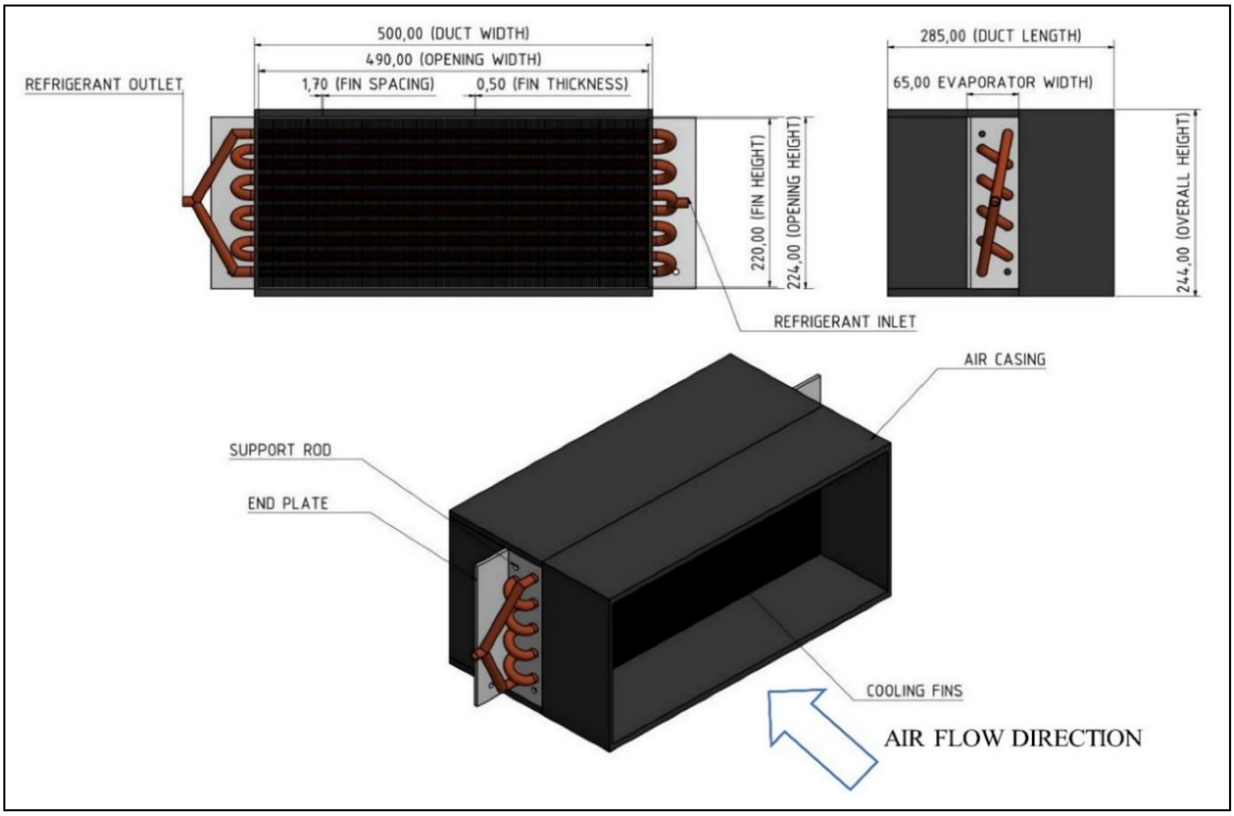

Figure 3: Evaporator HEX Design

2.2 Climate Conditions

The three climate conditions based on the low, mean and high temperature of the case study region and their respective relative humidity percentages are defined in Table 3. The differential temperature across the evaporator ($T_\infty - T_1$) was kept constant for all three scenarios at 20°C to maintain the same rate of heat transfer at each condition.

Table 3: Study Climate Conditions

Condition	Temp. [T_∞]	Relative Humidity [RH]	Dew Point Temp. [T_{DEW}]	Specific Enthalpy [H]	Apparatus Dew Point Temp. [T_1]
Condition 1: Low temperature	15°C	40%	1.7°C	25.9 kJ/kg	-5°C

Condition	Temp. $[T_\infty]$	Relative Humidity [RH]	Dew Point Temp. $[T_{DEW}]$	Specific Enthalpy [H]	Apparatus Dew Point Temp. $[T_1]$
Condition 2: Mean temperature	21˚C	65%	14.3˚C	47.1 kJ/kg	1˚C
Condition 3: High temperature	32˚C	65%	24.6˚C	82.5 kJ/kg	12˚C

3 RESULTS AND DISCUSSIONS

3.1 First Principal Calculations

Determining the cooling energy across the evaporator can be broken up into two parts, determining the rate of heat transfer across the HEX's copper tube and determining the rate of heat transfer across the HEX extended surfaces, i.e. the fins. The total thermal resistance across the copper tube comprises of the convection inside the heat exchanger tube due to the refrigerant flow ($\frac{1}{h_{tp}(\pi D_i L_T)}$), the convection outside the tube due to the air blown across the HEX ($\frac{1}{h_o(\pi D_o L_T)}$), and the thermal conduction through the tube and the fin thickness ($\frac{ln\frac{r_o}{r_i}}{2\pi L_T K}$). The rate of heat transfer across the fins was derived from the general equation for heat transfer across an insulated extended surface. The complete equation for the rate of heat transfer across the evaporator HEX, as derived by Thisani [7], is shown as Equation (1).

$$Q_{EVAP} = \underbrace{\frac{T_\infty - T_1}{\frac{1}{h_{tp}(\pi D_i L_T)} + \frac{ln\frac{r_o}{r_i}}{2\pi L_T K_{Cu}} + \frac{1}{h_{AIR}(\pi D_o L_T)}}}_{\text{Tube Equation}} + \underbrace{222(\sqrt{h_{AIR} P K_{Al} A_c}[T_b - T_\infty] \tanh\left[\sqrt{\frac{h_{AIR} P}{K_{Al} A_c}} \cdot L_c\right])}_{\text{Extended Surface Equation}} \quad (1)$$

Where:

Q_{EVAP} = Rate of heat transfer across the evaporator [W]
T_1 = Temperature of refrigerant on the inner wall of the tube (apparatus dew point) temperature [˚C]
T_∞ = Climate temperature [˚C]
$D_{i/o}$ = Internal / external diameter of the HEX tube [m]
L_T = Length of the HEX tube [m]
$r_{i/o}$ = Internal / external radius of the HEX tube [m]
K_{Cu} = Copper conductive heat transfer co-efficient [W/m·K]
h_{AIR} = Forced convection heat transfer co-efficient of air [W/m^2·K]
P = Perimeter of the fin [m]
K_{Al} = Conductive heat transfer co-efficient of aluminium [W/m·K]
Ac = Cross sectional area of the fin [m^2]

L_c = Length of the fin [m]
T_b = Temperature at the fin base where the fin and tube make contact [˚C]

It is approximated that the temperature at the base of the fin where it is connected to the tube (T_b) is the same temperature as the tube internal surface (T_1) due to the high thermal conductivity of cupper and the thin tube wall thickness. With the differential temperature being equal for each condition and all the other variables being constants, the rate of heat transfer across the evaporator is the same for the three conditions. The evaporator design specifications defined in Table 2 were inserted into Equation 1 to solve for the rate of heat transfer across the evaporator as follows:

$$Q_{EVAP} = \frac{20}{\frac{1}{7000(\pi\times0.0109\times5)} + \frac{ln\frac{0.006}{0.00545}}{2\pi\times5\times386} + \frac{1}{100(\pi\times0.012\times5)}}$$
$$+ 222\left(\sqrt{100\times0.0081\times170\times2\times10^{-5}}\right)\times[20]\tanh[\sqrt{\frac{100\times0.0081}{170\times2\times10^{-5}}}\times5])$$

$$\boldsymbol{Q_{EVAP} = 604.1W}$$

The useful cooling energy transferred by the evaporator to the air results in a change in enthalpy of the air. The final state enthalpy at each condition is determined using Equation 2. The initial enthalpy for each climate condition is shown in Table 3 and the mass flow of air across the evaporator was kept constant at 0.107 kg/s. The calculation of the final steady state enthalpy using Equation 2 is tabulated in Table 4.

$$H_{a2} = H_{a1} - \frac{Q_{EVAP}}{\dot{m}_a} \quad (2)$$

Where:
$H_{a1/2}$ = Initial and final enthalpy of air [J/kg]
Q_{EVAP} = Rate of heat transfer across the evaporator unit [W]
$\dot{m}_a$ = Mass flow rate of air [kg/s]

Table 4: Final state enthalpy

Condition	Cooling Energy [Q]	Mass Flow of Air [$\dot{m}_a$]	Initial Enthalpy [H_{a1}]	Final Enthalpy [H_{a2}]
Condition 1: Low temperature	604.1 W	0.107 kg/s	25 900 J/kg	**20 254 J/kg**
Condition 2: Mean temperature	604.1 W	0.107 kg/s	47 100 J/kg	**41 454 J/kg**
Condition 3: High temperature	604.1 W	0.107 kg/s	82 500 J/kg	**76 854 J/kg**

The initial and final conditions of the air at the three climate conditions as a result of the change in enthalpy are plotted on a psychometric chart presented in Figure 4. The cooling dehumidification process takes place from the initial condition of the air to the saturation line then to the Apparatus Dew Point (ADP) and back towards the initial state up to the final enthalpy as explained in [7, 15]. The initial and final air state data from Figure 4 is tabulated on Table 5.

Table 5: Moisture precipitation from initial to final state

Condition	Initial			Final			Differential
	Temp.	RH	Moisture content	Temp.	RH	Moisture content	Moisture condensed
Condition 1: Low temperature	15°C	40%	4.231 ml of water / kg air	11°C	48.5%	3.948 ml of water / kg air	**0.283 ml of water / kg air**
Condition 2: Mean temperature	21°C	65%	10.215 ml of water / kg air	18°C	70%	9.031 ml of water / kg air	**1.184 ml of water / kg air**
Condition 3: High temperature	32°C	65%	20 ml of water / kg air	29°C	71%	18.04 ml of water / kg air	**1.96 ml of water / kg air**

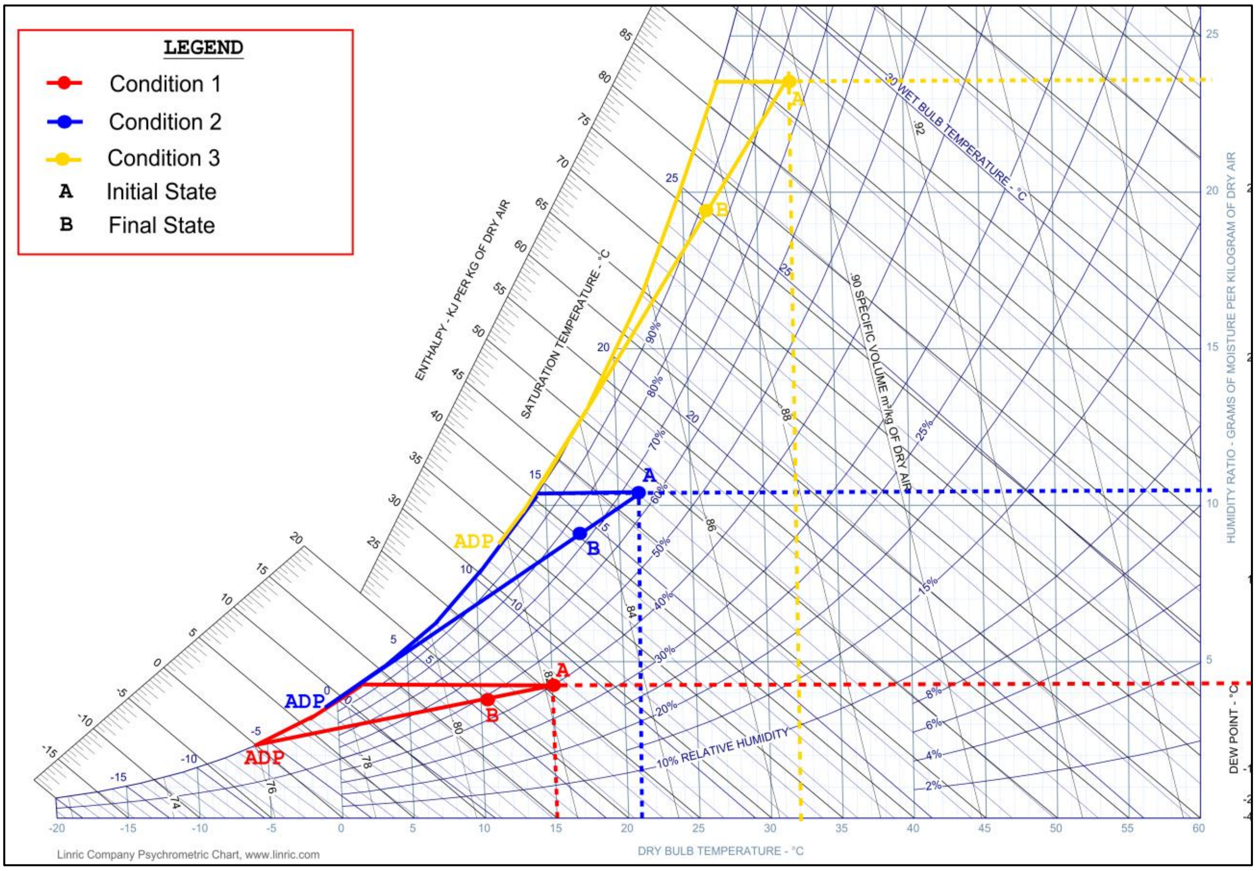

Figure 4: ***Change in air properties at three conditions plotted on psychometric chart***

3.2 CFD Results

The CFD analyses were conducted on the evaporator model shown in Figure 3 using the parameters defined in Table 1 and Table 2. The CFD results for the precipitation taking place across for evaporator HEX at the three climate conditions are shown on Figure 5, Figure 6 and Figure 7 for condition 1, condition 2 and condition 3 respectively. Table 4 shows a summary of the analysis results.

Table 6: Rate of condensation across HEX at three climate conditions

Condition	Control Parameters			Rate of condensation
	Temp	RH	Air flow	
Condition 1	15°C	40%	0.107kg/s	0.109 l/h
Condition 2	21°C	65%	0.107kg/s	0.456 l/h
Condition 3	32°C	65%	0.107kg/s	0.755 l/h

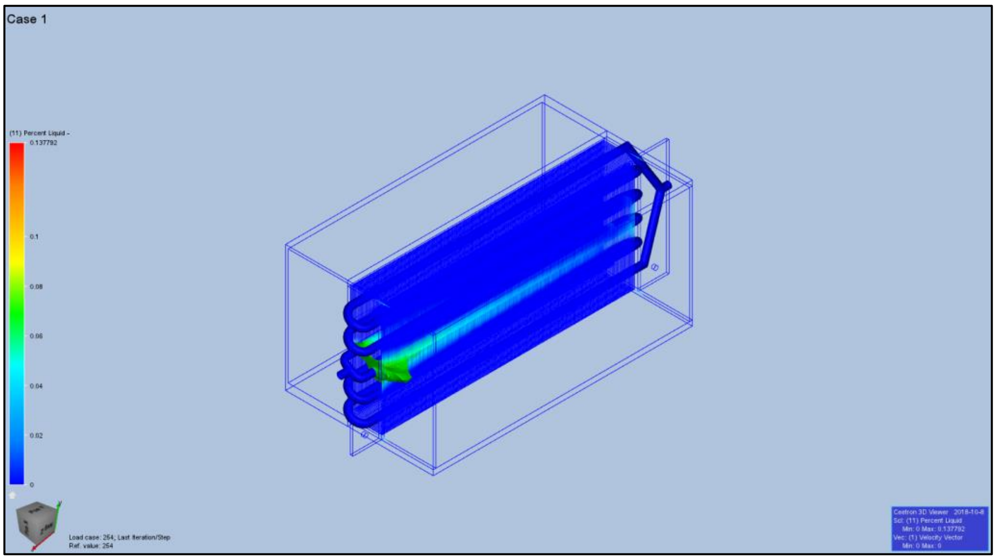

Figure 5: Water condensation - condition 1

Condition 1 yields very low water precipitant estimated at 0.109 l/h at the design air flow of 0.107kg/s. The precipitant is isolated to the mid-centre of the HEX where the chilled refrigerant initially enters. The poor condensation of water vapour is due to the low dew point temperature of the air at this condition and the low air moisture content available in the air. The results suggest that operation of a cooling condensation type AWG is inefficient at condition 1.

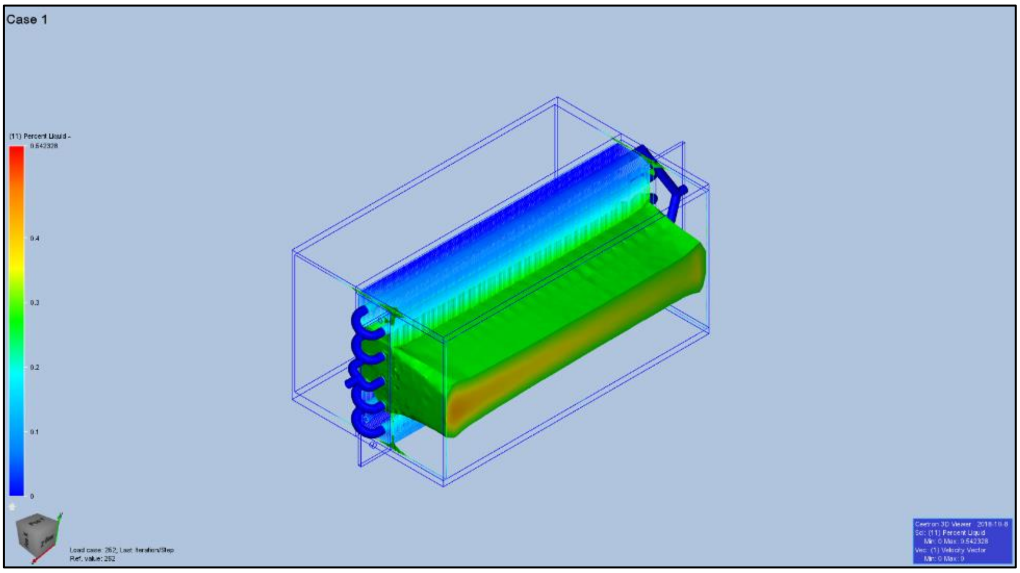

Figure 6: Water condensation - condition 2

Condition 2 is projected to have significantly improved water production when compared to condition 1 with calculations estimating a condensation rate of 0.456 l/h at the design air flow of 0.107kg/s. The condensation of the water vapour occurs at the central region of the HEX with limited condensation taking place at the outer ends of the HEX. The low condensation on the outer surface of the HEX is due to insufficient cooling energy from the refrigerant to cool the air to below due point across the entire surface area.

Condition 3 provides the most yield with a projected water vapour condensation rate of 0.755 l/h at the design air flow rate. At this condition the condensation once again only takes place in the central region of the HEX as the refrigerant reaches superheated vapour phase on the outer cooling surface and is unable to cool the air to below dew point. Greater water condensation occurs due to the higher moisture content in air at higher ambient temperatures and thus greater opportunity for precipitation at the same rate of heat transfer across the evaporator.

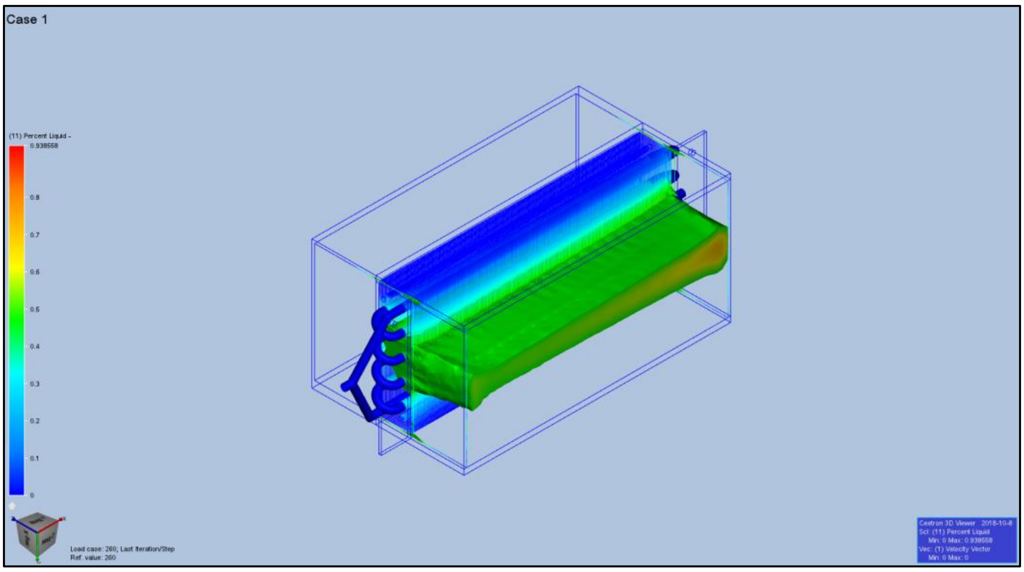

Figure 7: Water condensation - condition 3

4 CONCLUSIONS

The AWG performance projections at fixed cooling energy show a large variance over the three conditions which illustrates the major dependence of cooling condensation type AWG technology on climate for optimum performance. There are means to improve system performance through optimisation of air flow, evaporator geometry, fin arrangement, optimising the refrigerant flow and optimising the bypass factor. However, operating near the low temperature condition can be considered beyond the effective operational limitations of a cooling condensation type AWG due to the dew point temperatures being near freezing, the amount of energy required to cool the air to such low temperatures and the low moisture content available in the air for condensation.

The mean condition shows adequate potential for atmospheric water vapour condensation with projected yields of 0.456 l/h at a mass flow rate of 0.109 kg/s and cooling energy 604.1 W. The mean condition produces water at an efficiency of 1 litre per 1.32 kW of cooling energy which could be feasible in extreme drought conditions. The rate of water condensation at the high temperature condition is projected to yield the most water at 0.755 l/h with the same mass flow and cooling energy resulting in an efficiency of 1 liter per 0.8 kW of cooling energy. The high temperature condition is typically experienced in summer months and can be readily exceeded during extreme drought periods such as the 2015 South African drought. South Africa's temperatures are projected to rise over the next 30 years which will increases the future occurrence of the high temperature condition. This paper concludes that AWGs can be a feasible alternative water supply for east coastal KwaZulu-Natal's rural communities in the event of high temperature droughts with recommendations to further explore the potential use of this emerging technology for the country's growing water requirements.

5 ACKNOWLEDGEMENTS

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USING EXCEL SOLVER IN THE OPTIMIZATION OF PREPOSITIONED DISASTER RELIEF SUPPLY CHAIN IN A HUMANITARIAN OPERATION

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ABSTRACT

In this research, a transportation problem is resolved using Excel solver. This study intends to optimize transportation time and cost solution in order to assist humanitarian operations to prepositioned Distribution Centre (DC) in Southern African Development Community (SADC) countries. The objective of this research is to develop a holistic approach to regional humanitarian supply chain including all countries and their available transportation modes. Following a number of assumptions and constraints, the results reveal that incorporating all SADC countries and their available transportation modes into the transportation problem optimize the region response capacity by minimizing transportation cost during a disaster relief operation.

Key words

Disaster relief supply chain; Transportation problem; SADC; Humanitarian operation; EXCEL Solver

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1 INTRODUCTION

Disaster relief supply chain is the movement of personnel and humanitarian supplies to affected zones in order to alleviate the suffering of the vulnerable [1]. As documented by several researches, the impacts of natural and man-made disasters in the Southern African Development Community (SADC) region have been in the rise, with the prediction of more events in the future. According to the Centre of Research on the Epidemiology of Disasters [2], during the period 1900–2013, there was 642 drought events reported across the world resulting in a huge toll to humanity, killing about 12 million people and affecting over 2 billion [3]; [4]. The total economic damages are estimated at US$135 billion. In 1996, it was estimated over 100 disastrous droughts, floods and related epidemics and pest infections affected about 70 million people in the SADC region over the period of thirty years [5] [6]. Climate variability also impacted economic performance in Sub-Saharan African countries as they are dependent on primary production [7]. Based on the ever-increasing number of disasters in the past half century, Oseni and Masarirambi [8] believe the current situation is likely to worsen due to slow progress in drought risk management, while the populations in the region are increasing as well as the demand for water and the degradation of land and environment. With this eminent growing threat, many researches are acknowledging the need of increased scientific efforts in disasters mitigation in order to curb the disturbing trends.

Logisticians in humanitarian organization have to deal with various types of difficult and complex tasks producing delay in responses and ultimately loss of lives and resources [9]. Hamedi et al. [10] believe that with road transportation, the impact of delivery is constantly at stake and usually directly related to human lives and health. The research therefore intends to use excel solver to optimize the transportation humanitarian decision during relief operations throughout SADC countries.

2 LITERATURE REVIEW

Humanitarian logistics play a major role before and during disaster activities. Looking at the global increase in natural and man-made disasters, the use of logistic and supply chain management can help communities' pre or post-disaster recovery in different ways [11]. It is crucial to prepare and be pro-active to any disaster eventuality.

2.1 Transportation problems

Less literature have explicitly targeted the regional transportation problems and ways to optimize their efficiency (quick action) and effectiveness (low-cost) during a humanitarian operation. Mathematical optimization problem either maximize or minimize the objective function given the set of alternatives. Alternatives (feasible or constraint region) need to be considered in order to minimize the transportation and time in SADC region.

Among the alternatives with major impact to the model's objective function is the quality of infrastructure, the delay in border gates as well as prices associated with fuel, lubricants, tyres and bribes. According to Nikolic [12], the problem of minimization of the total transportation cost is commonly treated in literature as a basic single objective linear transportation model. With transportation cost (TC) reduction targetting important componeent of the total cost production, Rekha et al. [13] developed an algorithm with the purpose of determining the Initial Basic Feasible (IBFS) Solution of Transportation Problem (TP) to minimize the cost.

The transportation time is also relevant in a variety of real transportation problems. Vukadinović [14] highlights two types of problems regarding the transportation time: (i) minimization of the total transportation time (linear function, as aggregate the products of transportation time and quantity), called minimization of 1st transportation time, and (ii) minimization of the transportation time of the longest active transporting route (nonlinear function), called minimization of 2nd transportation time or problem of Barasov [15]. Hamedi et al. [10] paper minimizes the total number of units on transportation operation with longest time for minimization of the transportation time of the longest active transporting route.

2.2 Transportation Modes in SADC

In order to compute an optimal routing plan for first aid material, food, equipment, and rescue personnel from supply points to a large number of destination nodes geographically scattered over SADC region [16], information was collected from local and international organization operating in the region's databases. Table 1 shows the SADC countries, the geographical locations, potential disaster areas, distribution Centre, type of infrastructures, and type of disasters and exposes population.

Table 1: Exposed population in key cities in SADC

	COUNTRIES	GEOGRAPHICAL LOCATIONS	POTENTIAL LOCATIONS	DISTRIBUTION CENTRE	TYPE OF INFRASTRUCTURES	TYPE OF DISASTERS	EXPOSED POPULATION
1	ANGOLA	Sea Access	Luanda	Luanda	Marine, Railway, Airport, Road	Floods, Drought, Epidemic	6 945 386
2	BOTSWANA	Landlocked	Central	Serowe	Airport, Road, Railway	Drought, winds, Floods, Desert, Contaminated soil, Cyclone,	585 595
3	DRC	Sea Access	Katanga	Lubumbashi	Marine, Airport, Road, Railway	Volcanoes, Political conflicts, Epidemics, Artisanal and small-scale mining	5 608 683
4	LESOTHO	Landlocked	Berea	Berea Hill	Railway, Airport, Road	Seismic disaster, chronic food insecurity, HIV/AIDS, Poverty, wind, localized floods, early frost natural and pest infestations, Drought, Snowfall, landslide, lightning, fire and road accidents	300 000
5	MADAGASCAR	Island Access	Analamanga	Antananarivo	Marine, Railway, Airport, Road	floods, cyclone,	3 439 600
6	MALAWI	Landlocked	Lilongwe	Lilongwe	Railway, Road, Airport	Land degradation, Poverty, Drought, Floods, HIV/AIDS	1 346 360
7	MOZAMBIQUE	Sea Access	Zambezia	Quelimane	Marine, Railway, Airport, Road	Cyclones, Erosion, Deforestation	3 850 000
8	MAURITIUS	Island	Plaines Wilhems	Vacoas	Marine, Road, Railway, Airport	floods, cyclone, droughts, Earthquakes	368 621
9	NAMIBIA	Sea Access	Khomas	Windhoeck	Marine, Road, Railway, Airport	Floods, droughts, storms, wildfires	415 800
10	SECHELLES	Island	Mahe Island	Victoria	Marine, Road, Railway, Airport	Floods, Earth quakes, Tsunami, Cyclones	77 000
11	SOUTH AFRICA	Sea Access	Kwazulu Natal	Durban	Marine, Railway, Airport, Road	Wild fire, floods, hail storm, Tremors, Seism	10 456 900
12	SWAZILAND	Landlocked	Lubombo	Siteki	Road, Railway, Airport	food insecurity, HIV/AIDS, Chronic Poverty, droughts, floods, windstorm, hailstorm, environmental degradation	207 731
13	TANZANIA	Sea Access	Dar es Salaam	Dar es Salaam	Marine, Road, Airport, Railway	Floods, Tremors, Volcanoes, Air pollution, Artisanal and small-scale mining	4 364 541
14	ZAMBIA	Landlocked	Lusaka	Lusaka	Railway, Airport, Road	Lead Poisoning, Floods, Earthquakes	2 888 600
15	ZIMBABWE	Landlocked	Manicaland	Mutare	Road, Railway, Airport	Drought, Tremors, Earthquakes, erosion, water and air pollution, wildlife	1 753 000

2.2.1 Average transportation time and cost

Further cost to be associated within the Southern Africa is the delay cost. This cost relates to border gate, weighbridges, ports and lengthy customs processes. Simulation led to the suggestion that reduction on border delays could reduce transport costs. These delays cost over US$ 200 a day and represent a loss of US$ 120 million per year, given traffic volumes. The journey from Lusaka to Durban takes over eight days to complete, with almost four days spent at border crossings. While trucks can operate at 50–60 kmph, the effective speed along the route averages a little over 12 kmph. The costs of delays for an eight-axle interlink truck has been estimated to be around US$ 300 per day; given traffic volumes, this represents a loss of more than US$ 50 million annually [17][18][19]. The SADC corridor comprises thirty border crossings and for the benefit of the research, two active ones have been studied, Beit Bridge (a Border between South Africa and Zimbabwe) and Chirundu (a border between Zambia and Zimbabwe). Curtis [18] posited that Beit Bridge handles as many as 500 trucks a day; delays for northbound traffic are 34 hours and for southbound traffic 11 hours. Estimation for Chirundu border indicates that it takes northbound traffic approximately 39 hours to cross the border and southbound traffic 14 hours. The total cost of trucks standing at these two border posts is over US$ 60 million per year. The cost at other borders—such as Groblersbrug/Martins Drift and Kazungula—are factored, the costs increase with an additional US$ 100 million per annum ([18]; [17]). Additional costs include the following: “A Mozambican Company entering Zimbabwe must pay a road user fee of US$ 25 per 100 kilometers, an entry visa that costs approximately US$ 30 for a month, and a guarantee of US$ 120 per year” [20].

2.2.2 Transportation Infrastructures

2.2.2.1 Road

SADC region main trading artery is the North-South corridor, running north from the port of Durban in South Africa toward the Southern Democratic Republic of Congo and Tanzania. This corridor allows landlocked countries such as Botswana, Zimbabwe, Malawi and Zambia to have sea access. Durban port is also the main supplier for Swaziland and Lesotho, both landlocked countries also. Other corridor exists in the region, for instance Lubumbashi (DRC) has an alternative access to Dar es Salaam (Tanzania) instead of the 3000 km to Durban. Table 2 indicates the road conditions along major transit corridors in the region. Enhancing the capacity, the conditions and the safety of these alternative routes add into the decision-making factors and minimize the transportation cost.

Table 2: Road conditions along major transit corridors in the SADC [19]

	Condition (%)				Type (%)			Percentage in traffic bands (AADT)			
Corridors	Good	Fair	Poor	Unknown	Paved	Unpaved	Unknown	<300	300-1,000	>1,000	Unknown
Gaborone to Durban*	***97.1***	***0.5***	***0***	***2***	***99.5***	***0***	***0.5***	***0***	***0***	***96.5***	***3.5***
i) Botswana	90.5	0	0	10	100	0	0	0	0	100	0
ii) South Africa	97.4	0.5	0	2	99.5	0	0.5	0	0	96.3	3.7
Harare to Durban *	***72.9***	***25.3***	***0.5***	***1***	***100***	***0***	***0***	0.8	***3.3***	***94.7***	***1.2***
i) Zimbabwe	0	100	0	0	100	0	0	3.3	13.9	82.8	0
ii) South Africa	95.8	2	0.7	2	100	0	0	0	0	98.4	1.6
Lusaka to Durban*	***62***	***34.6***	***2.4***	***1***	***100***	***0***	***0***	**1.3**	***5.5***	***92.1***	***1***
i) Zambia	26.1	31.3	42.5	0	100	0	0	0	59	41	0
ii) Zimbabwe	0	100	0	0	100	0	0	4.2	8.7	87.1	0
iii) South Africa	95.8	2	0.7	2	100	0	0	0	0	98.4	1.6
Lubumbashi to Durban	***59***	***35.3***	***4.9***	***1***	***100***	***0***	***0***	**1.1**	***6.4***	***89***	***3.4***
i) Congo DR	0	100	0	0	100	0	0	0	0	0	100

ii) Zambia	46.2	28.4	25.4	0	100	0	0	0	23	77	0
iii) Zimbabwe	0	100	0	0	100	0	0	4.2	8.7	87.1	0
iv) South Africa	95.8	2	0.7	2	100	0	0	0	0	98.4	1.6
Lilongwe to Nacala	***27.2***	***60.2***	***12.5***	***0***	***61***	***39***	***0***	**0**	***0***	***34.7***	***65.3***
i) Malawi	78.4	18.5	3	0	100	0	0	0	0	100	0
ii) Mozambique	0	82.4	17.6	0	40.2	59.8	0	0	0	0	100
Harare to Beira*	***0***	***72.4***	***0***	***28***	***100***	***0***	***0***	**4.2**	***0***	***44.3***	***51.5***
i) Zimbabwe	0	100	0	0	100	0	0	8.7	0	91.3	0
ii) Mozambique	0	46.4	0	54	100	0	0	0	0	0	100
Gaborone to Walvis Bay	***59.2***	***17.3***	***0.1***	***23***	***100***	***0***	***0***	**11.5**	***44.3***	***44.2***	***0***
i) Botswana	50.7	5.1	0	44	100	0	0	8.2	65.4	26.4	0
ii) Namibia	68.8	31	0.2	0	100	0	0	15.3	20.6	64.1	0
Lusaka to Dar Es Salaam*	***68.9***	***19.1***	***9.8***	***2***	***100***	***0***	***0***	**34.2**	***23.6***	***42.2***	***0***
i) Zambia	70.1	19.3	10.6	0	100	0	0	63.7	26.1	10.2	0
ii) Tanzania	67.5	19	8.9	5	100	0	0	0	20.7	79.3	0

2.2.2.2 Railways

The Rail Transportation in Southern Africa is by far the most developed in the Africa. SADC has seven well-developed interconnected national railways going from Durban (South Africa) to Kasai (DRC). Unlike in other parts of Africa, Foster and Ranganathan [17] believe that the rail network in the SADC is integrated with the use of a uniform gauge. With 55,000 km of track, Sub-Saharan carries much more freights than any region in the continent, handling in overall 74 percent of Sub-Saharan Africa's freight traffic (including coal and minerals) and more than 80 percent of the total net tonne-kilometers. Table 3 shows rails corridors across Southern African railways and list various SARA (Southern African Rails Association).

Table 3: SARA rail Corridors

No	Rail Corridor	Sea Port	End Point	Rail Companies
1	Central	Dar es Salaam	Kigoma, Mwanza, Moshi	TRL
2	Tazara	Dar es Salaam	Lubumbashi	Tazara (RSZ/SNCC)
3	Nacala	Nacala	Beira	CCFB/CEAR (needs checking)
4	Beira	Beira	Lubumbashi	CCFB/NRZ/(RSZ/SNCC)
5	Plumtree	Durban	Lubumbashi	TFR/BR/NRZ/(RSZ/SNCC)
6	Beitbridge	Durban	Lubumbashi	TFR/BBR/NRZ/(RSZ/SNCC)
7	Limpopo	Maputo	Lubumbashi	CFM/NRZ/(RSZ/SNCC)
8	Ressano Garcia	Maputo	Johannesburg	CFM/TFR
9	Goba	Maputo	Manzini	CFM/SR
10	Richards Bay	Richards Bay	Phalaborwa	TFR/SR
11	Namibian	Walvis Bay	Johannesburg	TransNamib/TFR

2.2.2.3 Airways

Among the 60 Intercontinental routes in Africa, Johannesburg's OR Tambo is by far the busiest air transport hub in the region (Figure 1). Nairobi, Lusaka is also emerging as headquarters in the regions. According to Foster and Ranganathan [17], SADC region has the largest and most advanced domestic air transport market on the African continent, with South Africa considered to be the most important Intercontinental Gateway. The intraregional seats are also larger than other parts of Africa. SADC Countries such as Angola, the DR Congo, Mauritius, Madagascar, Mozambique, South Africa, and Tanzania have higher domestic connectivity; while Malawi, Zambia, Botswana and Seychelles have a much lower level of air connectivity.

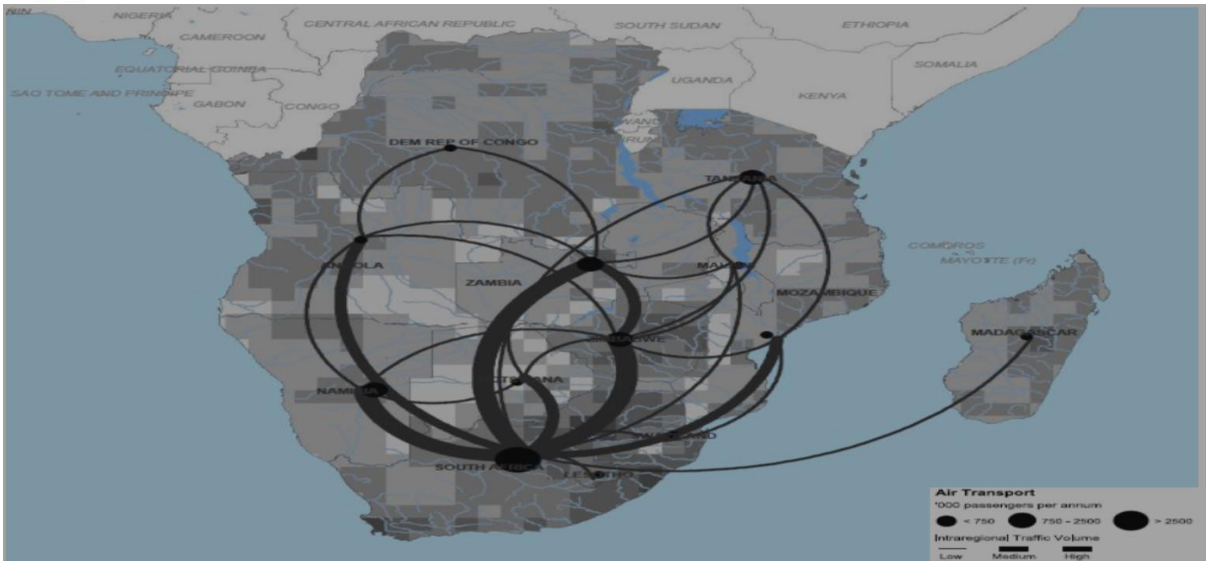

Figure 1: The SADC's regional airports and air traffic flows. *Source [19]*.

2.2.2.4 Seaports

For Ocean Shipping Consultants Limited (2010), Southern African ports have seen a considerable increase between 1995 [1,356.0 (TEUs) for the Container traffic and 2.7 (000s Tonnes)] for Cargo traffic and 2005 [3,091.8 (TEUs) for the Container traffic and 14.5 (000s Tonnes] for Cargo traffic. SADC is comprised of approximately 60 ports from which Durban and Dar Es Salam are by far the most important in terms of their utilization and capacity. Both mentioned ports have containers capacity exceeding 100%. According to the global average, SADC ports are 75 % more expensive and subject to unlimited number of delays. Across the SADC region, port terminals offer free storage for up to seven days, and thereafter they apply a daily storage charge. Table 4 shows all the major SADC regional Ports.

Table 4: Strategic SADC regional Ports [19]

No	Port	Country	Corridors
1	Durban	South Africa	North-South, Maseru Durban
2	Maputo	Mozambique	Maputo, Limpopo
3	Beira	Mozambique	Beira
4	Dar es Salaam	Tanzania	Dar es Salaam, Central
5	Walvis Bay	Namibia	Trans-Cunene, Trans-Kalahari, Trans-Caprivi
6	Benguela	Angola	Lobito
7	Luanda	Angola	Malange
8	Mtwara	Tanzania	Mtwara
9	Luderitz	Namibia	Trans-Orange
10	Cape Town	South Africa	Trans-Orange
	Matadi	Dr Congo	Kongo Central-Kinshasa

2.3 Transportation model

Rekha et al. [13] believe that a transportation model has an increasingly great impact on the management of transport. According to these authors, it is one of the subclass of linear programming problem with the aim of transporting various quantities of a single homogeneous commodity, that are initially stored at prepositioned Distribution Centres (DC) to different destination in such that the transportation cost, transportation distance or time is minimum. The pre-positioning problem falls into the area of humanitarian logistics, which has been formally defined by an advisory committee at the Fritz Institute as "the process of planning, implementing and controlling the efficient, cost-effective flow of and storage of goods and materials as well as related information, from point of origin to point of consumption for the purpose of meeting the end beneficiary's requirements" [22].

The two main elements in the development of transportation model involve a number of shipping sources (prepositioned Distribution Centres (DC)) and number of destinations [23]. It deals with the minimum cost plan to transport a commodity from a number of sources to destinations using initial feasible solution max min penalty approach [13]. The well-known methods are: Vogel's Approximation Method (VAM) [24], Balakrishnan's version of VAM [15], and H.H. Shore version of VAM [25]. In this paper we present a method which gives same minimization cost as Vogel approximation method.

3 RESEARCH METHODOLOGY

This quantitative analysis intended to enquire about the relief organizations challenges in the region, their level of their preparedness, the region quality of infrastructure, the quality of the transportation system available, the transportation modes utilized, the decision affecting the selection of those transportation modes, etc.

3.1 Linear Optimization problem

According to Vignaux and Michalewicz [26], transportation problems require the determination of a minimum cost transportation plan for a single commodity from a number of sources to a number of destinations. Prasad et al. [27] expressed the transportation problem in mathematical language. The mathematical language of the transportation problem is as follows:

$$Min\, z_q = \sum_{i=1}^{m} \sum_{j=1}^{n} C_{ij}^{q} X_{ij}, q = 1,2 \quad \textbf{(1)}$$

Subject to:

$$\sum_{j=1}^{n} X_{ij} = a_i \, , i = 1,2,3,4,5,6,7, \dots , m \quad \textbf{(2)}$$

$$\sum_{i=1}^{m} X_{ij} = b_j, \; j = 1,2,3,4,5,6,7, \dots , n \quad \textbf{(3)}$$

$$X_{ij} \geq 0, \qquad \forall i, j \quad \textbf{(4)}$$

With C_{ij}(t) as the unit cost of transportation from supply point m $i(i = 1,2, \dots , m)$ to demand point $j(j = 1,2, \dots , n)$ when the duration allowed for the transportation is t units and the destination q units. Now, setting X_{ij} to be the variable denoting the amount transported from supply point i to demand point j, let a_i be the availability at source points i and b_j the demand at demand point j.

3.2 Optimization problem using Excel Solver

Although various relief chain distribution problems has been encountered and studied [28], many countries in the regions (SADC) still have minimal available structures and resources for supply chain management activities and techniques that have relief solutions for the affected people caused by the disaster [9]. In order to obtain optimal humanitarian decision during disaster relief operations, the research made use of "Excel Solver" taking into account all relevant available information stated in this study. Excel Solver allows us to find solutions of optimization problems of all kinds (single or multiple variables, with or without constraints).

4 PROBLEM SOLUTIONS

In the development of Excel Solver, information was loaded using the following instructions:

- To each variable we have to attribute a position on the worksheet.
- Define the objective function.
- Define all constraints: The constraints are defined a bit differently than the objective function. A constraint is a relation linking two expressions.

4.1 Variable Definition

The first step in developing Excel Solver modeling process is to identify and label the decision variables. These are the variables that represent the quantifiable decisions that must be made in order to determine the daily production schedule or in this research case, humanitarian supply decision. That is, we need to specify those quantities whose values completely determine a production schedule and its associated profit.
Table 1 listed SADC countries with each one vulnerable city including the number of population exposed. Table 5 below determines each country supply quantities, represented respectively by the following symbols: *S*1, *S*2, *S*3, *S*4, *S*5, *S*6, *S*7, *S*8, *S*9, S10, S11, S12, S13, S14 and S15.

Table 5: Supply Quantity of reliefs for SADC countries

SC	*S*1	*S*2	*S*3	*S*4	*S*5	*S*6	*S*7	*S*8	*S*9	S10	S11	S12	S13	S14	S15
SQ	200	90	300	30	190	50	110	250	150	30	80	50	160	120	140

N.B: SC: Supplier code; SQ: Supply quantity (piece/day; 1 Batch of Maize = a Tonne

The demand for each country is represented respectively by the following symbols: D1, D2, D3, D4, D5, D6, D7, D8, D9, D10, D11, D12, D13, D14 and D15. Each variable relate to those following countries: Angola (S1, D1), Botswana (S2, D2), Democratic Republic of Congo (S3, D3), Lesotho (S4, D4), Madagascar (S5,D5), Malawi (S6, D6), Mauritius (S7, D7), Mozambique (S8, D8), Namibia(S9, D9), Seychelles (S10, D10), South Africa (S11, D11), Swaziland (S12, S12), Tanzania (S13, D13), Zambia (S14, D14), and Zimbabwe (S15, D15). The quantities demanded in each country are assumed in Table 6.

Table 6: Demand Quantity of reliefs for SADC countries

SC	*D*1	*D*2	*D*3	*D*4	D5	D6	D7	D8	D9	D10	D11	D12	D13	D14	D15
DQ	220	50	350	30	190	50	90	230	150	45	80	35	200	95	135

SC: Supplier code; DQ: Demand quantity (piece/day); 1 Batch of Maize = a Tonne

According to Chandrakantha [8], for optimization problems with more than two variables, we need to use complex techniques and tedious calculations to find the optimal solution. The spreadsheet and solver approach simplifies solving optimization problems as it organizes the spreadsheet to represent the model. Then it separate cells to represent decision variables; create a formula in a cell to represent the objective function and create a formula in a cell for each constraint left hand side. Once the model is implemented in a spreadsheet, next step is to use the Solver to find the solution [8].

4.2 Objective function Definitions

The next step in the modeling process is to express the feasible region as the solution set of a finite collection of linear inequality and equality constraints. The objective function could be to minimize or maximize as per the equation below.

$$Min\ Objective\ Z = C \qquad (5)$$

The function to be minimized or maximized is called the objective function and the set of alternatives is called the feasible region (or constraint region).

4.3 Constraint Definition

This was done by setting a maximum allowable time limit and optimizing the cost for that given time constraint. In order to keep the time and the cost at their optimal point, constraint must be set. There are five constraints that have been generated from the study and these are:

- Transportation time cannot exceed the decided Maximum reaction time
- Transportation cost must be minimized
- The transportation quantity has to exceed or equal the demand.
- The transportation quantity from each country cannot exceed its own supplier quantities.
- The transportation time must exceed zero

As per Table 1, disaster happen only one area in the country and all affected areas have international airport access. All landlocked countries are connected with a rail access and all 15 countries will be shipping countries and receiving countries with cost multiply by time (C X T= V).

With 15 variables (countries) as mentioned above (D1, D2, D3, D4, etc…), Baraka, Yadavalli and Ranil [29] indicated the equations below to embrace the above constraints. The finding of minimal transportation cost using different time constraints is highlighted on the Equation (5).

Subject to:

$$C = \sum_1^{15}(S_i) \tag{6}$$

$$T = Max\ (M_i) \tag{7}$$

$$M_i = d_i\ x\ E_i \tag{8}$$

$$S_i = d_i\ x\ O_i \tag{9}$$

$$S_i > CD \tag{10}$$

$$Q \geq T \tag{11}$$

$$S_i \geq 0 \tag{12}$$

Constraint (6) denote the optimal cost of transportation from supply points i to a demand point j while constraint (7) denote the maximum time it take for a supply to reaches it demand point. Constraint (8) denote a calculated time per country (in hours) by considering the given time per ton for countries and the quantity of aid (tons) shipped from countries. Constraint (9) denote a calculated cost per country by considering the given time per ton for countries and the quantity of aid shipped from countries. With Constraint (10) denote that the calculated cost per hour is superior to the country demand, while constraint (11) clarify that the maximum given allowable time (in hours) is superior to maximum transportation time. Lastly, constraint (12) specifies that the calculated cost per countries is superior to zero.

With

M_i: Calculated Time per country (in hours) $i \in I$

C: Optimal transportation Cost (in dollars)

T: Maximum transportation time (in hours).

S_i: Calculated cost per country (\$)$i \in I$

d_i: Variable quantity of aid (in tons) shipped from countries $i \in I$

E_i: Given average time per ton for countries $i \in I$ to country with disaster

O_i: Given cost per ton to countries $i \in I$ to country with disaster

CD: Given country demand

Q: Maximum given allowable time (in hours)

4.4 Interpretation of the Model

With the assumed demand and supply quantity, the assumed cost per tonnes for transportations and the time and distant; the following decision scenarios were developed Figure 2 and Figure 3. With the known supply and demand quantities, transportation costs as well as traveling times and distances between countries, this model goal is to identify which scenario gives the research an optimal point or the most valuable decision to make between the cost/time/country involved in the trade-off. The three scenarios are **a)** dividing the cost x time by the number of countries involved (Figure 2) **b)** multiplying the cost by the time (Figure 2), and **c)** dividing the cost by the number of countries involved (Figure 3).

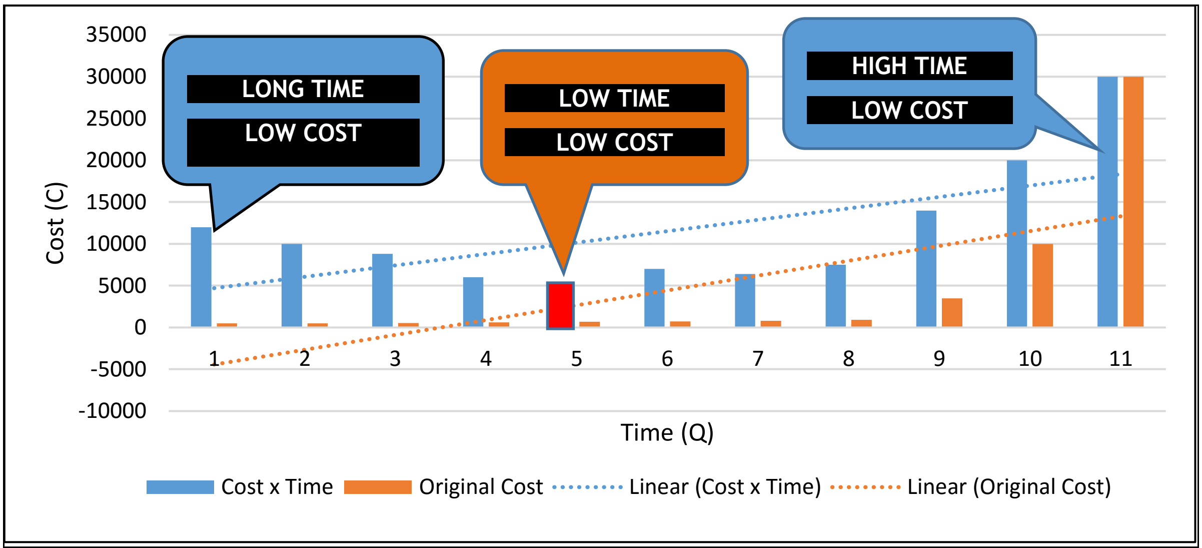

Figure 2: Original cost and Cost multiply by time

4.4.1 Decision 1: The variation of time for Original cost optimization

Figure 2 shows a visual illustration of the results obtained in the model. It is logical that the urgent the disaster, the quicker relief is required, the more expensive the transportation cost is. This method is unfavourable because the transportation time and cost increases simultaneously.

4.4.2 Decision 2: Cost x Time trade-off

Cost x Time equation gives the researcher an understanding of the best possible decision. Looking into the graphical representation in Figure 2, the yield shows the following: (1) longer times with lower costs are unfavourable for disaster such earthquakes, cyclones, etc, but favourable for disaster such as drought (2) higher costs with lower times are also unfavourable and that (3) a point near the optimal time can be achieved by minimizing cost and maximizing reliefs supply at an allowable time.

4.4.3 *Decision 3: Time versus Cost*

This is derived from value generated from Cost x Time divided by the number of countries involved and cost divided by the number of countries involved. This process gives this study a clear numerical view of the best possible decision to be made in the best possible time and in a cost effective way. Figure 3 shows in this scenario that increase the cities or countries involved simultaneously decrease the response time and cost. Under this scenario, the optimization of time and cost is reached.

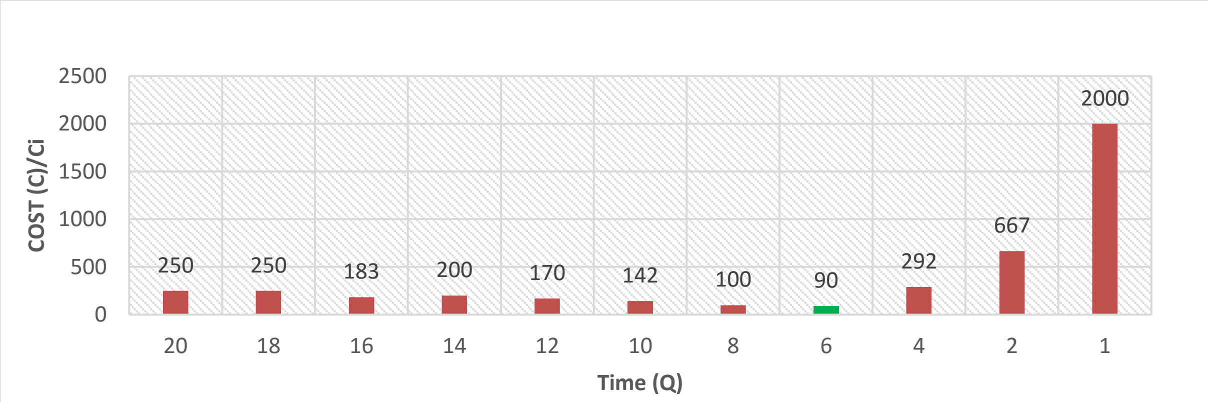

Figure 3: Time vs. Cost for countries involved ratio Result using EXCEL optimization tool

5 CONCLUSION

This study has used a quantitative analysis approach to determine the various decision making steps and procedures humanitarian logistics and supply chains. This research has highlighted locations for supply and demand, quantity to be supply, the cost, the time and the distance for the operation to be completed. Such operation has proven costly and time consuming, especially in a region with minimal infrastructure and preparedness for such events. The use of Excel Solver assisted decision maker to make cost effective decisions by calculation the feasible point especially for problems of more than two variables. With the minimization objective, the most feasible transportation point will be one that minimizes the transportation time and cost simultaneously.

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USING MULTI CRITERIA DECISION MAKING FOR HUMANITARIAN PLANNING DURING A LAST MILES RELIEF SUPPLY IN SADC

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ABSTRACT

Southern African Development Community (SADC) has seen an increase in drought disasters in the past decades causing thousands livestock's death, and triggering major foods, water shortages with related impacts on livelihood and businesses. With future prediction pointing toward aggravation of climate variability, this research intends to provide SADC and the world with a practical decision making mechanism capable of enhancing the effectiveness and efficiency of the regional relief operations. The study aims to optimize the pre-positioned relief supplies and demands in facility locations across SADC. The objective is to upgrade the regional humanitarian disaster planning and the drought disaster response capacities. The multi-criteria decision making (MCDM) and location criteria for site selection are utilized to minimize the multiple relief items, response times, capacity restrictions while maximizing the satisfied relief demand to the pre-positioned destinations.

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1 INTRODUCTION

A surge on natural disaster cases was encountered worldwide between 2002 and 2011, with 394 natural disasters recorded per annual average having killed 107 000 people, affecting 268 million people others, while causing an estimated US$ 143 billion's worth of damage [1]. A world Disasters report published in 2014 by the International Federation of Red Cross (IFRC) [2] showed the year 2013 as being the worst in recent time with a registered 337 natural disasters in 2013. According to [3], poor countries and areas are more vulnerable to disaster and are most severely affected than richer one. It is further estimated that 90% of all those affected by natural disasters are in countries of medium human development [4], and that two thirds of those killed are from countries of low human development [5].

FAO/WFP report presents Swaziland statistically as one of the most vulnerable country to climate variability in the SADC region [6]. This land locked country, with high poverty rate (63% in 2010/11), high unemployment levels and low Human Development Index, has a history of severe droughts that have affected over 80% of its rural-based population, which depend largely on subsistence farming and/or livestock rearing [7]. The 2015/2016 drought events alone have seen 5.5% of Swazi population in severe food and water insecurity and in urgent need of assistance, while another 18% with moderate food insecurity [6].

Although most African countries are in dire need of logistical support from the humanitarian community, [8] noted an absence of disaster planning in Africa. To mitigate such lack, this research provides SADC countries with both decision making and a methodological approach to disaster relief supply chain. A decision model is proposed for the optimization of decision making during a humanitarian planning of distribution centers. This study aims to optimize the pre-positioned relief supplies and demands decisions in facility locations across SADC in order to upgrade the regional drought disaster response capacities. This study outcome will likely guarantee an efficient and effective decision making during the inventory management for disaster response.

In order to accomplish the above aim, the following objectives will be addressed:

- The identification and quantification of drought impacts in SADC.
- The identification of the most appropriate locations for creating an efficient emergency response facility in the region.
- Determination of a multi-criteria decision making process with location criteria for site selection.
- Outline the results and ways to increase SADC drought disaster response with efficiency and effectiveness.

2 LITERATURE REVIEW

According to [9], 642 drought events were reported across the world between 1900-2013, causing about 12 million deaths, US$ 135 billion economic damages and affecting 2 billion more [10]; [11]. It is estimated that SADC region have seen over 100 disastrous droughts over thirty years period [12]. The current conditions in SADC are likely to worsen due to the slow progress in drought risk management in comparison to the growing population [7].

2.1 Drought's history in SADC

SADC covers an area of approximately 7 million square kilometres ranging from desert, through temperate, savannah and equatorial climates. Average annual precipitation ranges from 100 to 2000 mm/annum. About 75% of the SADC region is classified as arid to semiarid. Mean annual runoff is 650 cu.km in 16 main river basins of which 85% are shared [13]. Drought is a common SADC's disaster and ground fact shows that it is increasingly unusual for drought not to occur in the region each year. The 1991–92 drought events alone ravaged more than 80% of the region and affected thousands. Table 1 lists the number drought events, number killed, total affected, damage (US$ 000) as well as the population number per country and the proportion per population that has affected the Southern African region from 1900 to 2016.

Table 1: Drought events, number killed, numbers affected and cost of damages SADC from 1900 to 2016 [9]

Drought	Events count	Total deaths	Total affected	Total damage ('000 US$)	population number (million)	Proportion per population
Angola	7	58	4443900	0	25.83	17.2%
Botswana	7	0	1344900	47000	2.3	58.47%
DRC	2	0	800000	0	79.7	0.01%
Lesotho	6	0	2736015	1000	2.2	124%
Madagascar	7	200	3535290	0	25	14.14%
Malawi	8	500	24378702	0	17.75	13.7%
Mauritius	1	0	0	175000	1.28	0
Mozambique	12	100068	17757500	50000	28.76	67.70%
Namibia	8	0	1125700	115000	2.5	45%
Tanzania	10	0	12737483	0	55.16	23.09%
Seychelles	0	0	0	0	0.97	0
South Africa	9	0	20175000	3000000	55	36.7%
Swaziland	5	500	1630000	1739	1.3	125%
Zambia	5	0	4173204	0	16.7	24.9%
Zimbabwe	8	0	18512642	51000	16	116%

According to records EM-DAT [9] as per Table 1, SADC countries have had nearly 63 million people affected by droughts disaster from 1900 to 2016. Seychelles and Mauritius however have no population affected recorded although the later had encounter a substantial financial damages [9].

Figure 2 shows the proportion of affected countries to the country population revealing that Swaziland, Lesotho and Zimbabwe are respectively the most affected nations of drought in SADC. DRC, Mauritius and Seychelles have shown little threat to drought disaster in comparison the other twelve. It should be noted that the proportion per population calculation depicts the severity of the impact of the drought disasters to SADC population.

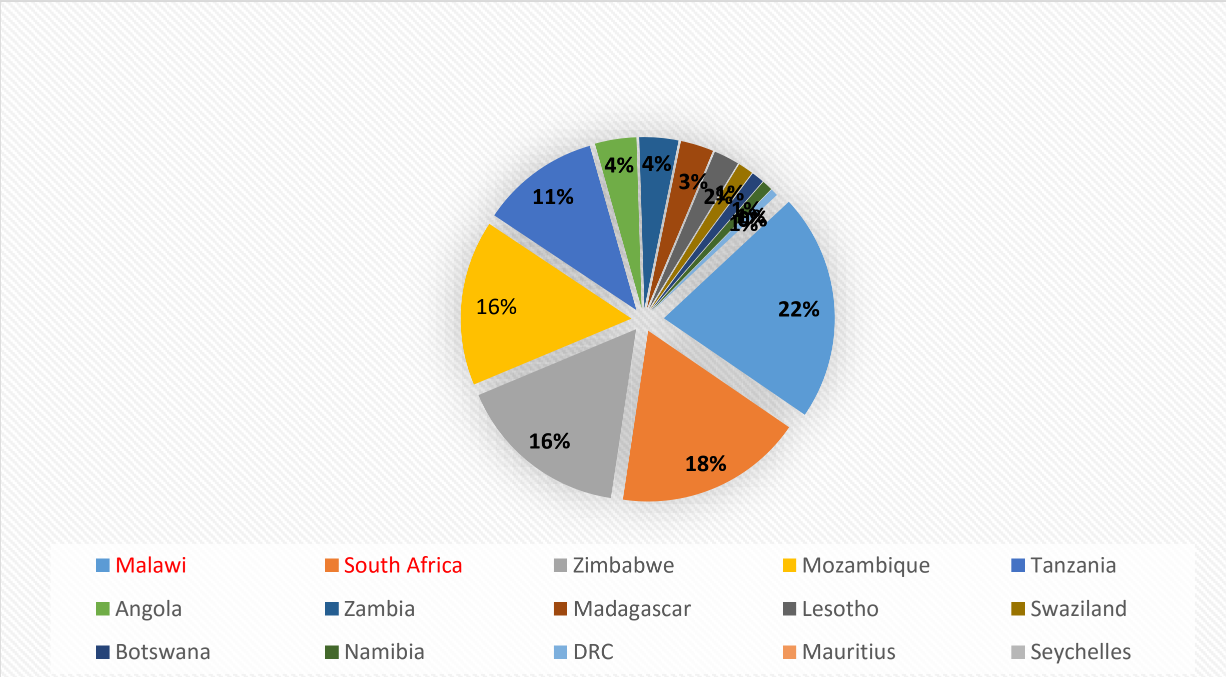

Figure 1: Ranking of SADC Countries affected by droughts from 1900 to 2016 [9].

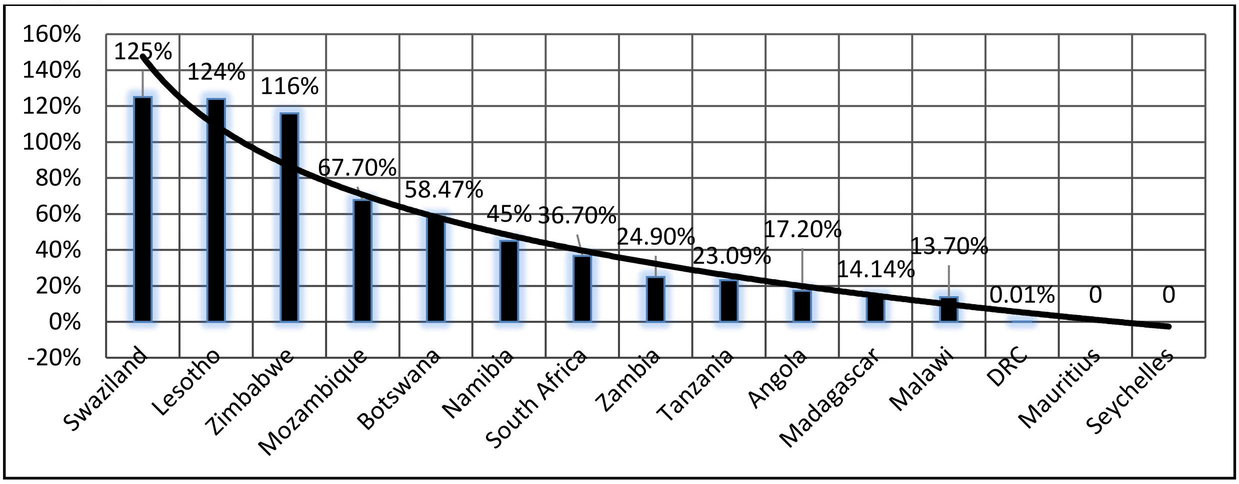

Figure 2: Proportion of population/number affected to droughts in SADC from 1900 to 2016 [9].

2.2 Models history

In the past years, prepositioning location facility emerges as one of the most effective tools in humanitarian disaster planning. The first research contributors [14] and [15], are among on the topic, using mathematical models to determine numbers and locations of Distribution Center (DC) to be included in a network of emergency facilities, including inventory management at the established facilities. A quantitative approach was introduced to multi-objectives prepositioning by maximizing the total expected relief demand of disaster areas covered by existing distribution centers through four objectives: (1) maximum response time limit, (2) budget availability, (3) multiple item types, and (4) capacity restrictions [16]. Then, [17] solved a multi-objective facility location problem in emergency logistics by integrating business 'best practices' such as just-in-time and campaign system in disaster relief chain, addressing therefore facility location problem in terms of material flow. The findings also include an escalation of orders from local DC to regional, continental as far as the main warehouse, to replenish the initial relief items that were distributed to affected area.

Multi-Criteria Decision Making (MCDM) is both a quantitative and qualitative way of optimizing the pre-positioning locations facility. The MCDM was first represented in the perspective of facility location problem by designing a framework and ranking them in terms of importance [18], then application of multi-criteria decision making in a small scale to a real life scenario in Bangladesh, helped bring more transparency in results [19]. MCDM was employed to provide a decision support framework for locations identification to address network design in Indonesia disaster relief supply chains [20].

MCDM is defined as a discipline of operations research that considers decision problems in a context of a number of decision criteria [21]. For [19], the benefits of applying MCDM are its ability to highlight the structure of the decision problem and therefore results are in a high transparency. The obtained model helps relief organizations make a well planned warehouse location decision instead of an often ineffective ad-hoc decision. In term of MCDM technique, two approaches are worth mentioning: 1) Analytic Hierarchy Process (AHP), and 2) Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE). Author [22] and [18] proposed to address the MCDM problem using Analytic Hierarchy Process (AHP) although each differ on the number of attributes (seven vs. five) as well as the application (traditional/manufacturing vs. humanitarian). AHP and PROMETHEE I+II frameworks include considerations on criteria (attribute) such as delivery time, costs, spatial distance, infrastructure, climate, economic aspects, personnel related aspects. Each of the frameworks' attribute, unlike in business setting, may not be applicable to SADC drought supply chain. Cost and available infrastructure, among others, play a crucial attribute role in humanitarian supply chain decision during a drought; unlike the climate attribute. From the SADC drought preparedness, Table 2 lists seven criteria:

Table 2: Definition of each location criteria for site selection

Series No	CRITERIA		DESCRIPTION
C1	Delivery time	DT	Time to reach a humanitarian Response Facility (HRF) with a loaded disaster transport
C2	Security	S	Concerning the risk factor, especially during the last mile distribution of HRF.
C3	Access to affected areas	AAA	Looking at the accessibility of reliefs to the most affected HRF.
C4	Population Coverage	PC	The number of population exposed to a natural disaster to cover in a HRF.
C5	Available infrastructures	AI	Availability of required infrastructure to access in a HRF decision.
C6	Cost	C	Implication of cost into the HRF decision
C7	Capacity of relief to be transported	CRD	Contribution of capacity of relief to be transported into a HRF

3 RESEARCH METHODOLOGY

Aside from the reviewed literature, the study has utilized disaster management databases such as: EM-DAT: The OFDA CRED International Disaster Database, SADC Meteorology Centre, SADC National Disaster Agency, World Bank, USAID, FAO/WFP, SADC REGIONAL EARLY WARNING UNIT, NOAA, NASA, US agency for developments, Famine Early WARNING Systems (FEWS) and other collaborating institutions.

3.1 Data Analysis

The research first identifies suitable locations for creating efficient emergency response facility in SADC region. Then, based on the generic multi-criteria decision making (MCDM) model with location criteria for site selection using Analytical Hierarchy Process (AHP) problems as developed by [23], the study followed the following sequence:

- Defines a set of location criteria for site selection in comparison to alternatives using available resources.
- Then, use cross-comparison of location criteria and AHP, the study determines of criteria weightage (score).
- Finally, with cross-comparison between cities and score of location criteria, defines the optimized configuration.

3.2 Fuzzy Analytical Hierarchy Process (f-AHP)

MCDM could be deterministic, stochastic, or fuzzy. Fuzzy logic deals with situations which are vague or ill-defined and gives a quantifiable value [24], which is appropriate in a humanitarian response [25]. Multi Criteria decision making involves alternatives, goals or decision criteria which are placed in hierarchical structure [21]. Two key elements of MCDM are the decision weight (based on importance) and the matrix (Evaluate decision criterion). And, f-AHP's role is to compute the criteria weightage (score), and criteria will be crossed to a linguistic term (Triangular Fuzzy Number) for pairwise comparison matrices as shown in Table 3.

1. Triangular fuzzy numbers (TFNs)

TFNs are convenient to use in applications due to their computational simplicity [26]. [27] defines TFN "A" by a triplet (l, m, u) and equation (1) defines its membership function μ_A(x):

$$\mu_A(\mathrm{x}) = \begin{cases} \frac{x-l}{m-l}, & l \leq x \leq m \\ \frac{u-x}{u-m}, & m \leq x \leq u \\ 0 & otherwise \end{cases} \quad \textbf{(1)}$$

Where "x" is the mean value of "A" and (l, m, u) are real numbers. Two TFNs "A" and "B" are defined by the triplets $A = (l_1, m_1, u_1)$ and $B = (l_2, m_2, u_2)$ [28].

2. Construction of f-AHP comparison matrices

This study utilizes modified synthetic extent f-AHP, which was originally introduced by [27] and developed by [29].The incompleteness of the synthetic extent f-AHP reflects its suitability in decision problems where uncertainty exists in the decision-making process [28]. Table 3 shows the standard 9-unit scale linguistic variables used to make the pairwise comparisons [30]. The values deriving from a pre-defined set of ratio scale values as presented in Table 3 serves to describe the pairwise comparisons [28].

Table 3: Linguistic terms and corresponding TFN

Numerical values	Definition	Fuzzy triangular Scale
1	Equally Important (Eq. Imp)	(1,1,3)
3	Weakly Important (W. Imp)	(1,3,5)
5	Fairly Important (F. Imp)	(3,5,7)
7	Strongly Important (S. Imp)	(5,7,9)
9	Absolutely Important (A. Imp)	(7,9,11)

3. Value of fuzzy synthetic extent

Let $C = \{C_1, C_2, \ldots, C_n\}$ be a N decision criteria set, where n represents the number of criteria and $A = \{A_1, A_2, \ldots, A_m\}$ be a M decision alternative set, where m is the number of decision alternatives. LetM^1C_i,M^2C_i, $M^mC_i, i = 1, 2, \ldots, n$ where all the M^jC_i $(j = 1, 2, \ldots, m)$ are TFNs. In line with the equation in the point on the TFNs, the value of fuzzy synthetic extent S_i in regard to the ith criteria is defined:

$$S_i = \sum_{j=1}^{m} M^jC_i \left[\sum_{i=1}^{n} \cdot \prod_{j=1}^{m} M^jC_i\right]^{-1} \quad \textbf{(2)}$$

Where (.) represents fuzzy multiplication and the superscript (-1) represents the fuzzy inverse [28].

4. Calculating sets of weighted values of f-AHP

For sets of weight values under each criterion to be determined, a principle of comparison for fuzzy numbers must be considered [27]. As demonstration, for two fuzzy numbers, M_1 and M_2, the degree of possibility that $M_1 \geq M_2$ is defined as:

$$V(M_1 \geq M_2) = \underset{x \geq y}{\mathrm{SUP}}[\min(\mu M_1(x), \mu M_2(y))] \quad \textbf{(3)}$$

Where sup represents Supremum, with $V(M_1 \geq M_2) = 1$. Since M_1 and M_2 is defined by the TFNs (l_1, m_1, u_1) and(l_2, m_2, u_2), respectively, it follows:

$$V(M_1 \geq M_2) = 1 \; iff \; m_1 \geq m_2$$

$$V(M_1 \geq M_2) = hgt(M_1 \cap M_2) = \mu M_1(X_d) \quad (4)$$

Where iff signifies 'if and only if', while d is the ordinate of the highest intersection point between the μM_1 and μM_2 TFNs, and x_d is the point in the domain of μM_1 and μM_2 where the ordinate d is found. The term hgt is the height of fuzzy numbers on the intersection of M_1 andM_2. For $M_1 = (l_1, m_1, u_1)$ and$M_2 = (l_2, m_2, u_2)$, the possible ordinate of their intersection is given by Equation (5). This Equation determines the degree of possibility for a fuzzy number:

$$V(M_1 \geq M_2) = hgt(M_1 \cap M_2) = \frac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)} = d \quad (5)$$

To obtain the degree of possibility for a convex fuzzy number *M* to be greater than the number of k fuzzy numbersM_i $(i = 1, 2, \ldots, k)$, the use of the operations max and min is needed [31] and is defined by:

$$V(M \geq M_1, M_2, \ldots, M_k = V[(M \geq M_1)\ and\ (M \geq M_2) and \ldots and\ (M \geq M_k)] = \min V\,(M \geq M_i).i = 1,2, \ldots, k \quad (6)$$

Assuming $d'(A_1) = \min V(S_1 \geq S_k)$, where $k = 1,2, \ldots, n, k \neq i$ and n is the number of criteria. A weight vector is given by:

$$W' = [d'(A_1), d'(A_2), \ldots, d'(A_m)] \quad (7)$$

Where A_i $(i = 1, 2, \ldots, m)$ are the m decision alternatives. Each $d'(A_1)$ as illustrated in equation (8) represents the perference of each decision candidate and W' as vector is nomalised as follows:

$$W' = [d(A_1), d(A_2), \ldots, d(A_m)] \quad (8)$$

If two fuzzy numbers, $M_1 = (l_1, m_1, u_1)$ and$M_2 = (l_2, m_2, u_2)$, in a fuzzy comparison matrix satisfy$l_1 - u_2 > 0$, then $V(M_2 \geq M_1) = hgt\,(M_1 \cap M_2) = \mu_{M_2}(x_d), \mathrm{where}\ \mu_{M_2}(x_d)$ is illustrated by [29]:

$$\mu_{M_2}(x_d) = \begin{cases} \frac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)}, l_1 \leq u_2 \\ 0, \quad otherwise \end{cases} \quad (9)$$

4 RESULTS

4.1 Definition of location criteria for site selection

A qualitative approach was used to identify the extent to which each SADC country is affected by drought disaster and the prevailing decision criteria's in each of those listed countries. A list of high risk locations as well as the types of criteria's customary to SADC countries being study for Drought events from Table 4 derived from literatures reviews and various agencies operating in the region. The high risk locations were determined based on the population density and the drought history.

Table 4: Risk criteria for the SADC countries

	Countries	Capital City	High Risk Locations	Type Of Criteria
1	**ANGOLA**	Luanda	Luanda, Uige and Benguela	Security, Infrastructure, Cost and population to cover
2	**BOTSWANA**	Gaborone	Central, Kweneng and Ngamiland	Cost, Access to affected Zone and delivery time
3	**LESOTHO**	Maseru	Berea, Maseru and Mafeteng	Security, Cost and delivery time

4	**MADAGASCAR**	Antananarivo	Analamanga, Vakinankaratra and Vatovavy Fitovinany	Security, Cost, Infrastructures, Access to affected zone, capacity to be delivered and population to cover
5	**MALAWI**	Lilongwe	Zomba, Blantyre District and Lilongwe	Cost, Infrastructures, capacity to be delivered, access to affected zone
6	**MOZAMBIQUE**	Maputo	Maputo, Nampula, Zambezia, Sofala	Delivery time, infrastructures, security, cost, capacity to be delivered and population to cover
7	**NAMIBIA**	Windhoek	Omusati, Ohangwena and Khomas	Cost, population to cover, access to affected zone and deliver time
8	**SOUTH AFRICA**	Johannesburg	Limpopo, Kwazulu Natal and Gauteng	Cost, population to cover, access to affected zone
9	**SWAZILAND**	Mbabane	Lubombo, Manzini and Hhohho	Cost, population to cover and access to affected zone
10	**TANZANIA**	Dar es Salaam	Dar es Salaam, Mwanza and Kagera	Cost, Infrastructures, capacity to be delivered, access to affected zone and population to be cover
11	**ZAMBIA**	Lusaka	Lusaka, Copper belt and Southern	Cost, Infrastructure, population to cover, access to affected zone
12	**ZIMBABWE**	Harare	Matabeleland north, Matabeleland South and Manicaland	Cost, Infrastructure, population to cover, access to affected zone

4.2 Weightage of location criteria

After identifying the potential humanitarian relief locations, a cross-comparison of location criteria and f-AHP is needed. To the weighted values of f-AHP under each criterion; a survey was conducted targeting relief agencies mentioned at the research methodology. In total, 60 questionnaires were dispatched, 48 were returned (80% response rate) [32]. The data collected from the survey responses were analysed using with SPSS version 21.0 [32]. The research reliability score computed exceeds the recommended value of 0.700 [32]. The survey outcomes displayed in Table 5 (in Weight % and rank) reveal drought response decision priorities using f-AHP calculation.

Table 5: Weightage of Location criteria ranking

S/n	**Criterion**	**Weight (%)**	**Rank**
C6	Cost (C)	25	1
C3	Access to affected areas (AAA)	17	2
C5	Available infrastructures (AI)	16	3
C7	Capacity of relief to be transported (CRT)	14	4
C4	Population Coverage (PC)	12	5
C1	Delivery Time (DT)	8	6
C2	Security (S)	8	7

Results show that criteria Cost (C6) and the Access to affected areas (C3) have priority ranking in drought disaster response unlike delivery time (C1) or Security (C2).

4.3 Determination of scores for Locations performance on criteria

Scores for locations expected performance on the criteria are generated from geographical and historical data. Thereafter, each criterion is analysed and the results are interpreted per country. The index value "1.00" as per Table 6 represents the best performing case (region, city or province) in term of criteria's scores within the geographic area of reference.

4.3.1 Delivery Time (C1-DT)

Delivery time (C1-CT) is one of the least priorities for decision makers in the SADC region (the sixth with only 8% of weight criterion). Unlike other natural disasters, drought have no direct impacts on transportation infrastructures, therefore, unless existing planning issues, the delivery time should not be directly affected. Table 6 shows the transportation time from the Central Distribution Center (main entry port) to affected areas Distribution Centres (DC).

4.3.2 Security (C2-S)

According to [33], nearly 29 million people were under food insecurity in SADC region in 2015 due to delayed and decreased rainfalls. Drought disrupts rain and temperature cycle which in turn affects farming and water reserve. Drought however, assuming that it is the only embattled disaster, causes minimal risks to humanitarian relief deliveries, facilities or personnel.

4.3.3 Access to Affected Areas (C3-AAA)

Access to affected areas is considered one of the most important humanitarian responses planning decision. This criterion is defined as the distance between the candidate location and the demand points. With the candidate location, also call central distribution Center (CDC), refer to a safe zone that is used for planning, procurement and supply to affected areas. Each demand point represents the distribution point (DC) of the affected areas. Table 6 shows that affected areas in the regions are accessed by air, road, by train even by sea.

Table 6: Deliver Time and Access to Affected Areas

	COUNTRIES	CENTRAL DISTRIBUTION CENTRE	HIGH RISK LOCATION	DEMAND POINT	DISTANCE FROM MAIN DEPOT (km)	AIR TIME FROM MAIN DEPOT (Hour)	ROAD TIME FROM MAIN DEPOT (Hour)	ACCESS TO AFFECTED ZONES INDEX
1	ANGOLA	**Luanda** (Fevereiro Int Airport)	Luanda	Luanda	11	0.0	0.3	**1.00**
			Uige	Carmona	290	0.3	4.4	0.98
			Benguela	Benguela	540	1.0	7.7	0.64
2	BOTSWANA	**Gaborone** (Sir Seretse Khama Int Airport)	central	serowe	314	0.5	3.4	0.95
			Kweneng	Molepolole	62	0.1	1.3	**1.00**
			Ngamiland	Maun	855	1.3	8.8	0.69
3	LESOTHO	**Maseru** (Moshoeshoe Int Airport)	Berea	Berea hill	37	0.0	1.0	0.85
			Maseru	Maseru	19	0.0	0.4	**1.00**
			Mafeteng	Mafeteng	65	0.1	0.9	0.54
4	MADAGASCAR	**Antananarivo** (Ivato Int Airport)	Analamanga	Antananarivo	13	0.0	0.6	**1.00**
			Vakinankaratra	Antsirabe	182	0.2	3.6	0.98
			Vatovavy Fitovinany	Manakara	583	1.0	10.9	0.75
5	MALAWI	**Lilongwe** (Lilongwe Int Airport)	Zomba	Zomba	325	0.8	4.4	0.97
			Blantyre	Blantyre	352	0.8	4.7	0.51
			Lilongwe	Lilongwe	26	0.0	0.6	**1.00**
6	MOZAMBIQUE	**Maputo** (Maputo Int Airport)	Nampula	Nampula	2035	2.2	26.2	0.42
			Maputo	Matola	6	0.0	0.3	**1.00**
			Zambezia	Quelimane	1559	1.8	18.3	0.74
			Sofala	Beira	1210	1.4	15.6	0.99
7	NAMIBIA	**Windhoeck** (Hosea Kutako Int Airport)	Khomas	Windhoeck	46	0.0	0.6	1.00
			Ohangwena	Eenhana	742	1.2	7.2	0.97
			Omusati	Outapi	808	1.3	9.4	0.51
8	SOUTH AFRICA	**Johannesburg** (O.R.Tambo Int Airport)	Kwazulu Natal	Durban	576	1.5	5.8	0.63
			Gauteng	Johannesburg	28	0.0	0.4	**1.00**
			Limpopo	Polokwane	307	0.7	3.7	0.97
9	SWAZILAND	**Sikupe** (King Mswati III Int Airport)	Lubombo	Siteki	34	0.0	0.5	**1.00**
			Manzini	Manzini	56	0.1	1.0	0.74
			Hhohho	Mbabane	92	0.0	1.5	0.45
10	TANZANIA	**Dar es Salaam** (Julius Nyerere Int Airport)	Dar es Salaam	Dar es Salaam	13	0.0	0.6	**1.00**
			Mwanza	Mwanza	1117	1.8	18.6	0.99
			Kagera	Bukoba	1377	7.8	22.4	0.55
11	ZAMBIA	**Lusaka** (Kenneth Kaunda Int Airport)	Lusaka	Lusaka	15	0.0	0.4	**1.00**
			Copperbelt	Ndola	335	2.8	4.9	0.51
			Southern	Choma	310	0.4	4.3	0.97
12	ZIMBABWE	**Harare** (Harare Int Airport)	Matabeleland South	Gwanda	568	1.0	6.5	0.44
			Matabeleland North	Lupane	457	1.0	6.2	0.79
			Manicaland	Mutare	272	0.5	3.4	**1.00**

The access to affected zones index was calculated by the means of the distance from main depot (km) with the shortest distance representing the index value (1.00).

4.3.4 Population Coverage (C4-PC)

This criterion defines the population exposed to drought per the potential locations and country. Local DC is selected based on historical data on drought disasters, on the number of population coverage and on easy accessibility to victims via transportation modes. The population coverage index is determined by dividing the exposed population to the area superficies. And the areas with higher population density signify higher disaster risk and vulnerability; for such, the coverage index used is (1.00). The coverage index on the table is determined from the population/m^2density with the value (1.00) representing the biggest population density. Table 7 shows the vulnerable population in each region per country as well as their densities.

Table 7: Population coverage in high risk location (Region, province or district)

	COUNTRIES	POTENTIAL LOCATIONS	EXPOSED POPULATION	AREA SIZE (mi^2)	DENSITY (population/m^2)	COVERAGE INDEX
1	ANGOLA	Luanda	6945386	933	**7444**	**1.00**
		Uige	1483118	22663	65	0.008
		Benguela	2231385	12273	182	0.032
2	BOTSWANA	central	585595	57039	10	0.21
		Kweneng	304549	13857	**22**	**1.00**
		Ngamiland	175631	11583	15	0.53
3	LESOTHO	Berea	300000	767	**391**	**1.00**
		Maseru	170000	1686	101	0.13
		Mafeteng	253000	818	309	0.52
4	MADAGASCAR	Analamanga	3439600	6736	**511**	**1.00**
		Vakinankaratra	1852200	6409	289	0.48
		Vatovavy Fitovinany	1454900	7569	192	0.19
5	MALAWI	Zomba	583167	1027	568	0.52
		Blantyre	809397	807	**1003**	**1.00**
		Lilongwe	1346360	2754	489	0.24
6	MOZAMBIQUE	Nampula	3985613	30506	131	0.68
		Maputo	1205709	8762	**138**	**1.00**
		Zambezia	3850000	39953	96	0.37
		Sofala	1642920	26262	63	0.15
7	NAMIBIA	Khomas	415800	14272	29	0.47
		Ohangwena	245446	4134	**59**	**1.00**
		Omusati	249900	10251	24	0.21
8	SOUTH AFRICA	Kwazulu Natal	10456900	36433	287	0.18
		Gauteng	12728400	7018	**1814**	**1.00**
		Limpopo	5518000	48554	114	0.05
9	SWAZILAND	Lubombo	207731	2258	92	0.19
		Manzini	319530	1581	**202**	**1.00**
		Hhohho	282734	1400	202	0.60
10	TANZANIA	Dar es Salaam	4364541	538	**8113**	**1.00**
		Mwanza	2772509	3655	759	0.113
		Kagera	2458023	9755	252	0.03
11	ZAMBIA	Lusaka	2888600	8454	**342**	**1.00**
		Copperbelt	242700	12096	20	0.05
		Southern	1907800	33136	58	0.18
12	ZIMBABWE	Matabeleland South	683893	20916	33	0.31
		Matabeleland North	749017	28967	26	0.14
		Manicaland	1753000	14077	**125**	**1.00**

4.3.5 Available Infrastructures (C5-AI)

Available Infrastructure criteria define suitable location with key infrastructure to support rapid humanitarian response. Infrastructure targeted includes air airports for relief cargo, good roads condition for connectivity, railways and seaports. Other key infrastructure includes railways and seaports.

Table 8 shows the existing infrastructures and computed the available infrastructure index for every potential location per country with 0.25 points representing every infrastructure type.

Table 8: Available Infrastructure Index

	COUNTRIES	POTENTIAL LOCATIONS	TYPE OF INFRASTRUCTURE	INFRASTRUCTURE INDEX
1	ANGOLA	**Luanda**	**Marine, Railway, Airport,**	**1.00**
		Uige	Road, Railway, Airport	0.75
		Benguela	Marine, Railway, Airport,	1.00
2	BOTSWANA	central	Airport, Road, Railway	0.75
		Kweneng	Road, Airport, Raiway	**0.75**
		Ngamiland	Airport, Road, Railway	0.75
3	LESOTHO	Berea	Railway, Airport, Road	**0.75**
		Maseru	**Railway, Airport, Road**	**0.75**
		Mafeteng	Railway, Airport, Road	0.75
4	MADAGASCAR	**Analamanga**	**Railway, Airport, Road**	**0.75**
		Vakinankaratra	Railway, Airport, Road	0.75
		Vatovavy	Railway, Airport, Road	0.75
5	MALAWI	**Zomba**	**Railway, Road, Airport**	**0.75**
		Blantyre	Railway, Road, Airport	**0.75**
		Lilongwe	Railway, Road, Airport	0.75
6	MOZAMBIQUE	Nampula	Railway, Airport, Road	0.75
		Maputo	Marine, Railway, Airport,	**1.00**
		Zambezia	**Marine, Railway, Airport,**	**1.00**
		Sofala	Marine, Railway, Airport,	1.00
7	NAMIBIA	**Khomas**	**Road, Railway, Airport**	**0.75**
		Ohangwena	Road, Railway	0.50
		Omusati	Road, Airport, Railway	0.75
8	SOUTH AFRICA	**Kwazulu Natal**	**Marine, Railway, Airport,**	**1.00**
		Gauteng	Railway, Airport, Road	0.75
		Limpopo	Railway, Airport, Road	0.75
9	SWAZILAND	**Lubombo**	**Airport, Road, Railway**	**0.50**
		Manzini	Railway, Airport, Road	**0.75**
		Hhohho	Road	0.25
10	TANZANIA	**Dar es Salaam**	**Marine, Road, Airport,**	**1.00**
		Mwanza	Marine, Road, Airport,	1.00
		Kagera	Airport, Road	0.50
11	ZAMBIA	**Lusaka**	**Railway, Airport, Road**	**0.75**
		Copperbelt	Railway, Airport, Road	0.75
		Southern	Road, Raiway, Airport	0.75
12	ZIMBABWE	Matabeleland	Road, airport, Raiway	0.75
		Matabeleland North	Road, airport, Raiway	0.75
		Manicaland	**Road, Railway, Airport**	**0.75**

4.3.6 Cost (C6-C)

Criteria cost defines value related to the costs of supply chain. According to [34], key findings useful for humanitarian supply chain cost in SADC region:

- Transportation of goods by road in Southern Africa move at velocity of 18.6 kilometers per hour. Meanwhile road freight cost in SADC around US$5 cents per tonne-km [35].
- The average regional costs per tonne is between US$100 and US$320 for rail, between US$120 and US$280 for road, and US$110 for container-cargo-handling, air transportation cost is between US$4000 and US$6000.

With Table 8 confirming "availability of infrastructures", Table 9 and Table 10 have computed two decision making scenarios: 1) Scenario 1 from Table 9 describes the supply chain decision prioritizing each SADC country's air transportation as 'main entry', then both road and train transportation used for last miles distribution to local DC. 2) Scenario 2 from Table 10 describes the supply chain decision prioritizing the enormous access to the sea most countries possesses while using road and train transportation for last miles. 9 of the 15 SADC countries are coastal countries possessing one or more seaports. The demand quantity from Table 9 and Table 10 was estimated based on historical data and the projected number exposed population (Table 7).

Next, the study calculated each candidate location transportation cost based on the demand quantity, the average regional cost per tonne (as mentioned above) as well as the distance to the local DC. The cost index is estimated from the sum of the estimated transportation modes, meaning that the estimated transportation mode with the lowest cost is the best decision making option with the index value (1.00).

Table 9: Estimate Cost decision index from Air, Road, and Rail using scenario 1

	COUNTRIES	CENTRAL DISTRIBUTION CENTRE 1	POTENTIAL LOCATIONS	ESTIMATED DEMAND QUANTITY (T)	DISTANCE FROM MAIN DEPOT (km)	ESTIMATED AIR COST FROM MAIN DC ($)	AIR COST INDEX	ESTIMATED ROAD COST FROM MAIN DC ($)	ROAD COST INDEX	ESTIMATED TRAIN COST FROM MAIN DC ($)	TRAIN COST INDEX	OPTIMIZE DECISION
1	ANGOLA	**Luanda** (Fevereiro Int Airport)	Luanda	90	11	$ -	0.85	$ 10,988.00	0.96	$ -	1.00	$ 10,988.00
			Uige	17	290	$ 72,930.00		$ 2,978.00		$ 3,230.00		$ 2,978.00
			Benguela	13	540	$ 59,020.00		$ 2,896.00		$ 3,250.00		$ 2,896.00
			Total	**120**	**841**	**$ 131,950.00**		**$ 16,862.00**		**$ 6,480.00**		**$ 16,862.00**
2	BOTSWANA	**Gaborone** (Sir Seretse Khama Int Airport)	central	15	314	$ 64,710.00	0.93	$ 2,412.00	1.00	$ 3,900.00	0.97	$ 2,412.00
			Kweneng	25	62	$ 101,550.00		$ 3,201.00		$ 2,500.00		$ 2,500.00
			Ngamiland	10	855	$ 48,550.00		$ 2,311.00		$ 2,850.00		$ 2,850.00
			Total	**50**	**1231**	**$ 214,810.00**		**$ 7,924.00**		**$ 9,250.00**		**$ 7,762.00**
3	LESOTHO	**Maseru** (Moshoeshoe Int Airport)	Berea	9	37	$ -	0.81	$ 1,520.00	0.95	$ 900.00	1.00	$ 900.00
			Maseru	14	19	$ -		$ 2,032.00		$ -		$ 2,032.00
			Mafeteng	7	65	$ 28,455.00		$ 1,442.00		$ 770.00		$ 770.00
			Total	**30**	**121**	**$ 28,455.00**		**$ 4,994.00**		**$ 1,670.00**		**$ 3,702.00**
4	MADAGASCAR	**Antananarivo** (Ivato Int Airport)	Analamanga	100	13	$ -	0.90	$ 12,267.00	0.97	$ -	1.00	$ 12,267.00
			Vakinankaratra	50	182	$ 209,100.00		$ 7,871.00		$ 6,500.00		$ 6,500.00
			Vatovavy Fitovinany	40	583	$ 183,320.00		$ 9,596.00		$ 7,400.00		$ 7,400.00
			Total	**190**	**778**	**$ 392,420.00**		**$ 29,734.00**		**$ 13,900.00**		**$ 26,167.00**
5	MALAWI	**Lilongwe** (Lilongwe Int Airport)	Zomba	17	325	$ 73,525.00	0.94	$ 3,297.00	0.98	$ 2,720.00	1.00	$ 2,720.00
			Blantyre	13	352	$ 56,576.00		$ 2,601.00		$ 2,470.00		$ 2,470.00
			Lilongwe	20	26	$ 80,520.00		$ 2,518.00		$ -		$ 2,518.00
			Total	**50**	**703**	**$ 210,621.00**		**$ 8,416.00**		**$ 5,190.00**		**$ 7,708.00**
6	MOZAMBIQUE	**Maputo** (Maputo Int Airport)	Nampula	30	2035	$ 180,000.00	0.91	$ 5,631.00	1.00	$ 9,600.00	0.96	$ 5,631.00
			Maputo	80	6	$ -		$ 9,616.00		$ -		$ 9,616.00
			Zambezia	35	1559	$ 194,565.00		$ 6,015.00		$ 10,850.00		$ 6,015.00
			Sofala	55	1210	$ 286,550.00		$ 8,814.00		$ 16,500.00		$ 8,814.00
			Total	**200**	**4810**	**$ 661,115.00**		**$ 30,076.00**		**$ 36,950.00**		**$ 30,076.00**
7	NAMIBIA	**Windhoeck** (Hosea Kutako Int Airport)	Khomas	35	46	$ -	0.90	$ 4,361.00	0.96	$ -	1.00	$ 4,361.00
			Ohangwena	20	742	$ 94,840.00		$ 3,888.00		$ 4,200.00		$ 3,888.00
			Omusati	25	808	$ 120,200.00		$ 5,025.00		$ 5,500.00		$ 5,025.00
			Total	**80**	**1596**	**$ 215,040.00**		**$ 13,274.00**		**$ 9,700.00**		**$ 13,274.00**
8	SOUTH AFRICA	**Johannesburg** (O.R.Tambo Int Airport)	Kwazulu Natal	40	576	$ 183,040.00	0.90	$ 8,847.00	0.97	$ 6,000.00	1.00	**$ 6,000.00**
			Gauteng	50	28	$ -		$ 6,246.00		$ -		$ 6,246.00
			Limpopo	10	307	$ 43,070.00		$ 1,739.00		$ 1,400.00		$ 1,400.00
			Total	**100**	**911**	**$ 226,110.00**		**$ 16,832.00**		**$ 7,400.00**		**$ 13,646.00**
9	SWAZILAND	**Sikupe** (King Mswati III Int Airport)	Lubombo	11	34	$ -	0	$ 1,649.00	1.00	**$ -**	0	$ 1,649.00
			Manzini	12	56	$ -		$ 2,031.00		$ -		$ 2,031.00
			Hhohho	12	92	$ -		$ 2,411.00		$ -		$ 2,411.00
			Total	**35**	**182**	**$ -**		**$ 6,091.00**		**$ -**		**$ 6,091.00**
10	TANZANIA	**Dar es Salaam** (Julius Nyerere Int Airport)	Dar es Salaam	100	13	$ -	0.93	$ 1,208.00	0.97	$ -	1.00	$ 1,208.00
			Mwanza	65	1117	$ 332,605.00		$ 12,434.00		$ 17,550.00		$ 12,434.00
			Kagera	35	1377	$ 188,195.00		$ 7,276.00		$ -		$ 7,276.00
			Total	**200**	**2507**	**$ 520,800.00**		**$ 20,918.00**		**$ 17,550.00**		**$ 20,918.00**
11	ZAMBIA	**Lusaka** (Kenneth Kaunda Int Airport)	Lusaka	38	15	$ -	0.91	$ 4,698.00	0.97	$ -	1.00	$ 4,698.00
			Copperbelt	29	335	$ 125,715.00		$ 5,835.00		$ 4,060.00		$ 4,060.00
			Southern	28	310	$ 120,680.00		$ 5,464.00		$ 3,640.00		$ 3,640.00
			Total	**95**	**660**	**$ 246,395.00**		**$ 15,997.00**		**$ 7,700.00**		**$ 12,398.00**
12	ZIMBABWE	**Harare** (Harare Int Airport)	Matabeleland South	30	568	$ 137,040.00	0.93	$ 5,702.00	0.97	$ 5,100.00	1.00	$ 5,100.00
			Matabeleland North	37	457	$ 164,909.00		$ 6,526.00		$ 5,550.00		$ 5,550.00
			Manicaland	68	272	$ 290,496.00		$ 10,442.00		$ 8,840.00		$ 8,840.00
			Total	**135**	**1297**	**$ 592,445.00**		**$ 22,670.00**		**$ 19,490.00**		**$ 19,490.00**
					TOTAL	$ 6,287,877.00	0.91	$ 364,906.00	0.96	$251,070.00	1.00	$336,698.00

Scenario 1 on Table 9 shows the calculated estimation of air, train and road transportation cost from the Main distribution center (DC) to the demand point (potential location considering the distance and the estimated demand quantity. The results of this scenario shows that

Airlifting relief supply increase accessibility and speed of delivery as most potential locations have airports. However, it cost between US$4000 and US$6000 per tonne to transport goods in the region, leading to an increase in overall transportation of relief in during a disaster response. Further air cost could occur if airlifting is used for last miles shipment. The study has revealed however that using road and train from the main airport "country entry point" to the high risk areas amid road and railway availability are the most cost effective way of connecting in the country. For instance, OR Tambo international airport is the main entry point for reliefs in South Africa; finding the best decision to supply goods from OR Tambo to Limpopo is to select the cheapest transportation options available to reach the destination. The environmental friendly nature of drought disaster allows decision makers to select using trains to transport 50 tonnes at the cost of only US$8847.

Applying scenario 2 (Table 10) decision making however, although the response time is lengthier and the connectivity reduced (especially with land lock and island countries), using the sea transportation is cheaper and appears the most suited for drought disaster. With 95% of SADC trade being done via the sea, maximizing the sea route, although increases the time, but reduces one of the key elements which are the transportation cost. With more than 60 available ports operating in SADC [34], coastal and landlocked countries have sufficient port options to choose from based on the distance, security, quantity of relief as well as the availability of the road or train transportation.

Table 10: Estimate Cost decision index for Road, Rail from Seaport using Scenario 2

	COUNTRIES	CENTRAL DISTRIBUTION CENTRE 2	POTENTIAL LOCATIONS	CAPITAL CITY	ESTIMATED DEMAND QUANTITY (T)	DISTANCE FROM MAIN DEPOT (km)	ESTIMATED ROAD COST FROM MAIN DC ($)	ROAD COST INDEX	ESTIMATED TRAIN COST FROM MAIN DC ($)	TRAIN COST INDEX	OPTIMIZE DECISION
		Luanda Port	Luanda	Luanda	90	11	$ 11 340,00		$ -		$ 11 340,00
1	**ANGOLA**	Walvis Bay	Uige	Carmona	17	290	$ 4 556,00	0.84	$ 3 230,00	**1.00**	$ 3 230,00
		Lobito port	Benguela	Benguela	13	12	$ 1 638,00		$ -		$ 1 638,00
		Durban	central	serowe	15	1229	$ 2 655,00		$ 2 550,00		$ 2 550,00
2	**BOTSWANA**	Maputo	Kweneng	Molepolole	25	1350	$ 4 575,00	0.58	$ 2 500,00	**1.00**	$ 2 500,00
		Walvis Bay	Ngamiland	Maun	10	855	$ 1 600,00		$ 1 400,00		$ 1 400,00
		Durban	Berea	Berea hill	9	660	$ 1 584,00		$ 900,00		$ 900,00
3	**LESOTHO**	Port Elizabeth	Maseru	Maseru	14	642	$ 2 450,00	0.59	$ 1 960,00	**1.00**	$ 1 960,00
		Richards Bay	Mafeteng	Mafeteng	7	574	$ 1 183,00		$ 770,00		$ 770,00
			Analamanga	Antananarivo	100	579	$ 15 700,00		$ 12 000,00		$ 12 000,00
4	**MADAGASCAR**	Toamasima	Vakinankaratra	Antsirabe	50	761	$ 8 450,00	0.55	$ 6 500,00	**1.00**	$ 6 500,00
			Vatovavy Fitovinany	Manakara	40	1162	$ 7 760,00		$ 7 400,00		$ 7 400,00
		Maputo	Zomba	Zomba	17	674	$ 2 839,00		$ 2 720,00		$ 2 720,00
5	**MALAWI**	Walvis Bay	Blantyre	Blantyre	13	856	$ 2 340,00	**1.00**	$ 2 470,00	0.504	$ 2 340,00
		Durban	Lilongwe	Lilongwe	20	754	$ 3 460,00		$ 3 600,00		$ 3 460,00
			Nampula	Nampula	30	765	$ 6 360,00		$ 9 600,00		$ 6 360,00
6	**MOZAMBIQUE**	Maputo	Maputo	Matola	80	25	$ 9 840,00	0.66	$ -	**1.00**	$ 9 840,00
		Nacala	Zambezia	Quelimane	35	518	$ 6 405,00		$ 5 250,00		$ 5 250,00
		Beira	Sofala	Beira	55	17	$ 6 710,00		$ -		$ 6 710,00
		Walvis Bay	Khomas	Windhoeck	35	56	$ 4 410,00		$ 3 500,00		$ 3 500,00
7	**NAMIBIA**	Cape Town	Ohangwena	Eenhana	20	742	$ 3 880,00	0.501	$ 4 200,00	**1.00**	$ 3 880,00
		Luderitz	Omusati	Outapi	25	808	$ 5 000,00		$ 5 500,00		$ 5 000,00
		Durban	Kwazulu Natal	Durban	40	14	$ 4 880,00		$ -		$ 4 880,00
8	**SOUTH AFRICA**	Richards Bay	Gauteng	Johannesburg	50	575	$ 9 100,00	0.68	$ 6 000,00	**1.00**	$ 6 000,00
		Port Elizabeth	Limpopo	Polokwane	10	876	$ 2 140,00		$ 1 500,00		$ 1 500,00
		Durban	Lubombo	Siteki	11	410	$ 1 936,00		$ 2 200,00		$ 1 936,00
9	**SWAZILAND**	Richards Bay	Manzini	Manzini	12	394	$ 2 076,00	0.56	$ 2 520,00	**1.00**	$ 2 076,00
		Maputo	Hhohho	Mbabane	12	376	$ 2 052,00		$ -		$ 2 052,00
		Dar es Salaam	Dar es Salaam	Dar es Salaam	100	10	$ 12 100,00		$ -		$ 12 100,00
10	**TANZANIA**	Mwanza	Mwanza	Mwanza	65	13	$ 7 865,00	0.89	$ -	**1.00**	$ 7 865,00
			Kagera	Bukoba	35	1377	$ 9 695,00		$ 3 500,00		$ 3 500,00
		Walvis Bay	Lusaka	Lusaka	38	1671	$ 6 688,00		$ 3 800,00		$ 3 800,00
11	**ZAMBIA**	Maputo	Copperbelt	Ndola	29	1200	$ 4 640,00	0.59	$ 4 060,00	**1.00**	$ 4 060,00
		Lobito	Southern	Choma	28	1927	$ 5 152,00		$ 3 640,00		$ 3 640,00
		Durban	Matabeleland South	Gwanda	30	1140	$ 5 520,00		$ 5 100,00		$ 5 100,00
12	**ZIMBABWE**	Walvis Bay	Matabeleland North	Lupane	37	950	$ 6 401,00	0.54	$ 5 550,00	**1.00**	$ 5 550,00
		Walvis Bay	Manicaland	Mutare	68	760	$ 11 084,00		$ 8 840,00		$ 8 840,00
						TOTAL	**$ 206 064,00**	0.62	**$ 122 760,00**	**0.37**	**$174 147,00**

Looking at Table 9 and Table 10 outcomes, Figure 3 reveals optimizing both decision shows that using scenario 2, although it takes longer to deliver reliefs is cheaper with US$174,147 than Scenario 1 (US$178,094).

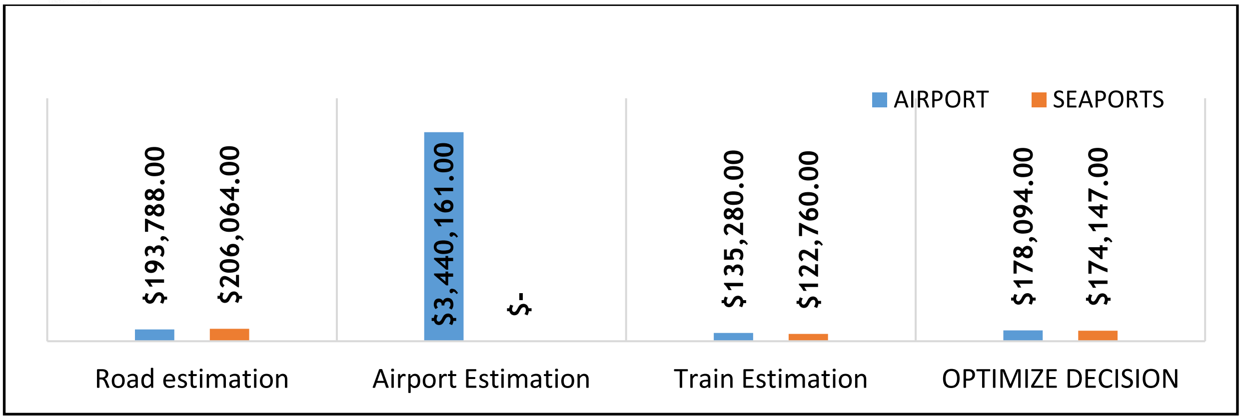

Figure 3: Cost comparison between the Airport and Seaports scenario

It should be noted that the difference is only $3947, future works will incorporate financial damages causes by the length of the delivery the affected zones.

4.3.7 Capacity of relief to be transported (C7-CRT)

Capacity of relief to be transported defines value related to the costs of transportation and coverage per affected area. This criteria index specifies the amount of goods to be transported to the candidate locations, then to the affected. Unlike previously described criteria, this criterion requires a thoughtful planning and evaluation of resources at affected areas. To ensure that resources are not either wasted or lacking, a thorough assessment with partners on the affected region is needed. The capacity was assumed to be based on each area past drought history as well as available historical data on drought disaster as shown in Table 7.

5 CONCLUSION

This paper has reviewed drought disaster impacts in SADC countries and listed ways the region could minimize the transportation cost during humanitarian relief response. A series of models were proposed among which a Multi-Criteria decision Making (MCDM) was selected based on it Analytic Hierarchy Process (AHP) approach. This approach defines, weighs and ranks seven location criteria's for site selection. The model provides a detailed decision support framework for the various organizations already active in the region. Drought disaster, based on its properties offers decision makers a planning advantage, therefore the developed scenarios permits decision makers to manage drought planning and response with cost effectiveness. Findings from both scenarios revealed that by excluding air transportation in drought disasters, countries even landlocked stand to gain on operational and delivery cost. To cope with these new global climate challenges, the region vast sea routes and many Seaports should be developed further and maximized in order to be included even into the last miles transportations efforts.

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THE USE OF DMAIC SIX-SIGMA METHODOLOGY FOR DISPUTES RESOLUTION IN A PACKAGING COMPANY

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ABSTRACT

Industrial engineering plays a vital role in production improvement and the optimization of systems. With the growing impact of globalization, championing the production of quality goods and systems is key to survival. Another notable effect of globalization is the rise of work-based conflict in recent years. This study intends to use DMAIC six-sigma in resolving these work-related conflicts. After the quality assurance staff raised complaints in regard to work overload and salary increases, management decided to use work study to evaluate these claims. The results of the case study highlighted a number of challenges including breakdown in communication between hierarchies and the lack of quality assurance standardized work processes. The study recommends the restructuring of work tasks and systems in order to optimize workers' productivity and improve motivation.

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1 INTRODUCTION

Globalization is a phenomenon that has affected people differently in diverse spheres of life [1] [2]. "Globalization is a powerful force that cannot be denied, as it has brought positive facets to some parts of the world, however, conversely, it has also threatened life, in a broader sense" [3]. According to Pasricha [4], globalization is a state whereby national boundaries turn totally porous with respect to the movement of goods and capital and, to an extent, porous with respect to people, which are viewed in this context as cheap labor or cheap human capital. Apart from its impact on state boundaries and association with movement of goods and capital; globalization has led to the rise of internal conflicts between hierarchies in various industries around the world. This research used Six-sigma as a tool to resolve the rising conflicts and reduce the impact on company productivity. Six-Sigma is a highly disciplined process that enables world-class quality and continuous improvement methods to achieve the highest level of customer satisfaction [5].

The implementation of a Six-Sigma methodology aims at achieving error-free business performance, focusing on improving quality by helping organizations produce products and services better, faster and cheaper [6]. In order to achieve Six-Sigma level quality, in relation to the study objectives, Six-Sigma provides an improvement framework known as Define-Measure-Analyze-Improve Control (DMAIC). A complaint was raised to top management regarding a dispute concerning Quality assurance (QA) staff, their supervision and their service departments (Printing, Extrusion and Lamination) at a flexible packaging company in Durban.

The study aims was to use six sigma tools in resolving workplace conflict through the following objectives:

- Definition of the QA staff's daily and individual activities;
- Measurement of QA personnel's job performance;
- Analysis of each QA staff member's daily and particular activities, performance and complaints;
- Based on the outcome of the analysis, highlight potential areas of improvement;
- Proposing mechanism for sustaining the improvement.

2 LITERATURE REVIEW

2.1 SIX-Sigma DMAIC

DMAIC is a "simple performance improvement model" of an existing process to help firms achieve significant performance improvement by reducing the cost [7]. DMAIC problem solving strategy relies on five phases: Define Measure, Analyze, Improve and Control in order to improve, and Pyzdek [6] described these phases as follows:

- **Define** phase - covers process mapping and flowcharting, project charter development, problem solving tools, and the so-called 7 Managements tools (Affinity Diagrams, Tree Diagrams, Interrelationship diagraph, Process Decision Program charts (PDPC), Matrix diagrams, Prioritization matrices, Activity Network diagram).
- **Measure** phase - covers the principles of measurement, continuous and discrete data, scales of measurement, an overview of the principles of variation, and repeatability-and-reproducibility (RR) studies for continuous and discrete data.
- **Analyse** phase - covers establishing a process baseline, how to determine process improvement goals, knowledge discovery, including descriptive and exploratory data analysis and data mining tools, the basic principles of statistical process control (SPC), specialized control charts, process capability analysis, correlation and regression analysis, analysis of categorical data, and non-parametric statistical methods.
- **Improve** phase - covers project management, risk assessment, process simulation, design of experiments (DOE), robust design concepts (including Taguchi principles), and process optimization.

- **Control phase -** covers process control planning, using SPC for operational control and pre-control.

Figure 1 shows the DMAIC Six Sigma process flow chart.

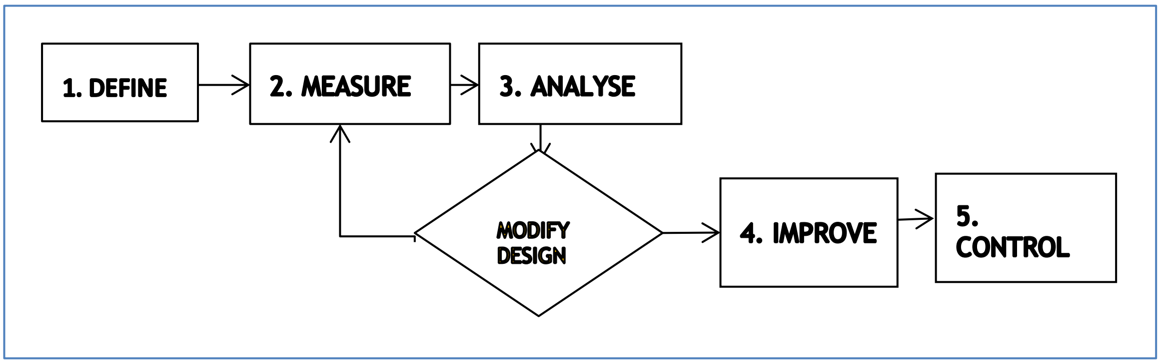

Figure 1: DMAIC process flow chart

DMAIC methodology guides the project team from the project definition (Define) to maintaining the results (Control) [8]. According Jones [9], Six Sigma (SS) main ideas and mindset is based on taking a business problem and converting it into an engineering problem that uses statistics, then develop an engineering solution, and finally converts that to a business solution. SS mindset is explained in Figure 2.

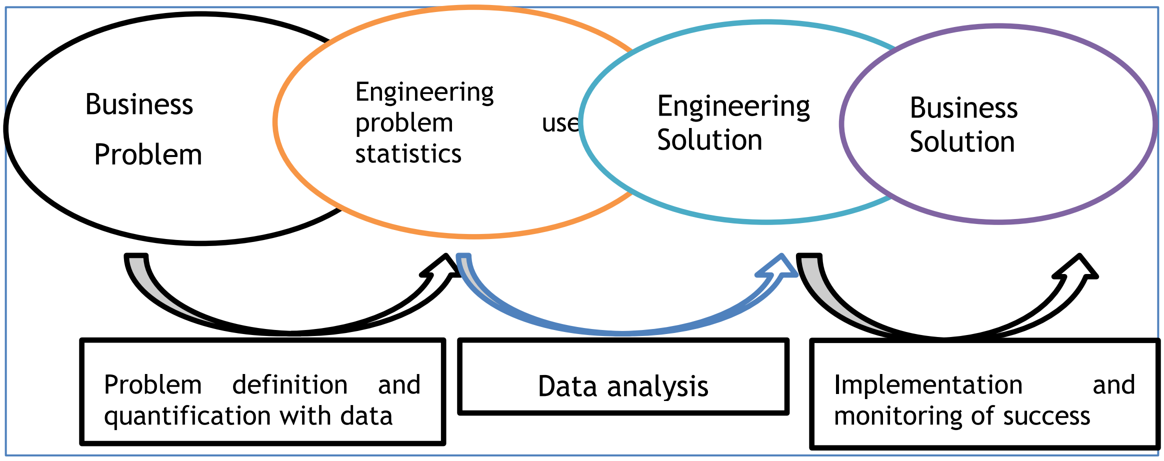

Figure 2: Role of industrial systems engineering thinking and methods [8].

Motorola USA proposed a meticulous six-sigma tool and data-driven methodology with the aim of generating a quasi-perfect production processes that would result in no more than 3.4 defects per 1 million opportunities as per the Table 1. It is vital to determine which elements in Six Sigma (SS) make it effective, but one of SS role is a structured improvement procedure and focus on metrics which contribute to quality management, and this improvement is found under DMAIC [10]. It is also similar to one of the well-known methods established by Juran called Plan-Do-Check Act (PDCA). While some argued that DMAIC method is a new method, it is easy to recognize that it is a revised version of well-known problem solving methods such as Plan-Do-Check-Action (PDCA) and Plan-Do-Study-Action (PDSA). Both PDCA [11] and PDSA [12] emphasize on a structured method toward problem solving and use similar tools and techniques as the DMAIC. The only difference is the addition of the Control phase in DMAIC. However, it can be argued that applying PDCA or PDSA is never a single cycle matter, the iteration of multiple cycle means an implicit control phase must be in place.

Table 1: Data-driven methodology proposed by Motorola, USA

Sigma(σ) Level	Sigma (with 1.5σ shift)	DPMO (Defect per million)	Percent defective	Percentage yield	Short-term C_{pk}	Long-term C_{pk}
1	−0.5	691,462	69%	31%	0.33	−0.17
2	0.5	308,538	31%	69%	0.67	0.17
3	1.5	66,807	6.70%	93.30%	1	0.5
4	2.5	6,210	0.62%	99.38%	1.33	0.83
5	3.5	233	0.02%	99.98%	1.67	1.17
6	**4.5**	**3.4**	**0.00%**	**9**		

2.2 Work Study definition and impact

According to Cheevakasemsook & Yunibhand [13], 'work study is a management service based on techniques such as method study and work measurement'. Both method study and work measurement are used in the examination of human work in all its contexts and that lead to the systematic investigation of all the resources and factors which affect the operation efficiency [14]. In order to achieve the work study objective, nine steps are vitally important [15]. These steps are subdivided into three stages as stated in the Figure 3, Figure 4 and Figure 5. The first stage as shown in Figure 3 represents the first three steps called "primary stage". The primary stage of the work study consists of selecting the study focus, recording of relevant data and breaking down of operations into elements.

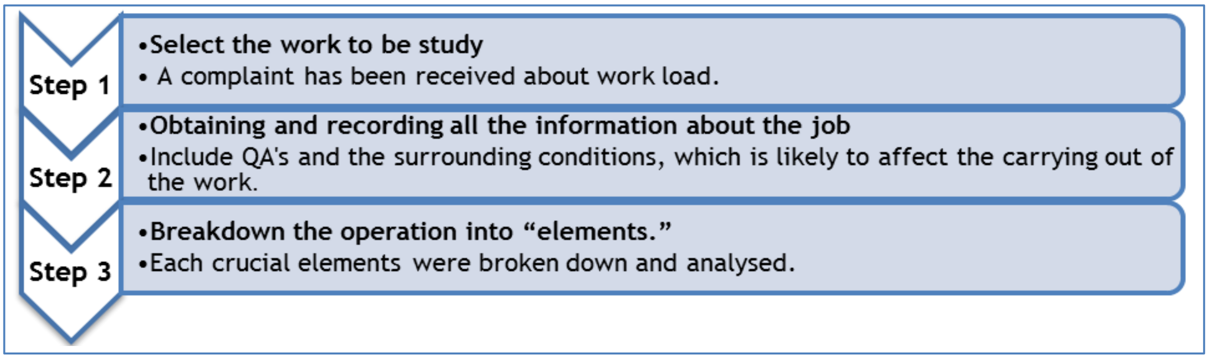

Figure 3: Primary work study stage

The second stage measures time taken to perform each operation recorded in the first stage. Then an assessment of the operator effectiveness is done followed by the adjustment of the observed time by rating factor. The secondary stage shown in Figure 4 is composed of the following:

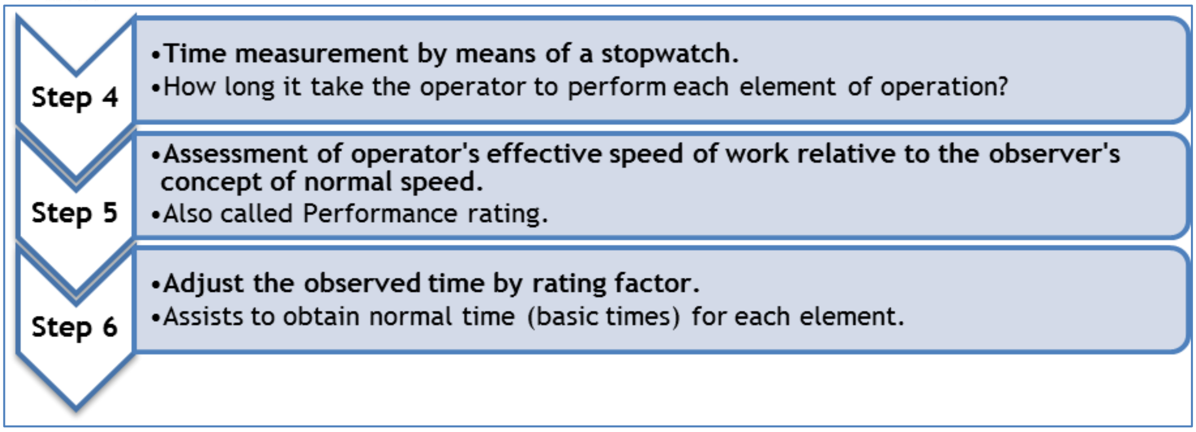

Figure 4: Secondary work study stage

Figure 5 represents the third and final stage which sums the normal times for each element and determination of the "standard time" for an operation. The third stage concludes the process and is characterized by reviews of standards whenever necessary. The tertiary work study stage is composed of the following:

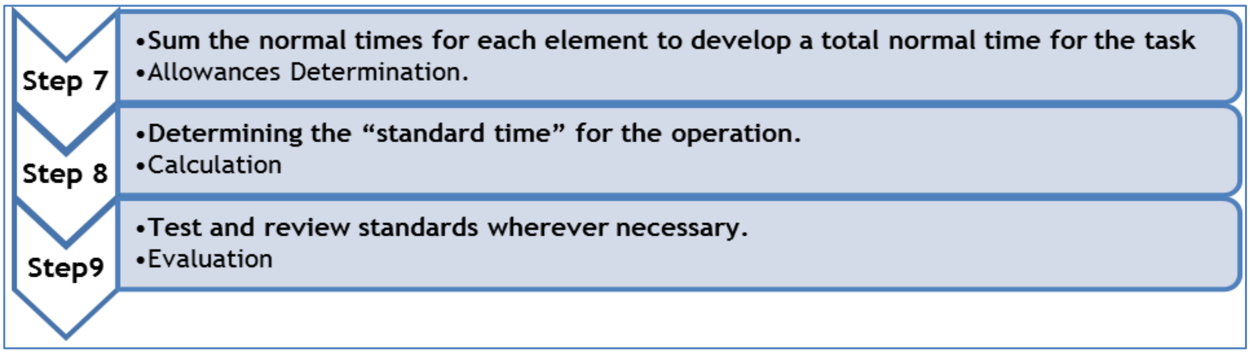

Figure 5: Tertiary work study stage

3 DATA COLLECTION

3.1 Flexible packaging company processes and QA job procedure

The Flexible packaging corporation comprised of eight printing machines (one of which is a flexo printing machine), ten lamination machines and four extrusion machines. Other machines such as the rewinding machines, slitting and packaging are not included on the study process. The role of the Quality Assurance department was to assess the quality of each batch manufactured from the printing, the lamination or extrusion machines. These machines were run by operators and each had one or two assistants depending on the work order and machine specification. All these operations required meticulous care in order to minimise wastage and customer complaints.

Quality Assurance Officers (QAOs) roles include collecting samples for quality clearance, from the machine of each reel before and after every operation (printing, lamination and extrusion). Production is executed in two shifts (8 hours and 12 hours) and each QA personnel per shift was allocated a machine for clearance, certification and recording the testing results to the JDE system for traceability and accountability.

The QAO's current job procedure consists of (1) travelling to the production line, (2) collecting the reel sample before printing. From the comfort of their laboratory, QAOs' testing procedure consists of the following: (3) oil testing, (4) ink solid testing, (5) Gas

Chromatography (GC) verification, (6) pressure test for foil, (7) bond strength of paper lamination, (8) heat resistance testing for ink, (9) extrusion coating mass, (10) adhesive radio and many more.

Table 2: QA service department and machine per section

QA/SHIFT	SECTION	LAMINATION	PRINTING	EXTRUSION	LAM
QA1	Section 1	L2	P11	E3	LA7
QA2	Section 2	L7	P10	E1	LA3
QA3	Section 3	L6	P6, P9	E7	LA5
QA4	Section 4	L8	P1	F1	LA4
QA5	Section 5	L1	P13, P8	E8	LQ3

The department is composed of 16 QA personnel, with five members of staff being rotated in both 8 hours and 12 hours shifts. Each QA staff member has a working section in the QA laboratory, as shown in Table 2. Table 2 also shows that each QA staff in an allocated section is responsible for quality clearance of at least one lamination machine, one printing machine, one extrusion machine and one LAM depending on machine production scheduling.

Figure 6 highlights the layout of the plant, specifically the locations of different machines as well as the layout of the QA laboratory. Quality Assurance Lab shown in Figure 6 includes the layout of the QA work sections (represented by 1, 2, 3, 4, and 5) and computers (represented by C1, C2, C3 and C4). Figure 6 also shows the daily itinerary of each QA per session as per Table 2. For instance, the QA in Section 1 (Itineraries shown in red arrows) services the printing machine (P11), the lamination machine (L2), the extrusion machine (E3) and the LAM (LA7).

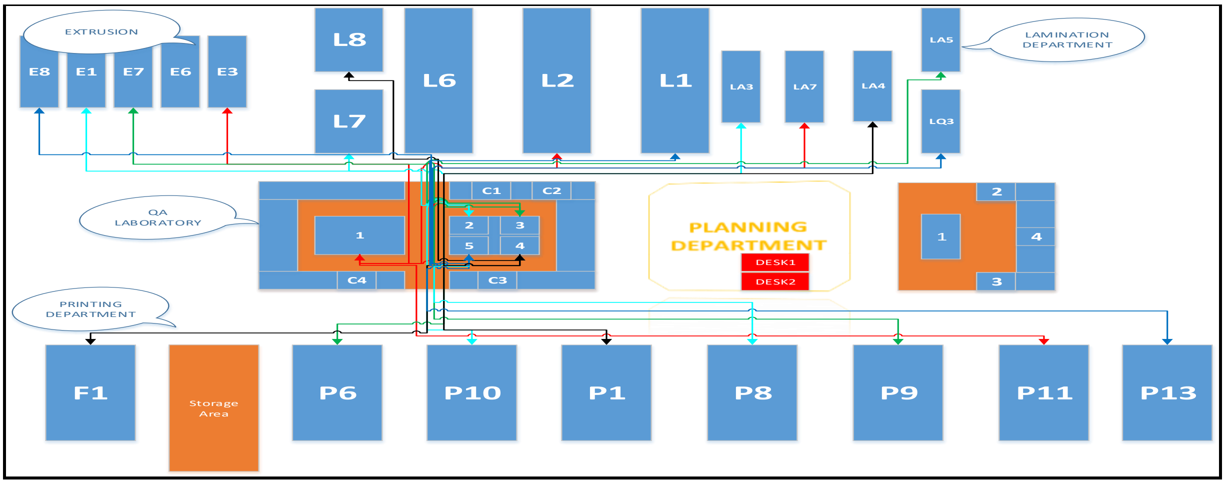

Figure 6: Layout of each department location with each section duties

The flexible plant being studied ran on 8 hours shifts (6am - 2pm; 2pm - 10pm and 10pm - 6am). The QA department however operates in two shifts system (12 hours shift and 8 hours shift). Of the five testing sections composed in the lab, two QAOs operated for 12 hours shift (6am-6pm and 6pm-6am) while the remaining three QAOs operated for 8 hours shift (6am - 2pm, 2pm - 10pm and 10pm - 6am). For diligence purposes, the QA routine work activities were observed in line with their job procedures and the production planning. This preliminary observation led to time study being conducted to all 16 QA members. The study was piloted for both 8 hours and 12 hours shifts QA personnel. Figure 7 shows that 2 QAOs were studied from section 1 (QA11 and QA12); another 2 were studied from section 2 (QA14 and QA15); 5

were from section 3 (QA1, QA2, QA3, QA10, QA13); another 5 from section 4 (QA4, QA5, QA6, QA7, QA16) while the remaining 2 QAOs were studied from section 5 (QA8 and QA9).

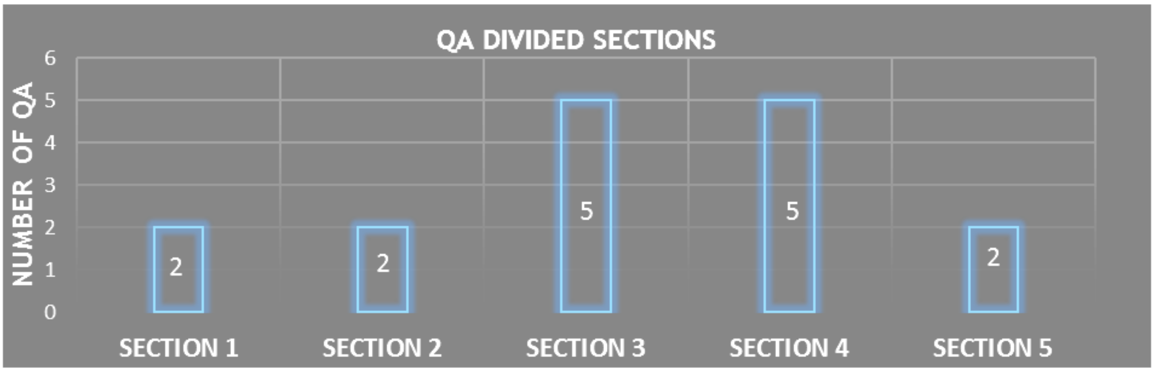

Figure 7: Number of QAOs studied per Section

3.2 Planning Department

The planning department is responsible for the production planning. On daily basis, if the maintenance department declares a machine to be fit to operate, the planning department assigns a work order to the machine operator and to QA personnel. The work order is offered for every job with all necessary information required to run that job.

There are factors worth noting that precede a successful production planning and scheduling; chief among them are the availability of material in the storage. Other factors include the (1) quantity of product to be produced, (2) machine availability or (3) machines not operating in their optimal capacity. Furthermore, factors that could lead to unsuccessful production is (1) machine speed being below the estimation and (2) the machine set up time taking longer especially when production variation is higher. Another factor that could lead to unsuccessful job production is long wait by machine operator waiting product be cleared for production by QAOs.

4 RESEARCH METHODOLOGY

Six-Sigma DMAIC has an ability to help organization make more money by improving customer value and efficiency [8]. With the research using DMAIC (Define, Measure, Analyse, Improve and Control) as framework to achieve the study aim, each step of the Six-Sigma tool had to be applied to the study to resolve the current disputes starting from the “definition” of the QAOs daily routines starting from the beginning of the shift to its end. The definition phase of Six-Sigma DMAIC isolates the top causes behind the CTQ (Critical-to-Quality Characteristic) or metric. “Define” objective also includes the work equipment used by the QA being studied, the process as well as the standard working procedures if existing any.

The following step was the “Measurement” of how long it takes for a QA to conduct his or her daily routines in an 8 or 12 hours shift. “Measurement” phase in Six-Sigma DMAIC is a crucial as it assists quantify numerically and exponentially each QAOs values. With all parameters included, “measurement” of the QAOs daily activities assists the relevant authorities to have in their possession facts allowing them to either support or debunk the QA request for more financial incentive as a consequence of being overworked. After measuring Critical-to-Quality (CTQ) characteristics of the study, the next phase involves analysing those CTQ. As part of the “analysis”, data gathered were analysed using an Excel spread sheet. Time Measurement Sheet was used to determine the average cycle time. From the cycle time, periodic operation, idle and tea time were calculated. Graphical representation of the results was used to identify critical cases.

The next step for the six sigma DMAIC framework is to “improve” the current work practices and environment. Improvement of the QAOs’ daily routine was based on the outcome of the research analysis. It should be noted that DMAIC is a cycle that can be repeated as long as improvement is needed. After improving the existing system, the final phase includes "controlling" the improved system in order to ensure lasting results and sustained changes. The best controls require little or no monitoring, such as process design or irreversible product changes, but usually there are also setup procedures, process setting, and other improvements that will necessitate monitoring and specific daily operation requirements [16]. Steps need to be taken to ensure that the process will not revert back to the "old way" of doing things.

5 RESULTS

As indicated in the objectives of the study, six sigma DMAIC steps were applied in order to achieve the needed results.

5.1 Define

The first step for the six sigma DMAIC process is QA complaints definition. A complaint was launched by QA personnel to the relevant authority with regards to their current working conditions, their relationship with their foreman, as well as their relationship with the various service departments (extrusion, printing, planning and lamination). According to the QAOs' complaints, their working conditions were characterised by "excessive work overload". They were convinced that servicing 5 machines per section daily is overwhelming especially when counting the frequent back and forth travelling between machines for samples collection. The other key issues of complaint were the salary imbalance between departments. According to the QAOs, machine operators, although supplemented by assistants, have less responsibility while being ahead in the company hierarchy and salary ranking.

Recently, further responsibility was demanded from the QAOs, causing further divides between QAOs and their management. The management requested capturing of the results of every test conducted by QA on the Oracle's JD Edwards software at every section in addition to their existing activities. However, the QAOs argued that there was insufficient time to yield to the managers' demand due to the lack expertise in operating the system, coupled with slow and insufficient computers with the JDE system in the lab (only 4 computers for 5 QAOs).

5.2 Measurement

Time study was conducted on each of the 16 QAOs using among other devices, a stopwatch. After weeks of observations, QAOs' daily activities were broken down and these activities were recorded per section as detailed in Table 2. The stopwatch was used to determine how long it took to fulfil each activity.

5.2.1 QAOs Routine and Particular Activities observed

As a key step to the time study, QA activities from each section were observed and recorded. As shown in Table 3, some activities were routine activities while others were particular. Table 3 also shows the findings of the observation conducted on the QAOs in all the lab sections. The observation also revealed how often "#" those activities took place.

Table 3: Daily Quality Assurance activities per Section

Section	#	Section 1	#	Section 2	#	Section 3	#	Section 4	#	Section 5
QA's Studied (16)	2	11, 2	2	14, 15	5	1, 2, 3, 10, 13	5	4, 5, 6, 7, 16	2	8, 9
Routine Activities Observed	2	Job Preparation	2	Job Preparation	5	Job Preparation	5	Job Preparation	2	Job Preparation
	2	New Chart filling	2	New Chart filling	5	New Chart filling	5	New Chart filling	2	New Chart filling
	2	Travelling to Machines	2	Travelling to Machines	5	Travelling to Machines	5	Travelling to Machines	2	Travelling to Machines
	2	Raw Material Analysis	2	Raw Material Analysis	5	Raw Material Analysis	5	Raw Material Analysis	2	Raw Material Analysis
	2	Finished Product Analysis	2	Finished Product Analysis	5	Finished Product Analysis	5	Finished Product Analysis	2	Finished Product Analysis
	2	Chart filling	2	Chart filling	5	Chart filling	5	Chart filling	2	Chart filling
	2	Tea Break	2	Tea Break	5	Tea Break	5	Tea Break	2	Tea Break
Particular Activities Observed	2	Capturing JDE	1	Planning department	1	Solving Non Conformity	2	Capturing JDE	1	Planning Department
	1	Gas Changing	1	Ratio Testing	1	Capturing JDE	1	Gas Changing	1	Gas Changing
	1	GC Resetting	2	GC Setting	1	GC Setting	1	Resetting of GC	1	Resetting of GC
			1	Capturing of JDE	1	Planning Department	2	Toilet break	1	GC Setting
							2	Solving Non Conformity	1	Solving Non Conformity
							1	Planning Department		
							3	Ratio Testing		
							1	making Photocopy		

5.2.1.1 Routine Activities Observation

Figure 8 shows that 5 sections out of 5 were routinely involved with activities listed in the "routine activities observed" shown in 3 although the machines are different in every section. Figure 9 reveals that all the 16 QAOs studied were involved the activities listed in each of the five sections.

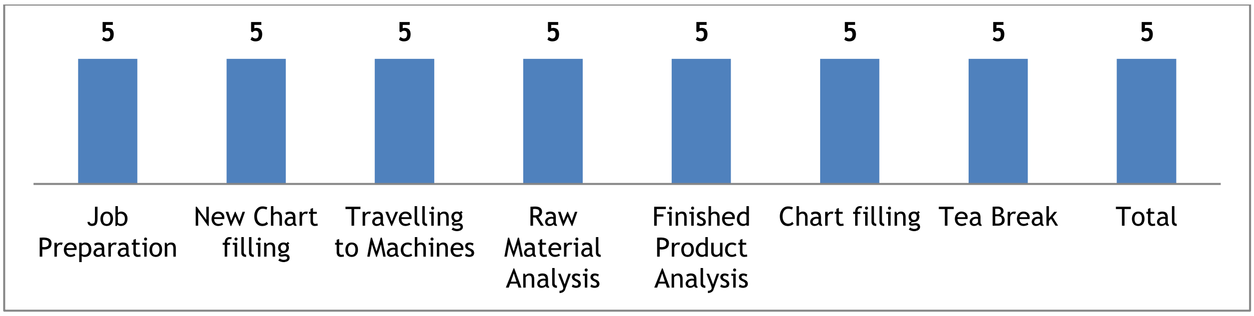

Figure 8: Daily Activities Observed per Section

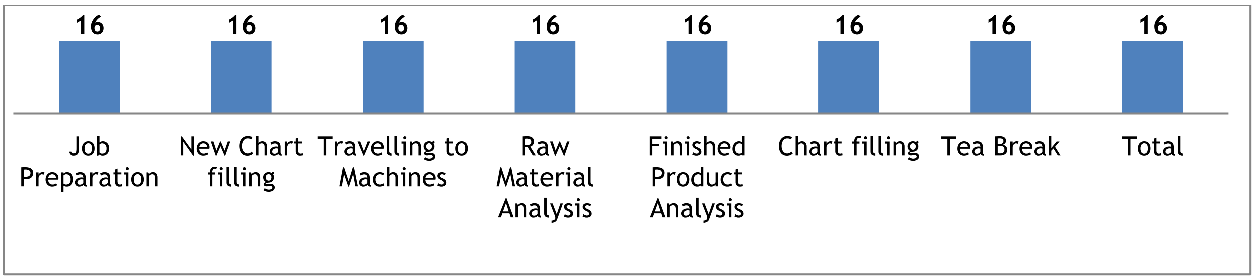

Figure 9: Daily Activities observed per number of QAOs

5.2.1.2 Particular activities Observation

Particular activities are one that occurred once after a while, often as a result or consequence of some anomaly. Particular activities observed included inquiring about missing or incomplete work orders from the planning department, gas changing, resetting of the GC, and capturing the JDE, ratio testing, solving non-conformity, GC setting and others. Figure 10 and 11 revealed that certain activities were not conducted by QAOs and did not occur in some sections.

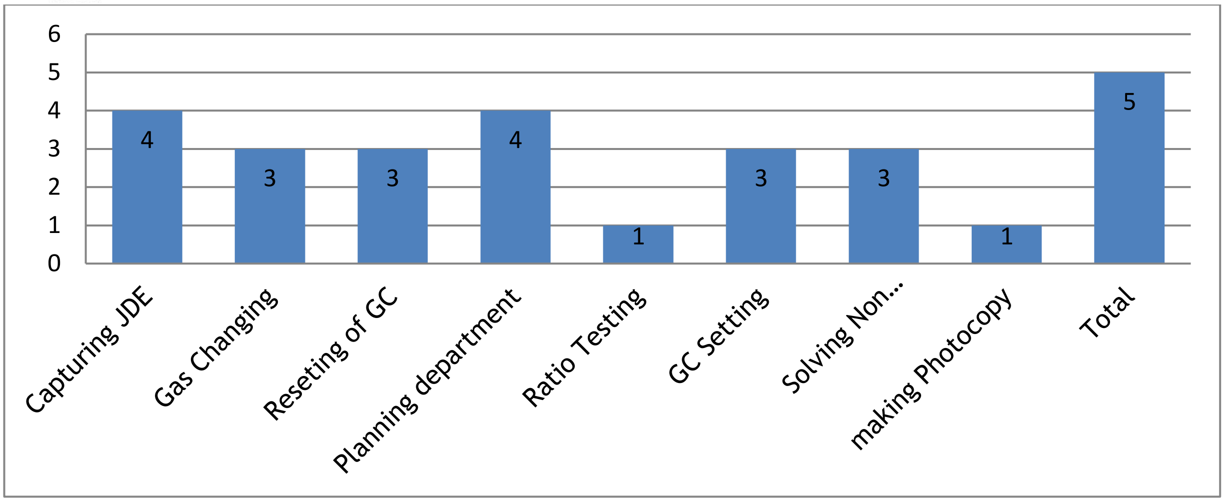

Figure 10: Particular Activities Observed per Section

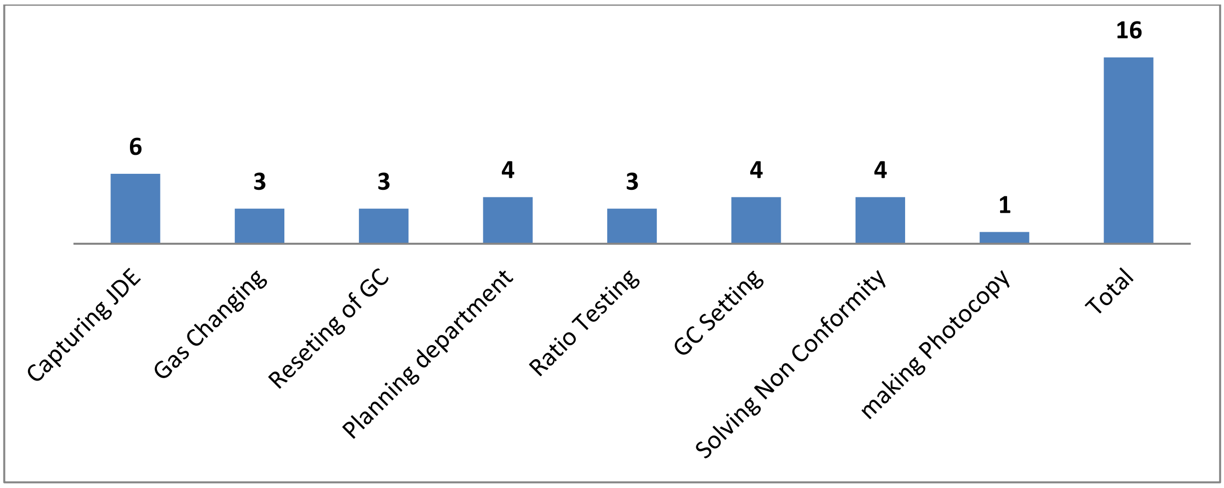

Figure 11: Particular Activities Observed per Number of QAOs

5.2.2 Time recording

From the outcome of the observation, Table 4 shows the recorded time for every activity conducted by QAOs from every section. The table below reveals the each QA periodic operation time, idle time and tea break time. Periodic operation includes preparation for the job while waiting for machines to run and work orders from the planning department. Other periodic operations include chart filling after every job, traveling to and from machines to collect raw materials, finished goods or even solving nonconformity, testing raw materials, solving nonconformity, production analysis, capturing of JDE, GC setting, Gas changing and reset, ratio test and going to planning department.

Table 4: Recorded time for each QA activity (Minutes)

QA	Preparation	Chart filling	Travelling	Raw Materials	Solving Nonconformity	Production Analysis	Break	Idle	Capturing JDE	GC Setting	Gaz changing and Reset	Going to Planning	Ratio Testing
QA1	0	15.53	16	4.68	0	255.97	70	60	0	0	0	0	0
QA2	52.42	19.89	19.67	2.45	0	302.97	18	31	0	0	0	0	0
QA3	37.3	13.37	23.84	41.85	23.75	215.63	55	55	0	0	0	0	0
QA4	60.08	30.01	23.19	16.25	0	180.2	41	92	0	0	0	9.38	5.23
QA5	92.02	2.32	39.9	15.47	0	100.99	53	108	8.1	0	18.63	13.48	0
QA6	62.99	7.11	54.72	17.89	4.18	178.75	70	45	0	0	0	0	3.16
QA7	5.37	6.6	27.92	2.54	0	63.42	73	117	0	11.48	0	0	3.23
QA8	17.67	34.79	79.83	10.23	0	178.59	83	53	0	0	0	0	0
QA9	0	45.19	76.96	6.35	0	138.49	81	34	51.34	36.59	0	0	0
QA10	0	2.18	13.85	2.2	0	64.73	62	96	22.91	0	23.79	0	0
QA11	0	11.71	60.75	5.44	0	135.68	68	118	54.08	0	0	0	0
QA12	107.99	16.28	35.85	3.77	7.38	149.07	58	25	0	9.69	43.62	32.19	0
QA13	77.25	14.63	30.49	7.69	0	159.74	77	82	0	0	0	7.1	0
QA14	92.61	10.59	26.28	14.6	0	109.63	69	53	39.94	9.27	0	5.54	10.32
QA15	60.72	9.64	29.63	16.3	0	171.01	78	71	0	16.96	0	0	0
QA16	63.75	3.71	46.76	5.31	14.46	172.12	68	84	2.1	0	0	0	0
TOTAL	730	244	606	173	50	2577	1024	1124	178	84	86	68	22

5.3 Analyse

Figure 12 shows that "production analysis" (raw material and finished good reels testing time in minutes) was the activity conducted by QAOs with the most consumed time with a total of 2577 minutes (Averaging 161 minutes per QA). While solving non-conformity (total of 50 minutes) and Ratio testing (22 minutes) were the least time consuming. Idle time (1124 minutes) and Break time (1024 minutes) came as second and third activities.

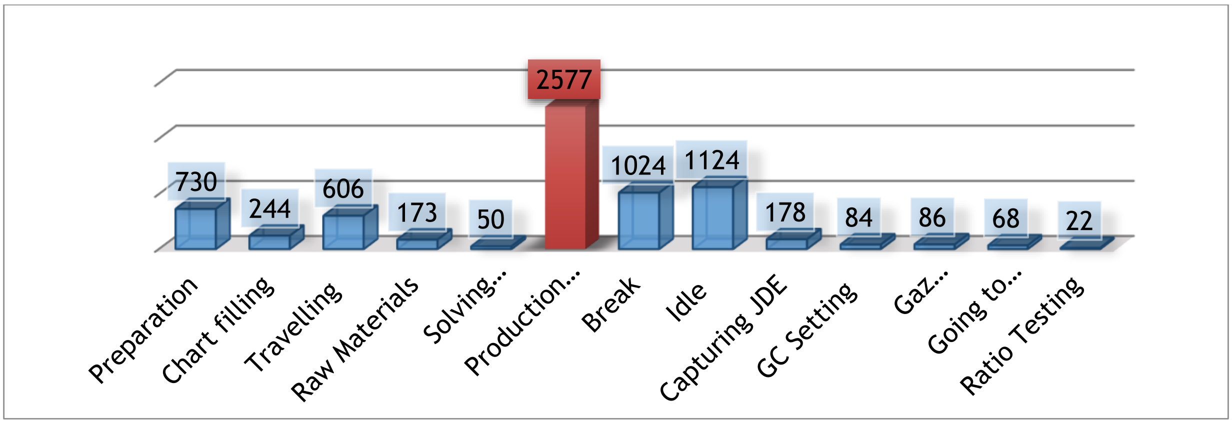

Figure 12: Recorded activities graph

Table 5 shows the sum of periodic operation time, the idle time and the tea break time per section from all the shifts (6AM to 6PM shift (12 hours), 6PM to 6AM shift (12 hours), 6AM to 14PM shift(8 hours), 2PM to 10PM (8 hours) and finally 10 PM to 6AM (8 hours)).

Table 5: QAOs Operation Time, Idle Time and Tea break (hour)

QUALITY ASSURANCE	PERIODIC OPERATIO	IDLE TIME	TEA BREAK	TOTAL (HOUR	SECTION	MACHINE /SHIFT	SHIFT
QA 1	5.83	1	1.17	8	SECTION 3	4	2 PM-10 PM
QA 2	7.18	0.52	0.3	8	SECTION 3	4	6 AM-14 PM
QA 3	6.16	0.92	0.92	8	SECTION 3	4	10 PM-6 PM
QA 4	5.78	1.54	0.68	8	SECTION 4	3	10 PM-6 AM
QA 5	5.32	1.8	0.88	8	SECTION 4	3	6 AM-14 PM
QA 6	6.08	0.75	1.17	8	SECTION 4	4	2PM-10 PM
QA 7	4.83	1.95	1.22	12	SECTION 4	4	6 PM-6 AM
QA 8	5.74	0.88	1.38	8	SECTION 5	4	6 PM-14 AM
QA 9	6.08	0.57	1.35	12	SECTION 3	4	6 AM-6 PM
QA 10	5.37	1.6	1.03	12	SECTION 1	3	6 AM-6 PM
QA 11	4.9	1.97	1.13	12	SECTION 1	3	6 PM-6 AM
QA 12	6.62	0.41	0.97	12	SECTION 5	4	6 AM-6 PM
QA 13	5.35	1.37	1.28	12	SECTION 3	5	6 PM-6 AM
QA 14	5.97	0.88	1.15	12	SECTION 2	2	6 AM-6 PM
QA 15	5.52	1.18	1.3	12	SECTION 2	4	6 PM-6 AM
QA 16	5.47	1.4	1.13	12	SECTION 4	4	6 AM-6 PM
MIN	4.83	0.41	0.3			2	
MAX	7.18	1.97	1.38			5	
AVERAGE	5.76	1.17	1.07			4	

Table 5 and Figure 13 show the periodic operation for each QAO and QA 2 had the highest operating time (7.18 hours an 8 hours afternoon shift) while QA 7 and QA 11 respectively have the lowest periodic operation time. Furthermore, Table 5 and Figure 14 reveal that QA11 has the highest "idle time" (1.97 hours for a 12 hours night shift) while the QA12 had the lowest time (0.41 hours for a 12-hour morning shift). As for the break time, Table 5 and Figure 15 show QA 8 as the Quality Assurance personnel with the longest Tea Break (1.38 hours for an 8 hours morning shift). It should be noted that tea breaks are used smoking QAOs as smoke break.

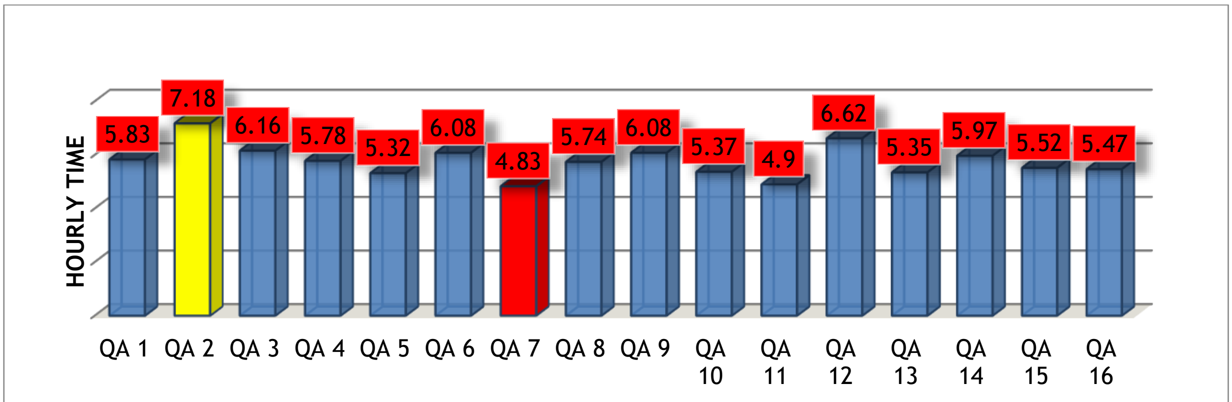

Figure 13: Periodic Operation per QAO Analysis

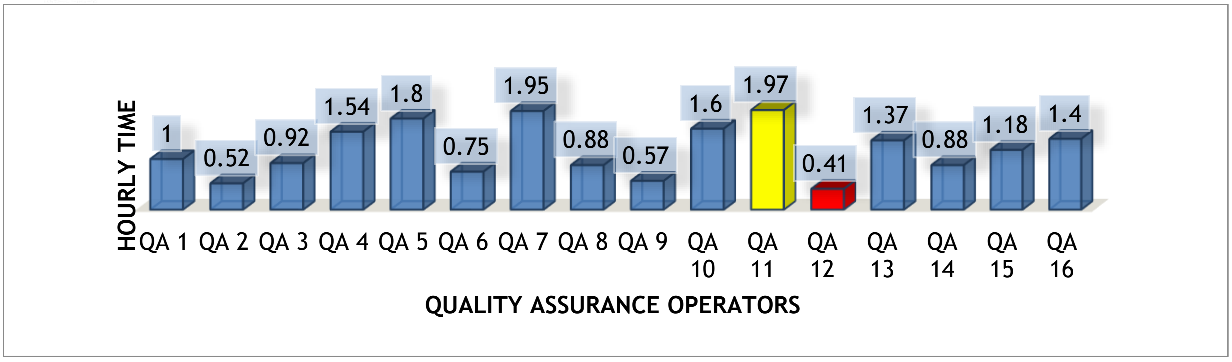

Figure 14: Idle Time Analysis

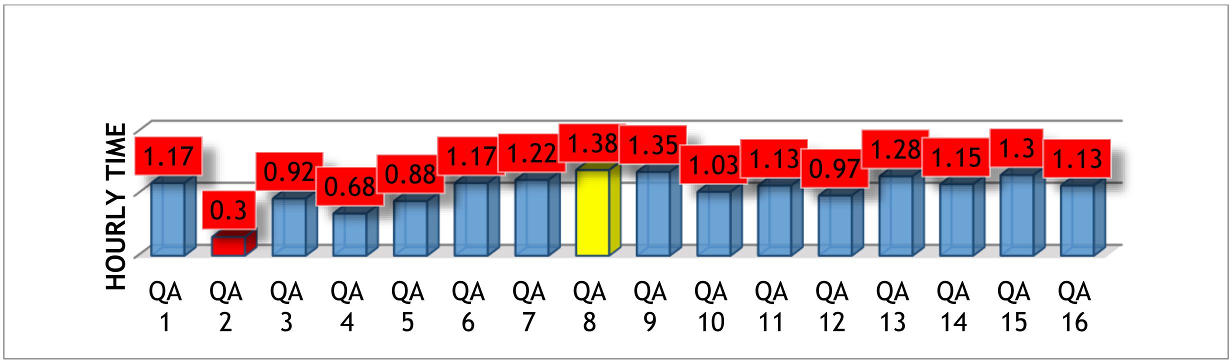

Figure 15: Tea Break Analysis per QAOs Analysis

Table 6 shows number of QAOs studied per section in every shift, including the average periodic time, average idle and average tea break per shift. According to Table 6 and Figure 16, the 12 hours shifts (both 6AM to 6PM and 6PM to 6AM) had the highest number of QAOs studied (5 QAOs for each), while all the 8 hours shifts (6AM to 2PM, 2PM to 10PM, 10PM to 6AM) had the lowest with 2 QAOs for each shift. Furthermore, Table 6 and Figure 16 reveal that the highest average periodic operation time was from the 6AM to 2PM shift, followed by the 10PM to 6AM shift. The 6PM to 6AM shift had the highest idle time, followed by the 10PM to 6AM shift. Finally, both Table 6 and Figure 17 conclude that the Break time is the highest in 6PM to 6AM shift, followed by 6AM to 6PM shift.

Table 6: QAOs Operation Time, Idle Time and Tea break per Shift (hour)

SECTIONS	No of QA	6AM-6PM	6PM-6AM	6AM-2PM	2PM-10PM	10PM-6AM
SECTION 1	2	QA10	QA 11			
SECTION 2	2	QA14	QA15			
SECTION 3	5	QA9	QA13	QA2	QA1	QA3
SECTION 4	5	QA16	QA7	QA5	QA6	QA4
SECTION 5	2	QA12	QA8			
TOTAL QAs PER SHIFT	16	5	5	2	2	2
AVERAGE PERIODIC TIME		5.90	5.27	6.25	5.96	5.97
AVERAGE IDLE TIME		0.97	1.47	1.16	0.88	1.23
AVERAGE TEA BREAK		1.13	1.26	0.59	1.17	0.80

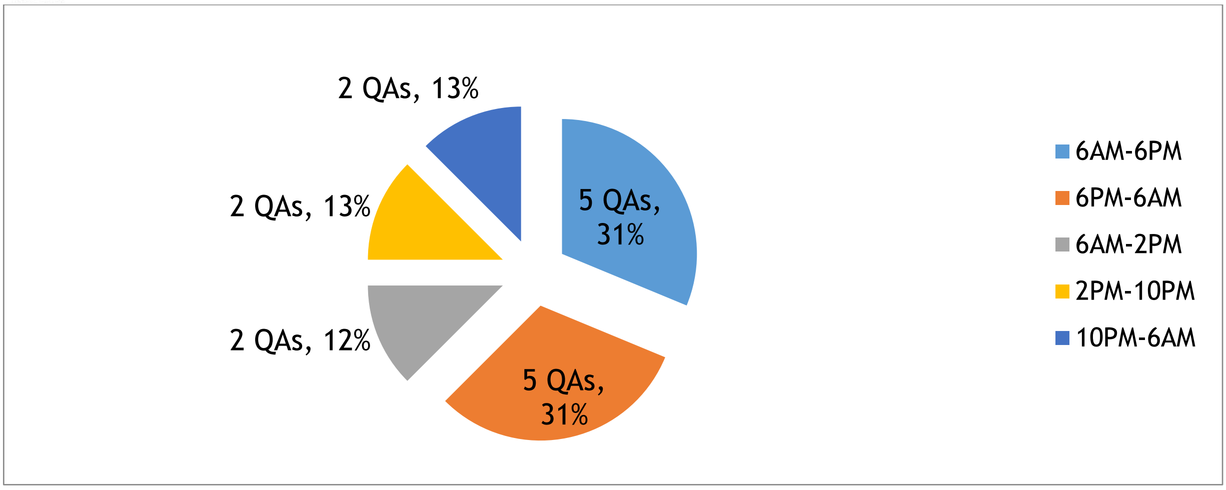

Figure 16: Number of QAOs studied per shift

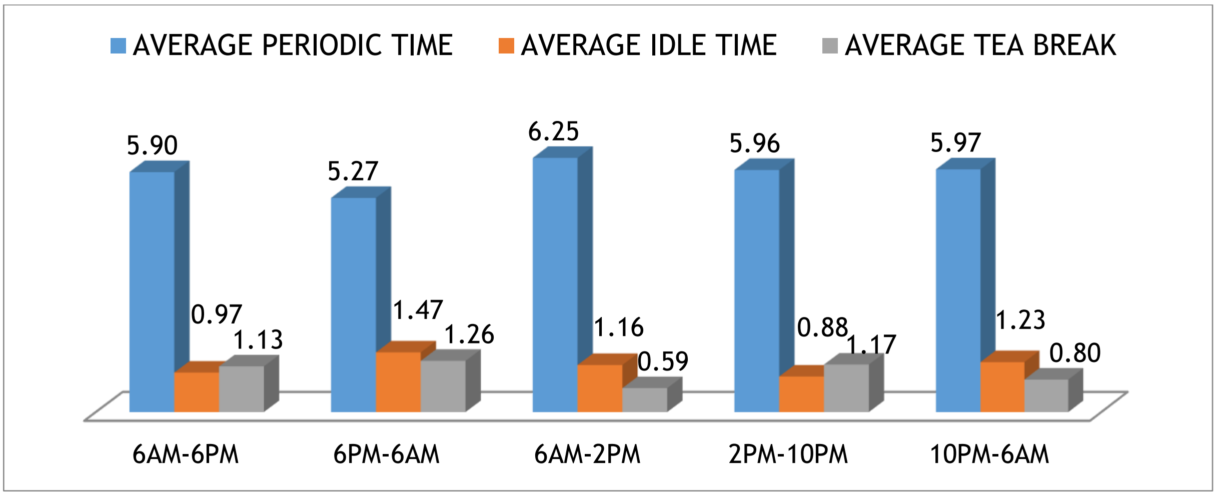

Figure 17: Time analysis per shift (hour)

5.4 Improvement

The analysis that was conducted led to issues causing disputes being highlighted. After detailed analysis, areas that were prioritised for improvement in order to resolve the current disputes are: (1) the QAOs staffs in comparison to their peers, (2) their daily activities and finally (3) their Performance rating and customer satisfaction. Table 7 highlights the current situations (Before) and the proposed improvements (After).

Table 7: Current situation (Before) Vs. Improvement plan (after)

BEFORE/AFTER	CURRENT SITUATIONS (BEFORE)	IMPROVEMENTS PLAN (AFTER)
QAOs staffs Vs. Service Department	Monthly salary being less than operators from service departments	Offer pay overtime for QA, restructure work activities by giving more responsibility of part quality to operators and their assistants
	No structured training, learn overtime from the most experienced	Develop of standardize work procedure for every QA working on the Lab
	Communication breakdown between QAOs, service department and QAOs management	QAOs daily activities and roles should be in line with the Job description

Daily activities	Only 6 QAOs of the 16 captured the JDE during the study. Many factors prevented capturing such as the number of machines running per section, as the job type, as the computer literacy of QAOs, and also the accessibility of the system and Lab computers.	Based on the study results, study cannot conclude after the analysis that QAOs have sufficient time to capture the JDE as per request. However, standardised work, job training as well promotion of team leadership in each shift can increase the QAOs time to capture the JDE as requested.
	Depending on the daily planning, sections and QAOs business per shift varies.	A team leader at every shift is needed for work redistribution. A team leader will encourage accountability, team work and unity for a common goal.
	Solving nonconformity is strenuous and time consuming for QA	Having a team leader per section promote communication to service departments and to QAOs management
	660 minutes was spent by QAOs travelling to machines to (1) check state of machine, (2) collect raw material reels before production and (3) collect finish goods after production	Travelling cannot be fully eradicated. Operators and assistants should be responsible of ensuring that the machine, the raw materials and finished goods are cleared before moving to the next step. QAOs should certify the machine readiness before any production occurs.
Performance rating Vs. customer satisfaction	Nonconforming products are one that had failed the Quality clearance	Clearing without delays raw materials before any production
	Daily activities includes Non-value added operation such travelling to collect samples, waiting and going for planning department for daily plan	Operators and assistant dropping the sample to the QA lab as a means of sharing responsibility. Ensuring that the daily plan is ready up on the QAOs arrival
	Performance rating in the morning (6AM to 14PM and 6AM to 6PM) and evening (10PM to 6AM and 6PM to 6AM) were the lowest. With an increased Tea breaks and idle time.	Ensure that all relevant information and tools needed for the commencement of each shift is available beforehand (work order, gloves, colour matching, etc.). A regulated break time, smoke time and other idle time is needed.

5.5 Control

For a permanent resolution of the disputes in the QAOs' laboratory, it is of primary importance that a leader is appointed for every shift for the reason stated in the improvement. With leadership, come responsibility, competition, accountability and reward. Furthermore, some activities are proven to be time wasting. It is therefore necessary to rebalance work activities, standardised the job procedure and processes then train all 16 Quality assurance staff on the new and upgraded job procedures. Any deviation of this new system, trained standard procedure, should result to disciplinary actions. Finally, improvements proposed in this study can only see success if management, QA department and all service departments show willingness to work together for customer satisfaction.

6 CONCLUSION

With the goal of accurately establishing how long it takes for each QAO to complete daily activities per section, this systematic examination of QA staffs activities has highlighted flaws. The Six Sigma DMAIC methodology would improve the effective use of time or money and set up standards of performance for the activities being carried out. Although no additional time was given for the implementation of the improvement proposal, Six Sigma improvement phase discussed the results of the analysis and underlined all areas for improvement. Future studies will possibly quantify this improvement in both financial and production terms.

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IMPROVING CUSTOMER SERVICE THROUGH FMCG MANUFACTURING FIRMS IN GAUTENG: A SERVITIZATION APPROACH

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ABSTRACT

This paper recognizes how FMCG manufacturing firms in Gauteng, deliver the best customer service in moving from product centric to service oriented. The cross functional relationship between products and services is crucially evolving and there is a need for FMCG manufacturing firms to embrace these service orientations in order to deliver surpassing customer service, hence the need to determine how the customers can be fully integrated into manufacturing to measure the influence regarding the customer services outcome outcome of the products paramount. According to the findings of the study, the interviews conducted with Research and Development specialists on two categories in FMCG, namely food and home and personal care, have revealed that servitization is paramount to most of the FMCG manufacturing firms and is seen as something that creates value to their customers. While 65% of the participated FMCG manufacturers said to be on servitization track, about 35% were found not pursuing the servitization journey due to limitations such as capital investment, negative return on investment and inadequate service strategies. The theoretical implications of the findings according to (Kindstrom, 2010) is that the limited interactions between suppliers and customers will thus have a negative impact on the enhancement of relationships meant to facilitate an improved customer sensing and information gathering.

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1 INTRODUCTION

Interest in 'servitization' has grown rapidly over the last decade, with products and services increasingly being bundled together to improve value capture [1]. Servitization is the term given to a transformation where manufacturers increasingly offer services that are tightly coupled to their products. A move towards servitization is a means to create value-adding capabilities that are distinctive, sustainable and easier to defend from competition based in lower cost economies [2]. The concept of servitization describes the shift of companies to becoming more service oriented [3]. At least according to Kindstrom [6], the limited interactions between suppliers and customers will thus have a negative impact on the enhancement of relationships meant to facilitate an improved customer sensing and information gathering.

Spring and Araujo [4] attest that the respective roles of products and services in delivering benefits to customers roles have become an increasingly studied issue, ''therefore a key feature of servitization strategies is a strong customer centricity. Customers are not just provided with products but broader more tailored 'solutions'. These deliver desired outcomes for specific customers, or types of customer, even if this requires the incorporation of products from other vendors'' [5]. In this paper, we have specifically focused on the FMCG manufacturing firms on the category of food and home and personal care in Gauteng, South Africa with the aim of identifying the consumers' influence with regards to products preferences.

Having a customer centric supply chain to meet personalised expectations will not only result in happy customers but also in happy shareholders where organisations are both satisfying customer's expectations and avoiding to incur unnecessary costs to the business. Going beyond this primary fulfilment, partners are further delighted when the organisation seeks opportunities, where feasible, to expand existing revenue streams from only manufactured products to include related services such are customer care [7].

As manufacturing businesses operate in an ever more competitive, global economy where products are easily commoditised, innovating by adding services to the core product offering has become a popular strategy. Increasingly, durable goods manufacturers choose to innovate their offerings by providing services to accompany their existing products throughout the life cycle [8].

While this practise has been done commonly by the first world countries, there is not much research published found to be applicable in the South African context on servitization. In international benchmarking, more corporations are adding value to their core corporate offerings through services. The trend pervading almost all industries, is customer driven, perceived by corporations as sharpening their competitive edges [3]. Modern corporations are increasingly offering fuller market packages or ''bundles'' of customer-focused combinations of goods, services, support, self-service and knowledge, however services are beginning to dominate [3]. These services are done through servitization. This research seeks to find out the strategic implications (that) FMCG manufacturing firms draw from servitizationby incorporating their customers up front.

To do so, it focuses on the following objectives,

1. To identify consumer's influence in the outcome of product manufactured at FMCG manufacturing firms =

2. To evaluate how the configuration of operations in FMCG manufacturing capitalizes on the ideas customers provide for suggested products and services
3. To identify the value proposition that FMCG manufacturing firms are offering to clients
4. To identify how much access up and down the supply chain FMCG manufacturing firms allow their customers

2 LITERATURE REVIEW

2.1 Servitization definition

Servitization is the innovation of the organisation's capabilities to better create mutual value through a shift from selling product to selling Product-Service Systems [9]. One author defines it as the transformational processes whereby a company shifts from a product-centric to a service centric business model and logic [10]. This study agrees with Green et al, [18] that it is therefore a logical assumption that a thorough understanding of value-creating processes is crucial for any organisation interested in servitization including FMCG manufacturing firms.

In trying to unbundle servitization, the model below served as a guideline to direct research questions posed during the research interviews with research and development units at FMCG firms to holistically focus on the customer value determination process. The model was adopted from *Woodruff* [14].

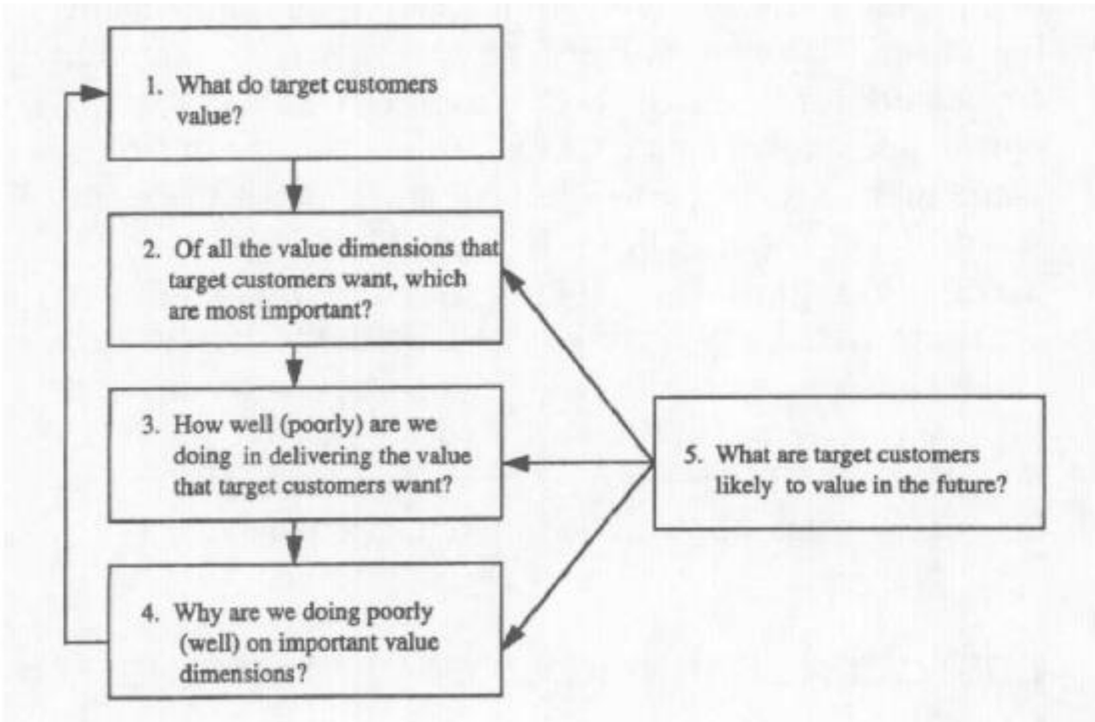

Figure 1: Customer value determination process, source (Woodruff, 1997)

2.2 Why servitization?

Raddats et al [11] suggest that motivations to servitize vary according to product complexity, although cost savings and improved service quality appears important as demand-based motivations for all manufacturing firms. Competitive motivations suggest manufacturers view their products as their primary resource 'Physical', with services as an important element of a differentiation strategy [12]. Wise and Baumgartner [13] have noted that servitization is rolled out ''because manufacturers have an intimate knowledge of their products and markets, they are well positioned to carry out many downstream activities. The authors acknowledge that exploiting these downstream opportunities, though, requires a new way of thinking about strategy''. This is an area where servitization is important.

2.3 Elements of the economic context influencing servitization

While servitization is important in the current era, competitive pressure and the need to differentiate have driven manufacturers to adapt their offerings to meet increasingly more heterogeneous needs, while exploiting scale economies from high-volume production [1]. The following elements featured belowa are the elements of the economic context, which influences servitization. They could either become a hindrance or a key advantage to achieving an orientation from product to service centric FMCG manufacturing,the points in summary are listed below;

- Infrastructural development. Miller et al., [23] notes that a well-developed infrastructure is vital to efficient servitization, since it connects customer-facing, front-end units with the firm's back-end units and facilitates product service supply to meet customer demands. In order to properly deliver services to customers and earn higher financial benefits, manufacturing firms have to move downstream [24].
- Level of education and qualification. Meeting the challenges of servitization requires a highly qualified and flexible human resource base, which is ready to facilitate a higher level of customer centricity, a more complex supply of product-service packages and a more relationship-oriented cooperation with customers and suppliers than typically found in traditional manufacturing firms [22].
- Technological development. According to Parry et al, [25], technology in servitization allows firms to look beyond the voice of the customer and the user's stated requirements, but it can provide visibility to the use of resources within customer specific contexts. According to Geum et, al [26] the development of technology in servitization can play three different roles: it can act as an enabler, a mediator or a facilitator for product-service integration.
- Development of business networks: In developing business networks, manufacturing companies need ''to take steps to develop their relationships to meet these customer expectations, and take advantage of the input their customers can make into creating their new offerings. These relationship-building competences must be developed in all parts of the organization; the new competences should focus on proactivity, continuity, and the ability to capture specific customer needs. As services and service development become increasingly important, building, enhancing and retaining business networks will grow to become a critical activity across all parts of the organization, and at all stages of the offering life cycle. Supplier/customer interactions will need to increase, and the enhanced relationships thus created should facilitate improved customer sensing and information gathering'' [6].

2.4 Benefits of Servitization

Servitization comes with the following benefits:

- Consolidated product related services. It is typical for organizations to find that services are an important component of the consumer satisfaction indicators, and to consider this integration the first step to improve the delivery of those services. Furthermore, the consolidation of these services also comes with the development of a monitoring system to assess the effectiveness and efficiency of the service delivery, Oliva and Kallenburg [21].

- Innovation. Aligning the needs of the manufacturer and the customer: Baines and lightfoot [1] attest that aligning the needs of the manufacturer and the customer will have the benefits of increased customer loyalty
- Strengthens financial stability. Manufacturers who servitize their products increase their product margins and establish a longer lived relationship with their customers, Kruse [20].

2.5 Value proposition

Spring and Araujo [4] have found that meeting the rising customer demands, manufacturers are also finding it necessary to develop 'advanced' service offerings that can enable deeper customer relationships and address requirements that are more complex. This commitment of meeting rising customer demands ''appear important for all manufacturers, with a popular focus on cost savings and improved service quality when an activity is outsourced''. This demand motivation is necessary and one of the key strategic choices of consideration for manufacturing firms in developed economies, particularly in ''customer oriented'' business world, so as to be competitive, sustainable, and differentiate itself for long run business perspectives.

2.5.1 Framework for customer value assessment

According to Keränen and Jalkala [15], effective data management is considered central to customer value assessment due to the need to collect and coordinate systemically a large amount of information to generate a detailed analysis for the customer. This paper considers and adopts this framework, which summarises the key processes, and activities involved in customer value assessment in B2B (Business-to-Business) markets as illustrated below.

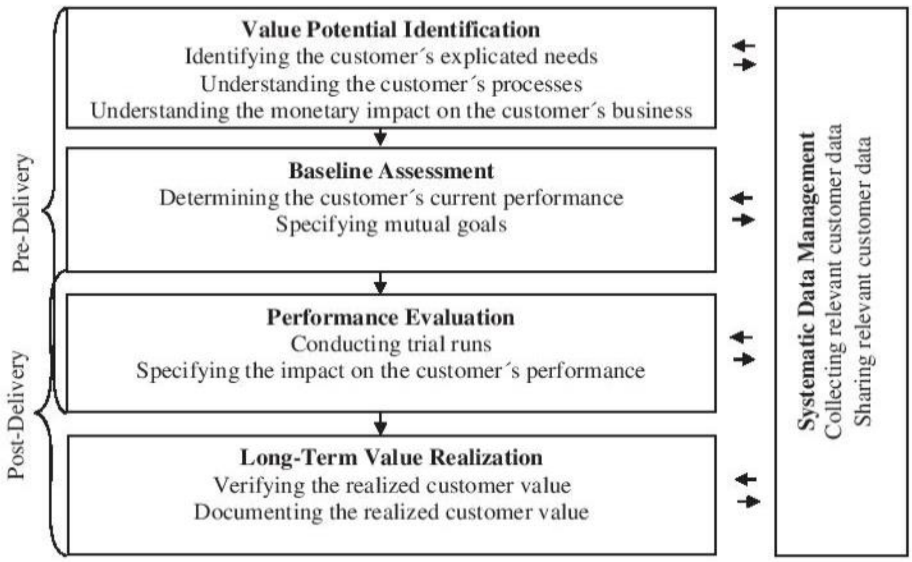

Figure 2: A proposed framework for customer value assessment: Source (Keränen and Jalkala, 2013)

The key components of the framework in figure 2 are given as:

Value Potential identification

The first key process for customer value assessment is value potential, which is concerned with understanding how a supplier can add value to its customer's business [15]. This Concept of customer value ''becomes an important management tool only when it is shared within an organization. Those involved in creating and implementing customer value delivery strategies need a common framework for thinking about customer value'' [14].

Baseline Assessment

Manufacturers have to understand deeply their customer's needs and problems first, then develop a new value proposition more customer oriented which will enable them build business models which allow generating and delivering expected value [16].

Performance evaluation

Another key process for customer value assessment is performance evaluation, which is concerned with evaluating the usual value impact on customer's business. Determining the customer's current performance is usually followed by specifying mutual outcomes including technical outcomes such as increasing efficiency or productivity and financial outcomes such as increasing cost savings or profitability [15].

Long term value realization

The creation of value is the core purpose of any economic activity and as such, forms the basis of competitive advantage [17].

3 METHODOLOGY

Research design

This paper conducted one-on-one interviews and discussions with participants where the researcher asked questions regarding the subject discussed [29]. The researcher chose the interviews method because participants are assisted to understand the questions posed, with additional questions also posed to collect more detailed information [30]. During the interviews in-depth data is collected and comprehensive understanding is gained where the interviewer probes explanation of responses [31].

Sampling

Seven participants from food and home & personal care categories in manufacturing firms participated in the study, each undergoing a semi-structured interview. The study was carried out in Gauteng province only. Participant's selection was made from operational point of view, with operations/production managers together with senior managers of research and development (R&D) teams of at least two years' experience in the FMCG manufacturing firms. These were considered as people who were likely to have the required information

Data collection and analysis

The interviews conducted were recorded, transcribed and coded into themes and sub-themes. Content analysis was used to analyse the information from interviews. During the analysis, the main themes that emerged from responses given by participants were identified and assigned codes, and thereafter responses were classified under the main themes that emerged from the responses by the participants [29].

4 RESULTS

Three themes emerged from the data analysis namely servitization drivers and practices, challenges of servitization and effects of non-servitization which were in line with the findings of Creswell and Poth [27]. The themes are summarised in the below table and are discussed in section 5.

Table 1: Servitization themes and sub-themes from FMCG manufacturing firms in Gauteng

Theme 1 : Servitization drivers and practices	Theme 2: Challenges of Servitization	Theme 3: Effects on non-servitization

• Product development on market research
• Capitalising on customer's inputs
• Consumer's influence on manufacturing
• Innovation in Servitization
• 3rd party solutions
• Value proposition
• Service delivery and performance (product market shares)
	• Capital investment
	• Formulation in manufacturing
	• Highly qualified and flexible work force /human resource
	• Institutional knowledge of servitization
	• Strong business infrastructure
	    • Flexibility in manufacturing process
	    • Market responsive to servitization
		• Negative ROI (Return on investment)

The findings of the research provide research and product development managers and manufacturing specialists/practitioners at FMCG manufacturing firms with insights concerning servitization practise encountered within their environment. It is very important that the FMCG manufacturing firms takes interest in their servitization process/journey as this could become one competitive edge and advantage in delivering the best customer service, being consistent with the value offered to their clients as well as expanding the customer base.

Spring and Araujo [4] allude to the fact that the key feature to servitization strategies is a strong customer centricity where customer's aren't just provided with products but rather more tailored solutions. In contrast to the finding of the research, few of the manufacturing firms that confirmed their current non-servitization strategies should take an advantage into exploring and leaning more towards becoming service oriented businesses in order not to lose their customers into more servitized markets

The pie chart below depicts the servitization status on participating FMCG firms which were summed up into three categorie These three categories included seven responses from seven different manufacturing firms. Fully servitized firms accounted for 3.8 participants which contributed 44% of participants, partially servitized firms accounted for 1.96 participants which contributed 28% of companies participated and the other 1.96 participants said to have not servitized which contributed an overall of 28% for companies which participated.

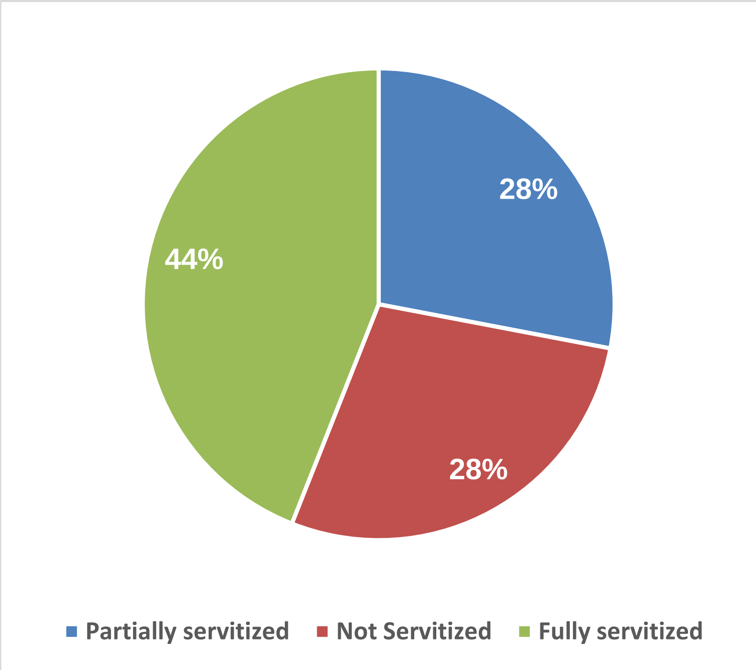

Figure 3: Servitization status on FMCG companies featured

The bar graph below depicts the current servitization practice per FMCG Companies which participated in the study reveals the current trends that led to the servitization progress respectively across the companies studied. A trend of servitization influence has been noted across the seven FMCG firms with reactive and proactive measures topping the influence while market research and product formulation appears to be on the same level of influence. Note the table below.

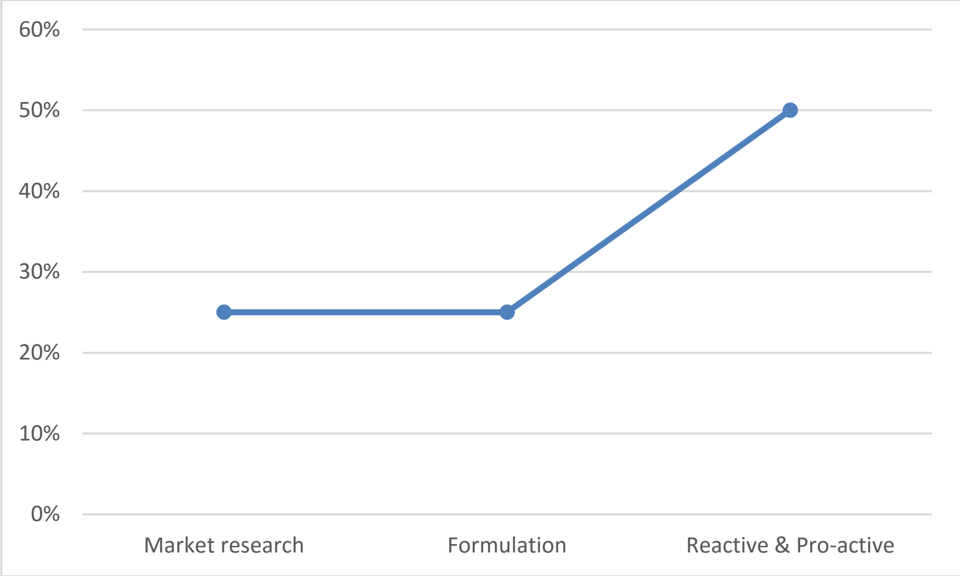

Figure 4 A bar graph indicating the servitization progress on companies featured

5 DISCUSSION

The results of servitization in participating Gauteng FMCG manufacturing firms are discussed under specific objectives.

5.1 Objective 1: To identify consumer's influence in the outcome of product manufactured at FMCG manufacturing firms

Four out of seven participants concede that consumers have a huge influence on their manufacturing processes while two other participants submit that it does happen but to an extent that the market is driving it, *'We are a business that is heavy on fixed assets. We have huge share with 20-30years life expectancy that are very expensive. Formulation changes in products, the consumer has huge influence from that by simply not buying it or buying it. We will work on the formulation of our product in the changing of our product manufacturing process because it is a standardised and not complex manufacturing process.''* (Participant 4)

5.2 Objective 2: To evaluate how the configuration of operations in FMCG manufacturing capitalize on the ideas customers provide for suggested products and services

Five out of seven participants indicated that they indeed capitalize on the ideas suggested by customers during the product manufacturing, *'we do capitalize on the ideas suggested by customers. How do we configure? It could be any change. Often we will go to a feasibility study for any process that we want to change in our business. Depending on the costs obviously there is a focus on the degree of the investigation, if it is more strenuous or not. So from the word go, we need to make sure that there is enough of the customer's needs to change the business*'' (Participant 2)

Since demand-based motivation is imperative to manufacturing, during the research a strong theme of FMCG firms responding to servitization need arose It has been found from most of the responses that an efficient responsive to servitization includes formulation in manufacturing, which may take a bit longer to implement due to internal processes and commercial viability of the change in process. *''So we are quite reactive, because to be number one you have to be the fastest, the most adaptive and creative. You are not number* *one because you are no one. You have earned that position. It takes effectively six to eight months to effect the servitization change because of our internal research. Depending on the costs obviously there is a focus on the degree of the investigation, if it's more strenuous or not. So from the word go, we need to make sure that there is enough of the customer's needs to change the business*'' (Participant 6)

While most of the participating manufacturers alluded to the fact that they still see themselves as product centric/conventional manufacturers leaning towards servitization, five out of seven participants pointed to lack of qualified workforce and certain necessary skills needed to make processes efficient. *''Having the correct skill of people at the correct places, because you need more people that are better equipped in communications. We cannot operate our business more in silos, we need people with abilities to communicate clearly and show what they need. Communication and information flow becomes a challenge. The flow of information can sometimes be too much and you find that it is not the correct flow of information*'' (Participant 7)

5.3 Objective 3: To identify the value proposition that FMCG manufacturing firms are offering to clients

Reinartz and Ulaga [28] attest to the fact that value is co-created through the mutual effort of firms, employees, customers, stakeholders, government agencies, and other entities related to any given exchange. About five of seven participants spoke to their value proposition offering in the areas of variety of foods, competitive price pool as well as guaranteed and consistency of supply, while the other participant mentioned the aspect of offering innovative products. *''I would say nutritional and affordable food. However, most importantly, it's always available and are affordable. While we manufacture our range of stable food and of good, quality and they are affordable. Our most important value offering is that it is always available. We have a very significant channel network''* (Participant 3)

In terms of value offering, around seven manufacturers were asked to measure their current target value offered by percentages and the response below is recorded as per different manufacturers. M represents manufacturer included with the percentage.

M	M1	M2	M3	M4	M5	M6	M7
%	65%	95%	80%	65%	70%	65%	60%

Table 2: Current target value per FMCG manufacturers participating

5.4 Objective 4: To identify how much access up and down the supply chain FMCG manufacturing firms allow their customers

Servitization process stems solely out of market research and not necessarily based on customer's innovative suggestions, ''Our new product development stems from market research. So we would go out and research the market and understand what the new needs of the customers are and what the future needs are. However, we do not develop products based on the customer. It does not bear any weight'' (Participant 7)

Innovation also plays a central part in the process of servitization. Three out of seven participants allude to the fact that the present offerings are supplemented by innovation in brining and maintaining other products already in the market. From their contribution, they imply that the innovation serve what the market intend and dictates the direction in which the brand is taking, *''But for me something like innovation says reduce the productivity , or even grow it. Innovation does not come as a cost. For me innovation should drive servitization, not servitization innovation. Because servitization will never understand the cost of innovation''* (Participant 1)

5.5 Summary of findings

- Not enough FMCG's are applying servitization in depth, many focus on traditional research and development (R&D) of the product or processes e.g. product design or manufacturing process design instead
- Servitization is costly
- The customer's suggestions are only valid when it makes a commercial sense
- Few FMCG manufacturing firms do capitalize on the ideas suggested by customers, however when it comes to configuration of products, manufacturing firms look at the strong customer needs in order to change the business
- Because of standardised nature of products in some FMCG's, formulation to service orientation becomes a challenge
- FMCG manufacturers suggest that Innovation should drive servitization, as it is cost effective to do so
- Institutional knowledge of service strategies is an inhibitor to servitization and therefore having lack of servitization champions within FMCG manufacturing firms cost a loss in customers and not getting the service levels on a desired scale
- The current and average customer satisfaction in Gauteng FMCG manufacturing firms is stable
- Capital investment is one of the hindrances to servitization

6 CONCLUSION

The research question sought to find out the strategic implications which FMCG manufacturing firms draw in servitization from incorporating their customers upfront. From the results found, barely a number of FMCG manufactures involves their customers upfront. Though few do not, most agree to the importance of servitization seeing it as something that creates value to their customers. In terms of business configurations on capitalising on ideas suggested by customers, almost all of the FMCG manufacturers strive to be on the journey but findings suggest that the limited resources, inadequate strategies and the institutional knowledge of servitization becomes a hindrance to them to fully apply it in their organisations.

The overall engagements with the manufacturing firms during the research has opened up a process of self-introspection for few FMCG manufacturers as this research has assisted them to review their current product offerings together with customer experience. Although there is currently little publication on servitization strategies in South Africa, this paper opens up important topic that FMCG manufacturers can look into, since service strategies are becoming the future of customer's value.

The study has some limitations, which leaves the room for future research to expand on. Some of the limitations speaks to sample size as they study used only a small sample of participants and specifically in the Gauteng region. The future research can expand to other FMCG manufacturing firms outside the province of Gauteng since this may have an impact on the generalisation of the findings. A larger sample size will reveal if ever the research findings will be applicable into a broader sector of FMCG manufacturing firms nationally.

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RISK MANAGEMENT IN SUPPLY CHAIN INFORMATION FLOW: A STUDY OF SELECTED FOOD PROCESSING COMPANIES IN SOUTH AFRICA

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ABSTRACT

The purpose of this study is to examine how Food Processing Companies in South Africa manage risk pertaining to supply chain information flow. Eventually, this study will help in determining the impact of contemporary risk management in supply chain information flow. As the Food Processing Sector in the country continues to drastically grow and increase in its complexity, so do the problems encountered in that industry [1]. Examples of such problems include more dynamic, differentiated and complex consumer demand, distorted supply chain information flow, the need for effective practices and the need to meet the dynamic market requirements [2]; [3]. All these problems pose risks to the business performance and the supply chain management effectiveness, which results in escalated costs and declining competitiveness. Since information is a resource for decision making and keeps all supply chain components updated, it is important to investigate information flow risk factors and the mitigation strategies employed by Food Processing Companies to better understand developments within the industry. Continued research can help in solving several problems such as uncertainties in demand and supply, network system problems, poor customer service, high inventory levels and lost sales and decision making necessary for further growth and success in the industry [1].

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1 INTRODUCTION

Information has been regarded by authors as important tool for the planning, coordination and integration of supply chain activities. Information connects the firm's different internal functional departments and external supply chain partners as well [4]. Paulina [5] classified the types of information shared in supply chains as follows; planning information, financial information, production information, performance information, quality information, demand information, among others.

As stated by David [6] the benefits derived from the smooth, timely and efficient supply chain information sharing are mainly realised in the areas of costs reduction, inventory reduction, optimised utilisation of capacity, efficiency of processes, on-time problem detection, improved visibility, reduced cycle time, increased productivity, elimination of bull whip effects, quick response, improved utilisation of resources, on-time delivery, possible tracking and tracing, development of networks, improved forecasting, improved customer satisfaction, and so on. It is imperative to note that information sharing is the perfect enabler for better planning and coordination of supply chain activities. Hence, first and foremost capabilities lies in the company's ability to utilise shared information in the most effective way. Although effective information flow provides numerous benefits like making the supply chain more agile, aligned and adaptive [7], it inevitably gives rise to a number of risks determined by range of factors.

Zahra *et al*., [4] listed the common identifiable information risk factors in supply chain comprising: information technology costs and reliability, anti-trust regulations, development of company's capabilities to use the information effectively, confidentiality, accuracy and speed of information, issues of incentives, among others. Disruptions to supply chain information flow can prove costly, as highlighted by Saxton [8] significant disruptions in information flow leads to high costs and increases supply chain risks.

From the moment a major disruption occurs, some supply chains will remain resilient while others will break down and take a long time to pull through; the vast difference between these supply chains are the cost effective and time efficient strategies. In addition to these, Pienaar & Vogt, [9] point out that to mitigate risks in supply chain, contingency plans need to be established. Studies shows that Information Technology (IT) plays an imperative role in improving the efficiency and effectiveness of supply chain information flow [10]; [11], however companies must acknowledge the issues of IT and other identifiable information flow risk factors.

This paper seeks to propose a conceptual framework for risk management in supply chain information flow of Food Processing Companies in South Africa. The paper is structured as follows; Introduction of the study to provide a background of Information Flow in particular; a literature review depicting theories and practices of supply chain information flow in Food Processing Sector in South Africa, information flow in supply chain, common identifiable risks in information flow as well as management of risks in supply chain information flow. Those theories and practices are aggregated to develop a conceptual framework in which risk management in supply chain information flow will be grounded on.

2 LITERATURE REVIEW

2.1 The Food Processing Sector in South Africa.

Food processing is generally considered the largest manufacturing sector in South Africa [12]. Das & Rajyalakshmi, [13] defines food processing as the transformation of raw food ingredients into liquid, solid, preserved and value-added food.

The South African Food Processing Industry, [14] classifies the food processing sector within the following 10 categories: These are: dairy products; meat and meat products; fruit and vegetables; fish and fish products; animal feeds; oils and fats; beverages; bakery and confectionary; milled grain products; and other foods.

South Africa has a large number of food processing industries; half of the companies operating in the food processing industry are located in Gauteng [12]. Food and Beverages sector accounted for 25.2% of total manufacturing production in South Africa in 2016-2017 [15]. According to the Department of Trade and Industry, [16] this sector contributes a significant 3.1% of manufacturing value add as percentage of gross domestic product and employs approximately 183 502 individuals.

This sector has a strong up and downstream linkages where value is added [16]. Upstream, the sector links with various agricultural suppliers across a range of farming products and models. Downstream, outputs are used as both intermediate products in which further value is generated and finished products that are marketed through a diverse array of wholesale and retail chains [16].

Despite significant contributions of this industry in the economy, it continues to encounter various problems, which prevent it from reaching its full potential and further develop [1]. Due to globalisation and the demise of the apartheid regime the food processing industry in the country has changed significantly; the purchasing power of most racial groups has improved [1]. The industry faces challenges of unpredictable customer demand and preferences owing to greater products variety and increased globalisation [1]; [17].

According to Mercer, [18] and Nguegan & Mafini, [1] other factors contributing to the challenges faced by the food processing industry includes: information exchange, technology development, food security and quality, perishability, market access, infrastructure deficiencies, regulatory issues, financial constraints, equipment and raw materials, social issues, environmental concerns, education and training, and land stewardship. All these factors impact business performance and supply chain management effectiveness within the food processing industry [1].

Today’s consumer demand is more differentiated, dynamic and complex than ever before [2]. Customers demand better quality products, reduced prices and high levels of service [1]. Changes in consumer demand patterns provides the food sector with both opportunities and threats [19]; [2]. These changes bring new opportunities for organisations to add value through innovation and product differentiation [19], which can lead to brand equity, higher margins, strong consumer preferences, less price competition and so on [2]. To do this successfully, certain competencies are required, which many organisations in the food processing industry have only to a limited extent [2].

In this era of information and communication technology, organisations apply effectual techniques to sustain their business strategies [20]. Supply chain management has a firm connection with operational competences of organisations capability to deliver promise, eliminate costs, design products and logistics services [20]; [21]; [1]. According to Nel & Badenhorst-Weiss, [21] supply chain flows are triggered by end customer demand for the product, which necessitates organisations to have greater understanding of market requirements.

Food sector is facing the issue of demand amplification due to information mismatch; therefore, food supply chain elements are still loosely linked and require more transparent and integrative models [3]. There is an increase in the value of, and demand for, flexible supply chains that respond swiftly to varying customer demand and unique market requirements [22]. To achieve this flexibility extensive supplier involvement and accurate, timely demand information are vital to link customer information with the manufacturing activities [22]. Effective information flows within and across organisations are vital to manage supply chains; supply chain management operations cannot be possible without effective information system management [23]. Ineffective information systems are major impediments to effective supply chain management [23].

2.2 Supply Chain Information Flow.

The objective of supply chain management is to provide a flow of accurate, reliable and timely high-quality information that will allow suppliers to provide an uninterrupted and precisely timed flow of materials to customers [24]. Supply chain information flows are bi-directional [25]. The flow of materials and finances are usually activated by an associated information flow [25]. Information flow also serves as the bonding agent between material and financial flow [24].

To thrive and compete in today's global economy, the manufacturing sector need to progressively share, create and assimilate up-to-date and appropriate information and knowledge [26]. Timely, accurate information must flow among the links in a coordinated fashion, which eliminate distortions [27]. Information enables companies to make better decisions in their operation leading to lower supply chain costs and better utilisation of resources [28]. Information flow provides resources for decisions making and constantly keep all components of supply chain updated [24]. It allows companies to respond swiftly to varying customer's demand [28].

Information sharing can increase supply chain efficiency by smoothing production and reducing inventories [29]. Especially, when the bullwhip effect arises from asymmetric information in supply chain each individual organisation make locally optimal decisions [24]. Information sharing among participants in a supply chain brings mutual competitive advantages in reducing costs and improving customer value [30]. Supply chain value adding activities such as order fulfilment, capacity status, inventory status, product and process design changes and demand are often triggered by information flow [24]. Implementing an effective supply chain requires a more efficient and accurate flow of information [24].

2.3 Supply Chain Information Flow Risks.

''Information risk can be defined as the probability of loss arising because of incorrect, incomplete, or illegal access to information. Under this definition, the bullwhip effect, that is the distortion and amplification of demand information as it moves up the supply chain can be categorised as one of the risk factors in information risk" [24]. The bullwhip effect occurs when variations in customer demand causes larger variations in orders placed upstream [31]. Aprile & Garavelli, [32] emphasized that the bullwhip effect leads to supply chain inefficiencies, which describes how lack of transparency, inaccurate information and a mismatch between production and real time supply chain information results in poor customer service, unrealised profits, high inventory levels and increasing lost sales. The effect signifies a lack of synchronisation amongst supply chain participants [33].

Lampret & Potočan, [31] listed the causes of the bullwhip effect in the FIGURE 1 below:

Table 1: Barriers in cooperation/causes of the bullwhip effect

BARRIERS IN COOPERATION	CAUSES OF THE BULLWHIP EFFECT		
Barriers due to different initiatives	Local optimization of functions or partners in the chain	Inconsistent initiative of sales staff	
Barriers in information processing	The demand bases on the orders and not on the actual demand	Denied access to full information	
Operative barriers	Ordering in bundles	Long delivery times	Speculative ordering
Pricing barriers	Quantity discounts tied to the amount of a single order	Short-term pricing promotions	
Organizational barriers	Lack of trust	Bad relations between partners	Lack of learning from mistakes

Figure 1: Barriers in cooperation/causes of the Bullwhip Effect [31].

The key problem organisations are facing, when attempting to eliminate the bullwhip effect is that there are many factors for its existence and that are often not noticeable [31]. One of the most important reasons for the increase in variability of orders is that information on the actual final demands are no longer available for higher chains [31]. Hence, inadequate information is highlighted as major contributor to the bullwhip effect according to Sentia *et al.*, [24] risk factors in information flow are as follows: price fluctuation; inaccuracies of supplier data; network system problem; machine problem; shipment and delivery accuracy; changes in ordering contract; inaccuracies in past demand data; uncertainties in supply; late payment; natural disaster; uncertainties in demand and inaccuracies in demand data.

As depicted in the FIGURE 2 below Paik & Bagchi, [34] found that delays in both materials and information would be possible causes of the bullwhip effect, however reducing time delays the amplification of demand was significantly reduced. Demand represent a series of orders that are coming from the downstream of the supply chain; incomplete information can tempt a higher chain of supply chain into excessive reaction to variations in the amount of orders received, which occurs in excessive increase of own order to the next chain in the supply chain [31].

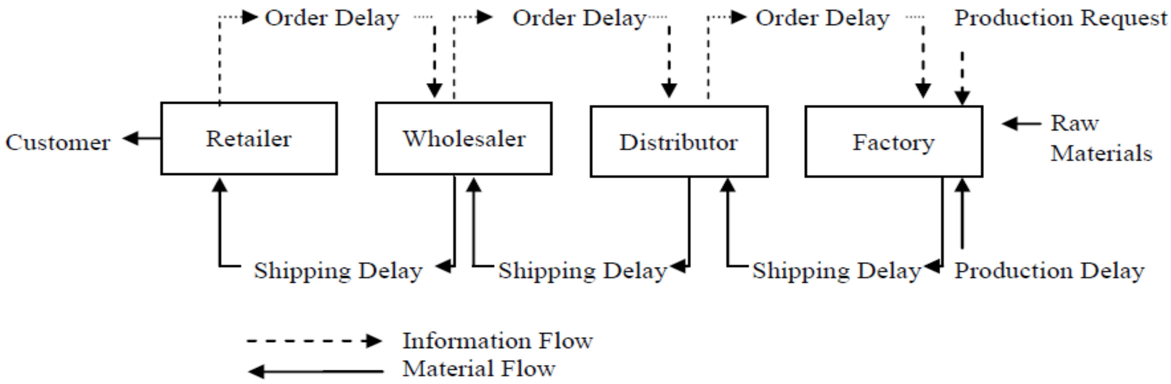


Figure 2: Structure and flows of the beer distribution game [34].

2.4 Risk Management in Supply Chain Information Flow.

Supply chain risk management is not only about identifying and mitigating against risks linked to natural disasters and other huge events however there are other various risks associated which includes; changes in information technology system, rapid growth, demand and supply fluctuations, contaminated and counterfeit products as well as changes to supplier base [24]. Information risk can be perceived as a contributing factor to supply chain risks [24]. *''Information risk management is the management of information risks in supply chain through coordination or collaboration among the supply chain partners so as to ensure profitability and continuity''* [35]. *''The collection of processes that collectively ensure that information risks are adequately reduced to an acceptable level''* [24].

Faisal *et al.*, [35] developed a model for information risk mitigation in a supply chain depicted in FIGURE 3; the model depicts twelve interacting variables based on their driving and dependence power towards information risks mitigation.

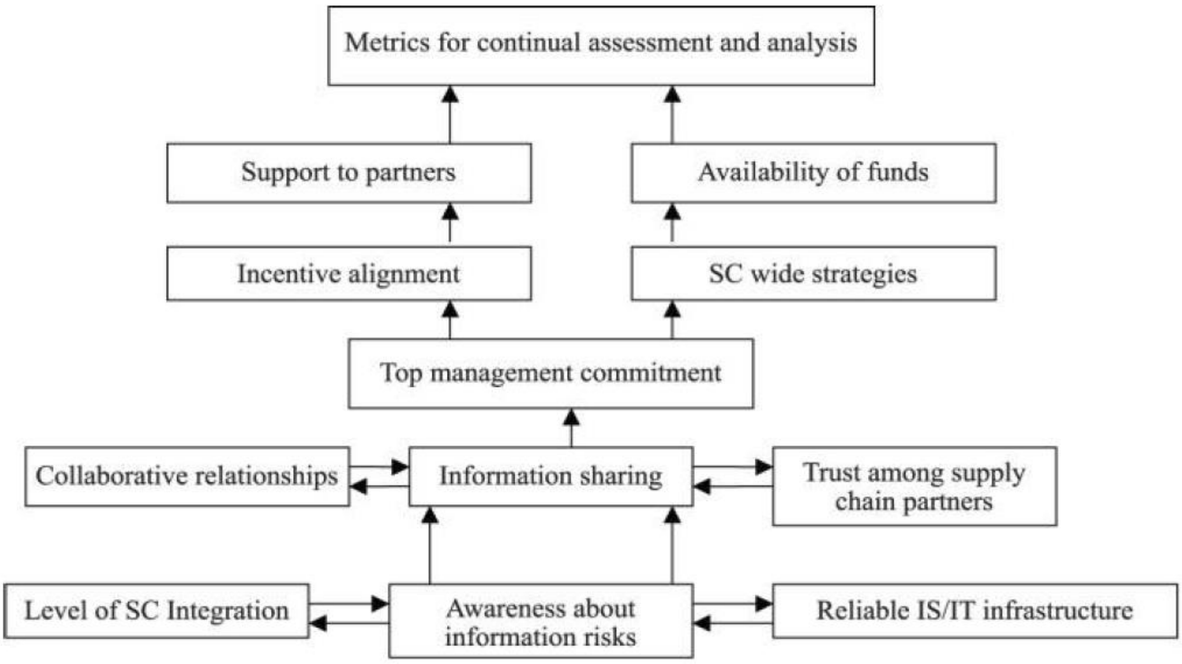


Figure 3: Interpretive Structural Modelling (ISM) based model for information risk mitigation in a supply chain [35].

Mitigation of information risks requires mutual efforts from partners in a supply chain [35]. To reduce information risks in a supply chain, mutual trust for long-term relationships and the confidentiality of information among supply chain participants is essential [35]. According to Simatupang & Sridharan, [30] information sharing aims to disseminate and capture timely and relevant information that allow decision makers to plan and control supply chain operations. Effective information sharing enables information risk mitigation [35]. Transparency of information guarantees enhanced mutual trust and commitment in a supply chain [36]; [37].

Information risks like system breakdown can be eliminated by a reliable IT infrastructure that is not possible without funds, under these circumstances the role of top management becomes more important [35]. The two important construct to IT infrastructure are consistency of data which should facilitate process integration comprising information flow by defining key organisations to achieve information sharing and cross-functional application integration which supports the management of supply chain related processes and fulfils the ability to interface with supply chain applications among participants in real-time [38].

Collaborative relationships allow supply chain partners to mutually gain a rigorous understanding of future demand, set realistic plans to fulfil that demand and coordinate activities to do so in the most effective way [39]. Advances in IT has made integrating of supply chain information flow feasible, putting IT a key driver of supply chain collaboration [39]. Once the information within a supply chain has been mapped and diagrammed they can individually be analysed and improved [40]. Information flow circuits which contribute to the bullwhip effect can also be identified and metrics developed for each [40]. *''Companies with the capability to use technology to automate relationships and produce new products will have a definite advantage over others''* [41].

Faisal *et al.*, [35] found that support to partners is facilitated by incentive alignment that refers to the level to which supply chain partners equally share benefits, risks and costs.

Sentia *et al.*, [24] also developed a supply chain information flow risk management model based on make to order production system; the model illustrates the mitigation activities, categories of information sharing and the information risk factors. The model focusses on the three fundamental processes, which are source, make and deliver and captures the information risk issues [24]. From the model given in Figure 4, information is shared from Deliver-Make-to-Order-Product (DMTOP) to Make-to-Order (MTO) and also from Make-to-Order (MTO) to Source-Make-to-Order-Product (SMTOP). Figure 4 components of DMTOP to MOT is further expanded by *Sentia et al.*, [24] in Figure 5 below, similarly the MTO to SMTOP components of Figure 4 is further elaborated by Sentia *et al.*, [24] in Figure 6 below.

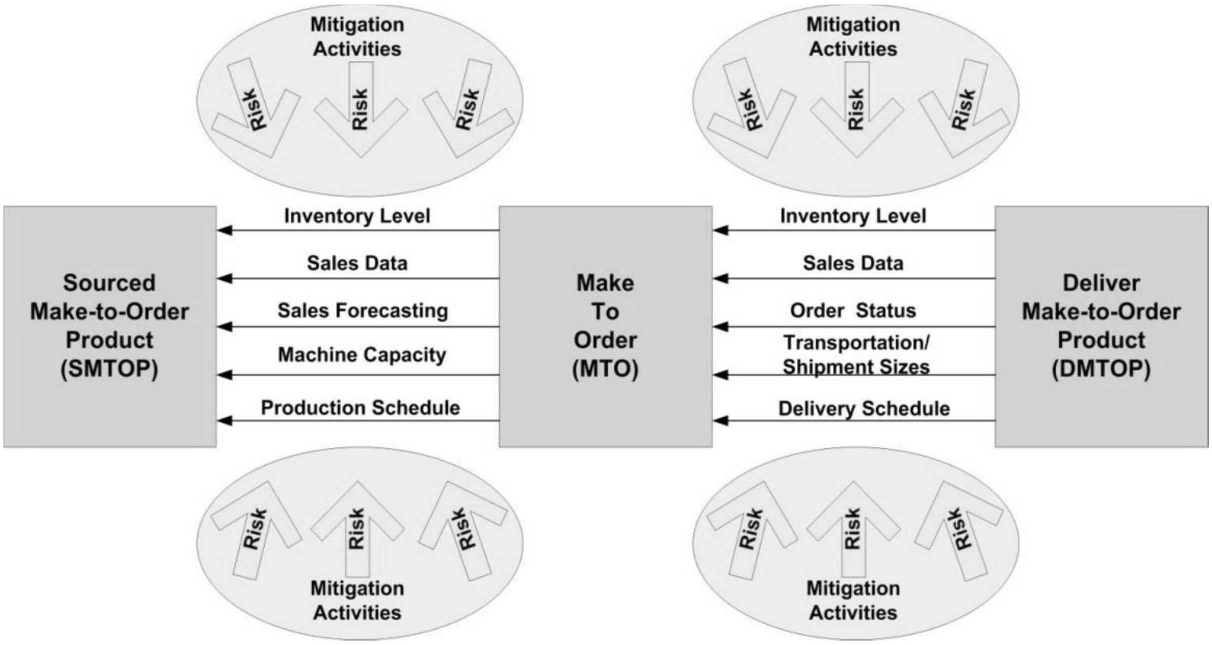


Figure 4: Supply Chain Information Risk Management Model in Make-to-Order [24].

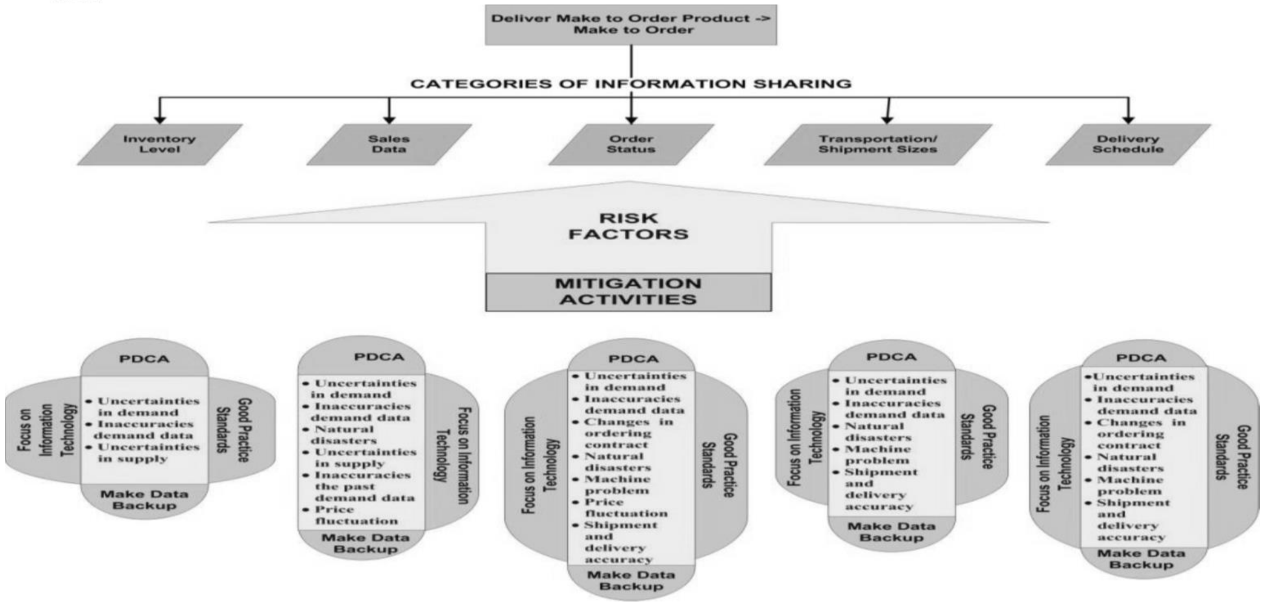


Figure 5: Information-Risk-Mitigation Model DMTOP to MTO [24].

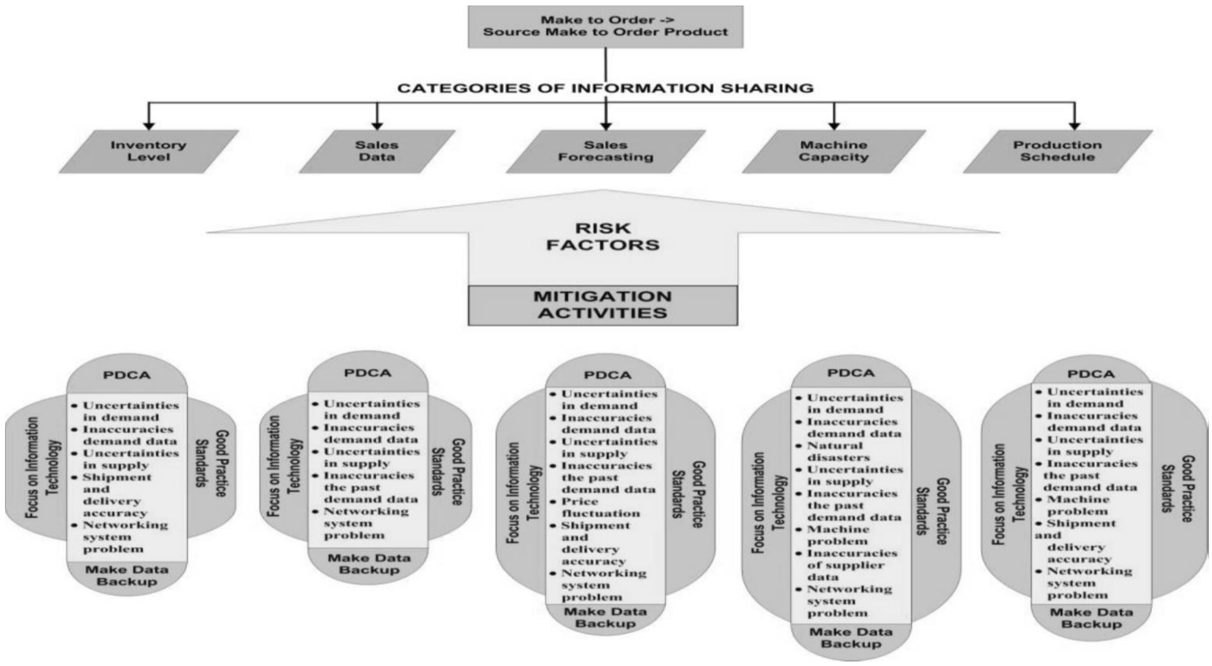
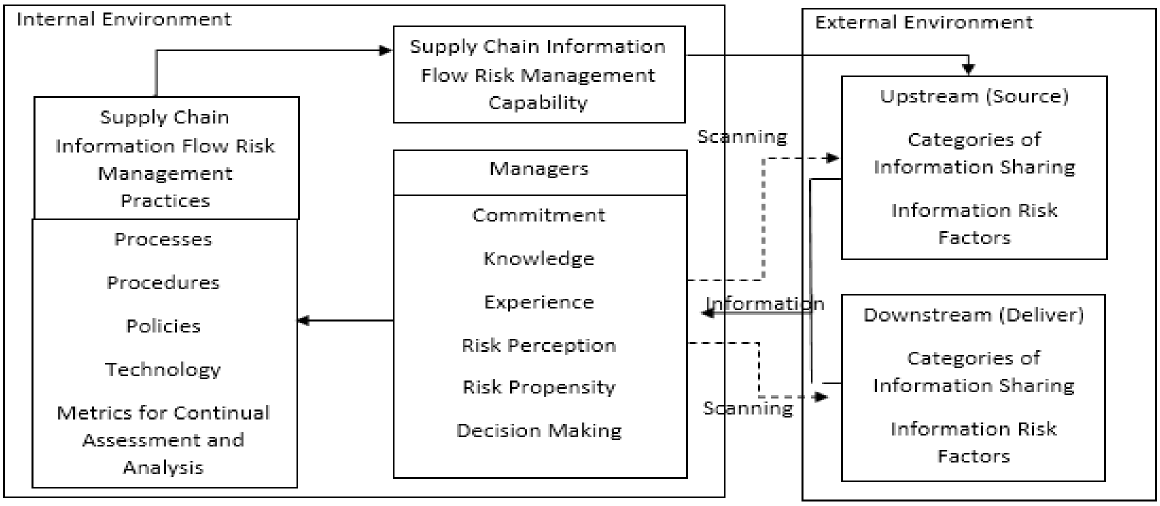


Figure 6: Information-Risk-Mitigation Model MTO to SMTOP [24].

3 CONCEPTUAL FRAMEWORK

The below proposed conceptual framework has been adapted from the literature review and incorporates some critical elements of that developed by authors (Sunjka & Emwanu [44], Faisal et al [35] and Sentia et al [24]); risk management practices; risk management capability; categories of information sharing and information risk factors. However, since this is tailored to risk management in supply chain information flow, great emphasis is placed on both the internal and external supply chain environment to completely identify and capture more important aspects related to the study phenomenon. Critical literature was reviewed to identify and determine the driving and dependence power of these critical elements towards risk management in supply chain information flow.

A comprehensive literature search was conducted through major databases such as google scholar, emerald etc., keywords were used and only publications which had clear reference to risk management in supply chain information flow in their titles, abstracts or keywords were considered as relevant for this study. Characteristics and differences within the exerted literature were identified to probe into prior theoretical concepts or the ones extracted through the continuous process of analysing and screening the literature to map connections between categories so as to explore relationships. After the aforementioned steps, the conceptual framework was formulated, demonstrating how risk in supply chain information flow can be managed by depicting risk management practices, risk management capabilities, categories of information sharing and information risk factors.



Conceptual Framework for Risk Management in Supply Chain Information Flow (Adapted by Author).

As adapted from the literature review this conceptual framework takes into account the key role played by managers of supply chain related activities (Logistics Managers, Inventory Controllers, Warehouse Managers and Others). As emphasized by Sunjka & Emwanu, [44] and, Faisal *et al.*, [35] through skills, knowledge, experience and daily activities managers are able to identify, scan and assimilate information from the external supply chain environment and the company's internal environment to make sensible decisions. This information is translated by the personal characteristics of managers into risk management practices [44]

Risk management practices include identification, analysis, response and monitoring and controlling of risks [45] through certain procedures and metrics for continual assessment and analysis. From both up and downstream supply chain there are several identified categories of information sharing which includes; inventory level, sales data and forecasting, order status, capacity, size of shipment and production and delivery schedule [24]. Information risk factors are those factors posing the risks to supply chain information flow, according to Sentia *et al*, [24] those factors include; demand uncertainties, inaccuracies in demand data, uncertainties in supply, natural disasters, networking system problems among others.

4 CONCLUSION

The conceptual framework for this study will provide a useful approach to address how risk in supply chain information flow of food processing companies can be effectively managed by increasing the understanding of the four afore-mentioned critical elements. Replication across theories and concepts in the literature further suggest that there is possibility for generalizability in the findings and the conceptual framework may contribute significantly to risk management in supply chain information flow in the context of food processing companies.

Improving risk management practices in supply chain information flow must be a key focus for many organizations. This is determined by a range of factors including the need to make more insightful decisions and improve the efficiency of business processes.

It is also imperative to understand that managers of supply chain related operations are key decision makers in the risk management of supply chain information flow as they make subjective judgement about the nature and severity of risk.

IT plays a crucial role in enhancing performance of supply chain drivers and improving the quality of information by eliminating human errors, thus eliminating information flow risks in supply chain. However, strong leadership is required to draw people and IT resources into action.

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THE STATUS OF GREEN SUPPLY CHAIN INITIATIVES IN MANUFACTURING ENGINEERING SMES

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ABSTRACT

Incorporating environmental thinking into the supply chain is a huge focus for businesses, governments and researchers alike because of declining natural resources and climate change issues. Regulatory and customer pressures are also contributing to this need for change. Businesses are transforming from traditional supply chain to circular economy.

This research was an exploratory study that examined green supply chain (GSC) initiatives in six Small and Medium Enterprises (SMEs) in the manufacturing sector in Gauteng, South Africa. This examination is important because manufacturing and production are most commonly perceived as enemies to environmental protection. The aim was to understand what GSC initiatives are implemented (if any), awareness and barriers faced by manufacturing SMEs in the Gauteng area.

A qualitative research methodology, using semi-structured interviews, was conducted with managers of SMEs. Findings revealed that most of the manufacturing SMEs are engaged in waste management, but that there are shortcomings in awareness of GSC concepts. Both regulatory and financial benefits were key drivers, while cost was the major barrier identified.

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1 INTRODUCTION

The supply chain is one of the main drivers causing significant environmental issues, such as CO_2 emissions, environmental pollution and waste [1]. Due to high levels of resource consumption and environmental pollution, which emanate from supply chain activities (raw material acquisition, manufacturing, use and disposal); the global environmental carrying capacity has been exceeded [2] Climate change and pollution issues have gained increasing global attention due to increasing human and industrial impacts [3]. The environmental problems have expanded from local and regional ones to global ones [4]. There are six risks that climate change poses for businesses [9]: regulatory, supply chain, product and technology, litigation, reputation, and physical.

Since the mid-1980's environmental awareness and sustainability have moved from political rhetoric to front and centre within the global business lexicon. The need to minimise an organisations footprint is no longer an order-winning marketing slogan, but a vital component of the strategic imperative of every responsible organisation [5]. Several other factors contribute to this need for change, including, government regulations, the advent of ISO 14001 and the potential publicity (both good and bad), as well as, increased demands from customers (industrial and consumer) for goods and services that are produced using environmentally friendly processes.

The Green Supply Chain (GSC) agenda has altered from a cause to save the planet to a full-grown, examined economy [6]. It is no longer a trend, but a cause to help companies achieve their business goals, gain competitiveness, whilst preserving natural resources for current and future generations. The study of GSCs is also highly attractive as it seeks to address the problem of environmental pollution. By employing GSC initiatives, companies not only limit their CO_2 emissions, but strive to optimise their overall supply chain performance [3]. Supply chains hold substantial potential to contribute to the achievement of vision 2025 which aims to improve South African energy mix by having 30% of clean energy by 2025 [7].

Small and Medium enterprises (SME) form a significant part of any large manufacturers supply chain. SME's are often the seedbed for innovation, producing customised products in niche markets in a flexible manner and are hence important for the sustainable development of emerging economies [8]. Large Original Equipment Manufacturers (OEMs) can, consequently, improve their productivity, increase innovation and access to markets by incorporating SME's into their value chains. SMEs are, however, resistant to implementing green initiatives because many lack the resources (people, money, or knowledge) [10]. While research has been conducted on environmental management in supply chains, little research has focused on green supply chain management in SMEs [10]..

This research thus sought to explore the status of Green Supply Chain initiatives in manufacturing engineering SMEs in Gauteng, South Africa.

2 LITERATURE REVIEW

2.1 Small and Medium Enterprises (SMEs)

The terms "SMME" and "SME" are used interchangeably worldwide. The National Small Business Act 102 of 1996 divides small business into survivalist, micro, very small, small and medium enterprises. The Act uses number of employees and annual turnover to define SMEs [11].

2.2 Importance of SMEs

[12], [13], [14], [15][15]and [16] unequivocally agree that SMEs are pivotal to the growth of a country's economy, more so for South Africa, which has one of the world's highest unemployment rate. Additionally, [17] highlighted that SMEs can help alleviate many of the socio-economic challenges in South Africa, as an absorber of retrenched labour in public and private sectors.

Furthermore, [14]and {15] amplified the fact that SMEs provide employment opportunities for communities within the second economy, helping to sustain the livelihoods to the dependants. SMEs contribute close to forty five percent to South Africa's GDP [15].

2.3 Green Supply Chain Management (GSCM)

The objective of green supply chain management (GSCM) concept is to integrate environmental thinking into SCM through waste elimination and minimising emissions [18]. Increased environmental awareness regarding CO_2 emissions, pollution, and waste gave birth to GSCM [19]. Due to competitive pressure in the 1990s, demands for ethical and social responsibility opened many firm's eyes towards green practices [20]. The direct relationship between supply chain and the environment is prevalent in literature[21]. Regulatory and customer pressures have led to increased acceptance and practice of GSCM [22]. Additional drivers for importance of GSCM are the depleting natural resources, overflowing landfills, and heightened pollution [21].

2.4 Green Supply Chain (GSC)

The term green supply chain (GSC) derived its origins from the incorporation of environmental management practices into the traditional supply chain, acknowledged throughout the literature [23],[21]. A useful framework that provides a structured approach to plan and implement a successful GSC is shown in Figure 1.

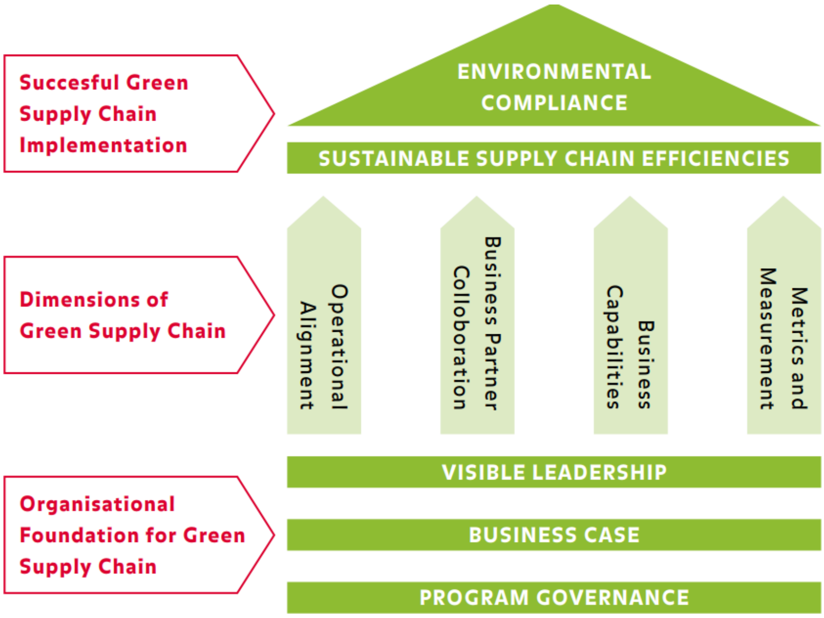

Figure 1: GSC framework [24]

2.4.1 GSC Initiatives

Reverse logistics

Reverse logistics was defined by [25] as a process of accepting used products from end users for recycling and remanufacturing purposes. The third leg of reverse logistics mentioned in the literature is the concept of re-use, collectively termed the 3R's (recycling, re-use, remanufacturing) [26]. Through reverse logistics environmental impacts are reduced; it promotes reuse, remanufacturing, recycling, and waste reduction [3]. Beamon illustrates the reverse logistics concept with the dotted lines in Figure 2 below.

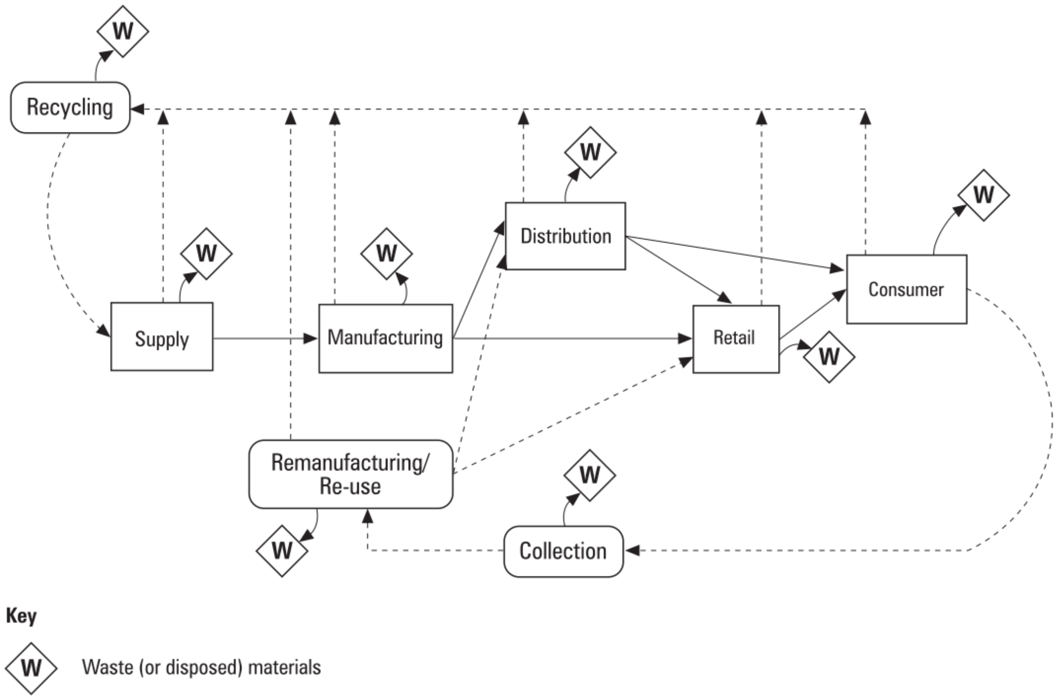

Figure 2: Conventional supply extended to include the 3R's [26]

- Recycle: process of collecting used products, components, materials from industry, disassembly and separating into categories, followed by processing into recycled products. Characteristics of the original product / material are lost.
- Re-use: process of collecting used components, materials or products and reselling them as "used" with no processing required.
- Remanufacturing: process of collecting used product from industry, assessing its condition, repair worn and damaged components with new ones, with the intention of returning the product to original specification. Product originality is retained.

Green Purchasing

Businesses that actively apply green purchasing consider environmental impacts of the products or materials they buy together with whether they were produced in an environmentally friendly manner by the suppliers [3],[27]. Initiatives around green purchasing include, among others, supplier environmental performance evaluation and assisting suppliers to achieve acceptable levels of performance[27],[28]. Assistance includes programs such as environmental awareness programs, site audits and recommendations on environmental activities [27]. Benefits for the supply chain include pollution and waste reduction and entrenchment to comply with the buying firm's environmental requirements [3]. Green purchasing is a pro-active approach as it deals with inputs to operations [27].

2.4.2 Benefits of GSCs

As from the 1990s many studies that were conducted to illustrate the benefits of implementing GSC initiatives in organisations resulted in a win-win perspective called the Porter Hypothesis [29]. [30] explained the fundamentals of GSC as a competitive initiative. They based their reasons on the fact that GSC is a waste eliminator and contributes to productivity improvements. Following on the views of Porter and Van Der Linde was [27] who stated that competitive advantage, increased business profits and market share are the outcomes of integrating environmental practices into the supply chain. [21] also added that going green was more than about being environmentally friendly but yielded economic gains.

However, [31] later came with a different viewpoint that the relation between strong environmental performance and economic gains was not linear but depended on many difficult factors embedded in political, social and scientific context. Survey results conducted by Florida International University in 2008 showed that four of the top five expected benefits generated by GSC initiatives were external, market-oriented benefits. The top two benefits that rated either most important or important was enhanced public relations and enhanced public image [32]. Furthermore, [6] highlighted further benefits for early adopters of GSC initiatives:

- Shift from competitor state to industry leader
- Enhanced credibility with stakeholders and attraction of investors
- Reduced operating costs
- Preferred suppliers in green supply chains
- Customer growth
- Enhanced employee satisfaction
- Build competitive advantage
- Public trust

2.4.3 Key drivers for adopting and implementing GSC initiatives

Several external forces are responsible for driving the need for adopting and implementing GSC initiatives, most notably regulations and pressure from customers. [21] pointed out three sources: economical, regulatory and customers. [33] pointed out internal and external factors, shown in Table 1.

Table 1: Motivation for GSCs [33]

Primary Motivations	
Internal	**External**
Risk management • Supply interruption • Long-term risk to human health and the environment • Competitive disadvantage	**Enhanced brand image** • Corporate culture of forecasting trends and moving proactively • Potential for harm to public image due to environmental concerns
Regulatory stance • Desire to go beyond compliance • Suppliers knowingly or unwittingly provide materials containing problematic substances • Supplier non-compliance poses production risk	**International purchasing restrictions** • Eco-labeling and product takeback gaining momentum • May drive the creation of systems for collection, • Frequently focused on high-profile brands transport, and disassembly or recycling
	Customer pressure • Often appears in conjunction with a threat to brand image • Frequently focused on high-profile brands
Secondary Motivations	
Cost reduction as suppliers apply pollution prevention	**Increased innovation** • Can result from supplier participation in new product development
Enhanced quality	

[34] pointed out additional drivers not accounted for in Table 2. These include

Internal drivers:

- People issues – employee involvement; culture; management involvement
- Strategic issues – alignment of company strategy with, delivery logistics and purchasing strategy
- Functional issues – purchasing and supply function; capabilities within purchasing

External drivers:

- Government – policy; regulation

- Competitors – exerting pressure
- Investors – exerting pressure
- NGOs - influence

2.4.4 Barriers for adopting and implementing GSC initiatives

[26] mentioned managerial attitude as one of the barriers to GSC implementation. [34] highlighted the following internal barriers:

- People – lack of management commitment
- Strategic issues – resources such ascost of implementation; organisation size (smaller firms); financial reporting that is not aligned with GSC; competitors who are not doing it
- Functional issues – lack of training; lack of understanding; other SCM priorities

3 RESEARCH METHODOLOGY

The research was exploratory in nature and supported the adoption of a qualitative investigation. Semi-structured interview questions were based on core themes related to the GSC theory and published literature. Semi-structured interview questions allowed for in-depth collection of valuable data since they provided the interviewer with opportunity to probe and expand on the interviewee's responses.

Since the research depended on human sources for information, one-on-one interviews with SMEs senior managers and owners were appropriate for data collection. All interviews were conducted in person at the premises of these managers and owners to save time and travel costs. The value in interviewing was not only because it built a holistic snapshot, analysed words, reported detailed views of informants; but also, because it enabled the interviewees to speak in their own voice and express their own thoughts and feelings [35]. Eighteen open-ended questions were developed.

The participant SMEs were selected thorough purposive sampling. The technique required the researcher to gather in-depth information from a small number of people with information-rich contribution [36]. Target respondents were senior managers and owners of SMEs who were knowledgeable about their supply chains and business, shown in Table 2.

Table 2 Manufacturing industries and sample of interviewees

Code Name	Industry Type	Position	Years of experience
SME 1	Manufacturing	Foundry Manager + Partner	24 years
SME 2	Manufacturing	General Manager	14 years
SME 3	Manufacturing	Manager	27 years
SME 4	Manufacturing	Managing Member	28 years
SME 5	Manufacturing	Technical Director + Shareholder	43 years

Collected data was analysed using a thematic analysis, which helped to identify major themes arising from the data [37]. Thematic analysis involves grouping together related codes. For example, using the theme "reverse logistics", thematic analysis includes grouping all codes (such as recycling, reuse, remanufacturing) related to "reverse logistics" to identify major outcomes / findings. Coding is a process of assigning appropriate names to a volume of text that best describes the quoted data. Two types of coding were used during data analysis: **topic and In Vivo coding**. Topic coding labelled data according to subject of interest. In Vivo coding created codes directly from respondent's exact words. Interview notes were supplemented with audio recordings to check for new meanings. When data diverged from codes created, a new code was opened [38]. Data comparison was the final stage which helped identify relationships amongst the constructs.

4 RESEARCH FINDINGS

4.1 Implementation of Green Supply Chain (GSC) Initiatives

"GSC initiatives" was coded into four themes (Figure 3): 1) green purchasing, 2) reverse logistics, 3) environmental management system, 4) supply chain environmental performance measurement.

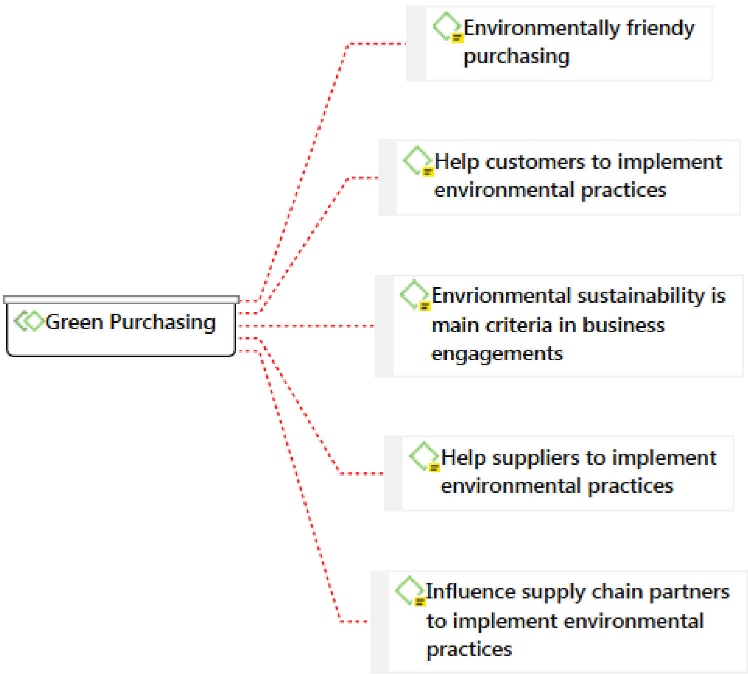

Figure 3: Sub-themes related to green purchasing

Green purchasing practices were not followed by all respondent SMEs. There was no strategy used in purchasing raw materials from suppliers, the only consideration was price and delivery time. SMEs main criteria for business engagement with suppliers did not have any foundation on environmental sustainability practices. To add onto this, raw materials were not sourced on their ability to be recyclable. Recyclable materials would help to minimise environmental impact and lower depletion rate of natural resources.

Furthermore, SMEs do not exert influence on their supply chain partners to implement environmentally sustainable processes. Not one single SME described involvement (in any form) in helping its supply chain partners towards implementing environmentally friendly design and selection of materials that are recyclable. This showed a lack of concern from all SMEs in pursuing environmentally friendly upstream purchasing processes.

Reverse logistics was coded into three sub-themes (Figure 4): 1) recycling, 2) remanufacturing, 3) reuse. The three sub-themes are consistent with [26].

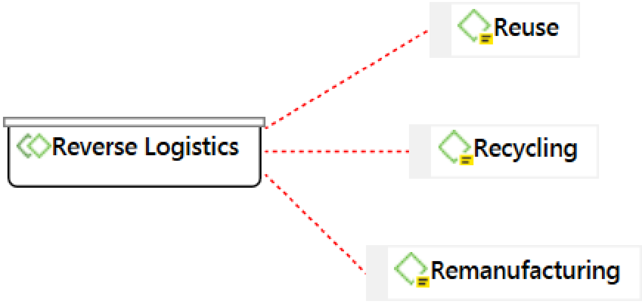

Figure 4: Sub-themes related to reverse logistics

The findings revealed that reverse logistics, remanufacturing and reuse are not pursued. The only prevalent activity that was used by all the respondents was recycling. Recycling refers to collection and selling of production by-products such as metal shavings and cutting fluids (coolant and oils) to 3rd party companies. These 3rd party companies sell the scrap to foundries to be used as input for steel production. The findings point to the fact that recycling is motivated by economic benefits gained from selling the scrap. Manufacturing operations produce a many by-products, metal shavings, water, and oil from their operations. Improper disposal of these has a detrimental impact on landfills. 90% of SA's waste is disposed of in landfills [15]. Oils can damage water systems and oceans, killing sea life and plants. Waste management was, therefore, a key concern for the SMEs.

Environmental management system was coded into three sub-themes (Figure 5): 1) ISO 14001 certification, 2) environmental activities, 3) good corporate citizenship

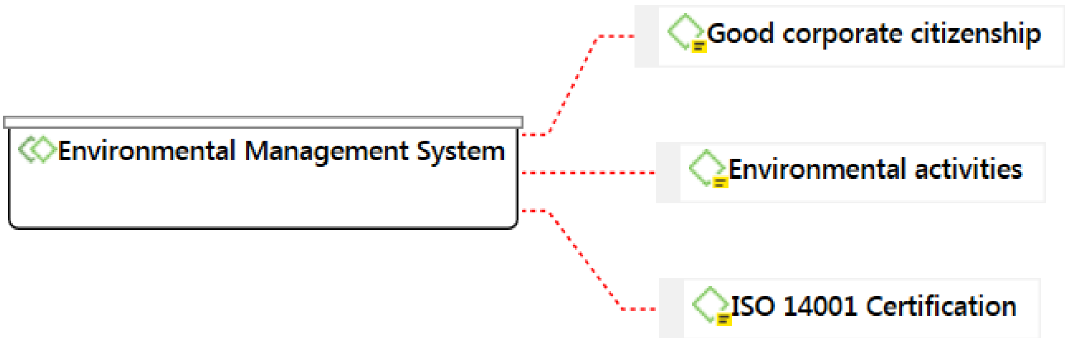

Figure 5: Sub-themes related to environmental management

Results revealed that none (0%) of the SMEs had an ISO 14001 certification (Figure 6), they commented that certification was an expensive "nice-to-have", but not strategically important for them. 40% indicated the existence of an in-house environmental management policy, while 60% did not have.

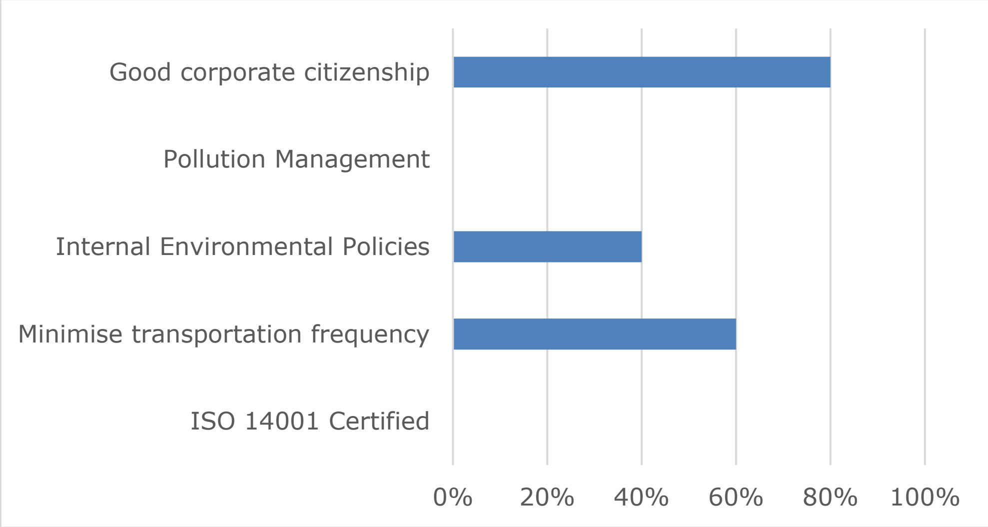

Figure 6 Environmental management methods

4.2 Awareness of Green Supply Chain (GSC) Principles and Practices

For analysis, the theme “Awareness” was coded into two themes: 1) drivers / pressures, 2) benefits of GSC practices.

Awareness was coded into five sub-themes (Figure 7): 1) regulatory, 2) customers, 3) green image, 4) competitiveness, 5) community.

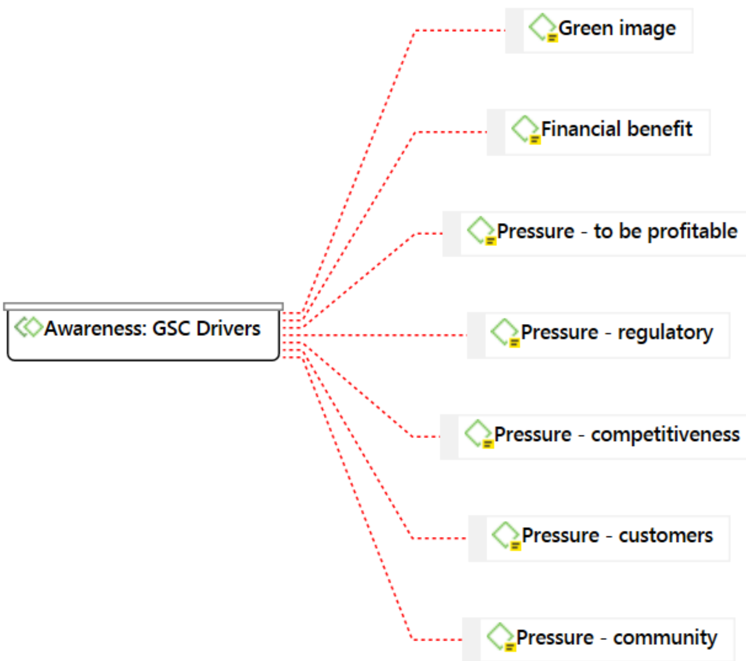

Figure 7: Sub-themes related to awareness of GSC drivers

Research revealed that green image as a driver, community and competitive pressures were non existent (0%). However, regulatory pressure was the prevalent driver most commonly mentioned by 80% of the respondents. Pressure from customers was only mentioned by 1 respondent.

Financial benefit was the most prevalent benefit derived from recycling activities by the SMEs. It was all internally motivated due to the additional revenue received. External motivation such as competitive advantage, increased business market share, as the outcomes of integrating environmental practices into the supply chain, did not emerge. The findings do not relate to the results of the survey conducted by Florida International University [[32].

4.3 Barriers to Green Supply Chain (GSC) Implementation

Barriers were coded into three themes (Figure 8): 1) people, 2) strategic issues, 3) functional issues.

Figure 8: Sub-themes related to GSC barriers

People as a barrier refers to 1) lack of Top Management support, 2) resistance to change. The interviews revealed that only one out of five (20%) mentioned internal resistance from management towards implementing a GSC initiative.
Strategic issues as a barrier refers to 1) cost, 2) business size, 3) business focus / strategy, 4) ROI too long, 5) high investment costs.
The interviews revealed that 100% of the SMEs raised cost an impediment.
Functional issues as a barrier refers to 1) lack of training, 2) lack of understanding, 3) other GSC priorities. There were no functional issues revealed as a barrier to GSC implementation.

4.4 Summary of key findings

Table 4 Summary of the key research findings

Themes	Research Findings
GSC initiatives - what is the status?	
1. Green Purchasing	0% source raw materials based on their environmental benefits such as recyclability, 100% sourced on low cost and fast delivery only 0% try to have influence on their suppliers to implement green designs
2. Reverse Logistics	0% are involved in remanufacturing and reuse practices

	100% scrap materials for economic benefits
3. Environmental Management System	0% are ISO 14001 certified because of cost, nor demand from key customers 0% supply chain partners are not certified 100% had some form of EHS policies exists EHS policies drawn by 3rd party consultants Good corporate citizenship emerged
4. Supply chain environmental performance management	100% not involved in helping their suppliers to implement environmentally friendly practices Business engagements are transactional, not strategically based on sustainability foundation
Awareness – of GSC principles and practices	
1. Drivers	Image / Publicity did not come out as one of the drivers – a lack of awareness about how image impacts businesses. Nike's reputation took a dive after reports emerged about its use of child labourers and paying practices, negatively impacting the brand's reputation and raising public outcry to ban Nike products. 100% would be driven by regulatory pressures to be aware
2. Benefits	Financial benefits were highly prevalent 0% stated external benefits, indicative of lack of awareness
Barriers - towards GSC implementation	
1. People	20% cited people issues, 80% did not have any people issues
2. Strategic	60% mentioned cost as a major deterrent to implementation 20% mentioned current economic climate was a high barrier 20% stated that they are still recovering from previous year's loss

5 DISCUSSION

The status of Green Supply Chain initiatives in manufacturing engineering SMEs in Gauteng, South Africa was explored through three aspects, namely, the level of implementation of Green Supply Chain (GSC) Initiatives, the awareness of GSC principles and practices and the barriers to implementation. Key findings indicated that none of the critical GSC initiatives, green purchasing, reverse logistics and environmental management systems were being implemented.

Several initiatives were mentioned as being in the pipeline such as energy initiatives i.e. solar power and use of generators and the installation of a reclamation plant and a spray booth. The main reason for implementing green initiatives is, however, the pursuit of stable power, rather than "green" as mentioned by the managing member of SME 4,

"The main reason is not really "green", it's not the thought behind it. It's the thought of power because we are having…we have a 100kVA generator which costs a lot of money to run when the power is off. So, we've had, in this area we have a tremendous amount of power interruptions. The reason for solar power will be to overcome that problem, and not, will be an advantage from a green perspective, but it's not the main criteria. The criteria are to have power or reliable power. Because running a diesel generator is not helping towards green initiative. Planned implementation towards end 2018"

While some SMEs are in the feasibility stages of GSC as indicated by the Manager and Partner of SME 1,

"We are in the middle of getting prices, doing some research into changing our systems, so putting in a reclamation plant. Purely because of the amount we are dumping. I would say, we've been doing this exercise for a year and a half now, getting a lot of prices. Implementation is planned 2 years from now. We are busy with feasibility studies"

A common theme among all respondents was that they want to do better and contribute to environmental sustainability, but cost was a significant factor hindering the implementation of GSC initiatives. Sadly, for the participant SMEs and certainly for many more out there, the demand from customers for products and service which are environmentally conscious certainly puts them at risk of facing decreased market share and reputational damage in the long run. The challenge may lie within the availability of resources within such SMEs to tackle the more significant sustainability requirements facing them while on a growth path or struggling to make market share in the dwindling economic conditions in SA currently. The issue of low business activity factored as a major deterrent to some SMEs towards investing capital amount in GSC initiatives.

There are numerous shortcomings in the knowledge areas of GSC main concepts such as design for environment, green purchasing and reverse logistics, observed across all participants. This was confirmed by non-articulation by all respondents when they were asked to explain what the main themes of GSC were. The answers were vague and the questions were not answered directly. More needs to be done in the education of SMEs regarding the effects of emissions and polluting the environment and how they can contribute to sustainability.

People are a barrier due to lack of management support / commitment. The interviews revealed that only one out of five mentioned internal resistance from management towards implementing a GSC initiative.

"Initial resistance, unfamiliarity with the new system I can say from my dad, the founder of the business, he wasn't too keen" (Manager and Partner, SME 1).

A strategic issue that received repeated mention was cost. The interviews revealed that 100% of the SMEs raised cost as an impediment.

6 CONCLUSION

The research findings revealed that waste management was the main activity pursued by manufacturing SMEs. This was attributed to the economic benefits gained from scrap material recycling. Literature empirically confirmed that economic benefits result in a win-win perspective called the Porter Hypothesis [29] and [30]. The research also revealed that ISO 14001 certification was still a long way to go. If there was no pressure from key customers or regulations enforcing this requirement, the status quo would remain the same. Results also revealed that supply chain environmental performance management was non-existent. SMEs did not consider environmental sustainability as a criterion for selecting supply chain partners. Supply chain partnerships are not strategically based in partnering for environmental sustainability but motivated by who's the cheapest supplier they can partner with. SMEs exerted no influence in their supply chain partner's operations as a reason.

6.1 Future research

The research shed light on GSC initiatives in SMEs in the manufacturing sector. GSC initiatives extend beyond a firm's operations, even its supply chain partners play a significant role in the entire chain. Further research may extend to other stakeholders in the supply chain, not only manufacturers, e.g. raw material suppliers, logistics partners, and product distributors. Further research can also be done on SMEs in other industry sectors, diverting from manufacturing, with the idea that this research can be replicated to look at large corporations to gain insights into their understanding, motivation, barriers and drivers in relation to adopting GSC initiatives.

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INFLUENCE OF IMPELLER BLADE COUNT ON THE PERFORMANCE CENTRIFUGAL PUMPS

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ABSTRACT

The objective of the project report was to design an impeller with a correct number of the blades that will be able to carry enough capacity of water through discharge of the pump casing. The selection of the suitable material for the impeller was taken into consideration because the number of blades of the impeller contribute to the amount of material required to do the impeller. Three impellers with different number of blade were designed to satisfy the aim of the project. The research was done on the different impellers that are currently functional in the industry and also look into the materials that these impellers work best from when considering all the properties that might damage the impeller and also cause decay to the designs. The calculations and simulation results obtained was observed that as the number of blades increases on the impeller the performance of the pump decreases. For material selection, Bronze is found to be a suitable material that is used to manufacture impeller and it also helps protects the impeller from corrosion or any sorts of decorations.

Keywords: Centrifugal pumps, pump performance, pump design parameters, Material

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1 INTRODUCTION

Centrifugal pumps are important mechanical devices for many different industries in the world. The first mechanical component that can be distinguished as a centrifugal pump was a mud lifting machine and it was discovered in the late 1400's [1]. A centrifugal pump is a mechanical device that is utilized to transfer fluids by the transformation of rotational kinetic energy to the hydrodynamic energy of the fluid flow [2]. The fact that centrifugal pumps became more popular is on the account of the new development of high-speed steam turbines, internal combustion engines and electric motors. Centrifugal pumps are comparatively high-speed machine and the evolvement ofhigh-speed drivers has made possible the evolvement of compact, efficient pumps [3]. A centrifugal pump is eminently a simple machine it is also known to be a member of a family called rotary machines, it is made up of two basic components known as the rotary part which is mostly pronounced as the impeller and also the stationery object commonly known as the casing of the pump. A centrifugal pump is a rotor dynamic pump that uses a rotating impeller to increase the pressure of a fluid. Centrifugal pumps are commonly used to move liquids through a piping system [3 - 6]. Figure 1 show a layout of a centrifugal pump with the two major components, impeller and volute.

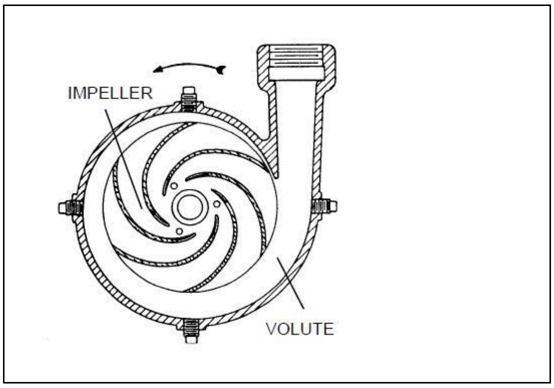

Figure 1: Centrifugal pump

In this project the focus is more on the impeller of the centrifugal pump because it influences the performance of pumps by its blade number/ quantity that helps its performance to be more efficient. Impellers are rotating devices designed to direct the flow and/or pressure of vapours, liquids, and gases.

2 DESIGN OF 3D SOLID MODEL OF IMPELLER

2.1 Design Concept

The design is of the impeller is focused on number of blade used on the impeller. The first impeller have six number of blades, second impeller have seven number of blades and the third impeller have eight number of blades. The number of blades of impeller is an important design parameter of pumps, which affects the characteristics of pump heavily [5, 6]. Computational fluid dynamics simulation and experimental verification are used to investigate the effects of blade number on flow field and characteristics of a centrifugal pump. The velocity and pressure head distribution for the three impellers which uses one centrifugal pump will be obtained.

2.2 Material Selection

For material selection, bronze is found to be a suitable material that is used to manufacture impeller and it also helps protects the impeller from corrosion or any sorts of decorations.

2.3 Impeller Detailed Design

The detailed dimension of the impeller of the centrifugal pump is as shown in figure 2. The sketch will be used to design the model of the impeller. The model of the impeller will be designed in different number of blades varying from 6 blates, 7 blates and 8 blates to determine the effect of parameters on the performance of the centrifugal pump. The impeller model was designed on solidworks and the perspective drawings was sketch as shown in figure 3.

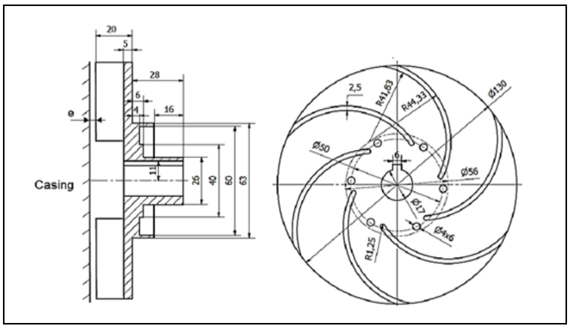

Figure 2: Centrifugal Pump Impeller Detailed Dimensions

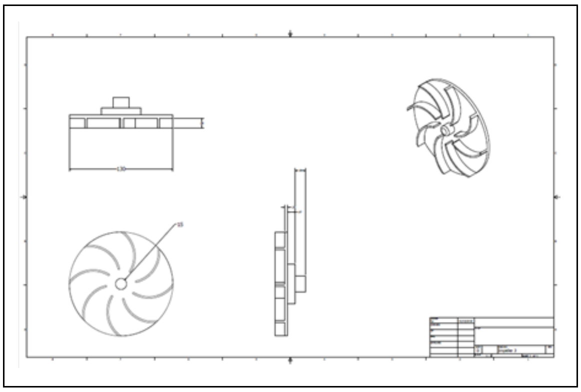

Figure 3: Impeller Perspective Drawings

3 CALCULATION AND TESTING SIMULATION OF MODEL

The calculations were done varying number blades of the impeller and same goes with the simulation. There were assumptions made when carry out the calculations. The simulation will be done varing number of blades to test the performance of the centrifugal pump. The simulations will be obtained using software called Ansys and flow simulations will be done for all the conceptual designs developed. Lastly, the results obtained are to be tabulated or represented on a graph.

3.1 Detailed calculations using appropriate formulae

Assumptions:

Linear velocity/$speed : c = 4.1\ m/s$

$pressure: p = 80.125 Kpa$

$Density\ of\ water: \rho = 998.284\ kg/m^3$

$torque:\ T = 1.7\ N.m$

$b_1 = 0.0025\text{m}$

$D_1 = 0.13\text{m}$

$\delta z = no\ of\ blades$

$r = 0.017m$

The following calculations are done for an impeller with 6 number of blades

$Q = b_1(\pi D_1 - \delta z)c_1 = b_2(\pi D_2 - \delta z)c_2$

$Q = 0.0025(\pi \times 0.13 - 0.005 \times 6) \times 4.1$

$Q = 3.879 \times 10^{-3}\ m^3/_s$

$H = Z_2 + \frac{P}{\rho g} + \frac{U^2}{2g}$

$H = 0 + \frac{80.125 \times 10^3}{998.284 \times 9.81} + \frac{4.1^2}{2 \times 9.81}$

$H = 9.0385m$

$Water\ power = \rho g Q H$

Linear velocity **C** is constant the for the driving shaft and also the impeller, hence

$c = \omega r$

$4.1 = \omega \times 0.017$

$\omega = 241.1761\ rad/sec$

$N = \omega \times \frac{60}{2\pi}$

$N = 241.1761 \times \frac{60}{2\pi}$

$N = 2303.0656 rev/sec$

$Rotation\ shaft\ power\ for\ input = \frac{2\pi n T}{60}$

$Rotation\ shaft\ power\ for\ input = \frac{2\pi \times 2415.41 \times 1.7}{60}$

$Rotation\ shaft\ power\ for\ input = 409.999\ W$

$Efficiency_{Pump} = \frac{water\ power}{rotation\ shaft\ power\ (input)}$

$Efficiency_{Pump} = \frac{343.352}{409.999}$

$Efficiency_{Pump} = 83.745\%$

7 blades of impeller calculation

$flow\ rate = 3.827 \times 10^{-3}\ m^3/_s$

$H = 9.0385m$

$Water\ power = 338.74892W$

$\omega = 241.1761\ rad/sec$

$N = 2303.0656 rev/sec$

$Rotation\ shaft\ power\ for\ input = 409.999\ W$

$$Efficiency_{Pump} = \frac{water\ power}{rotation\ shaft\ power\ (input)}$$

$$Efficiency_{Pump} = \frac{338.7489}{409.999}$$

$$Efficiency_{Pump} = 82.622\%$$

8 blades of impeller calculations:

$$flow\ rate = 3.776 \times 10^{-3}\ {}^{m^3}/_{s}$$

$$H = 9.0385m$$

$$Water\ power = 334.235W$$

$$\omega = 241.1761\ rad/sec$$

$$N = 2303.0656 rev/sec$$

$$Rotation\ shaft\ power\ for\ input = 409.999\ W$$

$$Efficiency_{Pump} = \frac{water\ power}{rotation\ shaft\ power\ (input)}$$

$$Efficiency_{Pump} = \frac{334.235}{409.999}$$

$$Efficiency_{Pump} = 81.521\%$$

Table 1: Results

No. of Blades	Flow rate. (m^3/s)	Head (m)	Water power (watts)	Linear velocity (m/s)	Rotational speed (rev/s)	Rotational shaft power .(watts)	Efficiency. (%)
6	3.879	9.03	343.3	241.1	2303.1	409.9	83.745
7	3.827	9.03	338.7	241.1	2303.1	409.9	82.622
8	3.776	9.03	334.2	241.1	2303.1	409.9	81.521

3.2 Simulation of model

Static Analyses

Impeller blades exerted with 20MPa of pressure

Simulation for 6 Blades

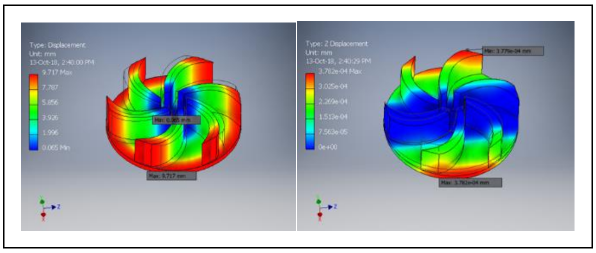

Figure 4: Simulation of Six Blades

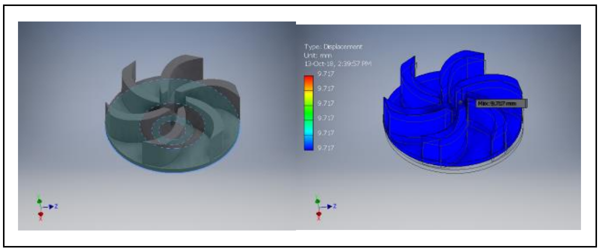

Figure 5: Simulation of Six Blades

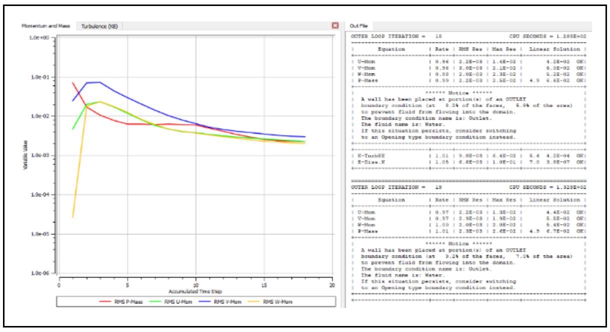

Figure 6: Graph of Six Blades

Simulation for 7 Blades

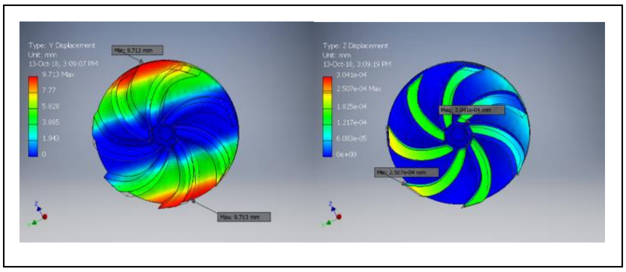

Figure 7: Simulation of Seven Blades

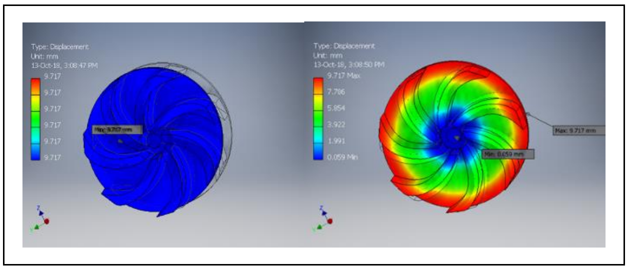

Figure 8: Simulation of Seven Blades

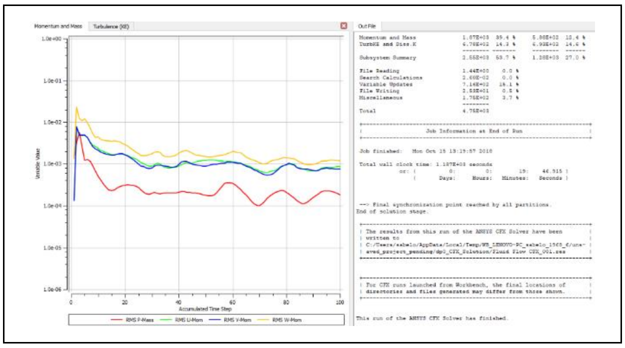

Figure 9: Graph of Seven Blades

Simulation for 8 Blades

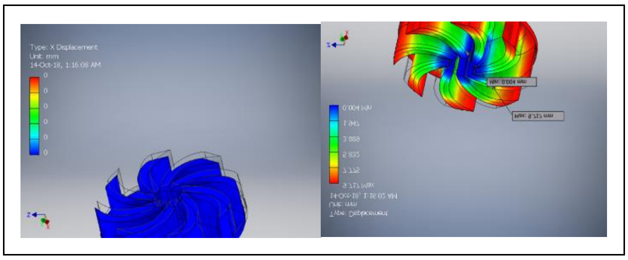

Figure 10: Simulation of Eight Blades

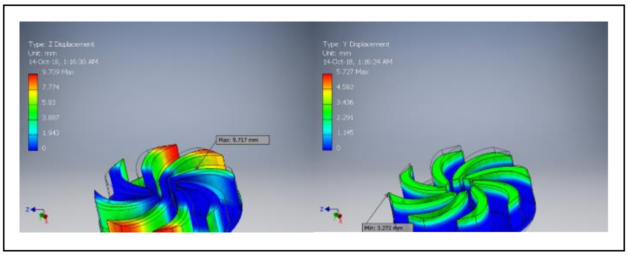

Figure 11: Simulation of Eight Blades

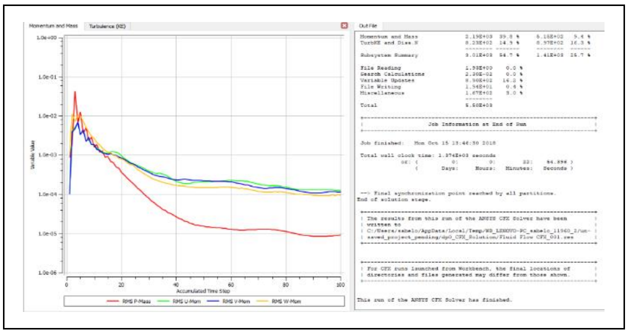

Figure 12: Graph of Seven Blades

4 DISCUSSIONS

4.1 Interpretation of calculations

From the results obtained through calculations, since the linear velocity is constant for all the pumps with impellers that have 6, 7 and 8 number of blades. From this, it implies that the angular velocity, rotational speed, and the shaft power will be the same for the different number of blades used on the impeller. Table 1 shows these similarities of the different blade numbers calculations.

- **Flow rate:**

It can be observed that as the number of blades on an impeller increases the flow rate decreases. Hence more the number of blades decreases the flow rate of the pump.

- **Water power:**

As the number of blades increases, it can be observed from table 1 that the water power starts to decrease from 7 number of blades and continues to do so at 8 number of blades hence the number of blades decreases the water power of a pump.

- **The efficiency of the pump:**

The efficiency of a pump is the most crucial part of the pump itself because it determines the performance of a particular pump performance. From the results obtained, it can be observed from table 1 that the efficiency decreases as the number of blades increases. so it can be said that the number of blades decreases the efficiency/performance of a pump and this is not ideal for a pump in any way.

4.2 Comparison of the two approaches.

The comparison between the calculated results and the simulations results agree with each other because on the calculated results as the number of blades increases the performance of the impeller decreases hence the simulated results seconds/show this trends in the graphs obtained from the fluid flow results. While on the other hand, the static results show us that the impellers have to have a certain pressure limit in order for it to be able to withstand the pressure being applied on it. The stresses obtained on the static simulation results also correlates with calculated results because as the number of blades increases the impellers begins to experience more stress on it.

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

5.1.1 Interpretation of stress graphs

The 1st and 3rd principal stress simulation results show an indirect proportionality relationship in terms of the intensity of the stresses on the impeller and the effect the stress are causing on the conceptual designs. This was expected since the number of blades does not strengthen the impeller but rather reduces its performance and strength to function. The 3rd principal stress was the one that was making the impeller experience more stress on it. Therefore, the minimum stress was found to be in the at the outermost of the impellers and the maximum was found to be in the innermost surface of the impellers

5.1.2 Discussion of locations of stress intensities

High-stress intensities were found to be in the outermost of the impeller surface. This is the part of the component which is most exposed to the highest pressure that was applied to the impeller. While on the innermost part of the impeller there was less stress experienced by the impeller. The outer stress at this location is 60% greater that the lowest outermost stress value.

5.1.3 Mitigating requirements for locations of stress intensities

Three mitigation plans were considered in the project report by a designing process. Mitigates include three different impellers with a different number of blade number count that is 6, 7,and 8 but the same material was used to design all three impellers.

5.1.4 Final materials selection for the design

Selecting the right pump type and sizing it correctly are critical components to the success of any pump application. Equally important is selecting construction materials. The initial cost of these materials is normally the first consideration. Operational costs, replacement costs and longevity of service and repair costs will, however, determine the actual cost of the pump during its lifetime.

Pump part materials such as cast irons, bronzes and low-carbon steels are typically the least expensive first cost -- and the most readily available for replacement. However, these materials can become more expensive if they cause premature failure and unexpected service and replacement.

Factors that must be considered in selecting materials for wetted pump parts are expected pump life, intermittent or continuous duty, pumping of hazardous or toxic liquids, condition of the liquid, pump suction energy level, and conditions of service, especially suction conditions.

Corrosion also is one of the factors that need to be taken into considerations. Corrosion is the destructive attack of a metal by chemical or electrochemical reaction with its environment. Corrosion by itself is usually not a difficult problem; in fact, many materials are available to handle most fluids.

For most water and other noncorrosive services, bronze satisfies corrosion resistance, abrasive wear resistance, cavitation resistance, strength and costs criteria for the impeller and thus is the most widely used impeller material for these services. And hence in our project bronze is a chosen material for manufacturing impellers while cast iron is chosen to centrifugal pump casing as it satisfies some of these criteria.

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A FRAMEWORK TO EMBED INSTITUTIONAL CAPACITY AT AN EARLY CHILDHOOD DEVELOPMENT CENTRE

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ABSTRACT

Significant progress has been made in the South-African early childhood and Grade R spheres. However, South-Africa has a long way to go to meet the needs of the majority of its children. Institutional capacity refers to the administrative and managerial aspects of an Early Childhood Development (ECD) centre. Failure to build this capacity impacts the quality of services delivered to the most vulnerable children in our society. Literature is scant when it comes to the approach, as well as embedment of institutional capacity, especially in the ECD environment. The purpose of this article is to provide a systematic review on existing approaches and frameworks for developing institutional capacity within an ECD environment. As a second contribution, we extract knowledge from existing approaches/frameworks that could be used as a baseline for an institutional capacity development approach (ICDA) for early childhood development for a South African context. The ICDA should be be useful to South-African ECD administrators, if they intend to improve institutional capacity, resulting in dramatic improvement in quality of services delivered.

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1 INTRODUCTION

The number of working parents, including single-parent families and families with both parents employed are rising, creating an ever-growing need for quality child care, according to Entrepreneur [1]. In the most recent community survey conducted by Statistics SA [2], children aged between 0-4 was 5,976,519 and showed a 5% increase from the previous survey held in 2011, refer to **Figure 1**.

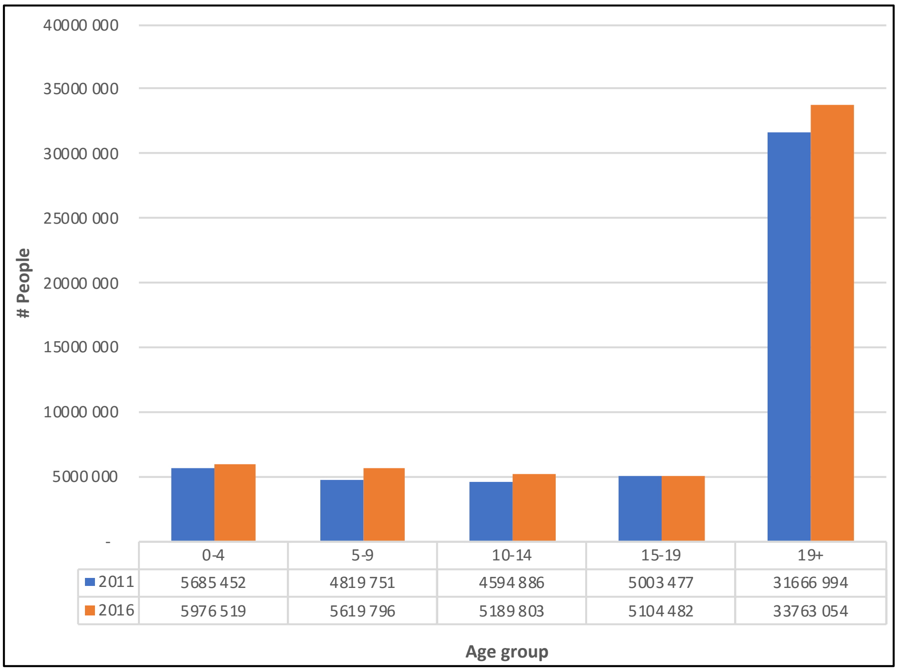

Figure 1: South-Africa population distribution, 2016 per [2]

The effective management and administration of ECD centres remain a major challenge, and enterprise engineering (EE), as an emerging discipline within industrial engineering, is poised to guide the systematic design of an IC development approach. Since IC development concerns may also be interpreted as enterprise design concerns, future work will demonstrate how we apply EE methods and practices within a different kind of enterprise, namely the early childhood development enterprise.

1.1 Problem context

Significant progress has been made in the South-African early childhood and Grade R spheres. However, Atmore [3] believes that South-Africa has a long way to go to meet the needs of the majority of its children. According to Atmore [3] various challenges exist within the early childhood sector:

- Infrastructure availability - providing basic infrastructure, such as running water and access to suitable sanitation;
- Nutrition - basic physical needs through healthy feeding schemes, preventing malnutrition and starvation;
- ECD curricula - various programs that exist within the ECD sector delivering a service to children, ranging from centre-based models to 'non-traditional' models, such as playgroups and family outreach programs;
- ECD teacher skill level - the need to promote quality teaching and learning as an essential mechanism for early development;
- Institutional capacity (IC) - effective administrative and management systems for the effective management of an ECD centre; and

- Funding - subsidies provided by government to ECD centres to acquire necessary resources needed by the ECD centre.

Of particular interest is IC, and the inability of ECD centres to execute its purpose effectively. Imbaruddin [5] finds that adopting the concept of IC, with institution as enterprise and capacity as the ability of an organisation to pursue its objectives, is therefore defined as the ability to pursue objectives at an enterprise; that is, delivering quality services as assessed by customers. Atmore [3] describes IC within the ECD sector further, and according to the Guidelines for Early Childhood Development Services [6], it is crucial that administrative and management systems are developed and put in place for the effective management of an ECD centre. Atmore [7] and Van Heerden [8] outline that community-based ECD centres lack proper administrative and management systems to meet the minimum standards set by the Department of Social Development. Clasquin-Johnson, cited by Van Heerden [8], states that there is an urgent need not only for more but for higher quality early learning centres globally as well as in South Africa. Van Heerden [8] mentions that in South Africa, teachers' and parents' views of high quality in early learning centres have received little attention despite researchers' and educators' attempts to identify the critical components for high-quality early learning centres.

1.2 Problem statement

The national integrated ECD development policy [9], stipulates that ECD centres need to have appropriate management, coordination, monitoring and evaluation systems in place to adequately plan for, measure, monitor and improve availability, quality and equity of access for all children. Within this context the problem statement is as follows:

The lack of institutional capacity is an impediment to operate a quality ECD centre, and the failure to build this capacity impacts the quality of services delivered.

From literature, very few South-African community-based centres have successfully managed to display maturity, let alone operationalise effective business management via processes and systems. In fact, Atmore [7] states that more than 50% of these centres do not have essential administrative and structural processes, which is a minimum standard prescribed by the department of social development.

1.3 Research questions

Literature review results prove that the educational 'business' language has not changed, or at least not perceived to have changed fast enough. Very few of the best practices and concepts from the ever-evolving business world is making its way into the educational sector, especially in South-Africa. Within the stated problem context, this article answers three research questions:

Question 1: What is the definition and understanding of institutional capacity within the ECD sector and its relation to service quality as a class-of-problems?

Question 2: Regarding solution areas, what approach, mechanisms and models are associated in literature to embed institutional capacity at ECD centres?

Question 3: Regarding solution areas, what measurement methods are used to measure quality at ECD centres?

2 A REAL WORLD PROBLEM

An early childhood development centre located in Pretoria, South-Africa was selected for this study. This ECD centre has 60 children enrolled, with a basic management structure. The administrator is the owner, and has a formal ECD bachelors degree with seven years teaching experience. This business endeavour, albeit well-aligned with the administrator's educational background, posed new challenges from a leadership as well as business management perspective. Majority of the administrator's time is spent on administrative as well as human resource related matters and very little time is spent on the development of a quality education curriculum and program. Everyday brings a new challenge, and the culture or behaviour has evolved into one of crisis management, slowly eroding the ability to do pro-active planning and setting goals for the ECD centre. The management time horizon has shifted to short term, and results in losing foresight of more strategic, critical factors that needs to be addressed as part of the broader eco system. There is a need for a more structured, systemic manner in which the administration and management functions are approached, i.e. a need to assist the administrator in embedding IC within the ECD centre to deliver quality services to all stakeholders concerned.

3 RESEARCH METHOD

The research protocol cover a broad perspective of IC, plus synonyms such as administration, operations management as a foundational concept, together with quality of an ECD centre. The study is exploratory in nature, investigating whether IC can be useful to increase the quality of services at South African ECD centres. We apply a systematic literature review (SLR) as research method to answer the research questions stated in section 1.3. Following Okoli & Schabram's [10] guidelines on conducting an SLR, the research method follows a three step process, namely: (1) define the SLR purpose, (2) execute the SLR protocol, and (3) produce an SLR synthesis (refer to

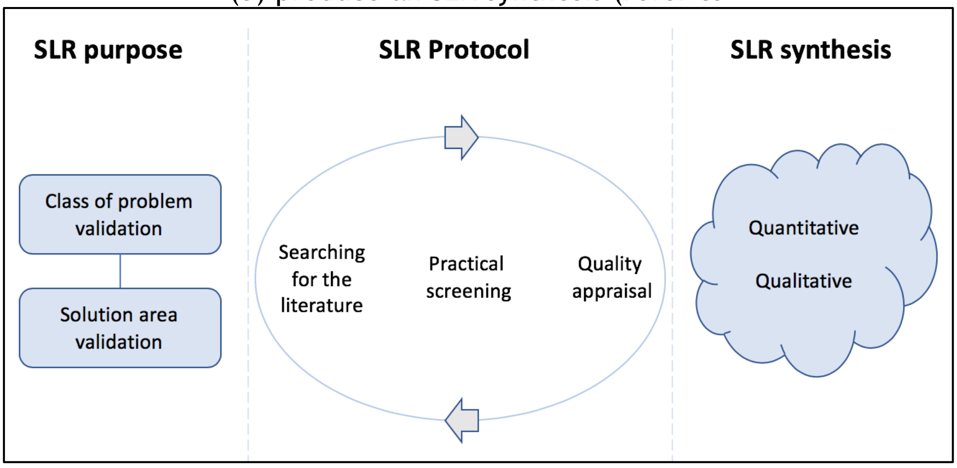

Figure 2). This research method follows an iterative approach up to a point where data saturation is obtained.

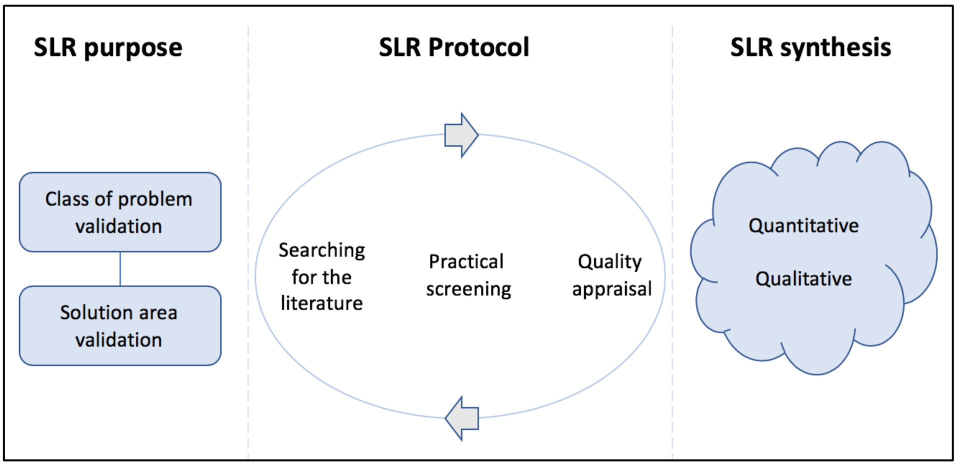

Figure 2: SLR research method, based on [10]

Text analysis forms part of this SLR, and the text analysis, interpretation together with analysis are used to develop the codebook in an iterative way, allowing for new codes to emerge. Two data analysts participated in the coding process to obtain an acceptable level of inter-coder agreement. An inter-coder agreement signifies the extent to which two or more data analysts code the same qualitative data set in the same way, as noted by Guest et al. [11, p 89]. The inter-coder agreement test is designed by adopting a subjective as well as percent agreement approach. Two analysts formed part of this test, and after three iterations, as well an in-depth discussion of coding results, the final codebook as well as definitions were accepted.

3.1 Purpose of the SLR

The purpose of the SLR cover two parts, namely (a) class of problem validation, and (b) solution area validation. The review will shed more light on IC in an ECD centre as a class-of-problems, whilst empirical evidence aims to demonstrate how IC embedment has been achieved within a similar context, with key outcomes and successes, specific to the quality of service offered. Another output from the SLR is to understand how IC embedment should be approached.

3.2 Searching for the literature

The initial investigation covers an informal search to find other SLR's that covers a similar analysis scope. Next, the research questions informed a search strategy across various resources to further help define and inform the keywords for this study, as reflected in Table 1.

Table 1: Keywords used for the search

Category	Keywords
Definition or implementation of institutional capacity in ECD centres	Institutional capacity, operations management, capacity development, implementation, quality service, administration, early childhood development

The search strings used to search the literature are presented in Table 2, and included all three categories across all resource databases.

Table 2: SLR search string used

Search string
Institutional capacity OR operations management OR capacity development OR implementation OR administration AND quality service AND "early childhood development"

Various resources were reviewed to ensure a thorough analysis of existing bodies of knowledge, and include (1) the internet, (2) databases, (3) library catalogues, plus (4) educational journals as reflected in Table 3.

Table 3: Search space and resources consulted

Resources	Search strategy	Date of search
Google scholar	full text	09 Jan-19
Science direct	abstract, title and key words	28 Jan-19
SpringerLink	abstract and keywords	28 Jan-19

Resources	Search strategy	Date of search
Scopus	abstract, title and keywords	29 Jan-19
ProQuest, Education database	abstract and key words	06 Dec-18
Early childhood education journal (SpingerLink)	abstract and key words	3 Mar-19
Early education and development (Taylor & Francis - 1556-6935)	abstract and key words	3 Mar-19

3.3 Practical screen

All articles identified through the search process were screened for in- and exclusion. Through a structured systematic method, aligned to the approach adopted by Schön et al. [12, p 82], articles were reduced to only include those that are relevant to the SLR objective. As seen in Figure 3, a six-step process was adopted to reduce the overall number of articles from 188,000 to 77. Step 1 (S1) comprised of the search string defined in Table 2, searching across all resources without any limitations or boundaries. A total of 188,000 articles were retrieved. Step 2 (S2) further reduced the total number of articles to 56,000. In Step 3 (S3), we applied selection criteria to guide inclusion and exclusion.

Inclusion criteria included papers that were written in English, that incorporated a well-articulated definition of IC (as well as related words as included in the search term string), together with IC as a key theme within the article. The first iteration of the six-step process only included IC as keyword, whilst subsequent iterations included associated words to ensure all relevant articles were included part of the SLR.

Exclusion criteria were applied to exclude articles where the full text was not available, exclude full books, where content was not aligned with the research objectives, articles not associated with IC (plus associated key words), IC as a foundational concept was not well articulated, IC as a concept articulated scantily, or IC was not demonstrated as a class-of-problems.

Step 3 (S3), scanned both titles and abstracts for inclusion, and this step further reduced the number of articles to 175. Manually screening for both titles (S4) and abstracts (S5) extracted most appropriate and relevant articles. The overall number of articles were reduced to 103, enabling a manual content scan resulting in 77 articles that were most applicable and relevant to the SLR's objective and purpose.

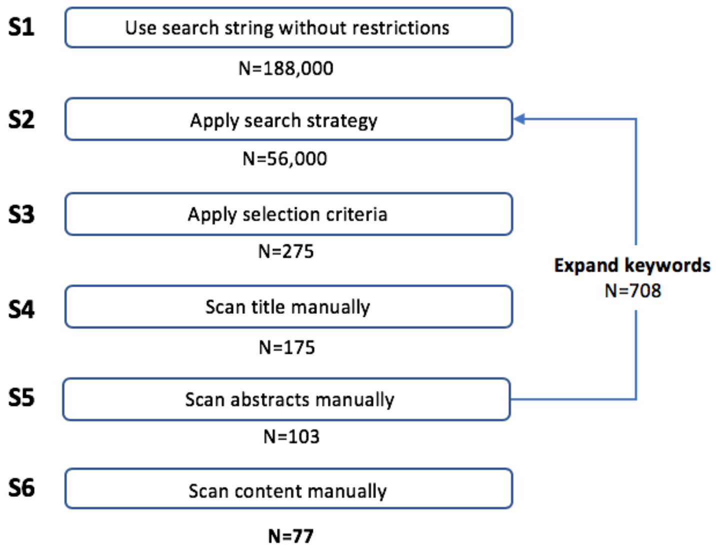

Figure 3: Search process consisting of six phases, aligned to Schönet al. [12]

A total of 77 articles, out of 188,000 articles were included as part of the SLR, with a timeline spectrum ranging from 1991 through to 2018 (refer Figure 4). Both older as well as recent discourse within the domain was incorporated as part of the SLR review and synthesis.

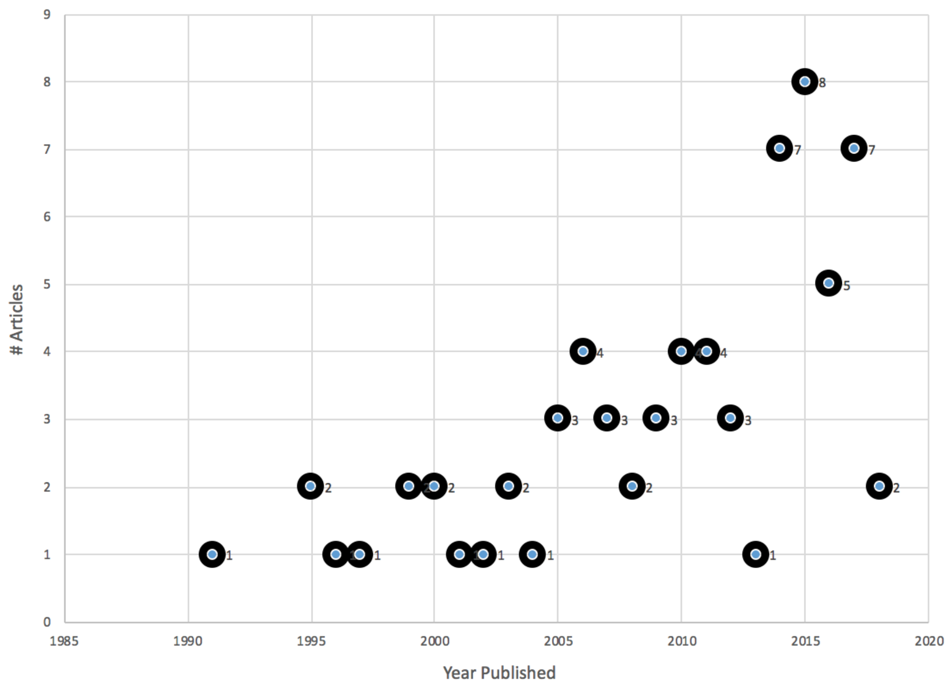

Figure 4: Articles grouped by date of publication

3.4 Quality appraisal

The practical screening process identified articles best aligned to the intent of the study. In addition, quantitative and qualitative appraisal techniques were used to further rank and prioritise articles for the purpose of this study, and is explained in subsequent sections.

3.4.1 Quantitative

Criteria were developed to test and score articles, ensuring that a consistent and replicable approach is adopted for article inclusion. A cause-and-effect table was used to rank and prioritise articles. To assist with the quantitative approach, a ranking mechanism was used to identify the most relevant documents, i.e. applying a range of weights where a weight of (1) indicates low importance, and a weight of (10) indicates high importance.

- Does the article have relevancy to the in terms of the research questions (10)
- Does the article clearly outline IC, and present a definition thereof? (6)
- Is the article focused on the educational, and more specific ECD environment (8)
- Code word count occurrence, being a cumulative number of code words (8)
- Does the article validate IC as a class-of-problems? (10)
- Does the article suggest solution areas and validation against quality measures where implemented?(10)

Each article was reviewed against the standard and assigned an impact score, with (0) demonstrating low impact, (5) medium impact, followed by (10) as high impact. The impact rating combined with the weighting of each quality criteria mentioned above provided an overall weighting recorded in the total column. Applying the scoring process, a total of 77 articles were reduced to 41 articles.

3.4.2 Qualitative

Analysing the qualitative merit of an article is the first necessary step when going beyond basic design structure and dissecting the logical arguments of the work, according to Okoli and Schabram [10, p 28]. Hart [13], as cited by Okoli and Schabram [10], mentions that every article should be screened for three items: (i) what claims are being made, (ii) what evidence is provided to support these claims, (iii) whether the evidence is warranted and how well the evidence is supported. Fallacies in arguments at this point, could lead to seriously downgrading an article's quality score. The qualitative screening protocol scored all 41 articles that were extracted during the quantitative prioritisation process against the following indexes: (-1) absence, (0) not stated, (+1) present. As an example, an article could score a maximum of (3) if it met all 3 criteria, resulting in a strong quality article. On the contrary, an article could score (-3) if all criteria were absent, indicating a weak quality article. In Figure 5, 41 articles are plotted against the quality index, illustrating 19 are of high quality (3), whilst 4 are of weak quality (below 0). Articles that scored 1 to 3 overall ratings (32 articles) are extracted and probed in detail due to the nature of their findings as well as evidence to support claims that are made in these articles.

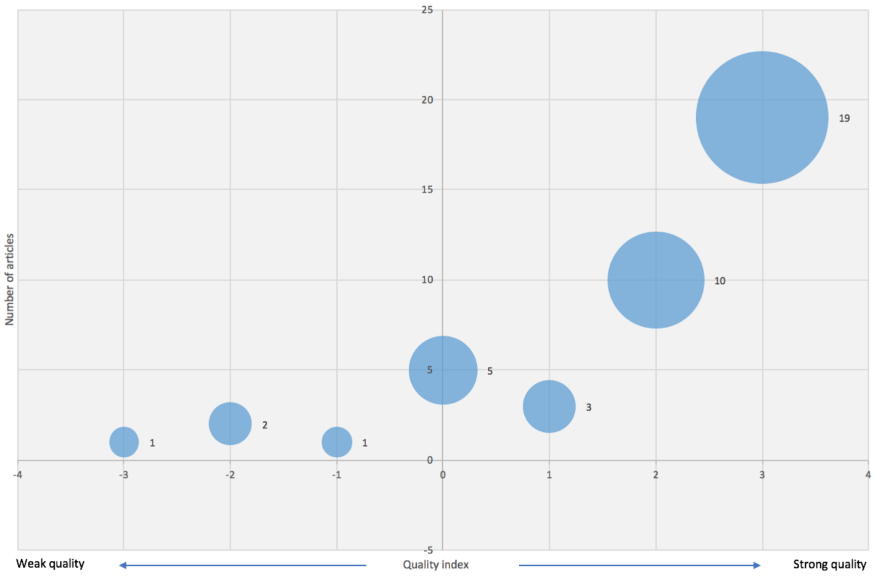

Figure 5: Qualitative quality appraisal

3.5 Data extraction

Up to this point in the SLR, a short-list of articles were extracted for the final review and data extraction. A detailed extraction form was created, aligned to the guidelines stipulated by Okoli and Schabram [10]. Data extraction was informed by the following attributes:

- Basic information (title, authors, publication date)
- Publication data (journal, conference, date of conference, publisher, volume, keywords and abstract)
- Research method (experiment, case study, lessons learnt, etc.)
- ECD or Non-ECD
- Developing or developed country
- Artefacts (models, frameworks or reports) suggested or used
- Short summary
- Results and contributions

All short-listed articles (32), were taken into consideration for the data extraction process. With a concise extract of pertinent data from the most relevant articles, the synthesis process commenced.

3.6 Synthesis of studies

During synthesis, content of the analysed articles are consolidated in order to make sense of a large number of studies. Under guidance of Popay et al. [14], the synthesis product, at a minimum, is a summary of the current state of knowledge in relation to particular review question(s). A narrative synthesis approach is helpful in the early stages of the review process, and can increase the chances for the product to be used in policy and practice [14]. The narrative synthesis approach is a form of story telling, and the four elements that guide the synthesis process are outlined as follows: (1) develop a theoretical model of how the interventions work, (2) develop a preliminary synthesis, (3) explore relationships of data, and (4) assess the robustness of the synthesis product.

4 SYSTEMATIC LITERATURE REVIEW RESULTS

The ensuing section outlines the SLR results, for both the class-of-problems as well as possible solution areas, together with the measurement of quality.

4.1 Results for a class-of-problems

In answering research Question 1 (see section 1.3) literature indicates that the ECD environment is complex, and there is a need for fresh new thinking to evolve early childhood education. A case is made to act and think more systemically to deliver higher quality programs and services that is sustainable over a longer period of time. There is evidence that a class-of-problems exist, i.e. although progress has been made in the provision of quality early childhood education via IC, room for improvement exist, especially in developing countries. The SLR identified various instances of this class-of-problems, excerpts as per Table 4.

Table 4: Class-of-problems validation

Source	Class-of-problems instances
[15]	Provision of quality service to the concerned stakeholder and satisfaction of the users is the manifestation and implication of institutional capacity.
[5]	This study confirms previous research findings indicating that clear and realistic organisational objectives, a less-hierarchical management approach and a more participatory decision-making processes contribute to better institutional capacity in

Source	Class-of-problems instances
	terms of an organisation's ability to deliver quality services as expected by the clients or service receivers.
[16]	Financial resources available influence the management structures, procedures and styles employed in the affairs of community schools, which affect the quality of education provided by either promoting or hindering institutional capacity.
[17]	Sound management and administration practices reduce staff discontent, decrease turnover, create increased respect, and status for the profession and significantly influence the quality of service delivery.
[17]	The implication for child care is clear - quality in the early childhood setting is closely linked to the administration function of the ECD setting.
[18]	A lack of institutional capacity leads progressively to governance stress and questionable financial viability, which ultimately leads to service delivery breakdown.

IC results pivot around the development, implementation as well as scaling-up to meet increased demand of early childhood care. It entails the business environment, administrative capacities, adequate funding as well as process components that have a direct impact on the quality of services delivered. The role of the director (administrator) is becoming more prevalent, considering the shift towards a business type institution. In a study conducted by Hayden [17], specific focus was placed on addressing the gap in understanding of directors, administration plus management functions in childcare and preschool settings. It is becoming increasingly clearer that 'process' components which make up the adult work environment have a powerful effect upon quality care in child care centres, and that the centre director plays a central role. Results indicate that when looking either at leadership and management [19], or defining a framework to develop appropriate skills [20], there seems to be a gap in defining the required administrative tasks. This is partly due to most directors in child care centres have had no professional training for leadership and administration roles [20], whilst ECD centres are now required to adopt management practices and business principles that were not essential previously [19]. The expansion of child care facilities and the increasing complexity of administration functions is exacerbating the need to provide support for existing administrators and to develop an infrastructure whereby the pool of potential administrators is enlarged. The most prominent variables impacting IC are (1) the administrator, (2) administrative competence, plus (3) resources, in form of skills, training as well as funding.

4.2 Results for solution areas

In answering research Question 2 (see section 1.3), a structured approach was followed to document and compare identified solution areas for the class-of-problems as an outcome of the SLR. In essence, four themes are identified in which the solutions and or frameworks are classified, namely: (1) leadership, (2) systems thinking, (3) assessments, and (4) enablement.

4.2.1 Leadership

The critical role of the administrator or leader within the ECD centre cannot be under-estimated, and according to Scripter [21] developing and embedding IC within the education environment will require good leadership. Quality in service delivery is closely linked to the administration function of the early childhood setting and the administrator is the key person to influence both organisational effectiveness and quality of care, cited by Hayden [17]. An increasing recognition of the importance of the administrator, calls for research about this role and about the characteristics of those who assume it. The leadership framework by Nupponen [20, p 156] focuses on (1) relational and pedagogical leadership, (2) intra and interpersonal skills, and lastly (3) education and training to master these traits.

4.2.2 Systems thinking

Findings from Jorde Bloom [22] research indicate that a systems approach for describing early childhood centres can lead towards a better understanding of the impact of change and can assist administrators to better understand the significance of their day-to-day roles and responsibilities. Albeit the components of the social systems model are well described, Nupponen [19] suggests that facets of leadership as well as business orientation to service delivery will be required.

4.2.3 Institutional capacity assessment

In order to affect improvement, an assessment needs to be conducted to ascertain gaps and areas that need to be addressed. The five dimensional framework by Grindle and Hilderbrand [23] is identified as a very useful systemic method to analyse determinants of IC, as cited by Imbaruddin [5, p 27]. However, since the early 1980's IC analyses have been undertaken in a more comprehensive and systematic way, introducing the three level approach [24]. In a practical sense, The United Nations Development Program (UNDP) applies the same three-level conceptual approach to analyse and assess the capacity of public institutions in a systemic manner.

4.2.4 Enablement

Scheepers [18] refers to work done by Lusthaus, Anderson and Murphy [25] that describe the elements needed to enable IC as: (1) strategic leadership, (2) human resources, (3) financial management, (4) infrastructure, (5) program management, (6) process management, and lastly inter-institutional linkages.

4.3 ECD quality

In answering research Question 3 (see section 1.3), a quality school climate enhances emotional and social well-being of the child, and the findings suggest that for mothers and teachers, quality concerns were not about what the the early learning centres have provided in terms of facilities (input indicators), but rather about the process indicators where centres promote children’s holistic well-being [8]. Various measurement methods exist, (refer Table 5), but the Program Administration Scale (PAS) is designed to reliably measure and improve the leadership and management practices of centre-based programs. The PAS was developed in 2004 by Talan and Bloom to fulfil the need to "look beyond classroom quality” when assessing early childhood programs, because “while there are several instruments available to measure the quality of teacher-child interactions and the quality of the classroom instructional practices, there does not currently exist a valid and reliable instrument that solely measures the administrative practices of an early childhood program" [26, p 49].

Table 5: Quality measurement

Measurement method	Source	Measurement areas
1. USDE and CHEA	[27]	(1) Student achievement and continuous improvement, (2) Curriculum, (3) Faculty, (4) Facilities, equipment and supplies, (5) Fiscal and administrative capacity, (6) student support services, admissions an information systems.
2. Trinidad and Tobago	[28]	Mixed set of process inputs: Teachers, pedagogy, internal structures.

Measurement method	Source	Measurement areas
3. ECD reflection tool	[29]	1. Teaching and learning, 2. Leadership and management, 3. Environment, 4. Policy and systems frameworks.
4. The framework	[8]	1. Input (structural), 2. Process, 3. Outcomes.
5. Three point scale	[6]	1. Staff, 2. Management, 3. Premises and equipment, 4. Active learning, and 5. Observation by reviewer.
6. Program administration scale (PAS)	[26]	1. Human resources development, 2. Personnel cost and allocation, 3. Centre operations, 4. Child assessment, 5. Fiscal management, 6. Program planning and evaluation, 7. Family partnerships, 8. Marketing and public relations, 9. Technology, and 10. Staff qualifications.
7. Quality components	[30]	1. Communication and Rapport, 2. Caregiver Practices, 3. Staff Characteristics, 4. Finances and Resources, 5. Visibility and Involvement, 6. Professionalism.
8. Early childhood environment rating scale (ECERS)	[31]	1. Space and furnishing, 2. Personal care routines, 3. Language reasoning, 4. Activities, 5. Interaction, 6. Program structure, 7. Parents and staff.

5 DISCUSSION

One of the biggest impediments to deliver quality ECD services is effective administrative and management systems to operate an ECD centre, and this is validated through the SLR as a class-of-problems. The inability to build and embed the necessary IC prohibit administrators to lead quality ECD centres.

5.1 The class-of-problems within ECD

The ECD environment is changing, and there is a need to adapt traditional thinking and approaches to better align with concepts more familiar to leaders within the business world. The dynamic environment demands a systemic approach to the management as well as delivery of ECD services. Administration has not been recognised as a skill area separate from teaching in childcare centres and, as such, has not been allotted sufficient credentials, recognition or rewards. Three variables have a direct impact on building IC competence, namely the leadership role, administrative competence, and resources.

5.2 Solution areas

Solutions to address IC is not a foreign concept, especially in typical business or non-educational domains. In fact, various approaches and solutions exist and is well-documented. In order to address the class-of-problems in the ECD context, solutions need to be fused together to create an approach administrators can use and adopt to build and embed IC. The focus on leadership, whilst adopting a systems approach to describe ECD centres can lead towards a better understanding of the impact of change. Through a structured IC assessment, the task on hand will be understood allowing IC enablement to take place.

5.3 Quality measurements

Quality of services in the ECD environment need to be broader than just the classroom or education. The quality measurement needs to ensure that both the educational outcome as well as administrative practices are adequately covered. The PAS measurement method ensures that quality is measured beyond the classroom, and thereby ensures administrative performance is included.

5.4 Summary

Various components of a solution to address the class-of-problems exist, but none of the solutions are structured in a manner to inform an approach for administrators to follow. Figure 6 portrays the variables impacting IC in the inner circle, whilst the solution areas are represented in the outer circle.

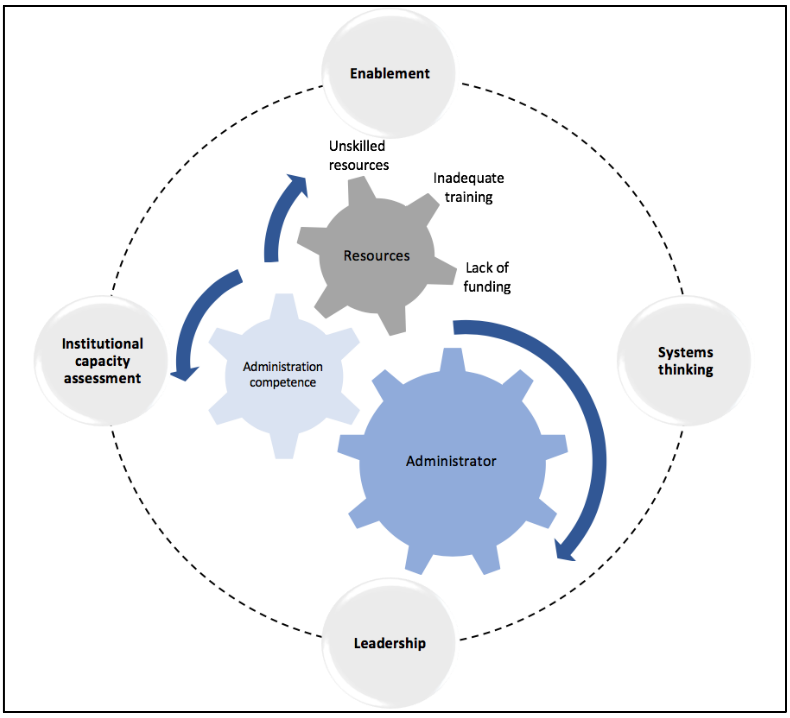

Figure 6: Institutional capacity solution model

There is a need for an IC baseline to be established, in order to design the ICDA approach to address the class-of-problems. Although many constructional design domains and facets contribute towards quality education, this study intends to extract existing prescriptive guidance for coherent enterprise design, in order to contribute towards quality education. The ICDA has to provide more systematic guidance to administrators of South-African ECD enterprises.

6 CONCLUSION AND FUTURE RESEARCH

In closing, and in response to this study's research questions, IC has an immediate and direct impact on the quality of services delivered to the most vulnerable in our society. Institutional capacity is well-defined in the educational domain, and the task at hand well understood. Literature is scant when it comes to the approach, as well as embedment of IC, especially in the ECD environment. The outcome of this study will take a step forward in addressing this gap through the development plus embedment of an IC development approach using Enterprise Engineering methods and practices.

As a future research contribution, enterprise engineering as an emerging discipline within industrial engineering, is poised to guide the design of an approach to integrate the concepts outlined as a result of this SLR in order to develop an IC development approach, i.e. ICDA. The SLR indicates that none of the existing frameworks, concepts or areas of concern are structured in a way to guide administrators of ECD centres in developing and implementing IC in a systematic, coherent and comprehensive way.

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FLOW PROPERTIES UPON TREATMENT OF ACID MINE DRAINAGE USING PERVIOUS CONCRETE

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ABSTRACT

The mining industry is one of the industries that have a positive influence on the economy of South Africa, however, it has a damaging impact on the environment. The acid mine drainage which is known as AMD is one of the products of the mining industry. Acid mine drainage is an acid rich-metal solution that is formed during mining operations. The shortage of water in South Africa calls for immediate intervention. Treating AMD will not only help to generate clean water, but it will also help to protect the environment against AMD. Some researcher has discovered that pervious concrete can treat AMD, however, there was no further investigation that established properties of pervious concrete that treat AMD. The aim of this study is to investigate and establish the relationship between the flow rate of AMD through a porous medium such as pervious concrete and the thickness of pervious concrete wall. This is done in order to achieve a low cost, yet effective method that can improve treatment of AMD for communities, especially in South Africa, affected by AMD. AMD samples are collected from South32 coal mine, which has high sulphate content, for laboratory testing. To predict fluid flow through pervious concrete as a medium, various tests is developed on cubes of pervious concrete. The results show that as AMD is filtered through the layers of pervious concrete precipitates of heavy metals may be removed. The pervious concrete layers also help to increase the PH level of AMD to more acceptable values making concurrent absorption and neutralization a possible alternative.

Keywords: *pervious concrete, AMD, hydraulic conductivity*

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1 INTRODUCTION

AMD (Acid Mine Drainage) is one of the most unsafe products of mining operations, because it threatens rivers of clean water and worsens its quality. Reduced quality of water is a danger to animal health. Tools such as MRPP (Mining Risk Prevention Plan) have been documented in the Department of Water and Sanitation to avoid the possible severe threat of AMD to the environment, MRPP is designed such that they can estimate contamination that are the results of AMD. Best practice guidelines (BPGs) were developed by the Department of Water and Sanitation in South Africa for the mining sector to enforce management guidelines or rules of wastewater. The BPGs were developed to ensure the safety of environment against AMD threats. Kuyucak [1] suggested that prevention of AMD is not possible, it must only be treated. There are treatment methods like Lime Neutralization, Biological redemption, permeable reactive media etc. that are already invented but they are expensive. There is a need for an affordable and efficient treatment method to treat AMD. AMD treatment properties of pervious concrete have been recognised but there were limited further investigations that establish those properties Collins [2].

1.1 Acid mine drainage

Sulphide ores from the active or abounded mine once they are exposed to atmosphere they undergo weathering, which results in the formation of AMD Vacillator [3]. AMD is known as a high metal concentrated solution Muzenda [4]. AMD physical properties include yellow, red and orange colour, this colour change is caused by the precipitation of ions. See Figure 1 for an orange AMD.

Figure 1: Yellow or Orange sediment in the bottom of a stream [5].

Another property of AMD is the low PH, the PH value is always different from different sources of water. And the AMD chemistry differs from site to site as its formation depends to different variables. The flow of AMD results in ecological damage in watershed and it contaminates human water sources with Sulphuric acid and heavy metals Muhamad [6]. AMD has an economic impact; the Government spends money for water purification. Left unresolved acid mine drainage can leave watercourses and areas downstream natural dead zones forever.

1.2 Treatment of acid mine drainage

Shortage of water in South Africa has activated the mining division to focus more on AMD treatment techniques. Treatment techniques that already exist are divided into two technologies known as passive treatment technologies and active treatment technologies. Passive treatment is mostly used in abandoned mines, whereas Active treatment technology is mostly used in mines that are currently operating. Table 1 shows the differences between these two treatment technologies. Each treatment technology is made of many different types, this work is based on a passive treatment technology known as Permeable Reactive Barrier.

Table 1: Differences between Active and Passive 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 lot of maintenance and routine monitoring	Requires less maintenance
Considered for high flow rates	Considered for low flow rate
Requires power or energy to operate	Does not need power or energy to operate.

1.3 Pervious concrete

Pervious concrete is a different type of concrete as compared to conventional concrete, it is made up of no fine, large aggregates with a high percentage of porosity. Pervious concrete is made up of interconnected voids which allow water to pass through, figure 2. The permeability percentage is about 15% to 30%, of which 15% is the minimum [7]. Pervious concrete was first used as a pavement surfacing and load bearing wall in the 1800s by Europeans because it was affordable compared to other types of concrete Chopra [8]. In former times the conventional concrete and cement was scarce, which increased the popularity of pervious concrete. In Europe, it was used specifically for housing Chopra [8]. The low price of pervious concrete compared to conventional concrete was not the only reason for its use, it was also recommended because of its permeability.

Figure 2: Pervious Concrete. (Cement.org website).

Pervious concrete is a mixture of gravel or granite stone, cement and water. It is intentionally designed to allow stormwater to pass through and remove bit pollutants. While the main focus of designing pervious concrete is for stormwater management, it has been found that pervious concrete has water treatment qualities Chopra, Park and Collins [9, 10, and 11]. However incomplete work has been done to establish these qualities. Pervious concrete was investigated for potential use as a PRB for treatment of AMD by treating polluted or acidic water by Shabalala [12]. It was found that pervious concrete can remove concentrated metals such as zinc, iron, sodium, magnesium etc. Pervious concrete can be used in many applications such as retaining walls, porous pipe, pilling, ecosystem restoration, firewalls and pavements. The present work covers treatability of AMD using the pervious concrete system and does not include investigation of lifespan or longevity of the treatment system.

2 EXPERIMENTAL PROCEDURE

2.1 Selection of cement type

It has been found that Pervious concrete with the following properties reduces the concentration of metals in AMD Shabalala [12].

- Water to cement ratio of 0.27
- Optimum porosity of 20 to 30%
- 9.5mm granite aggregate
- Portland Cement (CEM 1 52.5R) was used
- Fly Ash
- Size of concrete slab 100mm cube

From interviews conducted with Mr Darren Jacobs, who is the Technical Global Brand Manager at LafargeHolcim (a prominent supplier of cement, aggregates and already mixed concrete) it was found that when dealing with AMD the acidic nature of the water is destructive to concrete. This is normally addressed by using dense, impermeable concrete that is the opposite of pervious concrete. One consideration could be the use of Alkali Activated Cement (AAC) instead of Portland cement. The AAC is known to be far more resistant to chemicals Owens[13]. However, AAC cannot be used at the moment due to its hazardous properties Owens [13] According to Owens [13], cement type CEM 1 52.5 can be used where high early strength or reduction of curing time is required. The Concrete Institute of South Africa (The Concrete Institute website) has recommended CEM IV for the mixing of pervious concrete since it will be used as a reactive medium of acidic water. The Concrete Institute consultants confirmed that CEM IV is not good as AAC but it will respond better to AMD than CEM I. One of the major characteristics of AMD is a high concentration of Sulphate, therefore, the use of sulphate resisting cement will be an advantage. Table 2 shows the sulphate resisting common cement as per SANS 50197-7 [13].

From Table 2 it can be noted that CEM I and CEM IV are both sulphates resisting cement, however, CEM IV has a percentage of siliceous fly ash. Fly ash is collected from the exhaust flow of furnaces burning finely ground coal. The finer fraction is used as a Portland cement extender. Fly ash reacts with calcium hydroxide, in the presence of water, to form cementing compounds consisting of calcium silicate hydrates Owens [13]. In conclusion cement types CEM 1 and CEM IV were chosen for this study. The latter is chosen specifically because it has a percentage of fly ash, this will help to compare the results of AMD if a different type of Portland cement is used.

Table 2: Sulphate resisting common cements: SANS 50197-7 [13].

Main Types	Notation of the seven products (types of sulfate resisting common cement)		Composition (percentage by mass) – Main constituents: Clinker K	Blast Furnace Slag S	Pozzolana Natural P	Siliceous fly ash V	Minor Additional constituents
CEM I	Sulfate resisting portland cement.	CEM I-SR 0	95-100	-	-	-	0-5
		CEM-I-SR 3					
		CEM-I-SR 5					
CEM III	Sulfate resisting blast furnace cement.	CEM III/B-SR	20-34	66-80	-	-	0-5
		CEM III/C-SR	5-19	81-95			0-5
CEM IV	Sulfate resisting pozzolanic cement	CEM IV/A-SR	65-79	-	21-35		0-5
		CEM IV/B-SR	45-64	-	36-55		0.5

2.2 Materials and method

The AMD samples used in the present study were collected from two different coal mines in the Mpumalanga Province of South Africa. The samples from the two different coal mines are designated as E4 and R4 respectively. Pervious concrete cubes were designed on the 2^3 factorial experimental design principle using Cement type, water to cement ratio and aggregate as factors to obtain optimal results that will inform us as to which variable combination will give best pervious concrete to absorb metal concentrates from AMD samples. Table 3 shows the factors that were used and their levels.

Table 3: Factors and levels

Factor		Level	
Label	**Name**	**-**	**+**
A	Cement type	CEM 1 52.5R	CEM IV 32.5 N
B	Water to cement ratio (W:C)	0.24	0.3
C	Dolomite aggregate	6.7 mm	13.2 mm

The replicates were the thickness of concrete slab which ranges from 80mm to 200mm, while the surface area was kept constant at 100mm x 100mm. In this report, Dolomite stone was used instead of Granite stone. Granite stone is a very hard, granular, crystalline igneous rock which consists of three minerals quartz, alkali feldspar (which contain alumina and silica) and plagioclase feldspar (which contain sodium and calcium), whereas Dolomite stone is a sedimentary rock which consists of a high percentage of the mineral dolomite.

Thus the experimental runs involve different pervious concrete slabs built by Lafarge Holcim with properties summarized in Table 4. The purpose is to test the various combinations of properties of the pervious concrete on the response, which is the relative metal concentrate removal from the AMD samples. Hydraulic conductivity versus aggregate size and flow pressure relative to thickness could then be assessed. Dry ingredients were mixed for two minutes in a 200 L pan mixer, followed by the gradual addition of water over one minute and further mixing for one minute. Standard 100 mm cube moulds were each filled according to the required thickness. After placing each layer, the mixture was stamped 10 times then compacted using a vibrating table for 10 s. Water to cement ratio of 0.24 gave no paste or workability to the concrete as shown in figure 4, additional water was required.

Figure 1: Granite Stone and Dolomite stone.

Water to Cement ratio that is 0.24 and below doesn't give workability. The fresh concrete cast in cube moulds was finished and de-moulded after about 24 h. Thereafter, the cubes were placed in a water curing bath until 30 days age of testing. Altogether 16 cubes from each cube were cast. 8 cube for each AMD sample.

Figure 4: Poor paste for water to cement ratio of 0.24.

2.3 Constant head permeability test setup

The constant head permeability test setup involves the flow of water through a column of the sample under a constant pressure difference. In the tests, the thickness of the concrete cube was varied in order to evaluate its influence on AMD treatment quality and to determine the coefficient of permeability of pervious concrete using the constant head method. The permeability constant is a measure of how easily a fluid can pass through a porous medium. The constant head permeability test is a common laboratory testing method used to determine the permeability of granular soils like sands and gravels containing little or no silt. The constant head method is used in this case since a porous concrete is being tested. The constant head method is combined with Darcy's Law to find the coefficient of permeability using flow rate, specimen area and the hydraulic gradient. The apparatus illustrated in Figure 5 was used to collect data. The head was kept constant at 250mm.

Table 4: Details of pervious concrete cubes manufactured for testing

Mix	Thickness	Cement	Stone size (mm)	Water-Cement Ratio
1	80	CEM 1	6.7	0.34
2	200	CEM IV	6.7	0.27
3	80	CEM 1	6.7	0.3
4	120	CEM IV	6.7	0.3
5	80	CEM 1	13.2	0.3
6	120	CEM IV	13.2	0.3
7	100	CEM 1	13.2	0.3
8	80	CEM IV	13.2	0.3

The concrete cube was covered on the sides with tape, to make sure there will be no seeping of water on the sides. Container with a water supply that could supply water at a constant head was prepared at the same time with the apparatus. Water was run through the concrete cube until fully saturated. The flow was then measured on each concrete cube for 40 seconds at a constant head using a stopwatch. The amount of water that was collected in 40seconds was investigated.

3 RESULTS AND DISCUSSION

3.1 Chemical analysis

A number of concrete mixes were cast as per Table 4 and tested. A PH meter was used to check the PH and Atomic absorption spectrometer was used to check metal concentration. Chemical analysis was done to define the removal competence of existing metals on AMD.

Manganese removal level on E4 AMD was at an average of 70%. Comparing these results to the results that were found by [12], granite aggregate gives better treatment performance of an average 96% than the dolomite aggregate. This is evidence that pervious concrete does reduce metal concentration on AMD, the aggregate type has an influence on the metal removal of AMD. Pervious concrete also effectively reduces the concentration of iron and Zinc for both E4 and R4 up to an average of 98%. The metal removal capacity of pervious concrete looks very impressive; however, its hydrological properties have a great influence. The effect of flow distance was also investigated by placing the concrete cube thickness in a filtering position see Figure 5. The results show the increase in the PH as the flow distance increases. The PH of E4 AMD was increased from 6.5 to 8.5 and PH for R4 AMD increased from 5.4 to 7.8 over the flow distance of 250mm.

3.2 Hydraulic conductivity

In order to design pervious concrete that best treats AMD, eight concrete mixes were cast and tested. Water to cement ratio, aggregate size and cement type were the main variables.

Results have shown in Figure 4 a direct relationship between water to cement ratio and the compressive strength. As the water to cement ratio increases the compressive strength increases. While porosity remains the factor of interest, Luck et al 2006 [11], found that there is a linear relationship between the density of concrete specimen and porosity, density and permeability, porosity and permeability, and porosity and specific yield. As the density (kg/m^3) of concrete specimen increases, porosity decreases [14]. In terms of the flow of water through the pervious concrete, porosity and permeability remain the focus of the investigation. On the research conducted by [15], it is indicated that there is no standardized method in the laboratory that gives an accurate measurement of porosity. In this case, hydraulic conductivity was measured since it has a relationship to porosity as in Figure 8.

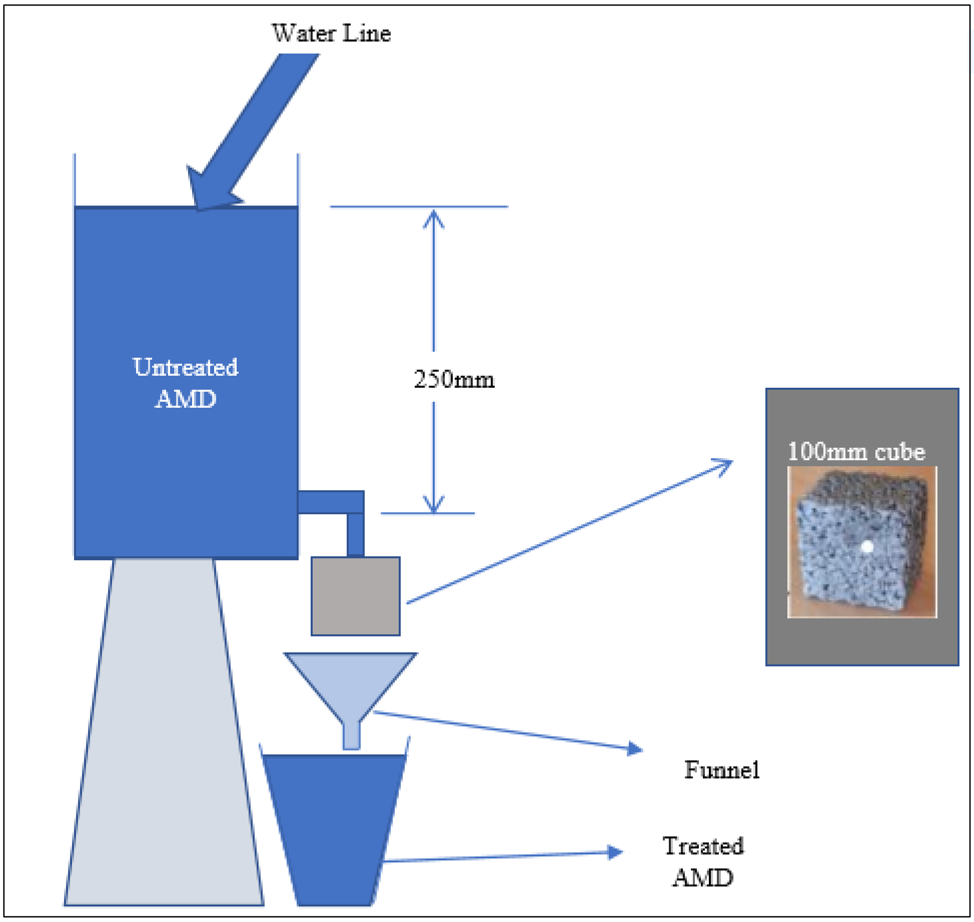

Figure 5: Schematic diagram of reaction columns (AMD – acid mine drainage.

It is also interesting to note in Figure 8 that the aggregate size has a relationship with hydraulic conductivity.

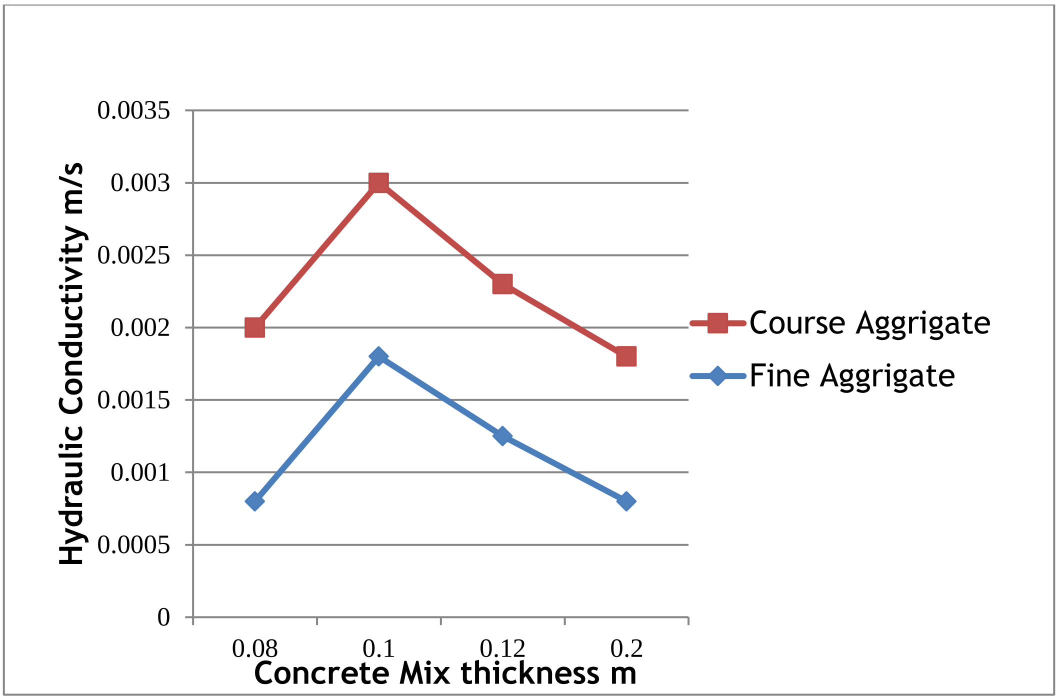

Figure 8: A plot of Hydraulic Conductivity versus concrete mix thickness for aggregates of different types and sizes

This resulted in an inconsistent range of hydraulic conductivity, but it tended to generally increase with an increase in thickness. Permeability and flow rate directly depends on the aggregate size, larger aggregates mean larger area available for flow, which results in more frictional resistance, hence resulting in high hydraulic conductivity.

4 CONCLUSION

In the foregoing discussion, constant head permeability test was performed to evaluate the potential use of pervious concrete as a treating media for Acid Mine Drainage and to establish qualities of pervious concrete that treats AMD. The following conclusions are made based on findings.

- Aggregate size significantly influences the hydraulic conductivity of pervious concrete, larger aggregates results in high hydraulic conductivity.
- Iron and Zinc were successfully removed from AMD, the pervious concrete also reduced the concentration of Manganese, comparing current results to Shabalala [12], and granite aggregate has better AMD treatment qualities than Dolomite.
- The flow distance (thickness) have an influence on the PH of AMD as it flows through pervious concrete.

5 ACKNOWLEDGEMENT

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RETAIL SUPPLY CHAIN MANAGEMENT: A STRUCTURED LITERATURE REVIEW

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ABSTRACT

This paper seeks to determine the current state of retail supply chain management (R-SCM) research by focussing on papers published over a ten year period between 2008 and 2017. The aim is to identify the most prominent themes in the area of R-SCM and to establish whether the topics were treated as a mere extension of general supply chain management (SCM) or focussed on the unique challenges of R-SCM. A systematic literature review approach was followed. First, prominent R-SCM authors were identified through a systematic review of academic journals in several scientific databases. Articles where then classified based on a retail value chain (RVC) process, and further analysed to identify the most prominent themes in each of the RVC categories. Five major themes emerged from the literature review, namely assortment planning, omni-channel, in-store logistics, forecasting, and Green SCM. R-SCM research is however still very much on the fringes of general SCM research. A larger body of research is required to provide a deeper understanding of these themes under different retail specific conditions, as well as end-to-end optimisation of the multi-echelon retail value chain.

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1 INTRODUCTION

Retailers have once been passive recipients of products, with manufacturers allocating stock to stores based on their forecasts of demand [1]. In the last 20 years retailers have taken control of the secondary supply chain. Retailers have built distribution centres (DCs) and now channel a large proportion of their product flows through their own warehouses [1]. Although this transition has started as far back as the 1980's and 1990's, many companies are still in the process of centralising many of the functions and systems associated with the end-to-end supply chain. Flowing stock through a central DC in an optimal way requires a level of synchronisation and optimisation that has only become possible in the last 15 years, mainly due to advances in commercial software packages to deal with the volume most retailers encounter [2]. The volume, combined with the fact that ordering happens on a daily basis, means that millions of ordering decisions need to be made daily across several different categories of products [3].

The Council of Supply Chain Management Professionals (CSCMP) defines Supply Chain Management (SCM) as "encompassing the planning and management of all activities involved in sourcing and procurement, conversion, and all logistics management activities. In essence, supply chain management integrates supply and demand management within and across companies."[4]. Although many of the supply chain challenges that retailers face have similarities with manufacturing, there are retail specific nuances resulting in a unique set of challenges that Retail Supply Chain Management (R-SCM) research needs to address. These include a mixture of factors such the number of stocking points, assortment variety, variances in sales velocity, long lead times and supply chain complexity.

In isolation each of these factors seem no different to the supply chain challenges faced by manufacturers. The challenge that makes R-SCM unique is the way that these factors combine in a single supply chain, resulting in a problem that is more complex than the sum of its parts. Retailers have to find solutions that are scalable across these challenges to provide answers that are optimal for their specific set of circumstances.

From the practitioner perspective, this provides an established foundation for retail industry optimisation [5], yet research has been slow to respond to the unique challenges faced by the retail supply chain [6]. Angerer [7] and Trautrims [8] have commented on the lack of academic research dedicated to the topic of retail store replenishment in the past. Since then several authors have contributed to the area of R-SCM in a wide range of focus areas. Randall et al. [6] however made the following comments regarding the shortage of R-SCM articles in the major SCM publications:

> *"R-SCM research has been more an opportunistic extension of manufacturing theory, along with consumer product marketing and distribution theory, rather than a holistic, ground up construction of a critical research domain. "*

This paper aims to assess the nature and focus of R-SCM research conducted in the past 10 years. The objective is to determine the extent to which SCM research has evolved to address the unique R-SCM challenges as well as to identify the key themes emerging during this time. The aim is to find research with a clear retail focus instead of treating R-SCM as a mere extension of SCM in general. The review also assesses whether the comments made by Randall et al. are still valid, and to what extend it has evolved in the subsequent years.

The approach used is a systematic literary review, which is detailed in Section 2. Section 3 provides a breakdown of the identified literature, while Section 4 presents the descriptive and thematic results of the literary review. Conclusions and findings are presented in Section 5.

2 APPROACH AND METHODOLOGY

The research approach and methodology are presented in this section. A research literary review is a systematic and reproducible design for identifying and evaluating an existing body of scholarly works [9]. In order to ensure a scientifically robust and transparent result, the literary review approach described by Denyer & Tranfield (2009) was adopted for this review. The approach defines the following steps as part of the systematic literary review:

Step 1: Question formulation;

Step 2: Locating studies;

Step 3: Study selection and evaluation;

Step 4: Analysis and synthesis; and

Step 5: Reporting and using results.

2.1 Question formulation

The research questions were formulated to provide guidance in the search for relevant articles. "Retail" and "Supply Chain" are both very broad topics, which increases the risk of finding scattered themes with little coherence. The aim was to identify the specific themes that emerge where these two broad topics intersect in a way that puts emphasis on retail as a specific research domain and not just an extension of general SCM theory.

The specific research questions for this review were defined as:

- Q1. What are the main themes addressed in academic research over the last 10 years in the area of R-SCM?
- Q2. Are the R-SCM themes uniquely retail or rather an extension of general SCM themes?
- Q3. Which academic journals contributed the most R-SCM related articles in over this period?

2.2 Locating studies

Systematic reviews aim to locate, select and appraise as much as possible of the research relevant to particular review questions [10]. An extensive search was conducted to identify the prominent authors in the area of R-SCM. This approach was followed to increase the probability of finding articles with a specific retail focus. General SCM articles are often tagged as "Retail" due to the touch points with the retail supply chain. This means that pure R-SCM based articles are hidden amongst thousands of general SCM based articles in normal searches. Starting with the list of R-SCM authors ensured that the final list of articles had a higher probability of containing pure R-SCM articles.

The review started with and extensive review of several databases, including Scopus, Science Direct, Google Scholar, and Worldcat.org. Reference lists of key articles were reviewed to identify additional R-SCM authors. Once the list of authors was identified, Scopus was used to identify all the work that they have published. This resulted in a list of 2572 references. Although this list does not represent an exhaustive collection of all publications in the area of R-SCM, it does represent a comprehensive sample of all the published work of recognised and active authors in the area of R-SCM.

2.3 Study selection

Study selection requires a transparent set of explicit selection criteria to assess the relevancy of each study [10]. Since one of the research objectives was to identify the major themes in R-SCM, a decision was made to only use the search terms "Retail" and "Supply Chain" to limit the articles further. The review adopted the unionist perspective provided by Larson and Halldórsson (2004) whereby logistics is a subset of SCM [11]. "Logistics" was therefore not used as a search term in the limitation of articles. This allowed all sub-themes within SCM equal opportunity without elevating logistics as a theme from the outset. Finally the list was also limited to articles published in journals over a 10-year period from 2008 to 2017. The review was conducted in 2018 and therefore 2017 was used as the end date of the 10-year horizon. Duplicates, where the same study was published as similar articles in more than one journal, were also removed. This resulted in a main list of 97 articles that were then subjected to a rigorous review to identify the key themes.

2.4 Analysis and synthesis

Analysis and synthesis consists of breaking down individual studies into their constituent parts and describing how each relates to the other [10]. The first step in this process was to populate a data extraction form to serve as the basis for further analysis and synthesis. Figure 1 provides the spread of the articles across the 10 years used for the review. The spread is fairly even with only 2012 and 2017 producing noticeably fewer articles. The most productive year was 2009 with 15 published R-SCM articles. The major conclusion here is that there was no significant increase in R-SCM based articles since Randall et al. [6] commented on the lack of such research. From a purely quantitative perspective this is surprising considering the increased prominence of retail in the end-to-end supply chain.

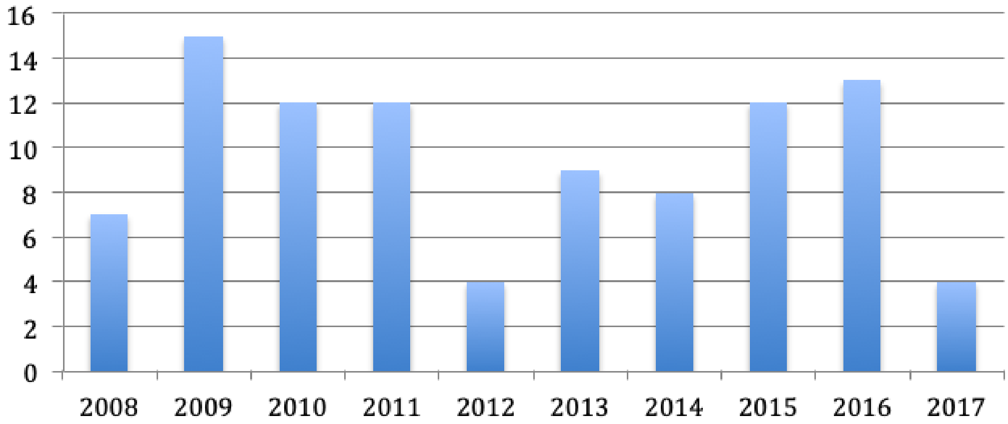

Figure 1: Number of articles per year

The articles were also analysed in terms of the way they relate to the overall supply chain. For this purpose the Retail Value Chain (RVC) process model was used (Figure 2). This model was adapted from The UCS Solutions Retail Academy course material [12] and is used by several management consulting firms to assess and review the maturity of retail processes at different retail customers. All core retail processes are covered here and are categorised in four major categories: Plan; Buy; Move; Sell.

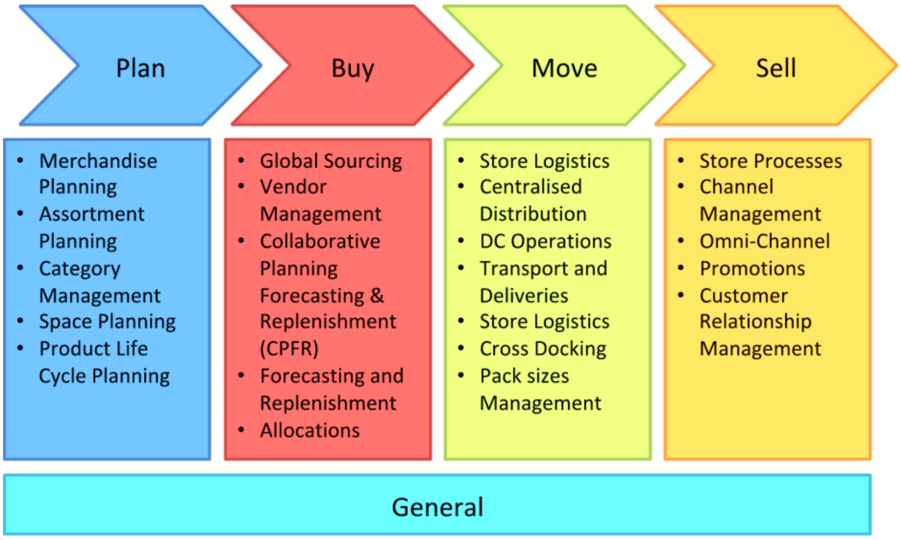

Figure. 2: The Retail Value Chain [12]

A fifth category was added to cater for articles that are focused on more general topics. Examples of these include articles focusing on research methodologies best suited for logistics research such as Aastrup & Halldórsson [13], as well as articles which span the entire retail value chain such as Edwards et al.[14], Nguyen et al.[15] and Bouchard & Fransoo [16].

Each of the articles in the review was classified according to these five value chain categories. The purpose of this was to assist with the synthesis of the articles to identify the key themes. This process of initial classification proved to be very useful by highlighting the core retail processes and thereby providing a valuable anchor point for finding retail specific themes across the list of articles. This was then further analysed to identify the most prominent themes in each of the RVC categories as described in section 4.

3 IDENTIFIED LITERATURE

Table 1 provides a breakdown of the most prominent journals covered in this review. The top three journals, which represent 28 of the articles reviewed, are: *International Journal of Physical Distribution & Logistics Management*; *Production and Operations Management*; and *International Journal of Retail & Distribution Management*.

Retail oriented journals such as *International Journal of Physical Distribution & Logistics Management (7); International Review of Retail, Distribution and Consumer Research (4) and The Journal of Retailing (1)* yielded only a total of 13 articles. This points to the conclusion that R-SCM research is published mainly as a category within general SCM research instead of general Retail research. There is a need for more differentiation to account for the unique nuances of the retail specific supply chain articles instead of categorising all SCM articles with any touch point to Retail as R-SCM.

Table 1: Number of articles per publication

Journal	Articles
International Journal of Physical Distribution & Logistics Management	14
International Journal of Retail & Distribution Management	7
Production and Operations Management	7
European Journal of Operational Research	5

International Journal of Production Economics	5
International Journal of Logistics Management	4
International Review of Retail, Distribution and Consumer Research	4
Management Science	4
Supply Chain Management	4
Benchmarking: An International Journal	3
Journal of Business Logistics	3
Manufacturing and Service Operations Management	3
Computers and Operations Research	2
European Journal of Marketing	2
Journal of Operations Management	2
Journal of the Operational Research Society	2
Operations Management Research	2
Other	24
Total	97

The majority of the articles originated from the United States (US) (42), followed by United Kingdom (UK) (30), Germany (22) and Netherlands (13). The review of prominent R-SCM authors in the last two decades points to an increase in US based R-SCM research in the last 10 years. Between 1998 and 2007 the UK was the predominate country for R-SCM research with 38 per cent of the full sample list of articles originating from there, followed by the US at 18 per cent. During the period from 2008 to 2017 this has switched around with 43 per cent US based articles and 31 per cent UK based articles.

4 MAIN THEMES IN THE LITERATURE

The first step in identifying the major themes covered in the article list was to categorise the articles based on the RVC to identify the primary focus of R-SCM authors. This was a subjective process based on the experience of the author. Although other researchers might categorise the articles slightly differently, this process was found to be useful in providing clusters of articles based on their position in the overall supply chain.

Plan

The “Plan” category, which represents 10 per cent of the articles reviewed, includes all processes associated with designing and planning the retailer’s market positioning and the offering to its customers. Processes included are Master Category Planning, Merchandise Planning, Assortment Planning, and Space Planning. These planning activities ultimately drive not only the profitability of the retailer [17], but also impact the overall inventory levels and store operations [18]. It provides the foundation for all the planning and operational activities in the end-to-end retail supply chain.

Buy

The “Buy” category recorded the largest percentage of articles in this review at 37 per cent. This category focuses on the activities and processes to source, procure and replenish products in the most profitable way. Global sourcing has been successful in driving down procurement costs [19], but has also resulted in increased emphasis on environmental implications [20] as well as ethical implications of workforce conditions [21].

Supplier management and collaboration are also included in the "Buy" category. Supplier collaboration is often seen as a powerful instrument in achieving an effective and efficient supply chain [22]. Forecasting and replenishment related articles made up over a third of the articles in this category. Promotional forecasting in particular is getting increased attention in the literature.

Move

The "Move" category caters for all the logistics processes within the retail supply chain. This includes DC activities, freight and transportation, materials handling and even merchandising activities in the store to replenish the shelves. In the last three decades retailers have taken control of the secondary supply chain by channelling more products through their own network of DCs [1]. This has resulted in an increase in the portion of logistical costs under the control of the retailer [23]. With an increase in online shopping and home deliveries, retailers also find themselves responsible for logistics activities all the way to the customer's doorstep [24]. A total of 26 per cent of the articles in the review focussed on this category and together with the "Plan" category account for almost two thirds of the articles reviewed.

Sell

The "Sell" category relates to activities associated with interaction with the end customer. This includes processes associated with store operations, omni-channel retail, promotion management and customer relationship management (CRM). The battle to gain new customers and keep existing customers is a constant focus for retailers. While many retailers seek out new geographies to drive growth [25], [26], the biggest expansion has been the growth in omni-channel retail to reach new customers and keep existing ones [27], [28]. Retailers are not just attempting to grow revenue with their omni-channel strategy, they are also attempting to provide a seamless shopping experience across the different channels [29].

General

The "General" category was used to categorise articles that do not fit into the four main RVC categories. This includes articles which e.g. have a relation to research methodologies in logistics such as Aastrup & Halldórsson [13] and Trautrims et al. [30], as well as articles which span the entire value chain. These articles include topics such as environmental considerations in the RVC ("Green SCM") [14], [31] as well the regulatory implications of operating in certain countries [15], [32]. A total of 10 per cent of articles were categorised in this group.

After this initial classification the articles were reviewed in detail to identify the main themes. The value chain categories were cross-referenced to identify prominent themes that received the most attention across all 97 articles. Each article was then tagged according to the major themes covered in the article. Articles could be tagged with several different themes, resulting in clusters of themes across the different RVC categories as can be seen in table 2.

Table 2: Prominent themes with the retail value chain

Category	Themes	Key Articles
Plan	• Assortment Planning • Category Management • Space Planning	• [17], [18], [33]-[40] • [34], [35], [40] • [17], [33], [37]
Buy	• Global sourcing • Forecasting • Replenishment • Out of stock causes and effect • Supplier collaboration	• [19], [21], [41] • [2], [42]-[49] • [2], [48]-[54] • [33], [55]-[58] • [22], [34], [59]-[63]
Move	• Pack size • In-Store Logistics • DC Operations	• [40], [64]-[67] • [37], [39], [65], [67]-[73]

	• Transportation • Vendor managed inventory	• [29], [66], [67], [74] • [75]-[77] • [78]
Sell	• Store Processes • Omni-channel • • Promotion management • CRM • International expansion	• [56], [68], [72] • [14], [24], [28], [29], [58], [74], [81], [82] • [42], [45], [58], [62], [83] • [60] • [19], [25], [26], [79], [80]
General	• Research methods • Regulations • Green SCM	• [13], [30], [84], [85] • [15], [32] • [14], [16], [20], [31], [86], [87]

Once these themes were identified, the most prominent ones in each of the RVC categories were identified based on this classification process, resulting in the following five themes:

- Plan: Assortment planning (10 articles)
- Buy: Forecasting (10 articles)
- Move: In-Store logistics (10 articles)
- Sell: Omni-channel retail (9 articles)
- General: Green SCM (7 articles)

These themes are discussed in more detail in the sections below.

4.1 Plan: Assortment Planning

A retailer's assortment is defined by the selection of products listed in each store. The aim of assortment planning is to maximise sales and gross margin within specific constraints, such as a limited budget allocation, store layout and size, limited display space and a variety of other considerations such as having multiple suppliers within each category [37]. The assortment decisions have a material impact on the revenue and gross margin, and hence assortment planning has received high priority from retailers, consultants and software providers [18]. It is a relatively new field of academic study that is growing rapidly [38].

The retail environment has become increasingly complex with a significant increase in the number of articles in overall store assortments over the last two decades [35]. Improvements in the capabilities of software packages such as JDA and SAS have resulted in an increasing number of companies investing in software to provide state of the art solutions in the areas of assortment- and space planning. Hübner & Kuhn [35] defined the planning questions in these areas as follows:

- Assortment planning: Listing decisions based on consumer choice behaviour and substitution effects.
- Shelf space planning: Facing and replenishment decisions based on space elasticity effects, limited shelf space and operational restocking constraints."

Both of these processes aim to provide the optimal mix of product on the shelf based not only on the price and cost parameters of the products but also the customers preferences and substitution behaviour during periods of stock-out [18]. During periods of stock-out retailers face the high cost possibilities of "leaving", "store switching" and "no purchase". Efficient assortment planning increases the likelihood of the lower cost option of "substitution", which is much more desirable for the retailer [33].

4.2 Buy: Forecasting

Demand planning is increasingly recognised as a fundamental part of supply chain operations and ultimately company profitability [43]. The accuracy of the demand plan has a direct impact on the replenishment process, which generates the orders for stores and DCs. Inaccurate forecasts, which is often most prevalent during promotions, can lead to overstocks and out-of-stock[42]. These promotional periods often lead to demand shocks which have unique behavioural implications for the decision making processes of inventory managers. Studies have shown that uncertainty regarding the timing or the magnitude of demand shocks result in a bias towards excess stock. The anticipated demand shocks causes the inventory managers to order too much stock too soon, which leads to overstocks.[47].

Forecasting the impact of the promotions remains one of the most difficult parts of the retail forecasting and replenishment process. Ali et al. [42] found that, while normal time series techniques are very difficult to beat during non-promotional periods, regression trees with explicit variables derived from the sales and promotion time series resulted in up to 65 per cent increase in forecast accuracy. This increase in forecast accuracy however comes at a cost. The data preparation and analysis required to determine and classify the variables in the forecasting process require substantial effort and cost. Although the benefits can therefore be substantial, it could also be outweighed by the cost [42]. Osadchiy et al. [44] developed a model to use financial market indicators to improve the quality of the forecast for the retailers. Although they managed to achieve a 15 per cent improvement in Root-Mean-Square-Error (RMSE) with their model, it failed to address the most challenging aspect of forecasting, namely the promotional forecast. The application of this approach would therefore be quite limited from a retail perspective at a product/store level.

4.3 Move: In-Store Logistics

The store itself remains a focus point for B&M retailers. Around 45 per cent of operational logistics cost in the retail supply chain occur in the store [70], while 75 per cent of the retail handling time also occur in the store [65]. Between 70-90 per cent of out of stock situations originate from causes at store level [88], [89]. Ten of the articles in the literary review focussed specifically on costs and efficiencies related to the retail stores. The topics that are covered include the role of the backroom in store operations [65], [72]; material handling and logistics processes in the store [70], [71]; the impact of pack sizes on in-store logistics and stock levels [67] and the impact of unsellable products on the in-store logistics processes [69].

Store management is tasked with monitoring the stock on the shelf and replenishing from the backroom. This increases operational complexity and the risk of out-of-stock [90]. Storing inventory in the backroom substantially changes the nature of the optimization problem faced by retailers, something Eroglu et al. [72] refers to as the Backroom Effect (BRE). The amount of inventory in the backroom is usually a function of the space allocation of the product on the shelf, the case pack quantity, the order frequency and the rounding rules. These variables should ideally be optimized jointly to produce an inventory policy which yields a global optimal. The reality however is that these variables are often derived separately and in a piecewise fashion by independent parties [72]. Out-of-stock on the shelf can occur when the shelf is empty but stock is available in the backroom. This happens because the replenishment of shelves from storage tends to be less reliable than replenishing shelves direct from delivery [67]. A contributing factor here is also that most replenishment systems treat the stock in the store as an aggregate stock figure and therefore no automatic trigger is activated to replenish stock from the backroom. This activity is left up to store personnel to identify and action, which could lead to empty shelves while the product is available in the store room [90].

4.4 Sell: Omni-channel Retail

There is an increased focus on omni-channel retail as B&M are expanding into online to increase their turnover [24]. Nine of the research articles identified focussed on omni-channel and the impact it has on the retail supply chain. A major theme that is addressed across these articles is the impact it has on logistics, especially “last mile” fulfilment. Retailers view omni-channel as way to increase market share and fend off new competitors, but success requires more than an appealing website and compelling prices for sought after products [29] .

Significant focus has been given to the transition from B&M retail to omni-channel from a logistics perspective. Retailers often expand their business from a single channel to a configuration of multiple channels [27]. In their research Hübner et al. [28] developed a framework for the transition from decoupled multi-channel retailing to truly integrated omni-channel retail. Table 3 provides a breakdown of the categories of this framework:

Table 3: Transition from multi-channel to omni-channel (Adapted from Hübner, Wollenburg, *et al*.,[28])

Category	**Multi-Channel**	**Omni-Channel**
Inventory	Channel separate inventory	Integrated inventory
Picking	Pick separate by channel	Cross channel picking using advance phase methods
Assortment	Limited online assortment	More extensive online assortment than offline
Delivery	Limited to postal delivery for distance orders	More delivery options including pick-up services
Return	Online Orders can only be returned via postal service	Online returns can occur across any available channel
Organisation	Channel responsibilities are separated	Integrated logistics units with cross channel responsibilities
IT Systems	Separated, channel specific IT systems	Integrated, cross channel ERP system with real time access

This framework highlights the fact that the transition to omni-channel is multi-faceted and includes far reaching organisational and system implications. This study from Hübner et al. [28] is also one of the very few studies in the literature review that touched on the organisational transformation implications of the retail evolution. In the survey conducted they found that, although 39 per cent of retailers surveyed still separated their logistical divisions by channel, 81 per cent of them believed that logistics would be managed and handled by an integrated organisational unit [28].

4.5 General: Green SCM

Corporate responsibility and environmental sustainability have become major themes for retailers and consumers alike as the media draws attention to labour conditions and the “clothing or food miles” of products sourced from increasingly distant countries. Consumers demand transparency from the companies where they spend their money [86]. The challenge is that consumers want to buy products that do not harm the environment, but at the same time expect cheaper prices which requires an increase in global sourcing [20].

Environmental consideration is not limited to category management or customer relationship management but also impacts the way supply chains are managed [20]. The retailers control an increased share of the supply chain carbon footprint, starting at the factory gate and extending all the way to the product delivery at the customer’s home. In the traditional shopping model the customers do a lot of the work (such as picking and transporting the products home), whereas in e-fulfilment, retailers must deliver personalised orders in narrow time windows across highly disperse locations [14]. Environmental awareness in retail requires a broad based approach across many different topics.

Kotzab et al. [20] developed an environmental maturity framework for a survey they conducted across 100 of the world's largest retailers. The main finding from this research was that 89 per cent of the companies surveyed had an average- or below average environmental ranking based on the framework [20]. It also highlights that environmental sustainability does not stand in opposition to the traditional supply chain focus of cost and service, but should rather complement it. An aligned sustainable SCM strategy should put an equal amount of weight on profit, service and the environmental considerations of customers [91].

5 CONCLUSIONS AND FINDINGS

This review set out to answer three research questions. Q1 was to identify the major themes in R-SCM research over the last 10 years. Five themes emerged, namely assortment planning, omni-channel, in-store logistics, forecasting, and Green SCM. Although contemporary topics such as omni-channel retail and Green SCM are gaining increased attention, the traditional topics of in-store logistics and forecasting are still a strong focus in R-SCM research over the review period. B&M retailers are still heavily invested in their store footprint and although there is a shift towards online channels, the need to reduce costs and improve efficiencies in stores still exists.

Q2 focussed on the positioning of R-SCM research and to determine if the highlighted themes are uniquely retail or rather an extension of general SCM themes. The themes that emerged from this review had a strong R-SCM focus. Although topics such as Green SCM and forecasting are extensions of general SCM research, the majority of the themes had a retail specific focus. This was however achieved through the review methodology that targeted active R-SCM authors and their references. Without this approach, search terms such as "retail" and "supply chain" yielded thousands of articles of which only a small percentage treats R-SCM as a differentiated field within SCM. This highlights the challenges faced by R-SCM researchers in finding retail specific articles amongst an overwhelming volume of general SCM articles in academic journals.

Q3 focussed on the journals that published the most R-SCM related research. The vast majority of the articles came from general SCM focussed publications with less than 15 per cent of the articles which came from journals where "retail" form part of the publication title. The *International Journal of Physical Distribution & Logistics Management* yielded the largest number of articles in this review with 14 articles, while *Production and Operations Management* and *International Journal of Retail & Distribution Management* yielding 7 articles each.

None of the articles in the review addressed the organisational impact of multi-echelon replenishment in retail. As the retailers restructure their centralised planning departments to handle the increased supply chain complexity combined with more sophisticated planning tools, new roles and functions emerge. Further research is required to study this evolution within the context of the changing landscape of R-SCM.

In conclusion, this review highlights that R-SCM specific research is still on the fringes of general SCM research. Only through an in-depth search of the most active R-SCM authors was it possible to find a higher proportion of articles that treat retail as a specific field within SCM and not just an extension of general SCM research. It can therefore not be described as an exhaustive representation of all R-SCM available research. More themes may emerge by using a wider set of search criteria. Such an approach would however also yield many more generic SCM related topics, which was not the aim of this review.

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FEAR, THE GREAT ENEMY

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ABSTRACT

The delivery of health services is a legal, but also a moral, duty of government. To improve health delivery, many industrial engineering interventions have been undertaken, both globally and in South Africa. This paper presents one of our recurring discoveries in lean implementations, in process improvements and in service delivery interventions. Fear is pervasive and systemic in health systems. It is used as a management strategy and as a result we have found that the pursuit of improvement is significantly and repeatedly compromised by unnecessarily vicious management approaches which lead to lower employee autonomy, reduced initiative and sense of ownership by the agents operating in the health system.

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1 INTRODUCTION

The sobering reality is that the South African Public Health system has been near total collapse for a long time. Inspections conducted by the Office of Health Standards (OHS) in 2016/17, showed that only five out of 696 public health facilities met the 80% 'pass mark' set by the Department of Health, which is concerning [1]. Between January 2012 and December 2013, the Medical Research Council, reported that the human cost of negligence in the infant population was more than 80 000 lives [2]. In 2017, the financial cost from medical negligence claims ran in billions – R18.6 billion in Gauteng province, R16.7 billion in Eastern Cape province and R9.2 billion in KwaZulu-Natal province [3].

It is easy to perceive that negligence takes place at the point of contact - where health providers and patients interact. This is the most common place for allocating responsibility, and the focus of many internal reviews —problems are perceived to be as a result of the lack of skills and incompetency of health providers. The political and media climate in South Africa, has responded by escalating the punishment for error, demanding that individuals be held responsible [4]. The motivation behind this is understandable, as ensuring the public safety of the population in crisis situations is bound to create anxiety and public uproar. Health providers are at the 'sharp end' of the transaction – they operate in a culture that underlies anger, blame, guilt, fear, frustration and distrust regarding errors [5].

2 INSIGHTS FROM THE LITERATURE

2.1 Mechanisms behind blame culture

To create an openness and promote trust in health organisations, it is important to understand the mechanism behind blame culture. Many definitions have been provided to describe blame culture, one of the definitions of blame culture is 'a tendency within an organization not to be open about mistakes, suggestions and ideas, because of a fear of being individually held accountable for them' [6]. When an incident occurs, the fear of being incriminated leads to the negative outcome of searching for additional culprits to blame, reinforcing a cycle of blame [7].

An individual who is blamed for an incident, will work to ensure that his/her self-image is protected by blaming someone else to avoid being held solely responsible. The culture of blame rapidly spreads as the goal of protecting the self-image, starts to be adopted by all members within the organisation[8]. Blame culture can be present in health organisations without health providers openly blaming each other as the fear of being blamed is equally effective in instituting this culture. In healthcare, the onset of blame culture starts early in the medical education stage, that focuses on increasing performance instead of improving patient safety and facilitating organizational learning. The is no room for making mistakes in healthcare, health providers are expected to exhibit a degree of perfection in their work that is humanly impossible. This leads to a fear of taking responsibility for errors and in turn promoting blame culture [9].

There are several negative consequences of blame culture in health organizations, the most critical being that when an incident occurs, the focus is on an individual instead of the system that is unsafe and broken. The attention is drawn away from the cause of the incident rather time and resources are allocated towards disciplinary actions and additional mandatory training. To protect themselves, health providers shift their attention from concerns of patient safety to unfortunately necessary actions like paperwork and establishing alliances to "cover themselves". This serves no effect other than to overwhelm and demoralize them, decreasing their health and well-being [6] [7].

There is a need to acknowledge the social context of blame culture, and how it causes mental harm to health providers to whom care for patients is entrusted. Blame culture creates a mistrust between the two entities, Leape et al, defines this as a volatile relationship whereby "...patients and physicians . . . live and interact in a culture characterized by anger, blame, guilt, fear, frustration, and distrust regarding health care errors" [10]. The experience of blame can lead to compassion fatigue, which makes health providers more susceptible to a diminished sense of personal safety and disrupted schemas around trust, vulnerability, meaning and control [11].

2.2 Bearing the brunt of blame

The emotional context of blame needs to be acknowledged rather than ignored as, it is a major factor that contributes to the high levels of stress that health providers experience daily [13].A failure to acknowledge the emotional context of health care and high stress levels is likely to make any attempts towards achieving lasting cultural change impossible. Health providers who are demoralised and under immense pressure will often be resistant to actively participate in actives that could lead to change [14].

The relationship between stress and error is significant as findings have consistently shown that health professionals in particularly doctors in South Africa, are under considerable stress. A study published in the South African Journal of Psychiatry showed that out of 67 doctors who participated in the study, 51% were found to be stressed and 27% morbidly stressed [15].High stress levels make health providers more perceptible to making errors and is likely to make any endeavours towards attaining cultural change impossible. In summary, these findings propose that one of the most effective ways to improve patient safety is by lowering the stress levels of health providers.

Oliver and Regrut, have shown that patient satisfaction is strongly correlated with cheerfulness, friendliness, and sensitivity of health providers. For health organisations and providers to improve and effect patient safety, there is a need of a supportive organisational culture, whereby management commitment is assured, this will benefit both quality and staff wellbeing [16].

Placing blame of errors on individuals enables unprofessional conduct (disrespect, suppression intimidation, stonewalling, bullying) and creates the smallest possible sense of ownership for the rest of the organisation. As such health providers are afraid of reporting any incidents in the event that they expose failings in their professional and individual ability, providing a basis for punishment. Bearing in mind that 'medical mistakes' are a high-profile and sensitive subject masked in secrecy some health organisations and providers have opted suppression, stonewalling, and cover-up to try and protect themselves [12].

3 PURPOSE

This paper explores the nature of blame on health providers and the quality of treatment for patients in South Africa. It raises the question: Why do medical incidents go unreported? Can we manage this? And finally, will this help create a culture free of blame and fear of retribution?

To understand this, we analyse several mixed method observations and surveys from reports that describe the perceptions of health providers when it comes to medical errors, evaluate the barriers to medical reporting and disclosure and the changes that must occur to enable a shift from blame culture.

4 METHOD

This paper represents a summary of survey results from South African reports and observations, conducted in both public and private health sector spanning over the course of years across all the nine provinces, in South Africa. Surveys were analysed according to, the contributory factors that led to incidents getting unreported and how to manage and achieve change that will help promote a just culture in healthcare. A thematic analysis was performed to identify the attitudes and approaches associated with incident reporting and blame culture.

Many of the observations were diachronic, following the news and articles reporting on medical negligence, changes in patient safety policy and hierarchical structures in healthcare.

5 PROBLEM AWARENESS: UNDERSTANDING WHY INCIDENTS DON'T GET REPORTED

There is a substantial level of 'under-reporting' of errors in healthcare due to inhibiting factors namely [17] [18] [19] [20]:

5.1 Threat of victimization

Health providers are reluctant to be open and honest regarding their involvement and experiences of errors due to the innate belief that they will be held individually responsible and punished. There are common stories of healthcare professionals being suspended and used as a scapegoat following an error. This perpetuates a feeling of unease preventing the reporting of incidents due to the fear of blame [20].

There are assumptions that openness and transparency, in the form of incident reporting, enables the allocation of individual responsibility therefore justify not reporting. A study conducted by the School of Clinical Medicine (SOCM) at the University of Witwatersrand found that 59% of health providers perceived the threat of victimization as an important barrier to disclosure of errors (there is no guidance on the safest and correct processes for disclosure) [18].

5.2 Purpose of reporting – Normalisation of errors

Accepting that errors are inevitable is vital to understand medical attitudes towards incident reporting. The notion that errors are going to happen, regardless of ability, may help explain the current approach of mitigating errors after they have happened. Since errors are considered to be inevitable this leads to more than their acceptance, it also gives rise to the 'normalisation' of errors as a part of daily operations. In the context of medical work mistakes are viewed as routine and normal as a result they are not deemed to be problematic or worth reporting [19].

5.3 Inhibit career development

Lawton and Parker's study of incident reporting established that reporting is inhibited within the professional hierarchies of healthcare. Health providers feel disinclined to report their experiences of error, rule violation or poor performance to their senior colleagues because of the presumption that it could impede career development [21].

There is a general sense of awareness that increased openness about individual competence could prompt an inquiry of professional practice resulting in: poor references, warnings from a senior colleague or could smear the reputation of the health provider. The internal blame reinforces and develops the problem of professional hierarchies with those at the bottom being most vulnerable.

5.4 Closed culture

The medical profession constitutes a 'closed culture' that inhibits openness, it is not just the fear of blame but also the desire to protect the symbolic façade of professional competence, as well as the status. Any issues of competence or wrongdoing are expected to be dealt with 'in-house' maintaining the exclusiveness of medical knowledge and preventing exposure [22].

Carmichael found that medical errors were mostly handled internally in Departments and this was agreed by 86% participants while only 2% disagreed while 12% remained neutral [18]. The task of having to report incidents, is viewed as un-medical, managerial and futile in handling the inevitability of medical errors. As a result, medical reporting is discouraged as it is perceived as a further extension of managerialism and an erosion of professional status [19].

5.5 Disruptive Alliances

Alliances can be both productive and disruptive, members within certain alliances are given leeway and forgiven for making mistakes - to avoid any blame and criticism. Certain members of staff, receive preferential treatment and their mistakes and behaviours overlooked, reinterpreted or forgiven, as long as they are a part of the alliance; or be scapegoated if they are outside it [23].

Disloyalty to the alliance is considered to be serious violation and offence, whistle blowers are cast out, reflecting a culture that forbids the telling of tales. This makes, any real change within the organisation difficult to achieve [20].

A study conducted at the University of Western Cape found that, 44.9% incidents go unreported because participants felt the need to cover up the mistakes of their peers (20.3%- were neutral and 10.1% dispute the concept all together) [17].

5.6 Guilt

There can be feelings of shame and guilt in making an error and damaging the doctor-patient bond. Fears of punishment due to litigation or victimization may encourage non-disclosure [18].Disclosures of error could be considered as an admission of guilt and can be used in a court of law to prosecute for negligence.

This makes the issue more complex, open discussion of errors is discouraged within healthcare organisations enhancing the feeling of guilt [5]. Matiso, found a major contributor to incidents not being reported came down to guilt, with 65.2% of the participants either agreeing or strongly agreeing [17].

5.7 Lack of Systems for reporting errors

There are currently no formal systems that allow for the reporting of both near-misses and actual adverse patient safety events. Lack of adequate systems were identified as a barrier to disclosure, with 66% of SOCM clinicians stating that they felt that the reporting systems in their workplace were not easy to use. A large majority of junior doctors either did not know what the systems were or did not think they were easy to use. There was agreement by 87%, that the system of notifying errors to a higher level (Regional level) are not well defined, with 7% disagreeing and 6% neutral on the issue [18].

5.8 Bureaucracy and lack of feedback

There is a tumultuous relationship between front-line staff and management - with strong revulsion being expressed for ‘bureaucracy’, ‘red tape’, ‘admin’ and ‘management’. This has a significant impact on the number of incident reports submitted to management, which would in turn help improve patient safety.

Health providers believe this is a futile task, since feedback is hardly provided, they would rather spend their time administering patient care. The constant rise in the number of bureaucratic hospital procedures are a point of concern and staff fear, this would reduce their capacity for ‘actual’ medical work [19] [24].

6 PROBLEM SOLVING: MANAGEMENT OF ERRORS

Management of errors calls for acceptance of errors towards attaining an understanding of the relationship between individual human behaviour and the factors that attribute to this behaviour. Error management requires that organisations seek out opportunities for change by identifying the underlying causes that result in errors and learning from them [25].

This has given rise to the patient safety movement, which is guided by a ‘learning culture’ that entails vigorously seeking out past experiences of error in an effort to make sure they do not occur again. This can be achieved by having open discussions, focusing on pro-active identification and adopting a systems approach. Through this philosophy, a 'blame free' environment is created that encourages the reporting of errors and harmful incidents [20].

Health providers need to actively engage in not only the identification of errors but also the organizational response. Frontline staff must take ownership of patient safety concerns and the improvement process by being active in the process of root-cause analysis, contributing to solutions that may assist in eliminating errors and conducting follow-ups. These tasks must be given priority status. However, taking ownership does not mean bearing the burden alone, the best approach towards spearheading change is to do it as a team - the most effective solutions to system failures are born of teamwork [5].

Further, collaboration among staff across all levels and disciplines must be facilitated, for lasting change to take place and stick. Organizational learning is heightened when leaders listen to their staff regardless of rank within the organisation, creating a 'just' culture [5].

Dr Lucien emphasizes that, "We need to quit blaming and punishing people when they make mistakes and recognize that errors are symptoms of a system that's not working right, go figure that out and change the system so no one will make this error again, hopefully. We have to change the culture, so everyone feels safety is his or her responsibility, and identifies hazards before someone gets hurt" [26].

The systems approach does not seek to substitute responsibility or professional judgment rather it enhances it by providing a model of shared responsibility between managers and practitioners "to create systems that enable trained, motivated and conscientious physicians and nurses to do safely what they already want to do, provide good medical care" [27].

For a systems approach to be successful, it has to be underpinned by a 'supportive reporting culture' where health providers are protected and encouraged to routinely document and communicate their experiences - which improves staff well-being and quality of care [5].None of this is possible without good leadership, we must hold the governing bodies and the people in charge accountable to ensure that the appropriate resources to allow for change are provided [20].

7 CONCLUSION

Changes in the healthcare systems can take a long time to come into effect, to achieve the required transformation, a paradigm shift is crucial. Healthcare management has not evolved much over the previous decades and so we need to look towards finding an innovative way forward. Management approaches must be agile to keep up with the ever-changing environment. Wasteful elements need to be eliminated from patient care and it is fundamental that health providers are empowered to be stewards of patient safety, regardless of their job title [12] [20] [5].

In environments where there is blame and finger-pointing, the opportunity for shedding light on the real explanation for serious incidents is lost [28]. Health providers are so frightened of being wrong. Mistakes are stigmatized in healthcare systems the result of which is secrecy and lack of transparency. Our hope for the future is to adopt a new conception of human ecology, one in which there is no blame or shame. We need to avert the obstacles that prevent staff from reporting incidents. The only way we will do it is by seeing our health providers for the hope that they are. Our task is to protect them so that they lead us into a safer and more robust healthcare system for a brighter future.

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SELECTION OF A COMPUTERIZED MAINTENANCE MANAGEMENT SYSTEM FOR MECHANICAL AND INDUSTRIAL LAB EQUIPMENT OF UNIVERSITY OF SOUTH AFRICA

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ABSTRACT

The research on which this article is based, sought a suitable computerized maintenance management system (CMMS) for use in the Mechanical and Industrial Engineering laboratories and workshop at the University of South Africa. The university plans to implement such a computerized maintenance management system, to keep track of past repairs, schedule future maintenance, and maintain a ready list of vendors or sources of parts. Currently, the department does not have a maintenance strategy or equipment history. The price of a product is an important factor when selecting a CMMS program. The recommended software will not place to great a stress on the departmental budget, is user friendly and can be used by two to five users.

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1 INTRODUCTION

Nowadays, maintenance is a strategic factor to guarantee high productivity of industrial systems as well as universities, but the global economic crisis has brought companies to reduce maintenance expenses with critical consequences for long-term reliability [1]. Industrial maintenance has two essential objectives, which are a high availability of production equipment and low maintenance costs [2]. However, a strong factor militating against the achievement of these objectives is the nature and intensity of equipment failures in plants and laboratories [2]. The cost of operations and maintenance can make or break a business, especially with today's increasing demand on productivity, availability, quality, safety and environment, and the decreasing profit margins [3]. A couple of years ago, CMMS was applied for hospital instrument maintenance. Now, CMMS is used by factories and production companies as well [4].Today's computerized maintenance management system (CMMS) can manage all of our possible requirements within the area of maintenance management [5]. The widespread mechanization and automation has reduced the number of production personnel and increased the capital employed in the production equipment and civil structures [6]. In many industries the equipment required to produce goods and services is expensive to own, operate and maintain and faults even in a single piece of equipment can halt an entire production [7].The primary uses of CMMS appear to be as a storehouse for equipment information, as well as a planned maintenance and a work maintenance planning tool [8]. Computerized maintenance management systems (CMMS) are required in order to manage and control assets and help schedule equipment maintenance. A CMMS is much more than merely a way of scheduling preventive maintenance (PM). By using a CMMS, administrators can create equipment logs to record events associated with a piece of equipment; create work orders automatically according to a schedule (or do so manually, from service requests); record the authorized use of equipment; and track scheduled services or PM, training, maintenance history, employee time, the downtime of a device, parts inventories and purchase orders [9]. Equipment should be properly maintained, if it is to fulfil its intended purpose [10]. In a plant, the numbers of pieces of equipment and service events are so large, that keeping and organizing related information can only be done via a computerised system. Thus, a CMMS software tool capable of running on a stand-alone computer – can be very useful for managing a plant and laboratory equipment maintenance programme [11].

CMMS can keep track of past repairs, schedule future maintenance, and provide a ready list of vendors/sources of parts. It can be used to generate detailed work orders for maintenance personnel [12] – orders which contain specific safety precautions and list the specialized tools needed for individual jobs. This system, when installed on a computer network, can further be used to manage the maintenance of several remote facilities from a central location [12]. CMMS programs thus offer a wide range of features, and it is up to the manager to decide which features are compatible with a facility and will generate the most helpful information. Maintenance has a very important role in the life cycle of any item or device, serving to maximize its performance by ensuring that it operates regularly and efficiently, attempting to prevent breakdowns or failures, and minimizing losses incurred through breakdown or failure [13].

Equipment management started with preventive maintenance, before advancing to productive maintenance. Facilities management, which is a strategic function, makes a notable contribution to business growth and company success [14]. The maintenance function has become increasingly important, due to its role in maintaining and improving availability, product quality, safety requirements and plant cost-effectiveness levels [15].

Machines must be maintained to ensure adequate levels of safety and quality. There should, similarly, be a regular maintenance and testing program for labs and workshop equipment. A qualified person (e.g., an artisan, technician, engineer or other maintenance person) must monitor, test, calibrate and maintain the equipment regularly, in accordance with the manufacturer's specifications and recommendations. Equipment maintenance may be done by in-house staff, contract workers or a combination of both.

Maintenance is not an expense, but an investment in improved organization. The aim of maintenance is to maximize machine availability under operating conditions, to obtain the desired quantity and quality output. Maintenance should be performed in a cost-effective way, to set safety and environmental standards. The performance of maintenance management is dependent on the proper distribution of resources (spare parts and other maintenance materials, the workforce, the necessary tools and instruments), for achieving life cycle profit for the organization [16]. Effective Computerized Maintenance Management Software (CMMS) that schedules preventive maintenance work orders on the equipment is an integral component of any efficient maintenance department [5]. Far too often organizations will purchase CMMS or EAM software with the expectation that their maintenance business will instantly operate more efficiently. As with everything else in life, CMMS can only provide to you what you put into it [17]. The aim of this study is to select the suitable computerized maintenance management system which will assist mechanical and industrial practice effective preventative maintenance on laboratories and workshop equipment.

2 METHODOLOGY

For the purposes of this research study, qualitative method in the form of interview was used to gather the necessary information. This method of data collection was utilised in order to overcome issues of cost and time. Several key questions were put to the three lab technicians employed in the Mechanical and Industrial Engineering department as well as six academic staff who utilize the equipment for teaching and research purposes, to determine the need for a CMMS. The technicians and academic staff assessed the current mode of operation in their labs and workshop and were subsequently interviewed. The questions posed, and members of staff's responses, are presented in table 1. Next, the authors studied the manufacturers' product maintenance recommendations, and took note of problems in the department with respect to equipment and machine usage. After discovering maintenance challenges, the department is facing, authors visited seven universities to find out if they are managing their lab equipment using CMMS. It was found that none of those universities use maintenance management system. Decision was made to look for the software that will suit our need. After considering 125 top CMMS programs for 2019, for the purposes of this study Capterra – a web service that helps businesses find software solutions – was chosen as a tool for selecting the best option. To this end, the authors considered the following features when selecting the best CMMS deployment, asset tracking, calibration management, inventory control, key & lock management, mobile access, PM, purchasing, scheduling, service history tracking, technician management and work order management. Thereafter, the software was further evaluated based on features, industry, size, price and ratings. The final stage involved contacting the suppliers of the top four products for prices and full details of each product. Apart from not depleting the department's budget, the product had to be manufactured by a reputable company that has been in business for a while and have all feature mentioned above.

3 RESULTS AND DISCUSSION

Table 1: Key Questions to Determine the Need for CMMS.

Key questions posed to members of staff in Mechanical and Industrial Engineering department	Responses
Do you have an effective way to generate and track work orders? How do you verify whether the work was done efficiently and correctly?	Do not have such a tracking system

What is the notification function upon completion?	
Are you able to access historical information on the last time a system was serviced, by whom, and for what condition?	No
How are your spare-parts inventories managed and controlled? Do you have either excess inventories or are you consistently waiting for parts to arrive?	Do not have spare-parts inventory
Do you have an organized system for storing documents (electronically) related to operation and maintenance (O&M) procedures, equipment manuals and warranty information?	We do not have such a system
When service staff are in the field, what assurances do you have that they are compliant with all life, health and safety-related issues (e.g., lock and tag) and are using the right tools/equipment for the task?	None
How are your assets, i.e., equipment and systems, tracked for reporting and planning?	No maintenance plan, equipment is reported only when broken

The responses from the three lab technicians employed in the Mechanical and Industrial Engineering labs, as presented in table 1, illustrate that the department does not have an effective way of generating and tracking work orders, therefore it is difficult to verify whether work has indeed been done efficiently and correctly. The lab technicians do not have access to equipment history either. There is no spare-parts inventory or organized system for storing electronic documents (related to operations and maintenance procedures around equipment in the labs and workshop). When maintenance personnel are working on the machine, the lab technicians do not have the assurance that such maintenance complies with all life, health and safety-related specifications, or that those personnel are using the right tools for the job. There is no maintenance plan, and no equipment tracking, or reporting is done. Based on these responses, there is a need to select and implement a CMMS in this department's labs and workshop.

Table 2: List of Best computerized maintenance management systems CMMSs Software.

Products	Recommendations	Size
eMaint CMMS	184	2 to 5 users
FT Maintenance	100	2 to 5 users
Hippo CMMS	70	2 to 5 users
agilit	10	2 to 5 users
eSpace	0	2 to 5 users
ss-CMMS	0	2 to 5 users
Maxpanda work order	0	2 to 5 users
manwinwin	0	2 to 5 users
Fixd	0	2 to 5 users
corrigo	0	2 to 5 users
Fleet maintenance pro	0	2 to 5 users
Maintenance coordinator	0	2 to 5 users
EZmaintain	0	2 to 5 users
I'monit	0	2 to 5 users
MASTIS	0	2 to 5 users

When the 125 products were evaluated for the second time, based on the features, industry, size, price and rating, only 15 products met the criteria. The industry chosen for this study was education, because the software will be used to track university equipment. Based on the number of technical officers in the department, the product size needed to be such that it could be used by two to five users. Given budgetary constraints, the cheapest software had to be chosen, with the price of the product including software licences, maintenance and support, installation, customization, data migration and training. Of the 15 products shown in Table 2, only four met the criteria and thus made the short-list.

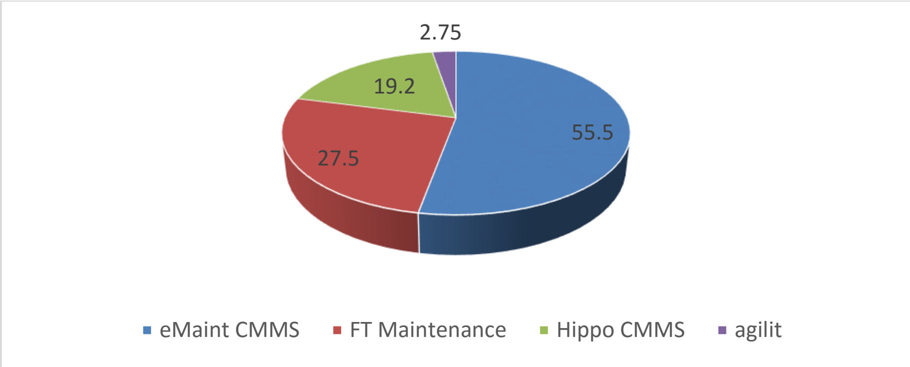

Figure 1: Recommended Software's

Figure 1 indicates that eMaint CMMS came highly recommended at 55.5%, followed by FT Maintenance with 27.5% and agilit with the lowest number of recommendations at 2.75%. Based on the highly recommended products percentages, eMaint CMMS was deemed the most appropriate maintenance software for use with educational equipment. Therefore, eMaint maintenance software is recommended for the Mechanical and Industrial Engineering labs and workshop of the University of South Africa.

Table 3: Software Review Based on the Product Establishment, Number of Customers, Deployment Mode, Location and Price.

Product	Est.	Customers	Deployment model	Free trial	Headquarters	Price (per month)
eMaint	1986	4,000+	Cloud, on premises	Yes	Bonita Springs, FL	$85 for 3 users min.
FT Maintenance	1989	20,000+	Cloud locally installed		Wisconsin, USA	$40 per user
Hippo CMMS	2001	55,000+	Web-based	Yes	Winnipeg, Canada	$ 125 for 3 users

The findings in table 3 shows that eMaint software is cheaper than the other products, despite its smaller customer base. eMaint software company was founded in 1986, which indicates that it has survived for more than 30 years in the game of selling CMMS – this implies that its software can be trusted. Hippo CMMS has a high number of customers but is more expensive than the other two products. Based on the price, deployment model and existence of the company, eMaint is thus deemed best suited for use in Unisa's Mechanical and Industrial Engineering labs and workshop. (Agilit software was not included in table 3, as the product did not come highly recommended).

4 CONCLUSION AND RECOMMENDATIONS

The selection of suitable, cost-effective software was achieved, as the proposed product will not break the bank and can be used by a minimum of three users at the same price. The selected software program will help the department access important information regarding the lab and workshop equipment, help in planning maintenance activities and make lecturers aware of the availability of machines, thus enabling them to schedule practical sessions timeously. Reports will be generated from the system to assist the department in reaching decisions relating to the lab and workshop equipment. By implementing this CMMS, the department will be able to keep track of virtually everything that happens in its labs and to its workshop equipment. Also, it will enable the department to move away from keeping paper records of service reports. The department will be able to determine how much time is spent on certain tasks, will have a record of maintenance activities and any materials purchased, and will be able to manage the lab technicians' time more effectively. Also, it will afford the latter an opportunity to create work orders for the equipment via the web when maintenance is needed and allow them to respond to these orders more efficiently. Extensive and targeted training is recommended, as it will be key to a smooth transition – it will prove to be well worth the expense. It is also recommended that trainees be given time to absorb the information and apply the skills/use the features they learn during one training session, before proceeding to the next. Also, the spacing between training sessions will be important, so as not to overburden trainees.

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EVALUATING THE IMPACT OF E-COMMERCE FREIGHT MOVEMENTS IN SOUTH AFRICAN CITIES

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ABSTRACT

E-commerce is rapidly increasing in supply chains with online shopping leading the way, increasing the number of freight movements. The impact of e-commerce on South African cities' freight movements are not well known and needs to be researched. It is necessary to consider how e-commerce impacted other countries and how they embraced the resulting change and growth in traffic volumes, in order to understand how South African supply chains can take advantage of opportunities arising from the growth in e-commerce in the country. To this end, this paper conducts a systematic literature review, which focuses on determining how other countries' urban areas were affected by increased e-commerce freight movements and how they managed it. The research is then considered on how it can be applied to urban South African supply chains. A conceptual solution for the way forward is also provided in order to provide guidance for better planning to accommodate future e-commerce growth.

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1 INTRODUCTION

The internet is changing the world, altering the ways in which people do business and function on a day to day basis (Rayport et al [1]). The internet has made it possible for a person to sit at home or work and order goods which get delivered straight to their door. Lately, the option of picking up the ordered goods from allocated collections points have also become a popular alternative. For all this to function efficiently, courier and delivery companies and the logistics behind them has to be planned extremely well (Nemat **Error! Reference source not found.**).

A term which has evolved alongside the internet is electronic commerce, or e-commerce. Wigand [3] refers to e-commerce as a marketplace where supply and demand come together for the exchange of goods and services. Wigand [3] states that e-commerce "includes any form of economic activity conducted via electronic connections", between different parties such as individuals and businesses. The evolvement of the internet and e-commerce have forced companies to change and adapt their business plans in order to grow with online shopping. Taniguchi **Error! Reference source not found.** note that e-commerce offers businesses new ways of selling goods and services to customers without having a physical location. Online stores are always open, they provide customers with a more personalised experience and they are cheaper to operate than the usual brick and mortar businesses (Goga et al [5]).

Various types of e-commerce models exist which can be differentiated by looking at the interaction between the parties involved. Nemat **Error! Reference source not found.** defines four types as follows:

- Business-To-Business (B2B): the business taking place between organisations in a supply chain, for example between manufacturers, wholesaler and retailer.
- Business-To-Consumer (B2C): the exchange of goods or services from businesses to consumers, for example, an individual buying a chair from a business.
- Consumer-To-Consumer (C2C): involves exchanges between consumers with help from third-party applications, such as *Bid or Buy* online auctioning.
- Lastly Consumer-To-Business (C2B): a commerce model where individual consumers sell products and services to businesses.

The two most popular interactions are B2B and B2C (Leinbach [6]) where trading between consumers and businesses are known to require physical methods of transport in order to assist with completing the transactions. For example, businesses have to transport goods between warehouses and retail stores and between stores and consumers. In most cases delivery trucks or third-party logistics companies and couriers are used for the last-mile delivery. The last-mile delivery movement is very important in the e-commerce environment because it is the part of the process which directly reflects on the company, and businesses want to make it as efficient as possible for themselves and their customers.

E-commerce statistics published by Jimenez et al [7] showed that online shopping revenues are increasing every year. By 2020 online retail in the United States (USA) is expected to be more than four billion US dollars, as shown in Figure 1.

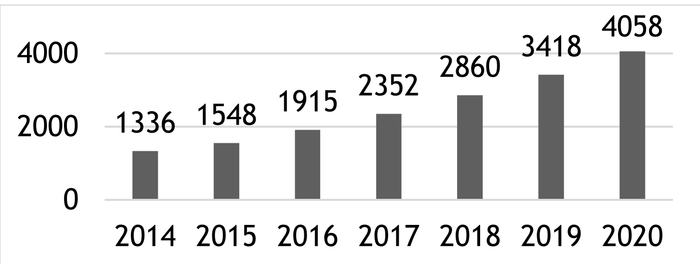

Figure 1: Projected E-commerce sales in U.S. billions (Jimenez et al Error! Reference source not found.**)**

In the UK, online shopping accounted for 14% of retail sales in 2016 and is expected to increase to 20% by 2021 (Allen et al [8]). The Netherlands expected a growth of 38% in traffic volumes of freight transport between 2000 and 2005. In 2014 the impact of e-commerce in the Netherlands was expected to grow even more, as it was antisipated that a third of retail stores will be closed down by 2020 because of online stores competion (Visser et al [9]). Sheffield [10] mentioned that e-commerce sales for the USA is projected to be 780 billion dollars by 2020, a 304 billion dollar increase from 2014. The expected growth will result in increased congestion in urban areas and will also cause more environmental issues (Taniguchi [4]).

Morganti et al [11] wrote in 2014 that the expected e-commerce growth until 2017 was 12% per year. In European countries, about 83% of citizens already had internet access in 2014, and 60% were shopping online. Thus, these countries have already been adapting with the times a lot sooner than South Africa, and have made changes to their e-commerce freight transport a few years ago.

According to Budree [12], South African e-commerce is still in its development stage with limited availability of statistical information. The growth of e-commerce in South Africa has been delayed as a result of expensive and substandard internet services and unreliable and costly delivery services (Goga et al [5]). However, recently a trend of significant increases in e-commerce and online shopping customers has been observed, as data prices are lowered and more delivery options are becoming available. Figure 2 illustrates the current and expected e-commerce growth in South Africa. At present, it can be seen that almost 40% of the population is online shoppers (eShopWorld [13]).

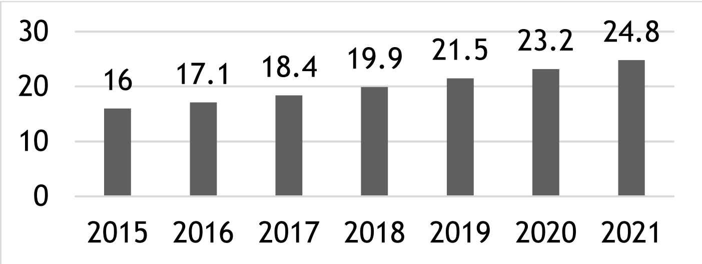

Figure 2: Expected number (in millions) of Online shoppers in South Africa from 2015 - 2021 (eShopWorld [13])

World Wide Worx [14] wrote in the 2018 e-commerce report that the total revenue for South African e-commerce sales added up to R14 billion, making up for about 1.4% of the total retail sales. It is expected that South Africa will reach the 2% mark by 2022. Even though this is a very small portion of the total sales, the increase looks very promising.

Retail e-commerce sales forecast are illustrated in Figure 3. It shows India growing at a rate of 17,8% for the projected period in terms of the B2C e-commerce, with South Africa at 9,9%, above global average (Clement [15]). This shows that e-commerce in South Africa is definitely busy developing and that attention needs to be paid in order to ensure deliveries and freight movements are functioning efficiently.

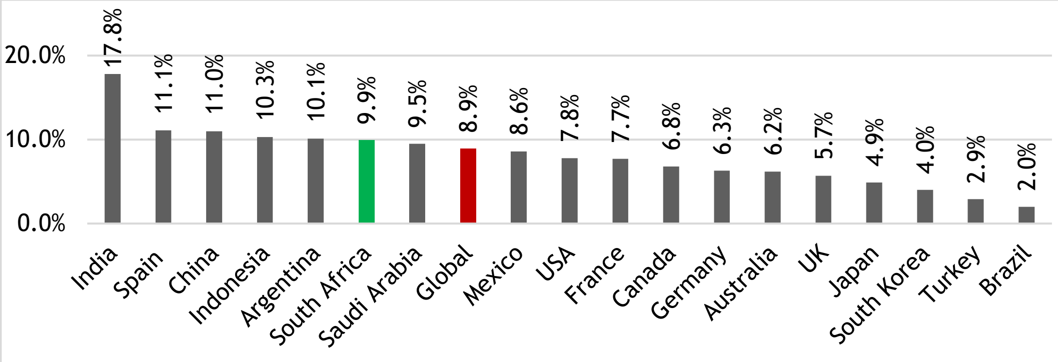

Figure 3: Retail e-commerce sales CAGR forecast in selected countries from 2019 to 2023 (Clement [15])

2 PROBLEM STATEMENT

The expectation and reality is that online shopping will increase, resulting in more freight transport and delivery vehicles in urban areas (Visser et al [9], Goga et al [5]). An increase in online shopping emphasises the need for committed delivery services. Morganti et al [11] also emphasize that delivery plays an important part in improving the e-commerce market, making it a two-way street. Efficient delivery will encourage more people to use online shopping, but promoting e-commerce also requires efficient delivery services and freight movements.

Very little attention has been paid to freight movement in comparison with normal urban transport (passenger transport), especially by city planners and policy makers (Wolmar [16]). In Europe, freight movement has been seen as a problem for some time and little has been done by the government to assist the problem.

Therefore, this paper concerns itself with studying the impact e-commerce growth had on freight movements in urban cities around the world and how they managed it. The research can then be applied to analyse e-commerce freight movements in South Africa and how it can be effectively applied to the supply chain. A Systematic Literature Review (SLR) methodology is used in order to evaluate this issue.

3 AIM AND RESEARCH OBJECTIVE

This paper concerns itself with identifying the potential impact of e-commerce on freight movements in cities, understanding how other countries embraced e-commerce growth, and exploring possible approaches for South African business to plan for future e-commerce growth whilst reducing the negative impacts of increased freight traffic in urban areas

The research objectives for this paper are:

1. To consider alternative methods to traditional home delivery urban cities across the world used to improve freight movements as a result of the e-commerce growth.
2. To research alternative methods in which e-commerce freight movements can be compared and evaluated.
3. To assess the applicability of the research in South African context.

4 RESEARCH METHOD

The purpose of this paper is to evaluate the techniques used in urban cities across the world in order to address the constant growth of e-commerce and its impact on freight movement. From this a better idea can be formed regarding the way South African cities can approach an increase in freight movement as a result of e-commerce growth. The method applied was based on the eight-step procedure for conducting a Systematic Literature Review (SLR) by Okoli & Shambram [17]. Each step of the procedure is explained in detail in the following sections.

4.1 Purpose

The paper concerns itself with doing an in-depth research regarding the impact e-commerce growth has on freight movements in urban cities across the world. The research also considers delivery alternatives and looks at ways in which South African supply chains can adapt in order to reduce the negative impact on urban freight movements.

4.2 Protocol

Once the purpose of the paper was established a research plan and protocol was developed. It consists of four steps:

1. Google Scholar and the University Library were used to find appropriate articles, journals or papers, by using specific keywords and terminology.
2. A screening process with inclusion and exclusion criteria was set up in order to refine the search process. Section 4.4 discusses the criteria used.
3. A paper was "quality checked" by reading its abstract and conclusion and considering whether it will assist in answering one or several of the research objectives.
4. Once several references were found, the sources were reworked and merged into relevant sections.

4.3 Search

The following keywords were used to search for articles and research papers on Google Scholar, they include: "E-commerce growth South Africa", "E-commerce freight movements South Africa", "E-commerce growth", "E-commerce freight movements", "E-commerce urban impact", "E-commerce statistics". More articles were found when looking at similar topics on some databases and forward snowballing (articles that have since cited that article (Okoli & Shambram [17])) was also applied. In some cases, websites were used to gather information for the SLR, but these are not included in the screening, extraction, quality or synthesis steps. A sum total of 50 articles and books were found.

4.4 Practical Screen

In order to sift through the research more easily only English papers were considered and articles written from 2010 to 2019 were evaluated first. Older articles were also used if their applicability to the topic is not outdated.

4.5 Quality Appraisal

The quality of the articles was based on the following quality assessment questions:

- Does the abstract and conclusion show the reader that it can be relevant to the current study?
- Does the tools and techniques used in the article lend itself to being applicable in South Africa?

4.6 Extraction

Figure 4 shows the number of articles per year considered for the study, taking the practical screen into consideration. From the 50 sources, only 24 articles and books were chosen. Figure 5 shows the chosen articles per year published. As seen, more recent work was used. The older articles are highly cited works in most cases.

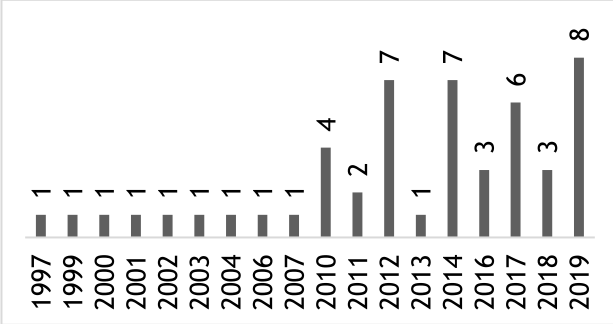

Figure 4: Number of articles per year considered for the SLR

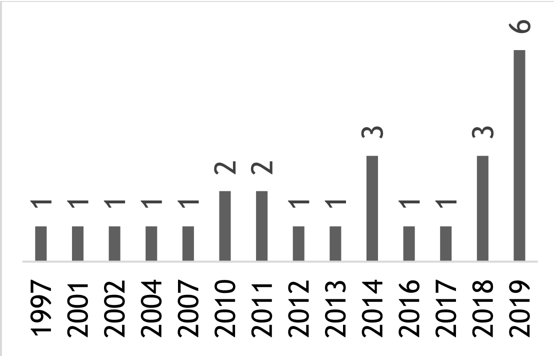

Figure 5: Number of articles per year actually used in SLR

4.7 Synthesis

Figure 6 shows the number of citations per study used in the SLR. Six of the articles or books had an unknown amount of citations and was not included in the graph.

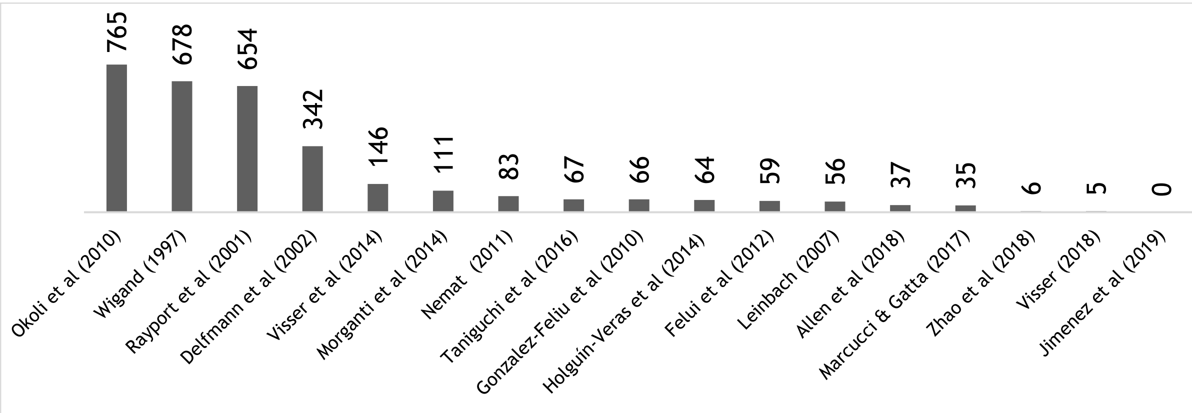

Figure 6: Number of citations per study used

4.8 Key Findings

The key findings are broken down according to the research objectives and are discussed in the next section.

5 LITERATURE REVIEW

Across the world e-commerce growth has been experienced. Some countries embraced the growth and accepted the change, where others are struggling to keep up with the changes e-commerce development require. Online shopping and e-commerce have played a big part in the development of the retail sector (Goga et al [5]) as well as transportation logistics. The reason for this is because goods ordered online results in increased freight movements due to multiple deliveries to different locations. E-commerce requires businesses to provide customers with fast and prompt deliveries, to ensure customer satisfaction and regular customers (Taniguchi **Error! Reference source not found.**). The role of e-commerce drastically changed the way in which a normal supply chains operate (Delfmann et al [18]), resulting in more complex delivery patterns. Therefore, the deliveries have to be planned and more importantly, executed effectively.

In order to evaluate the impact of e-commerce and research its international influence, a systematic literature review was conducted. The following sections addresses each of the research objectives with the hope of finding ways in which South Africa can embrace and accept the change e-commerce is bringing to urban cities across the country.

5.1 Home delivery alternatives in global urban cities

Home delivery is the traditional type of delivery where Light Good Vehicles (LGV) are used to deliver goods. It is seen as a more problematic, but preferred, type of delivery method even though it is costlier and requires more scheduling (Morganti et al [11]). Visser et al [9] mentions that outsourcing deliveries to a third-party logistics company is one way in which businesses have tried to consolidate freight movement in order to aim at reducing the number of LGV in urban areas, but this just shifts the routing problems to someone other than the business.

The last-mile shipments (the last leg of the delivery process), are the most problematic part of e-commerce freight movement. The last-mile is also the biggest cause of rescheduling for home deliveries when customers aren't home when the delivery has to be made. *Pickup points* and *Click and Collect* are alternative options consumers can choose when making purchases online (Morganti et al [11], Visser et al [9]) and these are some of the options urban cities across the world have implemented in an attempt to solve e-commerce freight movement problems.

Apart from the United Kingdom (UK), Germany and France are leading the European e-commerce industry and in 2012 these three countries were responsible for 71% of electronic commerce in Europe and in 2014 it was recorded that 45% of Europe's consumers made use of online shopping (Morganti et al [11]). Between 2010 and 2011, Germany and France's e-commerce turnover increased by 17% and 22% respectively. The increase in online shopping increased the demand for dedicated delivery services significantly compared to when only normal parcel deliveries were needed.

A study was done by Morganti et al [11] about the changes European countries have made regarding the growing e-commerce sector. Pickup Points (PP) and unmanned pickup points or retrieval lockers, reffered to as Automated Parcel Stations (APS), have been opened all over Europe. Between Demark, Finland, Norway and Sweden about 5 000 alternative distribution point were in operation in 2014. However, the leaders in this area are Germany at about 36 000 and France at around 18 000 PP sites. According to Morganti et al [11], 90% of the German population is within 10 minutes of a PP or every 600m, in rural areas this will be about 3km. In France, PPs have become the preferred delivery option as they are similarly located across urban and rural areas. In summary, Morganti et al [11] feels that consolidating deliveries in the form of PPs and APS helps delivery companies to simplify routing problems, decrease undelivered home delivery parcels and lower operating costs. Simpler routing also assists with the complex delivery routes, resulting in a positive impact on urban city traffic congestion as routes are automatically less complex and can be better planned.

Allen et al [8] did a case study in London, to assess the impact of e-commerce on freight movement and city logistics, and explains that e-commerce growth has increased the number of LGV on the road by 70% from 1995 to 2015. The reason for the increase is not fully known but one of the reasons mentioned is the growth in online shopping and consequently, the last-mile delivery. Packages cannot be delivered by the normal post-box option anymore as they cannot fit through the letterbox, thus courier vehicles are needed. Customers required to sign for packages is another reason why face-to-face delivery has become important, making collection points a viable option.

A few problems which have been picked up by the growth in e-commerce packages are discussed by Allen et al [8], most of which also affect the profitability of the businesses:

- Free delivery encourages customers to shop more frequently, increasing the number of packages that must be distributed, resulting in more complex delivery schedules.
- In some cases, customers can choose specific delivery time slots which places pressure on delivery companies, since late deliveries result in unsatisfied customers.
- Deliveries done during peak traffic periods place pressure on accurate delivery schedules, as these things cannot always be planned ahead.
- Product returns adds to complex routing problems and in most cases the customer does not know when they can expect the package to be picked up.
- Undelivered items are the biggest problem that businesses faced as a result of home delivery. Since alternative delivery options were made available, this problem has minimised.

Last-mile deliveries were researched in the case study by using tracking devices in vehicles to obtain more information regarding their delivery efficiency (Allen et al [8]). The city of London has been promoting walking, cycling and using the bus system, and implemented dedicated cycling and bus lanes for this reason. This resulted in less kerbside parking for courier and delivery vehicles and thus, from the data gathered it was seen that the drivers ended up having to walk 60% of their trip times in order to deliver goods. A large amount of parking fines was also obtained as a result thereof. Allen et al [8] gave a list of alternatives to home delivery (discussed below) in order to reduce the LGV traffic as well as its environmental and social impact. The alternatives provided are less costly, reduces the number of returned packages, allows larger parcel delivery, reduces the number of failed home deliveries and it hopes to reduces the number of LGV on the road.

- Click and Collect (C&C), a service provided by retailers such as *Walmart* in the USA, where customers order goods online and come to the store to pick it up (Visser et al [9]). The customers are mostly ensured of product availability and more options to choose from, for example when buying clothing or shoes, sizes are available on a bigger scale. Although C&C saves the customer time, it still requires them to drive to the store for collection. The retailers see this as an opportunity to get customers into the store to buy even more products (Allen et al [8]).
- Collection points or PP are locations where parcels are delivered by logistics companies and customers collect it at their own time. The costs for these types of deliveries are much lower than home deliveries (Visser et al [9]) and the problem of undelivered goods is eliminated (Morganti et al [11]). APS delivery is also very effective as customers place their order online and select a locker location of choice as delivery option. The only disadvantage of an APS is the fact that the purchase has to be small enough to fit in a locker, so customers can't, for example, purchase anything larger than a medium sized coffee machine. Using PP simplifies the routes delivery vehicles have to follow when transporting goods to consumers. It saves time and decreases the number of LGV on the road. They can also be provided as an alternative when home delivery options fail on first try. PP are used by *Royal Mail* and *Parcelly* in the UK. *Parcelly* even allows customers to order from various stores and collect it in the same place (Parcelly [19]). Verlinde et al [20] did a case study in Belgium and concluded that APS are only viable when the consumer does not use a car when picking up the package, except if the APS is located on a route the customer is already travelling by.
- Try-and-buy outlets, let customers order products online and then collect them in stores, where they can try on the items and immediately return them if necessary. *Zoot*, a Czech online retailer, follows this concept (Allen et al [8]).

- Last-collaboration, refers to the collaboration of courier and logistics companies to work together to simply the last-mile delivery. *Gnewt Cargo* is a logistics company in the UK who receives goods and packages via Heavy-Goods-Vehicles and then redistributes them on to LGV for a more efficient delivery service (Allen et al [8]).
- Logistic hotels are concepts where multiple partners use centrally located warehouses from where more environmentally friendly vehicles go to deliver the goods. Paris, France, is currently implementing two such logistic hotels: *Beaugrenelle*, a converted parking lot and *Chapelle International*, which has rail road connections (Allen et al [8]).
- Shared drop zones, which are areas on the side of the road reserved for delivery and collection. From there trolleys, bikes, carts or smaller electric LGV are used to do the last-mile delivery. These designated areas are very popular and useful in Paris.
- Delivery and servicing plans (DSP) are plans where customers are encouraged to rather choose one delivery per week than several small deliveries spread over the week. A pilot project carried out in 2009 in central London by *Transport for London* showed a 20% reduction in delivery trips (Allen et al [8]).
- Crowdshipping involves getting people (like taxis) who are already travelling to a certain point, to transport packages and drop it off at the required location. This type of freight movement is similar to *Uber Eats* or *Uber Freight*. *Uber Freight* is currently only available in the USA, and allows individuals to transport goods across states. Ballare & Lin [21] conducted a study on the possibility of combining micro hubs with crowdshipping. This concept involves crowdshipping packages to collection points like APS. The results proved to be very efficient and resulted in less freight movements.

Table 1 provides a brief summary of home delivery alternatives for e-commerce freight movement in term of their advantages and disadvantages.

Table 1: Summary of techniques as alternatives to home delivery

Technique	Advantage	Disadvantage
Click & Collect	No delivery vehicles have to be scheduled, eliminates undelivered orders.	Customer still has to drive to the store to collect.
Pickup Points	Saves the delivery vehicle from making various trips and eliminates undelivered orders.	Customer still has to drive to chosen PP to collect.
Automated Parcel Stations	Saves the delivery vehicle from making various trips and eliminates undelivered orders.	Customer still has to drive to chosen APS to collect and package has to be small enough to fit in “locker”.
Personal workplace deliveries	Eliminates undelivered orders.	Delivery vehicle still has to make various trips to different businesses.
Try-and-buy outlets	Eliminates the possibility of returning products.	Customer still has to drive to the store to collect.
Last-collaboration	Saves multiple courier companies/businesses from travelling to similar locations.	Integration of delivery information could be difficult if not managed properly.

Technique	Advantage	Disadvantage
Logistics hotels	Saves multiple courier companies/businesses from travelling to similar locations.	Some business or courier company has to carry initial cost of building "warehouse".
Shared drop zones	Saves the delivery vehicle time by not doing last-mile delivery.	The delivery vehicles are still on the road, driving to shared drop zone locations.
Delivery and servicing plans	Could decrease number of LVG on the road making small deliveries.	Customers have to plan ahead and place their orders in advance.
Crowdshipping	Saves multiple vehicles from driving to similar locations.	Serious organisation needed to ensure the packages reach the specified destinations and could be unsafe.

Daytime home delivery is a popular type of e-commerce freight movement. With the various alternative day time deliveries options discussed above, it is necessary to consider whether there is not an extremely different method which can be considered, such as after hour or off-hour deliveries.

5.1.1 Off-hour-delivery (OHD)

In order to assist with congestion and as an economic and environmental solution, the City of New York started an off-hour-delivery (OHD) program. The OHD program started in 2002 and showed that after hour deliveries could switch more than 20% of congestion time in the city to after-hours and also have major benefits on the amount of pollution. Lower delivery cost was also mentioned as a huge benefit. Holguín-Veras et al [22] provide an in-depth study into the implementation and valuable lessons taken from the OHD implementation. An important aspect which is pointed out is the importance of running multiple pilot tests.

Similarly, Marcucci & Gatta [23] studied the possibility of OHD in Rome, Italy in order to improve urban freight transport. 200 Retailers, located in the city centre, were involved. Overall 60% of them were willing to adopt OHD after the trial run was conducted. Compared to the OHD program in New York, the Rome OHD research was not implemented, only investigated. However, positive feedback was received from businesses in the city and other studies also show that it will benefit the urban area and improve freight movement and delivery.

OHD as well as normal day time home delivery alternatives are all possible solutions for efficient freight movement around urban areas. Their applicability in South African still has to be considered and evaluated. Another alternative is to consider moving freight by another method of transport, underground or off-road.

5.1.2 Underground/off-road freight movement

The negative impact of freight movements on urban areas can be significant, especially from a pollution and congestion point of view. Visser [24] and Zhao et al [25] did separate studies in order to assess the possibility of using the underground metro rails in Europe and Asia for freight movement and deliveries. Zhao et al [25] went a step further and added the use of metro rail hubs or micro hubs, by looking at the effect of transporting goods via metro trails and then delivering the packages to APS collection points close to the railway stations.

5.2 Methods to evaluate alternatives

Gonzalez-Feliu et al [26] modelled the distribution systems of three delivery structure types by creating algorithms that analyse the effects of e-commerce freight movement. The delivery systems included were home delivery, PP and a C&C and the algorithms took into consideration delivery zones, distances and number of deliveries. "Realistic" and "extreme" scenario families were set up in order to model the e-commerce trends more successfully. The three "extreme" scenarios (scenarios which are less likely to occur) were used to determine the limits of each delivery channel. The three scenarios were set up as: 100% of customers make use of 1) Click and Collect; 2) Home delivery; and 3) Pickup Points.

Four more realistic scenarios were modelled as a combination of the three delivery methods, for example 50% of customers make use of traditional shopping and the other 50% make use of C&C (scenario 1) or 50% make use of traditional shopping, 15% of home delivery and 35% of PP (scenario 2). The model showed that the best results were obtained through realistic data with a combination of home delivery and pick-up point collection. This scenario reduced the road occupation in urban areas with about 13%. The results collected by Gonzalez-Feliu et al [26] also show that more PP locations will improve freight movement and reduce traffic in urban areas.

Gatta et al [27] did a similar study in Rome, Italy with agent-based modelling, developing different scenarios with regards to people doing online grocery shopping. The study looked at the last-mile delivery in terms of customers using PP or home-delivery. The model used surveys for data gathering and considered the environmental impact of the different delivery methods. Gatta et al [27] mentioned that it is necessary to find a trade-off between efficient delivery systems and environmental friend and efficient freight movements.

Janjevic et al [28] and Bjerkan et al [29] developed surveys in which they evaluated the different characteristics of e-commerce users in the United States and Norway and their e-shopping behaviour. The conclusion was that customers preferred different last-mile delivery options depending on the product to be delivered (home delivery for heavier items such as furniture or appliances, and pick-up points for smaller items). Taking these two studies into consideration, it can be seen that home delivery cannot be eliminated as a delivery method and it will always need to be considered when planning. Thus, in the cases where home delivery is not needed, an efficient home delivery alternative should be used.

Doing studies that compare different delivery methods is useful when efficient delivery systems have to be developed. Similar studies can be conducted in urban South African cities to evaluate the best delivery system combinations for effective freight movement, in order to minimise traffic and counteract the impact of e-commerce.

6 E-COMMERCE APPROACHES IN SOUTH AFRICA

European countries have already started to grow and adapt as a result of e-commerce much earlier on than South Africa, but this gives the country the opportunity to learn from their successes. Taking into consideration the Literature Review conducted and all the different alternatives which were discussed, their implementation applicability in South African can now be analysed.

From the e-commerce freight movement solutions Allen et al [8] and Morganti et al [11] referred to, the PP and C&C options could potentially be the easiest to implement on a smaller scale, simplifying delivery routes. PP and APS are already being used in some areas in South Africa, but are still relatively new concepts with a lot of room for even further expansion and development. Companies such as *Takealot* and *Superbalist* have started to make use of PP, opening about 25 new locations across South Africa (Bulbulia [30]). Customers can also make use of the PP when returning goods to these companies, solving one of the bigger e-commerce growth problems (Allen et al [8]). Another South African example is *Pargo,* a logistics company which allows businesses, individuals or couriers to send and pick-up parcels at allocated *Pargo* points located in some retail stores (Goga et al [5]). *Pargo* points are available in some *Clicks* and *Old Khaki* retail stores in the country.

APS, or unattended lockers, are also already used in South Africa. *Makro*, a large retail warehouse and online shopping store, offers customers the option of APS instead of the more expensive home delivery or the store collection option. These designated lockers are usually located at petrol stations and customers receive a locker number and pin once their parcels are delivered at the APS (Goga et al [5]). *DSV,* a transport and logistics company, also use locker APS to distribute parcels. In some areas they share lockers with *Makro* (DSV [31]).

Several other alternative freight movement methods are available, most of which can be used in South Africa. Table 2 provides a brief summary of some of the home delivery alternatives, which were researched and implemented globally, as discussed in the Literature Review and their applicability in South Africa.

Table 2: Solution for effective e-commerce freight movement in South African cities

Initiative (Global studies)	**Impact**	**Applicability in South Africa**
Click & Collect (C&C)	Customers place their orders online and but must still to go into the store to collect their orders. Research showed that 20% of these clients buy even more products during collection (Goga et al [5]).	DisChem (Dischem [32]), Makro (Budree [12]) and Cotton On (CottonOn [33]) are some of the store in South Africa that offer this service. C&C is a form of personal shopping, where someone shops on behalf of the customer, but the customers still has to collect their goods in store at their own convenience.
Pickup Points (PP)	Reduces the number of stops delivery vehicles have to make and eliminates undelivered packages. Customers collect the orders from chosen PP at their own convenience.	Already implemented on a small scale by some South African businesses, such as *Takealot* (Bulbulia [30], *Pargo* (Goga et al [5]), and *Makro* (Budree[12]), and it is in the process of expanding even further.
Automated Parcel Systems (APS)	Same as PP, however, the package has to be able to fit in a specific size locker or storage unit.	Businesses like *Makro* (Budree[12]) and *DSV* logistics (DSV [31]) are currently implementing and using the APS delivery systems in order to accommodate more customers.
Try-and-buy outlets	Reduces the possibility of customers returning products but does not eliminate time taken to commute to the store.	Not currently known in South Africa, but could easily be implemented as most stores have an online presence/store.
Crowdshipping	Could reduce the number of vehicles on the road, and use people already going to a specific location to do the delivery.	Crowdshipping could easily be implemented in South Africa, along with *Mr Delivery* and *Uber/Bolt* transportation services. The logistics behind it will however need detailed scheduling and serious thought will

Initiative (Global studies)	Impact	Applicability in South Africa
		have to be given to the safety factor thereof.

Other home delivery alternatives which were researched on a global aspect was Off-Hour Delivery (OHD) and Rail Freight Transport. These two options and their possible implementation in urban South African cities is something which has to be researched and evaluated further. The successful implementation of the OHD program will lead to less day time traffic and could even provide quicker package delivery. A study done by Bean [34] on freight movements in the City of Cape Town, showed that after-hour deliveries definitely had financial benefits for freight companies, in comparison to normal day-time deliveries. But further analysis is definitely needed if OHD is to be considered.

The use of the South African Metro Rail as a freight movement alternative is a more questionable solution in comparison with OHD because of security reasons regarding package handling and whether it is realistic to set up APS lockers at Railway stations. Several above ground metro rails are available in most South African provinces, being the only option to consider if a similar application than that of Visser [24] and Zhao et al [25] is to be implemented in South Africa. The *Gautrain* in Gauteng only offers users ten stops, which can only partially assist with the distribution of packages across the province. The idea of using local bus services and apply their stations with APS, as a method for transporting packages is something that can also be considered.

7 CONCLUSION

E-commerce and online shopping are growing fields, showing constant growth world-wide on a yearly basis. E-commerce leads to an increase in freight movements which influence the congestion on the roads. South Africa's e-commerce industry is still developing and the country has to find ways to embrace the change.

By conducting a systematic literature review, various research objectives were set up and evaluated. Literature provided home-delivery alternatives which can decrease freight movements and simplify the routes of the delivery and courier vehicles, reducing the number of LGV on the road. PPs, APS and crowdshipping are alternatives that can be analysed in more detail in the South African context to achieve an efficient combination of delivery methods for the country. Off-hour-deliveries and underground/off-road freight movements validity can also be researched further when evaluating other freight movement methods for urban areas in South Africa.

Therefore, this paper investigates e-commerce in the South African context and provides alternative methods that businesses in the country can consider to enable more efficient e-commerce freight movements. The successful implementation of alternative delivery solutions could potentially provide urban South African cities with significant improvements in urban freight movements, also positively impacting the environment and improving congestion on roads.

However, since this paper only focuses on researching delivery alternatives used in global cities, more detailed investigations of each of the possible alternatives to home delivery in South Africa is required before selecting the most appropriate alternative for the South African businesses and cities.

Future work will include analysing specific delivery alternatives in more detail in order to establish which one, or combination will provide urban South African cities with the best possible freight movement plan. Collaboration with freight movement companies, in order to obtain realistic data will assists in investigating different delivery alternatives, in order to establish the best solution and way forward for e-commerce freight movements.

This paper conducted a systematic literature review with focus on the impact increased e-commerce freight movements had on global urban cities and how they embraced the change. The research was then used to discuss the applicability of some of the freight movement alternatives in South Africa and how it can be implemented in the future. However, more research and studies into the valid alternatives are needed in order for informed decisions to be made.

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DESIGN OF SOLAR -POWERED GRASS TRIMMER

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ABSTRACT

Common grass-cutter machines are operated by fuel and electrical energy, which are expensive, and need high maintenance. To keep environment clean and reduce use of fuel a solar powered grass trimmer has been designed in this research work. The purpose of this study is to design and fabricate a solar-powered grass trimmer which is affordable, easy to operate and environment friendly. The grass trimmer uses a 12V, - 100AH battery to power a 12V DC motor of 180W. A solar panel 1 000V system voltage is used to charge the battery. A solar charge controller of 20A is used to control the energy into the battery. The machine uses sheet metal blade to cut the grass. It can run for almost two hours when fully charged and there is no sun. It is easy to tell if the battery is fully charged or flat.

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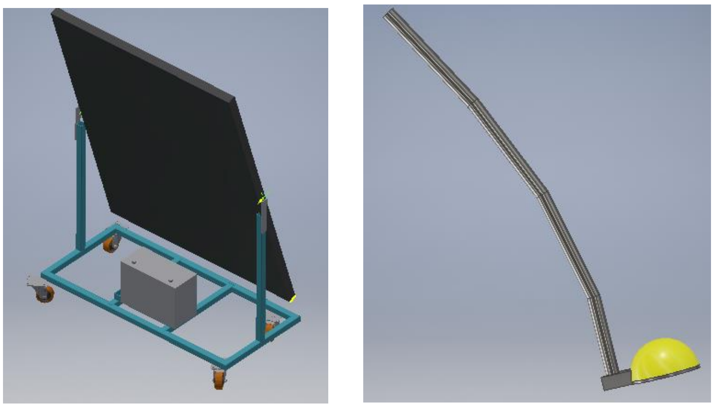
1 INTRODUCTION

Nowadays scarcity of fossil fuels induces the usage and necessity of alternate fuels. So researchers are busy in evaluating the sources, solar powered projects are given more importance; many fields are depended on solar energy now [1].The sun, an average star, is a fusion reactor that has been burning over 4 billion years. It provides enough energy in one minute to supply the world's energy needs for one year [2]. The natural environment which modern man abide, is usually covered with vegetation which includes forest trees or grass land [3]. Grass cutter machines are operated by fuel and electrical energy which are costly and requires high maintenance [4]. Most of the grass cutter available in today's market is of IC engine type and runs on fuel. This consume about 250 g fuel generally petrol [5]. Use of IC engine cutter release huge amount of carbon in the environment [5]. Pollution is a major issue for whole world. It is manmade and can be seen in own homes [6]. The name solar powered grass cutter provides the information that the usage of solar energy to power an electric motor which in turn actuates the rotor blade and that cut the lawn [7]. Grass cutter machines have become very essential to our daily living in maintaining the yards. Furthermore, environmental awareness on usage of grass cutting machines has caught a great interest among consumers [4]. energy consumption is becoming an increasingly important topic. In today's climate of growing energy needs and increasing environmental concerns, alternatives to the use of non-renewable and polluting fossil fuels must be investigated [8]. One such alternative is solar energy. A solar-powered grass cutter uses sliding blades to cut grass at an even length. Its construction is very simple. It consists of a DC motor, a switch for controlling the motor and a battery for charging it through a solar panel [9]. The first grass cutter developed by Edwin Budding in1830 in Thrupp [10].Budding's mower was designed primarily to cut the grass on sports grounds and extensive gardens. His first machine was 480 mm (19 in) wide with a frame made of iron. The mower was pushed from behind [11]. The older method of cutting grass is manually with the use of hand devices such as scissors. This requires more human effort and more time to do the work. The results are uneven. Engine-powered machines increase air pollution and noise and require maintenance [12]. Moving standard motor-powered grass cutters require hard work and are difficult for. Cutting grass cannot be easily accomplished by the elderly and children [13]. The advantage of powering a grass cutter by solar energy rather than by fuel is mainly ecological. With reference to current literature availability, there are different types of grass cutter that are exist in the markets, which may not fulfil the performance and operational cost criteria. The main concentration of this paper is to design and fabricate a solar powered grass cutter which is cost effective, easy to maintain, operated in rural areas, and easy to use. With the help of this portable Solar powered grass cutter, consumers can easily maintain and beautify their yards without any hassle. However, there are few design requirements that must satisfy the study objectives which are:

- To design and fabricate a solar powered grass cutter which is light in weight.
- Which is feasible in size.
- Which is cost effective.
- Which operates in rural areas.

2. METHODOLOGY

For the fabrication of a solar powered grass cutter we referred to various literature and papers. Different ideas were gathered and evaluated before designing and fabricating the grass cutter. Several rural areas were visited to find out the challenges in terms of access to electricity and gasoline. Based on these challenges, the idea of designing solar powered grass cutter came about to address this problem. Design and simulation were done by Autodesk Inventor Professional 2016 software which is shown in Figure 1 (a-b). Mathematical analysis was done before finalizing the design. Fabrication was done in Mechanical Engineering workshop at the university of South Africa. Energy from the sun is converted into electrical energy through the solar panel. The energy is stored in a 12V rechargeable battery. Between the solar panel and the battery, a charge controller regulates the amount of energy going into the battery and cuts off the energy when the battery is fully charged to prevent battery damage. From the battery the energy goes to a 12V DC motor which is connected to the blade. Information was gathered on different component options and evaluated based on the design, easy to maintain, size and cost. Components which met the design requirements were selected and used to fabricate the grass trimmer and are presented in table 1. The machine was tested on different types and lengths of grass in sunny and cloudy conditions.



(a) (b)

Figure 1: Drawing of Solar Powered Grass Trimmer. (a) movable stand and (b) trimmer frame

2.1 Components evaluation

2.1.1 Material Selection for the frame and stand

On this study, materials such as aluminium and mild steel were considered in fabrication of the solar powered grass cutter frame and stand. However, mild steel material was selected for both frame and stand since it is cheaper, easy to weld and readily available in the markets.

2.1.2 Solar panel

A solar cell, or photovoltaic cell, is an electrical device that converts the energy of light directly into electricity by the photovoltaic effect, which is a physical and chemical phenomenon [2]. Light shining on the solar cell produces both a current and a voltage to generate electric power [2]. Solar panel evaluation based on the four factors is presented in table 2. There are three options considered in this design and evaluated based on the following factors: peak power, peak voltage, peak current and maximum system voltage.

Tale 2: Ealuation of solar panel options

Factors	Option 1: Eggo PV module SA 148	Option 2: Eggo model SA 150	Option 3: Solar Frontier KK
Peak power (W)	148	150	165.0
Peak voltage (V)	17.3	17.6	85.5
Peak current (A)	8.56	8.52	1.93
Maximum system voltage (V)	715		1 000

2.1.3 Solar charge controller

A charge controller or alternatively a charge regulator is basically a voltage and/or current regulator, to keep batteries from overcharging [14]. It regulates the voltage and current coming from the solar panels and going to the battery[14]. Table 3 present the evaluation criteria used in selecting the suitable solar charging controller. Only two options were considered and evaluated based on the price, warranty and user friendly.

Table 3: Evaluation of solar charging controller

Factors	Option 1: Firestar solar charge controller 20A	Option 2: RoHS solar charge controller 12/24V auto
Price	R450	R529
Warranty	1 year	1 year
User friendly	Yes	Yes

2.1.4 Battery

A battery is used for storing the solar energy which will be converted into electrical energy. Solar cell modules produce electricity only when the sun is shining and do not store energy. It is therefore necessary to store some of the energy produced. The most obvious solution is to use a battery which chemically store electrical energy [15]. Two battery options and the factors used to evaluate this component are presented in table 4.

Table 4: Evaluation of battery options.

Factors	Option 1: Gamistar solar battery 12V 100AH	Option 2: Allgrand battery 12V 100AH
Price	R2 800	R2 200
Warranty	2 years	2 years
Availability	No stock	Available

2.1.5 Motor

This device converts electrical energy into mechanical energy. The conversion is done through the generation of a magnetic field by a means of current flowing into one or more coils. the blade is connected to the DC motor. Evaluation of motor options is presented in table 5. When the motor is switched on, the blades rotate at higher speed and cut the grass.

Table 5: Evaluation of motor options

Factors	Option 1: DC motor	Option 2: AC motor
Price	R2 000	R1 800
Power invertor required	No	Yes
Power invertor size	-	1 000w
Power invertor price	-	R2 000

2.1.6 Blade

A blade is the part of a tool, weapon or machine with an edge that is designed to cut, stab, slash, chop, slice and thrust, or scrape surfaces or material [15]. Two blades options were evaluated based on easy to replace, long-lasting, availability and presented in table 6. Selected solar powered grass trimmer components after evaluation and a block diagram are presented in table 7 and figure 2 respectively.

Table 6: Evaluation of blades

Factors	Option 1: wire	Option 2: sheet metal
Easy to replace	No	Yes
Long-lasting	No	Yes
Availability	No	Yes

Table 7: Components of grass trimmer

Item	QTY
12V 100AH battery	1
1 000W 7.5A solar panel	1
180W DC motor	1
12 m x 4 mm cable	1
20A solar charge controller	1
20A 1 lever double pole industrial switch	1
20 mm x 1.5 m round tube	1

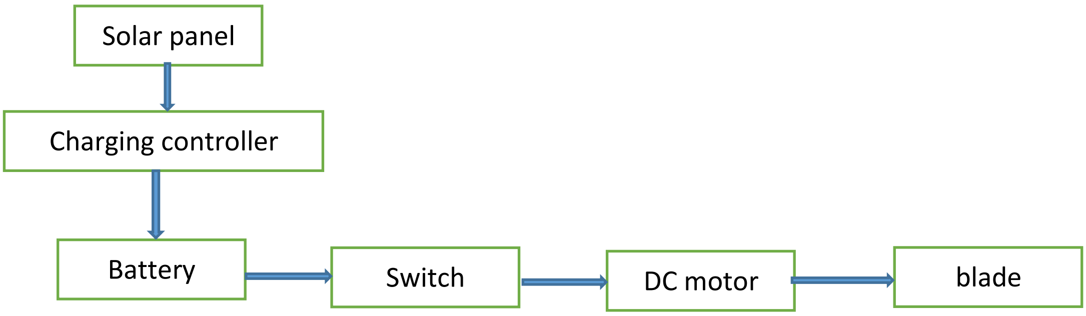


Figure 2: Block Diagram of Solar Powered Grass Trimmer

3 FINDINGS AND DISCCUSION

The department in which this project was conducted already had three different types of solar panels. Therefore, there was no need to buy or look for another solar panel. Of the three options presented in table 2, Frontier KK solar panel of a maximum system voltage of 1 000V, 1.93A and a maximum load of 2 400 pa was suitable for this design. From the options presented in table 3, Firestar solar charge controller of 20A found to be affordable, portable and easy to mount. Allgrand GEL-VRLA-battery of 6-CNFJ-100 was the best battery to be used because of its price and availability based on the evaluation in table 4. DC motor was the best option for this project based on the price and complexity of the design. The DC motor takes current straight from the battery, whereas the AC motor needs a power invertor to convert DC current to AC current to run the motor. The total price of the DC motor was R2 000, whereas the total cost of the AC motor was R3 800 because it included the price of the invertor. Based on the options in table 6, sheet metal blade is easy to connect or replace. It also lasts longer compared to wire blade. Wire blade needs another part to hold, which will make more complicated to replace the blade and more expensive. Sheet metal can be found everywhere, whereas grass cutter wire can be found in hardware stores or garden equipment shops. The complete design and fabrication of solar powered grass trimmer is presented in figure 3.

Figure 3: Solar-powered grass trimmer

4 CONCLUSIONS

The design and fabrication of a solar-powered grass trimmer that is environmentally friendly, produces less noise and affordable was achieved. The trimmer works up to 10 m away from the charging station, it is 1.5 m long and weighs about 6 kg. The charging station is movable and can be pulled to any place and distance. The sheet metal blade is easy to connect to the motor shaft by just fastening it to the motor shaft by a nut and the washer. The machine can be used to cut different types of grass and it can be used even on a cloudy day until the battery is flat. The battery lasts for almost two hours when it is fully charged if there is no sun on that day. The solar charge controller controls the amount of energy going into the battery. When the battery is fully charged, it cuts off and when the battery is flat, it switches on. This prevents damage to the battery by overcharging it. The machine can be used even in places such rural and poor areas and roadsides where there is no electricity.

5 ACKNOWLEDGEMENT

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FACTORS THAT INFLUENCE THE THROUGHPUT OF ENGINEERING STUDENTS

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ABSTRACT

The current throughput rate of engineering students is of significant concern, especially in light of the current financial pressure on universities. On the scarce skills list of South Africa, it highlights the importance of this problem that South Africa is facing, five engineering disciplines are in the top 10 scarce skills in South Africa. It is therefore important for universities to understand the factors that influence the throughput rate of engineering students, particularly those that the universities have control over.

The purpose of this study is to investigate and identify the factors that influence the throughput of engineering students at Nelson Mandela University. Focus is placed on those factors deemed to be under the control of the university. The quantitative research methodology was identified at the start of this study as being the most appropriate with eight variables identified for the purpose of this study.

The Cronbach alpha coefficient for all the variables was 0.7 or more, meaning that all the variables had an acceptable Cronbach's alpha coefficient. With the current trends in new technology that are constantly introduced to the public at large, it is clear from the respondents' points of view that technology could play a huge role in class in the future.

Based on the empirical findings, four of the variables indicated a positive influence on the throughput rate of engineering students. The remaining four variables either showed a slightly positive influence or close to no influence, translating into no significant influence from them.

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1 INTRODUCTION AND BACKGROUND OF THE STUDY

A manufacturing company cannot allow a build-up of material or parts within their manufacturing process without incurring significant cost. The same applies to universities, as low throughput rates (duration to complete studies) will result in unsustainable universities that will eventually have to close their doors. In particular, the throughput rate of students studying engineering is low with less than a third of South African engineering students graduating in the prescribed time. The low throughput rate of engineering students was one of the main reasons that triggered this study.

The low throughput rate of engineering students is a concern as high-level engineering skills are identified as a scarce skill in South Africa [1]. In addition, the profession needs to be transformed to show greater racial and gender representability. However, Fisher [1] identified poor schooling quality as one of the reasons that have constrained the pipeline feed into science, engineering and technology (SET) fields in higher education. Finally, another consequence of the current situation in engineering education is the high costs that students, their parents and the economy have to carry [1].

The goal for the education sector in South Africa was to increase annual enrolment levels from 950 000 in 2010 to 1.6 million by 2030 for the National Development Plan [2]. However, the drive to increase annual enrolments at universities will potentially make the throughput situation worse. It is one thing to enrol students, the challenge is to get those students to complete their studies as fast as possible for universities to remain sustainable.

Results from previous cohorts in engineering departments at Nelson Mandela University (NMU) that were extracted from the Higher Education Information Management System (HEMIS) clearly indicated that there was a throughput problem that needed to be addressed. The minimum duration to complete a National Diploma in Engineering is two years theory with one year practical, in other words, three years in total. Table 1 shows six cohorts over a six-year period that took an average of 4.3 years to complete their studies. Table 2 shows five cohorts with an average of only 17.5% of the students completing their studies within the minimum time, which is on the lower end of the range (10% to 40%) that Fisher [1] indicated in his report to the Engineering Council of South Africa (ECSA).

Table 1: Duration for students to graduate from the School of Engineering at Nelson Mandela University [3].

Qualification	Average Graduate Time in Years						
	2010	2011	2012	2013	2014	2015	Ave
Dip (Engineering: Civil)	4.0	4.4	4.4	4.6	4.4	4.6	**4.4**
Dip (Engineering: Electrical)	4.3	4.6	4.7	4.5	4.3	4.0	**4.4**
Dip (Engineering: Industrial)	3.9	4.0	4.5	3.9	3.4	3.8	**3.9**
Dip (Engineering: Mechanical)	4.1	4.3	4.3	4.2	4.3	4.7	**4.3**
Average	**4.1**	**4.3**	**4.5**	**4.3**	**4.1**	**4.3**	**4.3**

Table 2: Throughput rate of students at the School of Engineering at the Nelson Mandela University showing the minimum time to complete a qualification [3].

Qualification	2007	2008	2009	2010	2011	Ave
Dip (Engineering: Civil)	11,6%	19,8%	20,5%	20,0%	8,5%	**16,1%**
Dip (Engineering: Electrical)	13,3%	10,3%	6,2%	20,0%	19,4%	**13,8%**
Dip (Engineering: Industrial)	29,7%	37,5%	35,1%	19,4%	40,0%	**32,3%**
Dip (Engineering: Mechanical)	5,8%	5,1%	10,5%	11,1%	5,8%	**7,6%**
Average	**15,1%**	**18,1%**	**18,1%**	**17,6%**	**18,4%**	**17,5%**

Over a century ago, Thomas Edison predicted that the school system would be changed within ten years. It is distressing to think that this has never happened and that the classroom today shows no significant changes over the last century [4]. Technology that is currently available but not used in education, is an indication that the education system and structures are obsolete, with students not being prepared for the demands and pressure that they will need to face in the working environment [5].

2 RESEARCH QUESTIONS

This study builds on two previous studies that were done in South Africa, which documented challenges in South Africa that are influencing student throughput rate within a South African context. The first study was done for the Engineering Council of South Africa and was entitled "Improving Throughput in the Engineering Bachelor's Degree" [1]. The second study was carried out for the Council on Higher Education and was entitled, "Access and throughput in South African Higher Education: Three case studies" [6]. This study focused only on those factors that the universities had control over and for which the universities could implement interventions to improve the situation.

The research question for the study was:

- Which factors influence engineering student throughput rate the most?

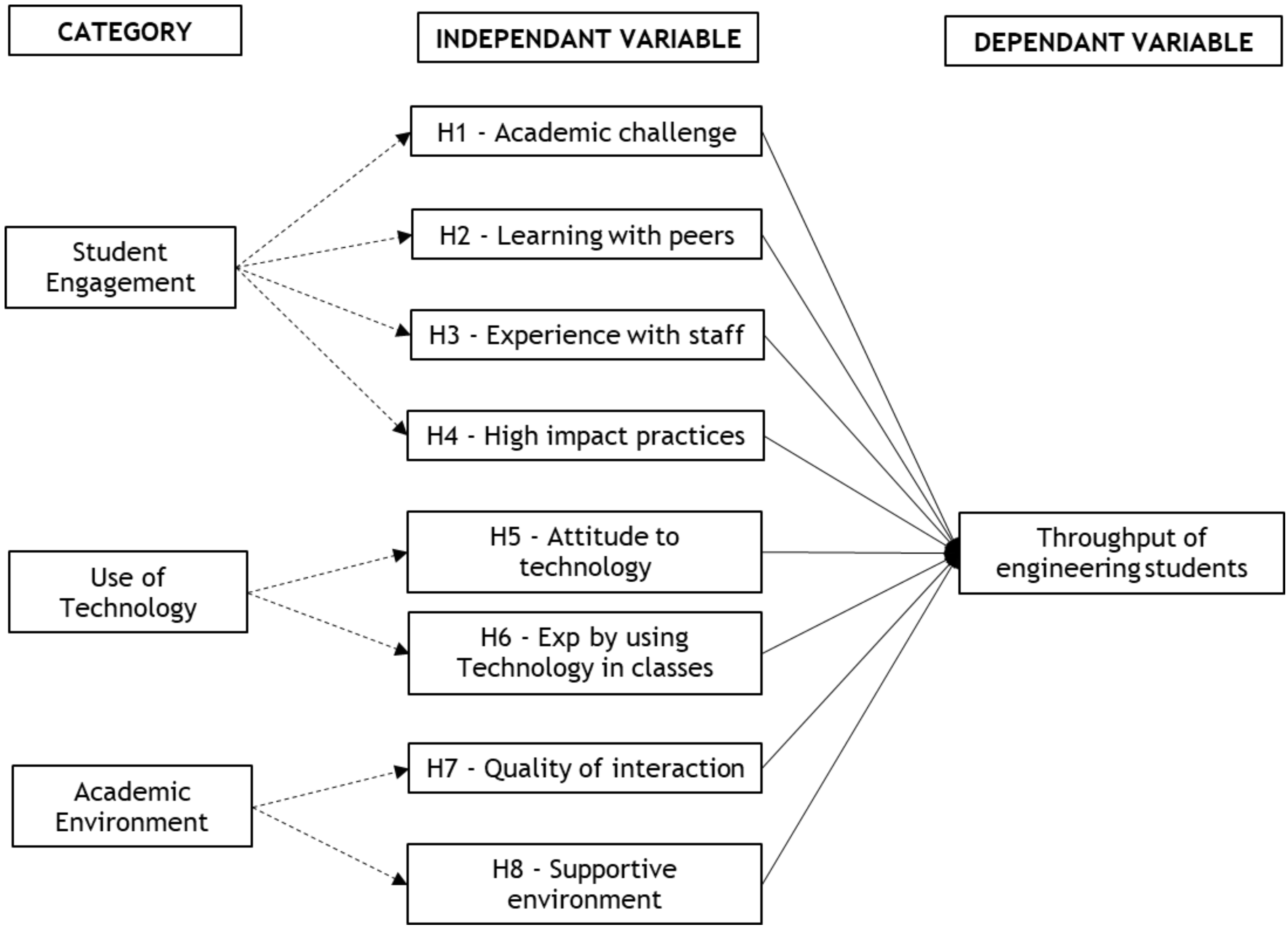

Figure 1: Categories and factors that are influencing the throughput rate of engineering students

Eight factors were identified from previous research in South Africa, these were grouped into three categories, namely, student engagement [7], technology use [8] and academic environment [9]. These categories and factors are illustrated in Figure 1.

3 LITERATURE REVIEW / THEORETICAL FRAMEWORK

3.1 Student engagement

Student engagement was identified in the United States as a significant predictor of student success [7]. Student engagement comprises of two key components, namely:

- Student effort: time and effort spent on academic activities by students that will lead to experience and outcomes that will result in student success
- Institutional resources and opportunities for students: other institutional activities that will encourage students to participate and benefit from those activities

Research that was conducted by the Association for Supervision and Curriculum Development (ASCD) has shown that students who are engaged are doing work that stimulates them. These students show more willingness to express their creativity and are more open to positive relationships [10]. The research reiterates that teachers and students dislike repetitive work that requires little or no thought. Three important characteristics of student engagement were identified in the research including:

Engaged students are:

- Attracted to their work
- Showed persistence in their work
- Showed enjoyment in accomplishing their work

It is essential for universities to understand the expectations of students so that initiatives can be aligned to nurture characteristics that are prevalent in engaged students with student expectations that will ultimately help to build good relationships and trust with staff [11]. It is also critical to align lecturing styles with the way students are learning to reinforce student engagement.

The National Survey of Student Engagement (NSSE) has identified five key indicators to measure the level of student engagement, which is used to determine the level of efficacy when new interventions are implemented [7]. The five key indicators to measure student engagement are:

- Level of academic challenge
- Active and collaborative learning
- Interaction with staff
- Campus environment
- High impact practices

The questionnaire to measure student engagement was based on these five key indicators. The challenge for universities would be to inculcate the five features into the culture of the university. For this study, each of the five key indicators was examined independently as sub-categories of student engagement.

3.2 Use of technology

Although new technologies have led to a significant change in many aspects of society in general, they have yet to make inroads into the higher education domain. However, the signs are there that technology is at the point of causing a complete disruption in education in the near future. According to Sagenmuller [12], disruptive technology could change the education content and the student experience completely. Of particular significance for this research is the possibility that disruptive technology will influence student attraction and retention.

Consequently, higher education is about to undergo change with four disruptive technologies poised to disrupt learning:

- Virtual Reality (VR)
- Collaboration Platforms
- Augmented Reality (AR)
- Artificial Intelligence (AI)

The use of technology will have a significant impact on both students and staff. To make the impact positive, staff will need to be the drivers of technology use. Thus, the importance of staff members buying-in on the idea of disruptive technology being used in education will avoid another century that has been without significant change in higher education [13].

A challenge in the South African context is that a high percentage of the students who come from previously disadvantaged backgrounds with little to no exposure to technology, making it extremely difficult to adapt to the expectations from a student at the university. The concern is that this could lead to a division in the curriculum and increased inequality among students [13].

Key trends that will enhance the successful implementation of technology in higher education were reported by Times Higher Education [14]. These trends will also help with the adoption of technology in education. These trends were identified as:

- Advancing cultures of change and innovation
- Increasing cross-institutional collaboration
- Measuring learning
- Proliferating open educational resources
- Increasing the use of blended learning
- Redesigning learning spaces

The questionnaire used for the "Use of Technology" study was based on the questionnaire that the EDUCAUSE Center for Applied Research used to understand student experiences and opinions concerning information technology at a university [15]. For this study, the category Use of Technology was divided into two factors, namely, attitude to technology and experience of using technology in class.

3.3 Academic environment

The environment that a person is living or working in has an impact on motivation. The academic environment will have a significant impact on student motivation resulting in a positive or negative impact on student engagement that will manifest into the throughput rate of students.

When the academic environment is examined, it is important to consider academic and non-academic factors that will influence students emotional, social and academic needs [16]. In addition, the academic environment was highlighted as a crucial element of student motivation [17].

Research has shown that departments with high teaching and research ratings displayed a constructive classroom experience with good faculty interaction and disciplinary growth for students [18]. Noteworthy from the research is that departments need to balance research and teaching to achieve desirable student results.

For this study, the category academic environment was divided into two categories, namely, quality of interactions and supportive environment. The two categories were identified by NSSE as critical for student success and were used for this study [7].

Four areas were identified as important for a successful academic environment:

3.3.1 Student autonomy

With the introduction of disruptive technology into education, it is important that lecturers shift from a lecture-based classroom to student-based learning making the students responsible for their own learning. Plaku [19] found that lecturers and students were acquainted with autonomous learning but with the drawback that students were not taking advantage of the opportunities that technology presented to help their learning process.

3.3.2 Quality of interaction

A constructive student/lecturer relationship is a very important ingredient to assist students in their journey through university. Students experience first-hand from lecturers how experts think when solving practical problems through their interactions with staff. The result is lecturers become mentors and role models that will give guidance to students for their continuous life-long learning journey [7].

3.3.3 Student support services

Student support services are playing a significant part of student success at Higher Education Institutions (HEIs) [20] to provide support to students with the goal of helping students to grow and develop academically during their studies.

3.3.4 Safe environment

A safe environment is one of the most important characteristics of an effective academic environment for adult learners [21]. Whether a person is a lecturer or a student, research showed that a person can only succeed academically if they feel mentally and physically safe [22]. A safe environment is very important to give a sense of belonging to students and lecturers.

4 RESEARCH METHODOLOGY

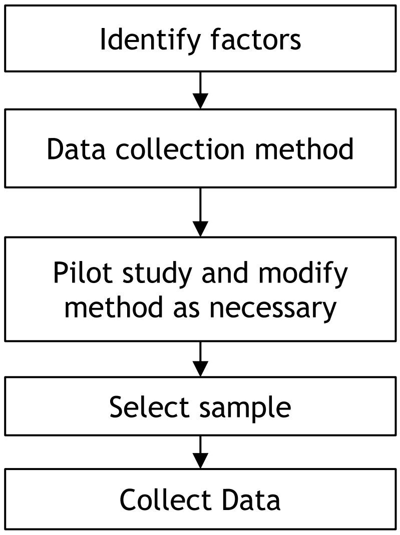

Figure 2: Research design for the study

South African Survey of Student Engagement (SASSE) [7] identified various factors that are influencing student success. Factors used in this research was adopted from the SASSE report. Quantitative research methods were selected for this study as it is the positivist research paradigm. Secondary data that was used for this study were the pass rates of engineering students that are available on the HEMIS system. The data from the HEMIS system underlined the extent of the problem at Nelson Mandela University as shown in Table 1 and Table 2. Figure 2show the research design that was used for this study.Primary data was collected from the population of the study with the use of a questionnaire (four-point Likert scale – where 1 indicate in the positive and 4 indicate in the negative). The population in this study were all the registered engineering students in the Faculty of Engineering at the Nelson Mandela University. In September 2017, there were 1392 registered engineering students when the ethics application was done. For the calculation of the sample size, a 5% Margin of error was used based Applied Business Statistics [26].A Pilot study was done on 20 students after which the sample was calculated. A sample size calculator was used with the following parameters to calculate the sample size [23]:

- Population size: 1392
- Margin of error: 5%
- Confidence level: 95%
- Minimum sample size: 306
- Maximum sample size: 612

A research instrument (questionnaire) was designed to facilitate the primary data collection. Questionnaires were distributed manually and electronically through Questionpro:

- Questionnaires issued: 617
- Questionnaires completed: 364
- Response rate: 59%

The questionnaire consisted of five sections. The first section gathered the respondents' demographic details. The second section focused on student engagement. The third section focused on the use of technology as part of the students' studies and lectures. The fourth section focused on the academic environment that the student experience on campus and a general section concluded the questionnaire.

All the data was captured in Excel and imported into Statistica. Inferential and descriptive statistics were then computed. The descriptive statistics used for this study were means, standard deviation and frequency distributions. Inferential statistics used for this study was the correlation coefficient.

5 FINDINGS

5.1 Demographic profile

Only the significant results of the study are discussed briefly. The gender profile of the respondents was in line with the gender profile of registered engineering students at Nelson Mandela University. Figure 3 shows that 25.5% of the respondents were female compared to 74.5% male respondents.

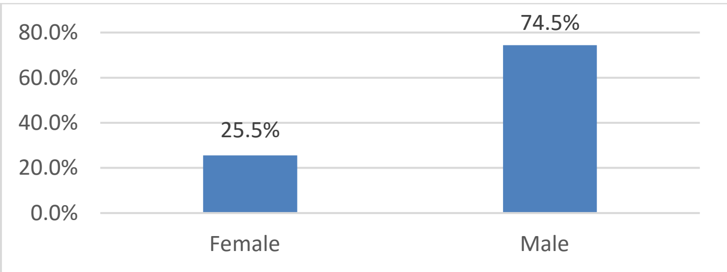

Figure 3: Gender profile of engineering students at Nelson Mandela University

Figure 4 shows the discipline spread of the respondents. Marine Engineering is a new qualification that only started in 2018 when the survey was conducted. This was evident as only 1.4% of the respondents were from Marine Engineering. A total of 29.7% of the respondents were studying Mechanical Engineering compared to 23.1% that were studying Industrial Engineering.

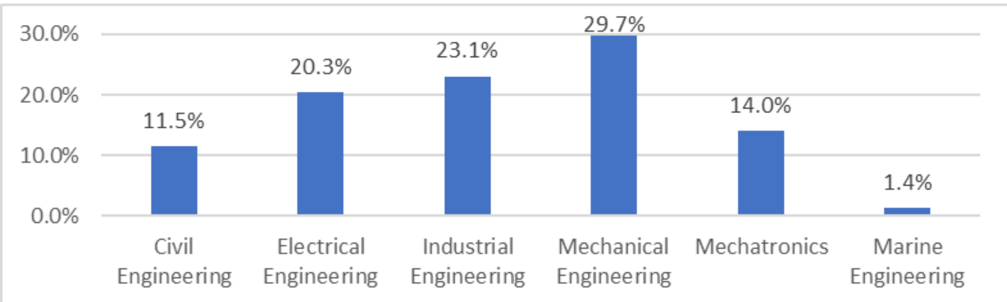

Figure 4: Discipline spread of respondents

Figure 5 shows the students' accommodation during their studies. A third (33%) of the respondents were staying with family during their studies. Two-thirds (67%) of the respondents were using accommodation that was either provided by the university or rented privately.

There was a clear indication of the accommodation challenges the students were facing that could have a significant influence on their success at the university.

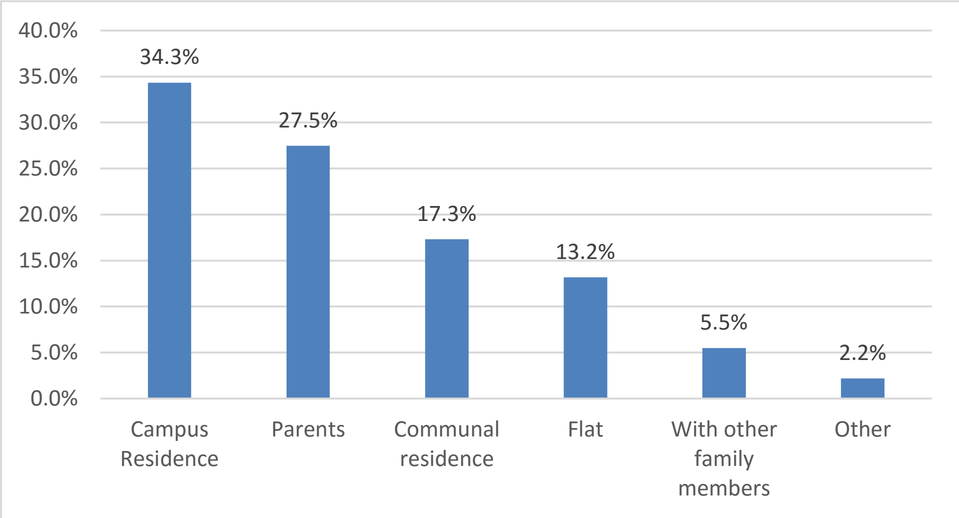

Figure 5: Accommodation during studies

Figure 6 shows that 38.5% of the respondents were first-generation students. First-generation students at university do not have anyone in the family that could guide them or prepare them psychologically for the transition to university. Many of the first-generation students arrived at the university without any arrangements for accommodation. The result was that many of them stayed wherever they could find a place to sleep making them a target for crime. Universities in South Africa need to be proactive to avoid continued student protests in 2019, currently one of the reasons for student protests in Kwazulu-Natal is over the shortage of accommodation [24].

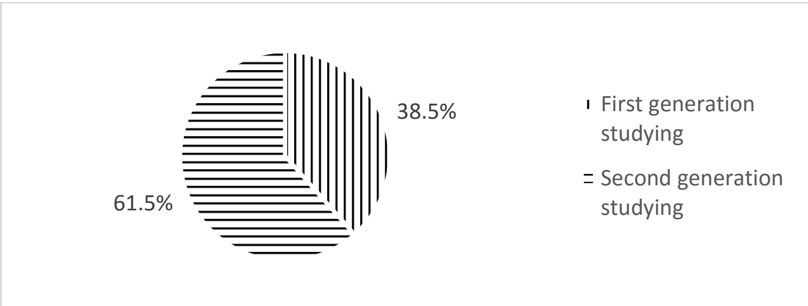

Figure 6: Percentage of first-generation students

Figure 7 shows the language profile of the respondents. It was of concern that only 17.9% of the respondents had English as their home language. Language is often a significant problem for engineering students when it comes to technical terms and definitions. As a result, the language was definitely one of the main challenges that the majority of students were facing at universities.

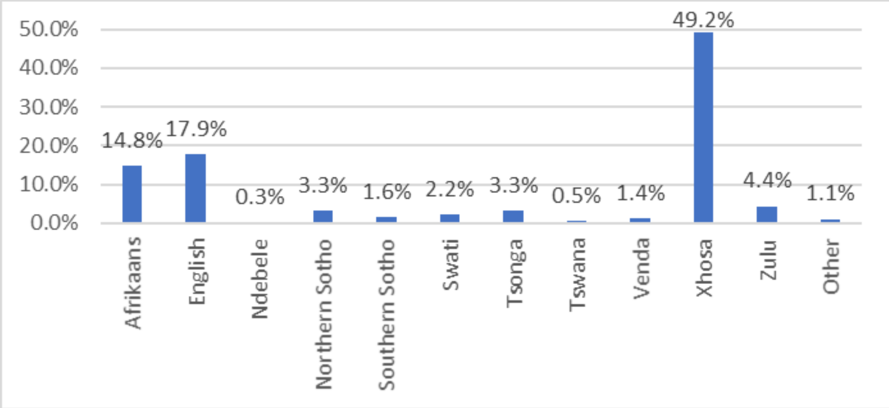

Figure 7: Language profile of respondents

5.2 Descriptive Statistics

Table 3 shows the mean, Standard-Deviation and Cronbach's Alpha results for all of the factors. The mean result indicated that two factors, namely, academic challenge and learning with peers out of the four factors of the category student engagement had a positive influence on students. Both the factors, namely, attitude to technology and experience by using technology in a class of the category technology use had a positive influence on students.

Table 3: Mean, Std-Dev and Cronbach's Alpha

#	Category	Factor	Mean	Std-Dev	Cronbach's Alpha
H1	Student Engagement	Academic challenge	**1.99**	0.39	0.78
H2	Student Engagement	Learning with peers	**1.97**	0.50	0.70
H3	Student Engagement	Experience with staff	2.41	0.52	0.77
H4	Student Engagement	High impact practices	2.27	0.47	0.73
H5	Use of Technology	Attitude to technology	**1.96**	0.42	0.72
H6	Use of Technology	Exp by using Technology in classes	**2.12**	0.60	**0.88**
H7	Academic Environment	Quality of interaction	2.38	0.64	0.77
H8	Academic Environment	Supportive environment	2.22	0.54	0.77

It is important to note that all the factors had a Cronbach’s Alpha Coefficient value of 0.7 or more indicating acceptable results for result reliability [25].

5.3 Inferential statistics

Table 4 shows how the correlation coefficient was interpreted, and none of the factors showed a strong correlation.

Table 4: Correlation Coefficient interpretation [26].

Correlation Coefficient		Interpretation of relationship
$r = 0$		No correlation
$0 < r < 0.40$	$0 > r > -0.40$	Weak correlation
$0,40 \leq r < 0,70$	$-0.40 \geq r > -0.70$	Moderate correlation
$0,70 \leq r < 0,90$	$-0.70 \geq r > -0.90$	Strong correlation
$0,90 \leq r \leq 1$	$-0.90 \geq r \geq -1$	Very strong correlation

Table 5 presents the results of the correlation analysis. Three of the relationships indicated a moderate correlation category ($0.40 \leq r < 0.70$) with the rest of the relationships indicating either a positive or a negative weak correlation. It is important to note that academic challenge and quality of interactions had moderate positive correlations with three other factors. The academic challenge had a moderate positive correlation with learning with peers, experience with the staff and on quality of interactions. Quality of interactions had a moderate positive correlation with an academic challenge, experience with the staff and with a supportive environment.

Table 5: Relationship among factors

Correlations (Data)								
Marked correlations are significant at p < 0,05000. N=364 (Casewise deletion of missing data)								
Factors	Academic challenge	Learning with peers	Experience staff	High impact practice	Attitude technology	Technology in class	Quality of interaction	Supportive environment
Academic challenge	1							
Learning with peers	0.44	1						
Experience staff	0.462	0.345	1					
High impact practice	0.367	0.269	0.393	1				
Attitude technology	-0.171	-0.105	-0.027	-0.12	1			
Technology in class	-0.227	-0.099	-0.127	-0.192	0.567	1		
Quality of interaction	0.413	0.332	0.486	0.304	-0.117	-0.21	1	
Supportive environment	0.347	0.198	0.472	0.398	0.002	-0.196	0.411	1

Based on the correlation relationship among factors, academic challenge and quality of relationships had the most influence on student success.

5.4 Primary research objective

The primary research objective of this study was to develop an understanding of institutional factors that were influencing the throughput rate of engineering students, which the university had control over and, which had an influence on the outcome. This was determined by using the eight factors that were grouped into student engagement, technology use and academic environment.

The empirical findings showed that four of the variables indicated a positive influence on the throughput rate of engineering students. Two factors, namely, academic challenge and learning with peers of the four variables that formed part of student engagement indicated a positive influence. The other two factors, namely, attitude to technology and experience by using technology in classes, showed a positive influence. The remaining four variables either showed a slightly positive influence or close to no influence, translating into no significant influence on them.

6 RECOMMENDATIONS

The following serve as recommendations based on the literature review, the empirical findings and the respondents' opinions to the open-ended questions provided in the survey.

6.1 The transition from high school to university

Initiatives with schools should be considered, especially schools from rural areas to create awareness for future students and to prepare them for the significant jump from high school to university. First-generation students that faced the same challenges should be used in these initiatives, as it would be easy for school students to relate to those who had faced the same challenges yet had managed to be successful.

6.2 Language

From the respondents, only 17,9% had English as their home language. The challenge for the majority of the respondents was to understand technical terminology that was used in engineering. An advanced engineering language initiative would be very beneficial for students who were facing language challenges in engineering.

6.3 Learning with peers, quality of interaction with peers

The learning with peers factor did not show significant results from the research. It was, however, highlighted throughout the results that the respondents were learning a significant amount from group members when working on assignments or projects. More group work or group discussions in class must be encouraged or made part of lectures. A mechanism needed to be implemented to avoid free riders or students who did nothing but sit back while the rest of the group worked.

6.4 Technology use

The institution could reduce the number of modules offered per semester and rather create an online learning programme for students. With the use of Moodle, videos of recorded classes could be posted online for every lecture. Tutorials could then be provided online as well. The advantage would be that tutors could help students from different areas simultaneously while the infrastructure on campus was safe to avoid overcrowding. In order to post more lectures and work online, the institution would need to consider Wi-Fi access for students living off-campus. Podcasts could also be used for lectures or new work that was done in class.

Computer illiterate students should be taught the basics of computers and programs, besides it being a compulsory module. Students should be given sufficient practical periods for computer use and training in terms of programmes, such as MSWord, Excel, email and Microsoft projects.

6.5 Academic environment

Overcrowding is a challenge that academics face annually. The implementation of technology could possibly alleviate the problem. Overcrowding is causing a negative attitude among students and staff, possibly resulting in student failures. In addition, classes should be more interactive.

Respondents did not feel safe on campus and felt that fences should be erected to protect the students and staff and ensure that it was a safe environment for everyone. Safety measures must be implemented at the university for students who preferred to study at night.

7 CONCLUSION

This paper highlighted areas that can assist the throughput of not only Industrial Engineers, but all the engineering fields. After all, the majority of the engineering fields are listed on the scarce skills list. The improvement of engineering education can positively increase the availability of Industrial Engineers that can design and implement solutions for the future that will make a difference in industry and the economy of South Africa.

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IMPACT OF A WORK PLACE ORIENTATION WORKSHOP ON ENGINEERING STUDENTS' WORKPLACE READINESS

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ABSTRACT

One of the strengths of the engineering national diplomas has always been the work integrated learning (WIL) component as it provided valuable industry exposure to students and assisted them with workplace integration. Informal feedback from students, prior to embarking on the compulsory one-year WIL, indicated that many felt fearful of and unprepared for the realities of the working world. To address this, a Workplace Orientation Workshop (WOW) was designed and presented to final-year industrial engineering (IE) students. The aim of the WOW was to better understand the concerns and expectations of IE students and provide them with practical co-curricular advice to prepare them for the workplace. Results of the data collected from post-WOW questionnaires in 2017 and 2018 indicated that the workshops had successfully addressed student concerns and contributed positively to their workplace preparation. The exclusion of the WIL component from many of the new engineering programmes curriculated in the new Higher Education Qualifications Sub-Framework (HEQSF) has resulted in a lack of pre-graduation work experience and workplace exposure. Hence, this research contributes to informing higher education institutions (HEIs) that co-curricular interventions are necessary to better prepare students for the workplace and work-life balance.

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1 INTRODUCTION

One of the strengths of comprehensive universities (CU) and universities of technology's (UoT) engineering programmes has always been the one-year experiential training or WIL component of the national diplomas. The one-year WIL programme provided valuable hands-on industrial exposure to students and served as a potential employee-screening process for companies employing these students. In an effort to prepare IE students, a WOW was designed and presented to students about to enter the workplace in industry for their compulsory one-year WIL component.

However, the commencement of the new Bachelor of Engineering Technology degree at UoTs and CUs meant that the one-year WIL component no longer constituted a component of the formal academic programme. As a result, there was be a need for some form of workplace orientation as well as the sharing of workplace knowledge and experience to better prepare students for the world of work in addition to managing students' workplace expectations. Previous departmental research conducted with IE first-year students (2014 to 2016) indicated that 70% of the respondents' parents held higher education qualifications, however, 30% of respondent parents held no higher education qualifications. Therefore, 30% of the students could be regarded as first-generation students (FGS). Furthermore, the average results from the first-year IE students (from 2012 to 2016) indicated that 35% of the respondents had family members employed in manufacturing and operations management industries, whereas 65% did not [1].

These results reinforced the need to assist students to make the transition from university to the workplace and to prepare them for what would be expected from them in the workplace. It also reinforced the need to address the expectations they had of employers and the perceived expectations they thought that employers would have of them as student-employees. As a result, the WOW was aimed at senior students about to enter the workplace. Originally, the WOW was intended for National Diploma students about to enter their one-year WIL. With the commencement of the Bachelor Engineering Technology (in IE), the WOW would focus on graduates about to enter the workplace, either full-time employees or students. The objectives of the WOW were orientation, preparation and sensitisation of students entering the formal workplace so as to facilitate realistic expectations.

Accordingly, the aim of this research was to better understand IE student concerns and expectations before commencing their one-year WIL. It was, therefore, necessary to establish if the WOW assisted in addressing their fears and concerns as well as clarifying their prior perceptions and expectations, by providing a more realistic view of what would be expected of them in the workplace. Hence, the purpose of this paper is to discuss the WOW content and the findings of the questionnaires that were completed by students attending WOW.

2 ENGINEERING PROFESSIONALS' EXPECTATIONS

Much has been accomplished to provide developmental and growth opportunities at the university and to teach skills that would assist students in life and for the world of work. All engineering students at the university take part in a one-year mentorship programme, and women engineering students may join Women Engineering Leadership Association (WELA). In addition, lecturers usually incorporate teamwork projects and practical assignments into the curricula. These extra-curricular activities are conducted to develop the students' non-technical skills in addition to meeting the learning outcomes as prescribed by the Engineering Council of South Africa (ECSA) [2]. In addition, a study conducted within the department in 2011 indicated that employers surveyed were of the opinion that the National

Diploma's WIL component provided valuable workplace skills to students and that it was an essential part of the engineering programme [3]. Employers, however, noticed that students often lacked certain non-technical skills such as teamwork, communication, time-keeping and taking responsibility.

Cox, Cekic, Ahn and Zhu [4] summarised the findings of past studies exploring student professional skills development. Table 1 shows some of the findings.

Table 1: Professional Skills Development [4]

Major finding	Author
Students experience difficulties working in teams, communicating and understanding workplace expectations	Katz [5]
Engineering students who enrolled for additional non-technical courses perceived that they were better prepared for industrial jobs	Keenan [6]
Students identified weaknesses as working in a multidisciplinary team, leadership, practical preparation and management skills	Martin, Maytham, Case and Fraser [7]
Students did not know how to work in teams and industry needed to work closely with academia to make their needs clearer	McMasters and Matsch [8]
STEM programmes must include information sharing and teamwork, adaption to changing work environment as well as ethical decision-making and behaviour	Meier, Williams and Humphreys [9]

From the findings in Table 1, it is evident that problems experienced in 1993 still exist for engineering students currently. Informal feedback from IE students revealed similar challenges were still being experienced.

As a result of these national and international findings, academics in the IE department who have had previous experiences with graduates in the workplace promoted the development of a WOW to better prepare students for the world of work.

3 WORKSHOP STRUCTURE

The WOW has been offered for the past ten years (since 2008), and over time, the programme has been adapted as new needs have arisen. Speakers for the 2017 and 2018 WOWs were selected to discuss specific topics that the IE department felt would be beneficial to integrate students into the working environment.

Speakers included an engineering manager, human resource managers, a finance manager, a social media strategist, university staff, recently-graduated industrial engineers and IEs completing their WIL. These speakers delivered presentations on their workplace experiences, the expectations they had on entering the workplace versus the reality they experienced, expectations of students entering the workplace and advice on how students should conduct themselves in a professional and respectful manner. Topics ranged from workplace conduct, CV writing, financial planning advice, positive social media presence to remaining self-motivated. The 2017/2018 WOW programme topics? details are outlined in Table 2.

Table 2: WOW Programme and Brief to Speakers

Guest speaker	Instructions
Engineering managers	- Provide students with information regarding the expectations of a formal work environment, proper workplace conduct and preparation for the world of work. This includes the

	perspective of an engineering manager on what to look for in a prospective candidate. - Inform students on what is expected from them in the workplace, desired traits and characteristics, tips and hints as well as workplace practices of which to be aware. - Inform students on what makes them stand out as excellent employees (to help with their becoming permanent, have contracts renewed and be considered for promotion). - Provide the engineering manager's views of a corporation when recruiting and managing engineering students and potential engineering employees.
Human Resources managers	- Provide students with information regarding the expectations of a formal work environment, required workplace conduct and preparation for the world of work. - Prepare students for the interview process, questions to ask, types of questions that can be asked, how to prepare for an interview, how to create a good impression and what to wear during an interview. - Outline the general status of employment for engineers in the Eastern Cape. - Advise students on CV writing. - Provide information on moving between companies often.
Social Media Strategist	- Inform students of dos and don'ts of social media usage as a student, potential employer and employee. - Discuss the use and relevance of LinkedIn.
Management accountant	- Provide students with information on how to use their weekly/monthly income wisely. - Assist students with managing debt, accounts, living within their means, budgeting, saving and credit card use.
WIL students and recently graduated	Provide students with information regarding the expectations of a formal work environment, required workplace conduct and preparation for the world of work This includes: - Lessons learnt - How to address colleagues and superiors in the workplace - Tips for survival - Basic expectations in the workplace - What adjustments students need to make as they enter the working world - What the transition was like from student to employee - Budgeting tips - "What I would tell/advise my university self" - after being in the working world - Perception vs Reality - How student goals have changed since working
University staff	A session regarding motivation and maintaining resilience in achieving long-term goals.

4 METHODOLOGY

The purpose of the WOW was to assist final-year students with their preparation for the workplace and the concerns they might be faced with as they transitioned from student to employee. All final-year IE students at the university (a total of 85) were invited to attend the half-day WOW workshops in 2017 and 2018.

4.1 Sample

In total, 64 out of 85 final-year students attended the 2017 and 2018 WOWs (see Table 3).

Table 3: Number of students attending WOWs (2017-2018)

Year	Number of final-year students	Number of students attended
2017	45 (53%)	38 (59%)
2018	40 (47%)	26 (41%)
Total	85 (100%)	64 (100%)

4.2 Research Instrument

Students who attended the workshop were requested to participate in the completion of pre- and post-workshop questionnaires.

A mixed methods approach was used, and the two questionnaires consisted of open-ended questions where respondents were asked to list or describe answers. In addition, there were questions where respondents were asked to rate their responses on a 5-point Likert scale. This method was used to gather further information from students on their feelings towards WOW and entering the workplace, together with the quantitative data collected.

Pre-Workshop Questionnaire

The pre-workshop questionnaire consisted of six questions and was distributed prior to the commencement of the workshop. Only the questions selected for the purpose of this paper, have been listed below:

1. **WHAT ARE YOUR THREE BIGGEST CONCERNS/FEARS OF ENTERING THE WORKPLACE AS A WPL STUDENT?**
   a.

   b.

   c.

2. **HOW CONFIDENT DO YOU FEEL ABOUT FINDING A PLACEMENT (A COMPANY TO EMPLOY YOU?)?**

1	2	3	4	5
Not at all				Extremely

3. **HOW CONFIDENT DO YOU FEEL ABOUT BEING ABLE TO DO WHAT YOU IMAGINED IS REQUIRED OF YOU IN THE WORKPLACE?**

1	2	3	4	5
Not at all				extremely

4. **WHAT ARE THE QUESTIONS THAT YOU WOULD LIKE TO HAVE ANSWERED BY THE GUEST SPEAKERS TODAY?**

Post Workshop Questionnaire

The post-workshop questionnaire consisting of six questions were distributed at the end of the workshop. Only the questions selected for the purpose of this paper have been included:

1. NAME THREE THINGS YOU LEARNT TODAY

a.

b.

c.

2. WERE ANY OF YOUR FEARS AND CONCERNS ANSWERED OR ADDRESSED TODAY? STATE WHICH WERE.

3. HOW CONFIDENT DO YOU FEEL NOW ABOUT FINDING A PLACEMENT (A COMPANY TO EMPLOY YOU)?

1	2	3	4	5
Not at all				extremely

4. HOW CONFIDENT DO YOU FEEL NOW ABOUT BEING ABLE TO DO WHAT YOU IMAGINED IS REQUIRED OF YOU IN THE WORKPLACE?

1	2	3	4	5
Not at all				extremely

5. WHAT WAS HELPFUL ABOUT TODAY'S WORKSHOP?

ITEM	YOUR COMMENTS	RATING SCALE (WRITE DOWN THE NUMBER) *
Information from HR manager/recruitment specialist		
Information from engineering managers		
Information from students		
Information from university staff		

RATING SCALE *

1	2	3	4	5
Not at all	Slightly	Neutral	Very	Extremely

The objective of the two questionnaires was to determine the expectations students had of the working environment before attending the workshop compared to after the workshop, once they had listened to the advice and experiences of the guest speakers.

The findings from each questionnaire were summarised and, where applicable, a comparison between the findings from the pre-workshop and post-workshop questionnaire were made.

5 RESULTS AND DISCUSSION

The following findings were drawn from the gathered data.

5.1 Confidence in finding placement with an employer

Using a Likert-scale, students were asked to rate how confident they felt about finding a work placement with an employer for their in-service training. This question was included in both the pre- and post-workshop questionnaires. Using a rating of 1 (not at all) confident to 5 (extremely) confident, 56% of students scored themselves as feeling 4 (very confident) or 5 (extremely confident) in finding placement before the workshop, while 81% of students scored this positively after the workshop. The results showed that students felt more confident in finding placement after the workshop had taken place.

5.2 Confidence in being capable in the workplace

Using a Likert-scale, students were asked to rate how confident they felt about being capable of performing the tasks they imagined was required of them in the workplace. This question was included in both the pre- and post-workshop questionnaires. Using a rating of 1 (not at all) confident to 5 (extremely) confident, 66% of students scored themselves as feeling 4 (very confident) or 5 (extremely confident) in their capabilities before the workshop, while 84% of students scored this positively scoring the workshop. The results showed that students felt more confident of their capabilities after the workshop had taken place.

5.3 Concerns for entering the workplace

In the pre-workshop questionnaire, students were asked to express their concerns or fears on entering the workplace as WIL students as well as state the questions they would like answered by the guest speakers. In the post-workshop questionnaire, students were asked to state whether any of their concerns and questions were addressed during the workshop and to express what they had learnt from the guest speakers. These open-ended questions were posed to determine if the workshop had had a positive impact on the students, by alleviating some of their initial uncertainties about entering the workplace.

The students' concerns and questions for the guest speakers were summarised and are listed, together with how these concerns were addressed by the guest speakers during the workshop. Student concerns included:

- Students feared that some employers would not recognise their potential and were, therefore, concerned with finding employment as well as seeking advice on how to successfully compose a CV to sell themselves.
    - HR representatives provided advice on where to search for jobs and how to apply as well as advice on CV writing and how to promote themselves positively in their CVs and in interviews. Students felt more assured that they would be capable of finding employment by listening to the employment stories of past students as well as receiving advice from HR representatives on recruitment.
- Students were concerned that they would not obtain adequate and relevant experience during their WIL and that they would be unable to complete tasks assigned to them from the employer.

  - The workshop included an engineering manager who provided students with advice on accepting all tasks as an opportunity to learn and grow themselves and that it was up to students to learn as much as possible from those with whom they worked. It was also up to the students to take initiative and involve themselves in projects that they felt would benefit them and not wait to be included. In this way, students would achieve adequate and relevant experience during their WIL.
  - Students stated that during the workshop, they had learnt that it was important to ask questions if they were uncertain of any tasks or responsibilities and that maintaining a good attitude at work helped with acquiring knowledge more effectively. This knowledge would assist them in completing tasks effectively.
- Students wanted clarity on what was expected of them in the workplace and how to transition from university into the workplace (including applying theoretical knowledge in the working world).
  - The workshop consisted of guest speakers who were students in the process of completing their WIL as well as students who had graduated and had been working for more than one year. From the advice of these speakers, students stated that they had learnt::
    - to transition from university to the work environment and were enlightened on the challenges that they might face in the workplace.
    - to be open-minded and flexible to the variety of tasks given to them in the workplace.
    - to read their employment contracts carefully to determine what was expected of them.
    - to be punctual in the workplace as the company paid for their employees' time.
    - to be honest in their interviews.
- Students were concerned with how they would handle the workload at their place of employment and failing in the working environment.
  - The engineering manager provided advice to the students, from the importance of being on time to how to conduct themselves in the workplace. From this guest speaker, students noted that they had learnt the following:
    - That preparation for any task provided to them was vitally important and expected. Students would be assigned roles and responsibilities by their supervisors and needed to understand their tasks to carry out these roles.
    - That seeking help was important when they required it and to ask questions, instead of leaving it until it was too late.
- Students were concerned about managing work and studying part-time.
  - Students stated that they had received advice on how to cope with their part-time studies while completing their WIL. The workshop included guest speakers who were graduated students currently working and studying towards their BTechs.
- Students were concerned with how to complete the two phases of their WIL (Practical 1 and 2) successfully.
  - A senior lecturer from the department of IE, advised students on the requirements for completing their WIL successfully as well as how to overcome some obstacles that they might face.

- In addition to these concerns, students also expressed what they had learnt from the financial management and social media guest speakers, namely:
- Students stated that they had learnt how to better handle and work with their finances as well as how to budget more effectively. They had also learnt the importance of being debt free as far as possible.
- Students learnt that the manner in which they portrayed themselves on social media could affect their employability. They also learnt that they should be cautious of what they posted on social media and how social media could impact on the way prospective employers viewed them. Students were also informed about having an online presence on LinkedIn and how to conduct themselves differently on this platform, compared to Facebook and Instagram.

6 CONCLUSION AND RECOMMENDATIONS

Overall, the students found the WOW informative and helpful. Students were advised on how to cope in the workplace, what to expect before entering the workplace, how to prepare for the recruitment process and how to better manage their finances as well as their social media presence. Students expressed that they felt less anxious after the workshop, as they had received clarity on workplace expectations.

The results from the questionnaires also showed that the students felt more confident in finding work placement and were more confident of their capabilities after the workshop had taken place. The importance and value of WOW had become evident as the student feedback was analysed, and hence future workshops would be offered as a one day workshop and also include topics such as SARS issues, conflict management, dealing with bullies and strong personalities.

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EFFECT OF DISCHARGE DIAMETER ON CENTRIFUGAL PUMP PERFORMANCE

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ABSTRACT

This report presents a study on the effects of the discharge diameter on the performance of the centrifugal pump. The performance of a centrifugal pump changes when one of the performance characteristics changes. The aim to analyse what happens to the discharge pressure and the stresses experienced at the discharge area when the diameter of the discharge. For most water and other noncorrosive services, stainless steel material satisfies these criteria for the impeller and the casing of the pump. Design constraints and limitation were identified. Boundary conditions were selected. Design of the pump assembly was done on SolidWorks. Results obtained from SolidWorks were interpreted and simulated with ANSYS to determine high stress points and deformation. Graphs were displayed as the results of possible calculations. From the calculated results, it was observed that the discharge pressure, velocity, and the head increases as the discharge diameter decreases. From the simulated results it was observed that as the diameter decreases the maximum stresses experienced as the discharge area also decreases.

Keywords: Centrifugal pumps, pump performance, pump design parameters, Material

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1 INTRODUCTION

Centrifugal pumps (see figure 1) are a part of vibrant axisymmetric work-absorbing turbo machines. Hydrodynamic energy of flow of a fluid arises as a result of the conversion of the revolving kinetic energy when a fluid is being transported. This rotational energy is normally from an electric motor or an engine [1]. The fluid enters the pump at the suction side and is accelerated by the impeller to flow in the radial and outward direction into the discharge side of the pump. The centrifugal pumps have different torque characteristics depending on the size, specification and application. The amount of energy given to the liquid relates to the velocity at the edge of the impeller. Their uses include, but not limited to water, sewage, petroleum and petrochemical stations [3]. This project seeks to understand how the overall performance of the centrifugal pump is affected by the change in diameter on the outlet or rather the discharge diameter. Series of the test has been performed with different outlet diameter and results for each test has been recorded and analysed. Fluid flow/flow rate, stress, pressure and Head is analysed as the discharge diameter changes.

Centrifugal pumps are normally affected by the factor called cavitation, this project unfolds the factors causing cavitation as well as how to minimise it. Pumps are generally over designed in terms of the weight and material used hence the project looks into developing a model that will assist in how much material and which type of material is needed in its manufacturing to increase its efficiency and cost effectiveness [2].

2 DESIGN

A centrifugal pump that uses water as a fluid form to operate is designed. The internal design of the centrifugal pump casing has a volute that allows for fluid flow. An impeller is installed to drive the fluid entering through the suction inlet. This impeller is connected to a driving motor by means of a shaft. The considered material for both the volute casing and the impeller is either cast iron or cast steel. The centrifugal pump is designed at three varied discharge diameters to evaluate the behaviour of pressure, stress and strength of the material.

2.1 Conceptual Designs of volute casing of the centrifugal pump

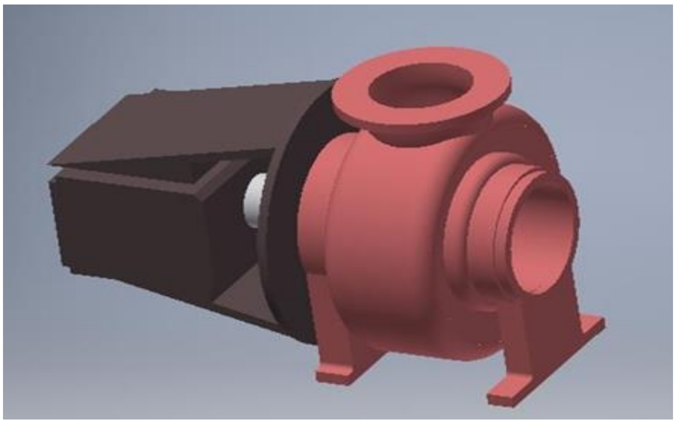


Figure 1: Conceptual Designs of volute casing

2.2 Detail Design

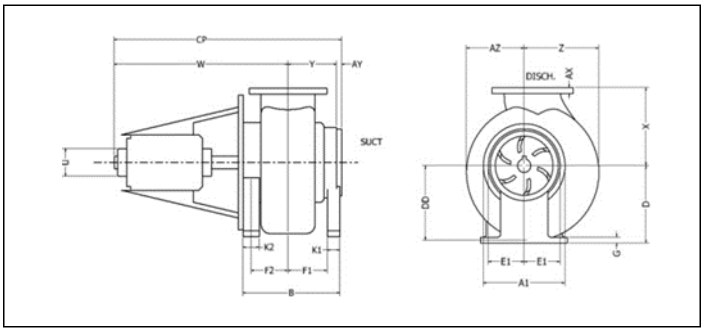


Figure 2: Detail Design

2.3 Material Selection

For the centrifugal pump design, the material used is steel because of its corrosion, erosion and cavitation resistance properties. Material performance requirements were analysed and alternative solutions were evaluated among steel, cast iron, aluminium alloy, titanium alloy, ceramics and composites. Mechanical properties including tensile strength, wear resistance, thermal conductivity and as well as the costing were used as the parameters in the material selection stages steel is used for this components because it provides good wear resistance with high thermal conductivity and the production cost is low compared to other centrifugal pump materials.

3. CALCULATIONS AND TESTING SIMULATION OF MODEL

The calculations and testing simulation of the model will be carried out considering the different diameter of the discharge. This will be done to analyse the performance of the centrifugal pump with different diameters of the suction of the pump.

3.1 Detailed calculations using appropriate formulae

- **Test 1**

$$Flow\ Rate = 0.232\ m^3/sec$$

$$Inlet\ Area\ (A) = \frac{\pi d^2}{4} = \frac{\pi(.305)^2}{4} = 0.0731 m^2$$

$$velocity\ of\ the\ water\ at\ the\ inlet$$

$$U_1 = \frac{Flow\ Rate}{Area} = \frac{0.232}{0.0731} = 3.174\ m/s$$

At h = 1.5m

$$P = \rho g h$$

$$P = 1000 \times 9.81 \times 1.5 = 14.715\ kPa$$

$$H_1 = z_1 + \frac{P_1}{\rho g} + \frac{U^2}{2g}$$

$$H_1 = 0 + \frac{14.715 \times 1000}{1000 \times 9.81} + \frac{3.174^2}{2 \times 9.81} = 2.013\ m$$

$$Outlet\ Area = \frac{\pi d^2}{4} = \frac{\pi(.254)^2}{4} = 0.051\ m^2$$

$$U_2 = \frac{Flow\ Rate}{Area} = \frac{0.232}{0.051} = 4.549\ m/s$$

$$H_2 = z_2 + \frac{P_2}{\rho g} + \frac{U^2}{2g} = 8.02m$$

$$P_2 = \left(H_2 - \frac{U^2}{2g}\right) \times \rho g$$

$$P_2 = \left(8.02 - \frac{4.549^2}{2 \times 9.81}\right) \times 1000 \times 9.81 = 63.133\ kPa$$

- **Test 2**

$$Flow\ Rate = 0.232\ m^3/sec$$

$$Inlet\ Area = \frac{\pi d^2}{4} = \frac{\pi(.305)^2}{4} = 0.0731m^2$$

$velocity\ of\ the\ water\ at\ the\ inlet,$

$$U_1 = \frac{Flow\ Rate}{Area} = \frac{0.232}{0.0731} = 3.174\ m/s$$

At h = 1.5m

$$P = \rho gh$$

$$P = 1000 \times 9.81 \times 1.5 = 14.715\ kPa$$

$$H_1 = z_1 + \frac{P_1}{\rho g} + \frac{U^2}{2g}$$

$$H_1 = 0 + \frac{14.715 \times 1000}{1000 \times 9.81} + \frac{3.174^2}{2 \times 9.81} = 2.013\ m$$

$$Outlet\ Area = \frac{\pi d^2}{4} = \frac{\pi(.230)^2}{4} = 0.0415\ m^2$$

$$U_2 = \frac{Flow\ Rate}{Area} = \frac{0.232}{0.0415} = 5.59\ m/s$$

$$H_2 = z_2 + \frac{P_2}{\rho g} + \frac{U^2}{2g} = 8.65m$$

$$P_2 = \left(H_2 - \frac{U^2}{2g}\right) \times \rho g$$

$$P_2 = \left(8.65 - \frac{5.59^2}{2 \times 9.81}\right) \times 1000 \times 9.81 = 69.23\ kPa$$

- **Test 3**

$$Flow\ Rate = 0.232\ m^3/sec$$

$$Inlet\ Area = \frac{\pi d^2}{4} = \frac{\pi(.305)^2}{4} = 0.0731m^2$$

$velocity\ of\ the\ water\ at\ the\ inlet,$

$$U_1 = \frac{Flow\ Rate}{Area} = \frac{0.232}{0.0731} = 3.174\ m/s$$

At h = 1.5m

$$P = \rho g h$$

$$P = 1000 \times 9.81 \times 1.5 = 14.715\ kPa$$

$$H_1 = z_1 + \frac{P_1}{\rho g} + \frac{U^2}{2g}$$

$$H_1 = 0 + \frac{14.715 \times 1000}{1000 \times 9.81} + \frac{3.174^2}{2 \times 9.81} = 2.013\ m$$

$$Outlet\ Area = \frac{\pi d^2}{4} = \frac{\pi(.210)^2}{4} = 0.0346\ m^2$$

$$U_2 = \frac{Flow\ Rate}{Area} = \frac{0.232}{0.0346} = 6.705\ m/s$$

$$H_2 = z_2 + \frac{P_2}{\rho g} + \frac{U^2}{2g} = 9.85m$$

$$P_2 = \left(H_2 - \frac{U^2}{2g}\right) \times \rho g$$

$$P_2 = \left(9.85 - \frac{6.705^2}{2 \times 9.81}\right) \times 1000 \times 9.81 = 74.149kPa$$

3.2 Simulation

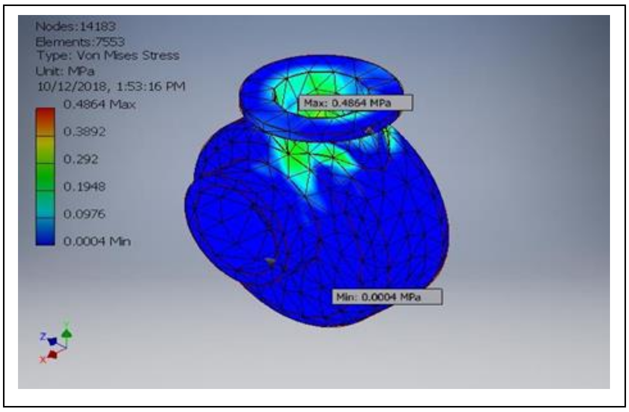


Figure 3 distribution of Von Mises stresses at the discharge area

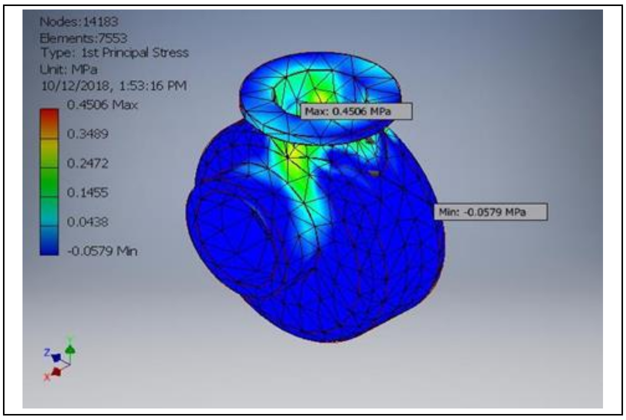


Figure 4 distribution of the 1st principle stresses at the discharge area

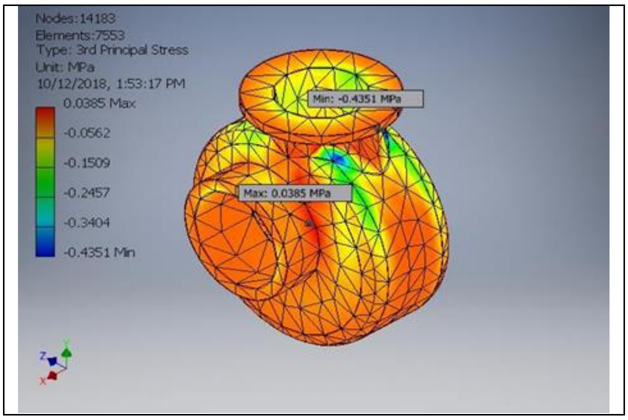


Figure 5 distribution of the 3rd principle stresses at the discharge area

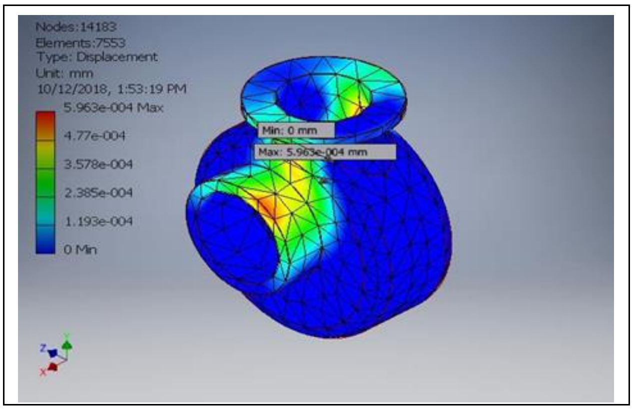


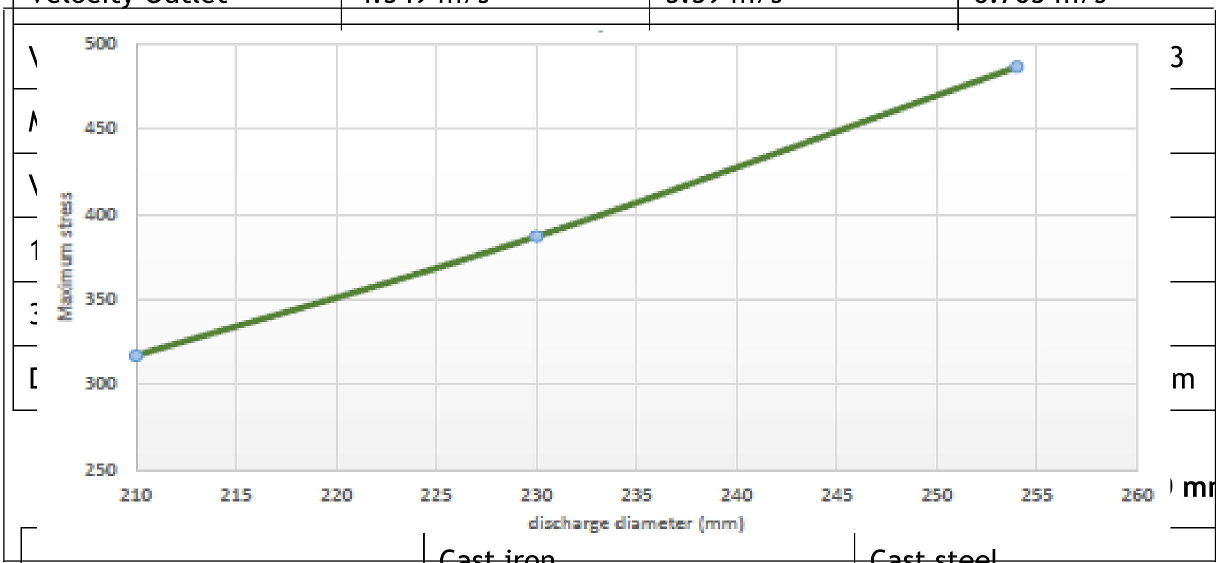
Figure 6 the displacement that occurs when discharge area is under pressure

3.3 Results table

Table 1: Results of each experiment

	Test 1	Test 2	Test 3
Discharge Diameter	254 mm	230 mm	210 mm
Discharge Pressure	63.133 kPa	69.23kPa	74.149 kPa
Velocity Inlet	3.174 m/s	3.174 m/s	3.174 m/s

Velocity Outlet	4.549 m/s	5.59 m/s	6.705 m/s



	Cast iron	Cast steel
Volume	77765400 mm^3	75798300 mm^3
Mass	556.022 kg	595.009 kg
Von Mises Stress	0.386855 MPa	0.486376 MPa
1st Principal Stress	0.416055 MPa	0.450617 MPa
3rd Principal Stress	0.0343212 MPa	0.0385337 MPa
Displacement	0.000522332 mm	0.00034216 mm

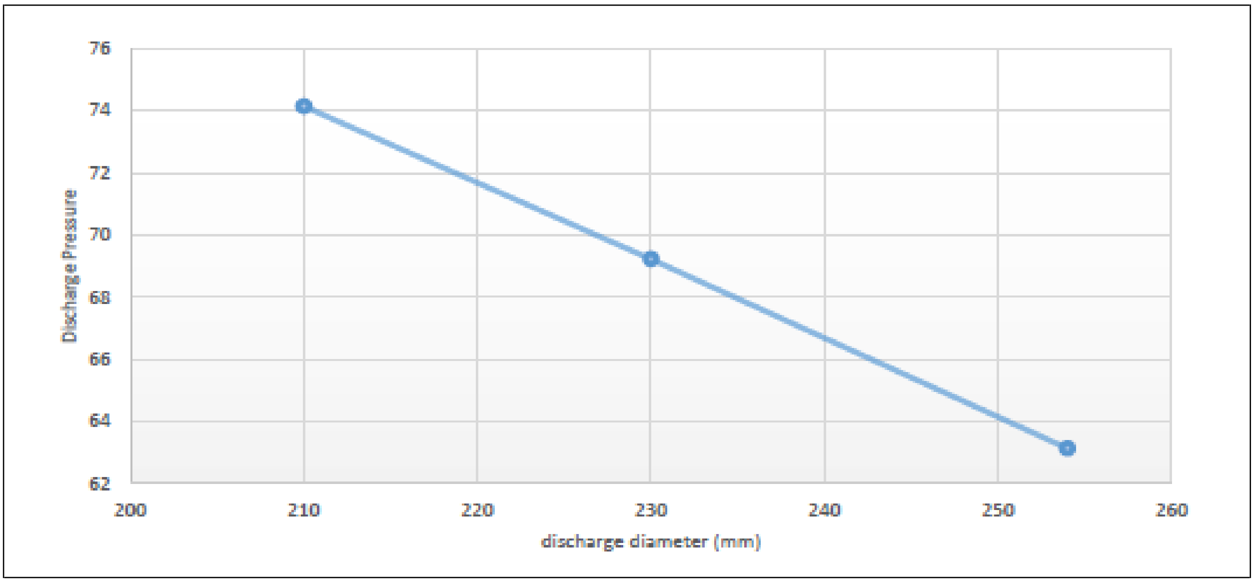


Figure 7: Graph of discharge diameter vs. discharge pressure

Figure 8: Graph of discharge diameter vs. maximum Von-mises stress

4 DISCUSSION

A series of three test tests were conducted whereby the discharge diameter was varied from 210, 230 and 254 mm. From these varied diameters, calculations were done to determine the discharge pressure that was used to obtain the maximum stresses on the Autodesk Inventor. The static pressure was obtained together with the total head by means of relevant formulas.

4.1 Interpretation of calculations

The discharge pressure was found to be increasing as the diameter at discharge decreased from 254mm to 210mm. This is due to the decrease in the outlet area which then increases the velocity of the fluid. It has been observed that as the velocity increases the head also increases by a relatively small margin. These results are expressed in a tabulated form and a graph of discharge and pressure is plotted.

4.2 Interpretation of simulations

Simulated results are populated from Autodesk Inventor and stress analysis results are obtained. Stress intensities on Autodesk simulation analysis are expressed in the form of different colours. The colour range expresses different stresses whereby the maximum stress is represented by a red colour, the minimum by a blue. The average stress zone is represented by a mixture of colours ranging from orange, yellow and green as displayed in the simulation report. It has been observed that as the diameter decreases the stress also decreases this is because as the diameter decreases the thickness increases hence increasing the strength of the pump material.

5 CONCLUSION

The relationship of maximum stress and discharge diameter can be seen as a linear, because an increase in diameter causes and an increase in stress. It has been observed that the maximum stress at the discharge area occurs where the volute has a minimum thickness. In order to reduce the maximum stress intensity, the following measures can be applied

- Increase the thickness of the volute
- Decrease the discharge diameter

Change the material from a low strength material to a high strength material. Cast iron is selected for the final design of the centrifugal pump. This selection is based on the material's convenience of machinability, cast ability, low stress concentrations and it's cost effective.

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CREATING LEARNING COMMUNITIES FOR FEMALE ENGINEERING STUDENTS THROUGH MENTORING

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ABSTRACT

South Africa faces a shortage of engineering skills and particularly a shortage of female engineers. Often students entering engineering programmes do so from positions of inequality in terms of schooling, finances and other resources. Along with these challenges, academia is also grappling with calls for decolonisation of the curriculum and humanising the pedagogy, while developing interventions to support, develop and retain engineering students. As a result, a Women Engineering Leadership Association (WELA) was established at a South African university as a learning community, and strategies and interventions were developed in the form of co-curricular interventions to support female engineering students and practicing engineers. The aim of this research is to investigate the potential benefits of establishing learning communities to assist in the development and retention of students within the context of the challenges facing South African universities currently. Accordingly, this research discusses the characteristics and benefits of developing learning communities and reports on data obtained from a survey conducted with student mentors who were members of WELA. The results of the survey indicated that learning communities could lead to more motivated female engineering students, increased life-skills, greater social tolerance and appreciation of diversity as well as increased personal and interpersonal growth. In addition, increased academic effort and a greater sense of self-efficacy were reported. It is proposed that the establishment of a learning community can benefit students from all disciplines in the institutional quest to support, develop and retain both male and female engineering students.

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1 INTRODUCTION

In 2010, the Council for Higher Education (CHE) noted that "students entering university do so from positions of extreme inequality, most obviously in schooling, but also in terms of financial and other resources" [1]. Furthermore, the CHE observed that higher education institutions had to consider the influence of teaching and learning practices, methodologies and pedagogical resources available and most relevant to students. Student background and academic readiness, socioeconomic factors, institutional culture and environment were identified as additional factors that could positively influence retention and throughput and produce desired academic results [1]. Therefore, Higher Education Institutions (HEIs) need to implement measures to attract more students, especially female students, to the engineering field.

Furthermore, universities need to engage with students as well as design measures and interventions to assist underprepared students to complete their engineering studies successfully. In addition, engineering is a profession that is very gender-biased [2], and Thompson (2015) [3] noted that 70% of women engineering graduates reportedly felt isolated in their jobs after starting their careers and, consequently, left the sector. It thus becomes apparent that interventions to attract, develop and retain engineering students, with a specific focus on women engineering students, is imperative for South African universities.

2 BACKGROUND TO THE STUDY

In 2011, with support from merSETA[1], the Women in Engineering Leadership Association (WELA) was established at a South African university. WELA goals include attracting, supporting and developing female engineering students to improve the academic success and retention not only of female students, but also of women already working in engineering-related fields. The underlying premise of WELA was to improve the self-efficacy of female engineering students by developing/cultivating/fostering a sense of belonging. In accordance with this mandate, a Leadership Development Programme was developed for female engineering students who are WELA members. This leadership programme, embedded in WELA, consists of various co-curricular interventions such as workshops, short courses, seminars and factory visits. As mentoring is regarded as a tangible expression of a humanising pedagogy, underpinning WELA is a mentoring role. Senior WELA mentors attend mentor-training workshops to prepare for the role of mentoring junior WELA members [4. As mentoring is regarded as a tangible expression of a humanising pedagogy, underpinning WELA is a mentoring role. Senior WELA mentors attend mentor-training workshops to prepare for the role of mentoring junior WELA members [4]. Given the composition of the mentors and mentees, combined with these WELA characteristics, it can be argued that WELA is a learning community.

Learning communities exist in many forms [5] and exhibit common academic and social features [6] that are mirrored in WELA. The importance of establishing learning communities is also grounded in the current atmosphere of uncertainty in higher education. As the academic community recovers and manages the impact of the 2016 #feesmustfall campaign, questions focusing on decolonising the engineering curriculum and entrenching a humanised pedagogy have become more pertinent. According to Salazar (2013:121 [7]), a humanising pedagogy is "crucial for both teacher and student success and critical for the academic and social resiliency of students". Universities can institute a humanised pedagogy by encouraging and actively pursuing the establishment of learning communities and a collaborative pedagogy [8], and these are goals that WELA strives to achieve.

This study overview provides a backdrop against which a survey was conducted with WELA mentors in their role as leaders of a learning community. The purpose of the survey was to gain an understanding of the factors that influenced the retention and development of female engineering students.

The findings of the survey can, firstly, provide greater insight into the challenges female engineering students face and, secondly, serve as a motivation to strengthen the development and establishment of learning communities. It is further proposed that this research would be applicable not only to female engineering students, but also to male engineering students and, possibly, have relevance for any student entering a university. This article reports on the findings of a survey presented to WELA student mentors who were asked to provide feedback on their experiences as engineering students.

3 LEARNING COMMUNITIES

At the beginning of each academic year, an invitation to join WELA is offered to all female engineering students across all five engineering disciplines. An applicant, who decides to join WELA, is required to complete a series of co-curricular developmental workshops over a four-month period to gain full WELA membership. On gaining membership, a mandatory two-year Leadership Development Programme must be completed. This allows the member to obtain a certificate that is offered as a short learning programme [4]. A learning community is formed through individual participation in the WELA leadership programme. The following basic characteristics of a learning community [9] is explicitly promoted by WELA:

- Organising students and academic staff members into small groups
- Developing/instituting an integrated curriculum
- Establishing student academic and support networks to help students
- Socialising students so that they are able to deal with university expectations
- Connecting academic staff to students in more meaningful ways
- Sharing of mutual learning outcomes by academic staff and students
- Providing a setting for a community-based delivery of academic support programmes
- Providing a lens through which the first-year experience can be critically-examined

As WELA's objectives are far broader than pure academic development, WELA intentionally promotes greater connectivity that, in turn, facilitates a seamless university experience. Owing to the various interventions and workshops, WELA members gain greater exposure to academic, university professional and support staff, which, in turn, allow students to be socialised into acquiring expected academic attributes. In so doing, students and academic staff were integrated in more meaningful ways that provided a context for the delivery of effective community-based academic support programmes.

4 ESTABLISHING A LEARNING COMMUNITY

Most learning communities include learning activities and promote complementary academic and social activities that extend beyond the classroom [5]. Zhao and Kuh [5] have extracted commonalities from several studies ([10], [11]; [12], [13], [14], [15]) revealing the range of benefits learning communities offer. These benefits include:

- Increased academic effort as a hallmark of positive behaviour change
- Greater diversity and social tolerance
- Measurable personal and interpersonal development

In addition, benefits relating to retention, success and personal development have been widely-noted. Being part of a learning community has also led to active and collaborative learning amongst WELA members, and fostered closer relationships with faculty and peers [5]. Studies have found that communities of learning have prompted students to create their own peer support groups that extend beyond the classroom. These students inevitably become more involved in both in-class and out-of-class activities. Furthermore, students who spend more time and effort on educational activities became more involved and take more responsibility for their own learning [18]. Other researches [5] have corroborated these benefits derived from participating in a learning community. These researchers observed that learning communities were associated with better academic performance, greater integration of academic and social experiences, skills development, increased competence and knowledge that contributed to an overall satisfaction of a student's university experience. Furthermore, it has been suggested [5] that forming learning communities is an important educational practice that could lead to the greatest success if students are introduced to different kinds of educational activities associated with learning communities early in their university experience.

5 WELA AS A LEARNING COMMUNITY

WELA members are required to attend a range of approximately 22 workshops, interventions and short learning programmes over a minimum period of two years. A team of academic and professional university staff members as well as external service providers present these offerings. Once WELA members become involved in several outreach and community projects, they gain access to a dedicated meeting venue for the exclusive use of WELA members. The venue, known as the WELA homeroom, is furnished with comfortable chairs and provides a study and group-work area. Members have 24-hour access to this space and use it on a daily basis for study group meetings, mentor/mentee meetings, completion of homework or for relaxation between classes [4].

One of the registered activities of the WELA Leadership Development Programme components is a mentoring programme. Senior WELA members are invited to be trained as mentors to junior WELA members. The mentors attend a one-day training workshop where they receive a comprehensive manual providing detailed guidelines to enable them to become effective mentors. Junior WELA members are assigned to senior WELA member on an annual basis. A concerted effort is made to match the mentor and mentee according to their engineering discipline. Mentorship is viewed as a critical component of the WELA programme owing to the potential impact mentorship can have on the learning experience. Research underscores the role of mentorship in improving assessment performance, reducing stress and anxiety as well as enhancing participation and engagement in the academic community, thus adding value to students, both as mentors and mentees [16].

6 RESEARCH DESIGN

This section describes the research procedure that was followed and the measuring instrument used.

6.1 Methodology

This research reports on selected qualitative findings that emerged from the mentorship survey completed by the 2016 cohort of WELA mentors at the commencement of academic year. A qualitative approach was followed to capture the phenomenological expression of the mentors' experiences which allowed for the extraction of meaningful information for thematic analysis. The aim of the survey was to determine the potential impact of the mentor as a leader of a learning community.

6.2 Participants

During the period this research was undertaken, 17 WELA members were trained as mentors and assigned to 47 junior WELA members (see Table 1).

Table 1: WELA members trained as mentors

Number of Mentees in Current Cohort	Number of Mentors in Current Cohort	Number of Mentors who Completed Pre-Mentorship Questionnaire	% response
47	17	16	94%

6.3 Data collection tool

At the beginning of the academic year, soon after the mentors had been trained and briefed, they were asked to complete a short "Pre-Mentorship" questionnaire comprising of eight questions using a 5-point Likert scale response format. Institutional ethics clearance was obtained, and participants completed a consent form prior to completing the questionnaire.

One additional open-ended question was included. The researchers intended to add a "Post-mentorship questionnaire" at the end of the academic year, but this was circumvented in 2016 owing to the #feesmustfall crisis. The findings from the pre- and post-mentorship questionnaires are under consideration for future in-depth research.

The mentors were asked to respond to the grand tour question, "What did you wish someone had told you?" This research reports on the mentors' responses to this pertinent question. The mentors were also required to identify the three things they wanted to teach their mentees. By using this semi-structured questionnaire format, mentors where required to anticipate what they regarded as the most important support required by junior WELA members. An excerpt from the questionnaire is illustrated below.

	I wish somebody told me this/ Three things that I want to teach my mentee
1	
2	
3	

6.4 Data analysis

Reponses to the grand tour question, "I wish somebody told me this" requiring "three things that I want to teach my mentee" were analysed by organising the data into categories based on themes and concepts [17]. The observed themes were coded and the data was closely-examined to observe and categorise phenomena [19]. This process was repeated until the data was saturated. The data categories are illustrated in Table 2.

Table 2: Categories of data identified

Categories	Number of responses
Mentoring importance	3 (6%)
Dealing with failure	7 (13%)

Developing holistic skills	13 (25%)
Fostering perseverance and motivation	14 (26%)
Dealing with academic issues	16 (30%)
	53 (100%)

From Table 2, it is evident that the themes identified and represented the majority of responses related to dealing with academic issues.

7 FINDINGS AND DISCUSSION

Feedback and responses from the mentors were based on their personal experiences as senior WELA members within their learning community. Owing to the generational nature of the mentorship programme, the cohort of mentors would have been junior WELA members the previous year, therefore, many of them would have continued their mentor/mentee relationship with their mentors as their studies continued. As a result, the cohort would be active in both roles as a mentor and mentee within a learning community context.

In Section 7.1, where possible, direct quotes have been used to capture the voice of the mentors.

7.1 Importance of utilising mentors

Mentors reported that they would encourage their mentees to “make full use of the WELA mentor” assigned to them, regretting that they themselves had not fully-used their mentors in their junior WELA year. Mentors reported that the mentorship programme provided a safe space in which they could practice their leadership and teamwork skills. They also found that they transferred newly-acquired skills and character virtues into the classroom. This transference became apparent when they noticed that they had become more assertive in academic classes and found themselves leading class team projects effectively. In addition, they reported that they valued the opportunity to be in a position where they could help and support their female engineering mentees, noting that the majority were in their first year.

By adopting a mentoring process, a learning community was created. The primary aim of a learning community is to socialise students through meaningful experiences in a small group so that they can engage with the expectations of their engineering faculty more effectively [9].

7.2 Dealing with failure

Generally, engineering students performed well academically at high school. However, when confronted with a new university environment charged with higher social and academic demands, they often experienced an initial drop in their marks. Consequently, students reported, “at school we were in the top ten, but at university we are failing!”

Within the intimacy of the mentorship relationship, vulnerability to share a setback such as failing a module was enabled. Dealing with failure as a student is critical since, if left unresolved, the student may define herself as a failure and this negative mind-set could become an invisible barrier to success. Since a learning community is about sharing experiences, Salazar [7] argues that a humanising pedagogy is “critical for the academic and social resiliency of students”.

Strategies to build a community of resilience included reminding mentees that failure could happen, and they needed to accept that failure was "part of the game". Concerns about failure, or perceived failure, was a recurring theme in the feedback provided by mentors. Furthermore, mentors felt that it would be important to caution mentees and inform them that unplanned events could occur in their personal and academic lives, and to remember that "you don't get everything you wished for". By sharing their own real-life challenges, mentors attempted to normalise the students' journey to success. This practice normalised failure experiences, and students realised that others experienced similar challenges. This realisation made their challenges more manageable and reduced their sense of being overwhelmed or emotionally-isolated.

This exchange meant that mentors became the face of a humanising approach, and, in so doing, they reduced stress and anxiety in the mentees. In addition, mentors enhanced the mentees' participation and engagement in the academic community [16]. This demonstrated that a WELA community was a means of creating a humanising pedagogy within a learning community.

7.3 Holistic skills development

Several mentors listed skills to which they would like to teach or expose mentees, based on the gaps they identified from their own experiences. These skills were related to budgeting, flexibility, adaptability, leadership skills, teamwork, dealing with pressure, stress management, managing time, planning, developing patience and using opportunities "to expose oneself" by working with other engineering students. The range of skills listed revealed the level of insight that the mentees had gained through being involved with others [5]. By sharing their knowledge and experiences, and identifying the opportunities for growth and development in their mentees, the mentors raised their own self-awareness and awareness of others within their learning community.

7.4 Fostering perseverance and motivation

The development of perseverance and motivation does not occur in a vacuum, and the WELA community demonstrated that it flourished in the context of shared goals. The development of these skills underscored the intentionality of the mentors to motivate mentees so that their mentees could actively pursue goal achievement.

The majority of the mentors stated that they aspired to motivate their mentees by encouraging them to persevere in their studies. They would remind the mentees that "university is hard … engineering studies is hard", but a university life, and especially one that involves WELA membership, "is a lot of fun." They would tell their mentees that they would "gain valuable skills and knowledge" by belonging to WELA. They would also emphasise that mentees must "never give up, work hard, and endure" since "life is what you make it". Furthermore, mentees needed to believe in themselves, develop a drive to do anything that they had set their minds to and be consistent in their pursuits. In addition, mentees should stick to their commitments and stay focussed. These response excerpts illustrated that the WELA learning communities were founded on reaching shared goals.

7.5 Managing academic demands/challenges

Dealing with academic challenges was a theme that recurred most frequently in the findings. In particular, the mentoring process was intentional in helping students adjust to university life and underpinned the community-building mandate of WELA. As a result WELA, as an extra-curricular organisation, served as a learning community fostering social integration. In addition, WELA, as an 'out-of-class' experience, positioned female engineering students to take responsibility for their own learning [18], [5].

The mentors stated that they would advise their mentees "to take their studies seriously", "to pay attention in classes", "ask questions" and "listen to what the lecturer says". They believed that class attendance was very important and emphasised "not falling behind with their academic work". Furthermore, mentees needed to become involved in university life, but needed to strive to maintain a balance between extra-mural, social and academic activities. Some mentors mentioned that they never realised they would be spending "a whole day at school (university)" and that most mornings they would have to "wake up very early". This emphasis on sharing knowledge underscored its contribution to WELA as a community of learning.

8 CONCLUSION AND RECOMMENDATIONS

By adopting a mentoring process, it could be argued that WELA had established a learning community. It had achieved this by weaving strands of shared knowledge, shared experiences, shared goals and expectations among female engineering students in the WELA community. A collective idea of promoting awareness that led to growth in self and in others was a key principle that made the WELA community a strong base for developing mastery over transitional challenges at university.

Feedback from mentors as senior engineering students revealed aspects of student life that needed to be addressed by WELA and academic departments. Focussing on and actively addressing these issues could lead to increased academic effort as well as the promotion of diversity and personal development. Furthermore, new and important life skills could be developed leading to an increase in overall satisfaction with the university experience. It thus becomes evident that learning communities have an important role to play as an educational practice that could contribute to student success and retention.

The feedback from the mentors clearly demonstrates that through a mentor and mentee relationship, WELA had intentionally-created the notion that each of the female engineering students was an architect of her own learning. It is, therefore, proposed that learning communities be established across all disciplines so that the benefits thereof can be extended to all students in the institutional quest to support, develop and retain both male and female students.

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DECODING PRODUCTION EFFICIENCY THROUGH ASSEMBLY LINE BALANCING AND LEAN: A CLOTHING MANUFACTURING PERSPECTIVE

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ABSTRACT

The study explores the impact of line balancing and lean application principles on clothing assembly production. Lean thinking and its principles are successfully applied to the manufacturing and operational environment to harness improvement and productivity. In today's world, it has become increasingly important for companies to be able to compete on a global competitive market. Customers are constantly looking for manufacturers that can produce high quality products at an affordable price, faster, and meet all of their requirements. For companies to be able to compete on this level they must strive to produce their products more effectively and more efficiently than ever before. Line balancing is part of lean methodology, and has been increasingly popular in the clothing industry, because it offers organizations a proven sensible path to long-term sustainability. This paper decodes the application of assembly line production in the clothing industry through the application of case study methodology to provide a fundamental basis for productivity improvement.

Key words: lean, line balancing, work measurement, method analysis

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1 INTRODUCTION AND BACKGROUND

The clothing industry shrunk by approximately fifty percent over the last 4 decades. This has meant job losses to thousands of clothing employees. The industry is comprised of small, medium and large manufacturers. The larger manufacturers shrunk to become small, medium and micro enterprises (SMME's) with the elimination of industrial engineering departments. This led to management taking decisions in areas, which they are not familiar to operate. More organisations are feeling the inefficiencies and loss of productivity due to a lack of strategic focus. Given the increased challenges facing organisations today, the trend is either to keep up or disappear [1,2,3,8].

The phenomenon of globalisation is spreading worldwide and is impacting on all organisations. Markets in South Africa opened up phenomenally after 1994 and trade between nations increased. Globalisation and international competition became the driving force of organisations [5;7;9]. Due to the elimination of industrial engineering departments, it is necessary that management of organisations understand the importance of industrial engineering. The industry is grappling with labour inefficiency, poor quality, late delivery and poor productivity. Industrial engineering process improvement tools could save the South African clothing manufacturing industry through planned strategies, leadership and commitment. In this study, line-balancing methodology is decoded as case study. A sample of 20 industrial engineering personnel were chosen through the snowballing technique. Informal discussions were held to solicit the necessary information [6;8].

2 METHODOLOGY

Principally the qualitative approach was adopted as it enables the researcher to focus in a particular area and gather information through various means. In this case study, data was collected through the review of existing literature and triangulated with informal and telephonic discussions. An exploratory research design was followed in this study. An exploratory research design is undertaken with the objective to explore an area where little is known or to investigate the possibilities of undertaking a particular research study [10].

3 LITERATURE REVIEW

Lean is a philosophy that can be applied throughout the entire business process. Lean is a strategy that affects every aspect of the organization. Although, lean practices started in manufacturing, the methodology can be applied in every aspect in an organization. Lean based methodology focuses on eliminating non value-added activities and streamlining operations by coordinating all of the activities. Non- value added activities are all activities that do not directly increase the value of a product or service. The primary objective of lean manufacturing is to improve manufacturing operations, increase productivity, reduce lead time to deliver product to customers, and improve quality of the products. A lean operation is a flexible system that uses considerably less resources, inventory, people, and floor space than a traditional operation. These improvements are accomplished by eliminating non- value added activities, shortening manufacturing lead times, improving product flow, and establishing a process of continuous improvement [24;25;27]. Lean thinking is a way to specify value, line up value creating actions in the best sequence, conduct these activities without interruption whenever someone requires them, and perform them more effectively. The key lean principles are: define value from the customer's perspective, identify the value streams, make the value flow, implement pull-based production, and strive for perfection continuously.

The key goal of the 5 Lean Thinking principles are to establish a perfect value stream by continuously identifying, and eliminating activities considered waste, and focus on activities that truly creates value [23;24].

Quality is meeting or exceeding customer expectations. The customer is the one who makes the decision if a product is considered to be a quality product or not. It is the responsibility of an organization to be able to meet all of the customers' requirements in the most efficient way possible. If the company cannot meet all of the customer's requirements, the customer will most likely find another supplier who can meet the requirements, or they will not continue to purchase products in the future. Once the organization has determined that the product design does fully satisfy customer requirements, it then becomes the responsibility of the manufacturing department to be able to produce the product so that it meets the specifications of the product design. The term quality of conformance is used to describe that the manufactured product consistently upholds the specifications in product design, as this is of the utmost importance in clothing manufacture [11;12;15]].

Defect detection uses inspection, testing, and analysis to determine the existence of defects. This information is then used to draw conclusions on the quality of the overall process. The value stream in clothing manufacture is measured continuously to ensure adherence to time schedules. Defect inspection helps ensure that the faulty products do not reach the hands of the customer. The problem with defect detection is that it does not improve the quality of the product nor does it help reduce the amount of waste associated with rework and scrap [13;14;15].

Line balancing can be regarded as a low level and detailed planning stage which concentrates on planning the work load for each machine and worker within the sewing line. It deals with optimally determining outputs from each worker and workstation while ensuring that the target achievement per style is synchronized with the planned factory target and, hence, the garment labour cost. This is not complicated and the formula to calculate the theoretical balance is simple. The challenge is to ensure that supervisors and workers understand what is expected and deal with issues that affect the balance timeously and adequately [16;19;20].

4 RESULTS AND DISCUSSION

Introduction

In this section the process of decoding line balancing and the application of lean principles as applied to line balancing is explained through the gathering of information from industrial engineering personnel in the clothing industry. The information is presented in themes of particular interest to clothing manufacturers.

Line Balancing is the process of assigning tasks to workers and workstations, so that everyone has the same amount of work to perform. No one is over or under-burdened and work flow is smooth with minimum delays. This is evaluated through work measurement and method studies. Work measurement enables the establishment of standard times for each operation while defining methods of operation.

Important aspects to consider when balancing a line:

- Knowledge of the product being manufactured
- List of operations that can be grouped together during manufacturing
- Capacity of the work places in terms of machinery and worker skill levels

The main steps to balance a line properly are:

- Constructing an Operation Sequence list (operations, standard times, machinery and work-aids)
- Calculation of the labour requirement for each operation
- Determining a theoretical line balance
- Allocating the workers
- Determining the best possible flow
- Balance Control

Line balancing can be separated into the following stages:

- SETTING UP the line
- RUNNING the line

4.1 Setting up a line

The set-up stage generally deals with mathematical formulations, practical allocations and finally understanding where problems can be expected and what to do to overcome these. The following 2 methods may be used to establish the required worker allocation and expected outputs:

- Establish how many workers will be required to achieve a required output.
- Establish the output to be expected from a specific number of workers.

For either method the following information is required:

1. A list of all processes required to manufacture the product i.e. The Operation Sequence,
2. The standard minute values for each process.
3. A list of machinery and equipment required.
4. The number of workers to be used.
5. A list of the skills possessed by each worker i.e. Skills Matrix/Chart.

4.1.1 The Operation Sequence

This is a list of all processes/operations involved in the manufacturing of a particular product and in the correct sequence. Knowledge of processes performed that may be split and re-grouped together in order to maintain some level of specialization and improve efficiency. A listing of all processes together with the standard times for each, the machinery required and special work-aids and attachments. The processes/operations will usually be split and listed logically and in sequence under each part name in the product.

4.1.2 Theoretical calculation of the line balance.

1. Using the operation sequence enter the standard minutes against each process/operation. Total all the operation times for the style (total standard minutes for the style).

2. Divide the total time by the total number of workers allocated in order to establish the "Pitch time".

3. Calculate the theoretical operator allocation per process/operation by dividing the each operations standard time by the "pitch time".

4. Round the theoretical number of workers to the nearest quarter/half to get an approximate idea of how workers will be allocated in practice.

5. If there is an odd "half" operator, round this to the next whole number. This worker can be used to help out in problematic areas on the sewing line.

6. List the type of equipment required for each operation at the side of the rounded-off figure.

7. Where "half" operators are required on specific processes/operations, attempt to combine this with another process requiring similar equipment to ensure that the worker is optimally allocated.

8. Calculate the output to be expected from each operation per hour. (multiply the number of allocated workers per operation by 60 minutes then divide the answer by the operation standard minute value e.g operators required per operation x 60 ÷ operation standard time.

9. This establishes the theoretical number of garments to be produced at each operation.

10. Allocate operators to each operation based on your knowledge of the operators who will give you the best possible output on each operation or combination of operations. Using the skills matrix/chart will facilitate this function.

11. Establish the Theoretical Output to be expected from the allocated number of workers i.e. number of workers X 60 divided by the total standard minute value for the style.

12. Establish the lowest output process/operation by reviewing the output column on the line balance (this will be the bottle-neck process on the line and usually restrict the output to be expected.

13. The lowest output divided by the theoretical output will give an idea of how efficient the line is balanced.

This exercise is expected to be completed well in advance of the new product going into the production line. The supervisor's journey then begins with the objective to ensure that the allocated workers begin their jobs on the new product at a pre-determined time and that they achieve the required output targets. Since these output targets are also based on a mathematical equation these will require 100% performance from each worker. Should workers be unable to achieve 100% performance then additional challenges may surface. It may be an idea to apply worker efficiency levels to each of the expected output targets calculated in step 8 above. This will shed new light on the line balance, however, supervisors and managers will be forewarned and can be able to adjust plans and anticipate problems before the product reaches the line.

4.2 Running the line

4.2.1 Keeping the Line Balanced

This is the final stage of the line balance and is concerned directly with direct supervisor interaction on the sewing line. Even though a great deal of planning and co-ordination is undertaken at the beginning of a new style it should be expected that the balance may not be maintained due to different reasons viz. changes in performance and off standard time. Generally short term changes can be overcome by maintaining a level of work-in-progress. Indications of trouble generally are visual on the sewing line i.e. work build up (bottle-neck) at a particular operation or operators sitting idle.

Supervisors are expected to use their experience and skill to overcome these situations by constantly anticipating these problems and planning ahead so that production losses are minimized or avoided. It is, therefore, necessary for the supervisor to continuously reassess the situation and constantly re-balance the line. A thorough understanding of what can be done by the supervisor is required in order maintain the line in balance.

4.2.2 Problem Solving on the Line

Most solutions to problems experienced exist within the factory and it is the management's responsibility to use their acquired knowledge and skills to overcome the problems. Anything that stops an operator from continuously working will have a direct or indirect impact on the balancing within the sewing line. If the impact is not felt immediately then one should expect it at sometime within the next few days. In order to minimize the effect of a problem on production it is essential for a supervisor to have an understanding that "every minute is important". Within the sewing line, 1 minute could mean a loss of between 1-5 garments at any operator workstation. Any delay in approaching the problem will immediately and solving it will lead to a loss of work-in-progress at some stage. There is always a root cause to any problem and this has to be overcome. It may sometimes require a deeper analysis and understanding of the problem in order to lead to the final solution. Alternately, and in most cases, the fast speed of the sewing line does not permit the time needed for root-cause analysis and some quick work-around will be implemented. Quite often this overcomes immediate production losses but creates the issue of increasing the cost of production. Since every garment contributes a certain amount of money to the running costs and profit it is essential that management minimize and/or eliminate losses. At some stage when production is back on target the problem and root causes should be reviewed in order to implement the correct solutions.

4.2.3 Lack of skilled workers

The sewing industry is regarded as the most unskilled industry in the manufacturing sector because most of the jobs require manual labour. It is easy to set up sewing factories in remote parts of a country where there is an abundance of labour and teach people to sew in a relatively short time period. However, the supervisor will know that this is not easy to maintain. Very often situation will arise that new styles will require specialized skills in order to meet production targets.

It is becoming more necessary to have additional multi-skilled workers (floaters) within every sewing line to protect production rates against the effects of absenteeism, low skill levels, un-anticipated delays etc… There should be a minimum of one additional machinist per sewing line. Usually 10% caters for the effects of absenteeism and down times experienced within the line. The additional 10% workers should possess multiple skills and be able to adapt to any situation on the line and be expected to move from one operation to the next at any time during the day when required.

All operator skill levels should be updated on a constant basis so that the latest skill level is always available and adaptability is the key to overcoming production challenges. Sewing factories should become accustomed to the idea of constant change as this facilitates adaptability to new operations. This can only be achieved by continuous skills upgrading i.e. every worker should be trained to perform multiple operations.

4.2.4 Absenteeism

It should be understood that people do not only stay away from work due to genuine issues. Sometimes people stay away because they feel the factory or management has been treating them badly. Supervisors and managers need to be tactful when dealing with workers, especially when a new style starts and it has some difficult operations. A multi-skilled worker will help to ease situations of absenteeism. Sometimes additional incentives can be implemented to alleviate the absenteeism situation.

4.2.5 Sewing Machines

One has to ensure that the correct machinery and equipment is available when required and these are in efficient working condition. It is also advisable to have additional machines to cater for instances when machine breakdowns do occur. Mechanics should understand the effects of machine break down on the planned production and should make every attempt to avoid major repairs in the middle of the sewing line. Approximately 5 minutes should be sufficient to assess, repair or make a decision about the extent of work required to fix a machine and get the operator operational again.

In order to accommodate this there should be available space within the sewing line and there should be a spare machine available either on the line or in the workshop. The mechanic should have a preventive maintenance program in place so that major breakdowns can be avoided.

4.2.6 Work-in-progress levels

Work-in-process protects the line against unanticipated delays and ensures that production will continue even when some workers are affected by problems. A reasonable amount of work-in-progress is about 30-60 minutes of work between operations. If level of work-in-progress fall below 30 minutes then it will affect the management reaction times to problems and lead to the delays. It is not necessary to have more than 60 minutes work-in-progress for any operation.

Work in progress should always be kept in good order and fully visible. Supervisors should understand that the amount of work waiting for each operation will increase or decrease over a period of time, and it is not until the amount becomes too much or too little that he/she should take action. Supervision could carry out ‘balancing duty’ regularly at two hour an interval, checking every operation on the line to ensure that the Work In Progress level is within the correct limits. If a bottleneck keeps occurring at a particular place in the line, improve the method to eliminate the bottleneck, or if possible reduce the work content of the operation.

4.2.7 *Poor Operator Performance*

Standard times are based on the level of performance of the qualified worker. During the setup stage of line balancing these standard times are used. Workers do not perform at the same levels throughout the day and every day of the week. Lack of skills and knowledge of the job and a variety of issues may affect the performance of a worker.

Some steps that can be used to overcome these problems:

- Check that the operator selected has the skill to perform the work at hand
- Check that the worker is using the correct method
- Check that the machinery is in good working order
- Ensure that work supply is sufficient and no idle time occurs
- Check the speed of the operator and compare to the expected speed
- Boost operator performance by taking production scores for shorter time intervals

4.2.8 *Quality Problems*

Quality problems that can affect the smooth running of the sewing line are to be expected and these arise from different sources. In order to overcome quality problems and minimize the effect on the balancing of the line it requires quick thinking and fast reactions on the part of the supervisor and technical or quality control staff.

The supervisor has to have a thorough knowledge of the specifications. This is usually discussed at the pre-production sample stage, but notes are also available and should be attached to the sample. Furthermore, supervisors should ensure that quality management systems provide instant information for them to act upon. The inline quality controller is also expected to play a huge role in early detection of problems. There should be team working between the inline quality controller, workers and supervisors to solve these issues as quickly as possible. Relationships with workers should be such that they are not afraid to inform supervisors about the mistakes and defects made by them.

VBCS

April 28 2010

Line Balance Report

Order: 1111

ID	Operation	Machine	SMV	Theory Bal	Round Off	Output	Efficiency
0	Attach Label	SNLS	0.095	0.22	1	631	18.23%
1	Join 1st Shoulder	SNLS	0.32	0.75	1	187	61.5%
2	Attach Neck Binding	3TFL	0.31	0.73	1	193	59.59%
3	Join 2nd Shoulder	5TOL	0.28	0.66	1	214	53.74%
4	Tack Neck	SNLS	0.19	0.45	1	315	36.51%
5	Attach Sleeves	5TOL	1.51	3.55	4	158	72.78%
6	Join Sideseams	5TOL	0.96	2.26	2	125	92%
7	Hem Bottom	3TFL	0.49	1.15	1	122	94.26%
8	Hem Sleeves	3TFL	0.52	1.22	1	115	100%

Total SMV = 4.68 | **Number of Operators = 11** | **Line Balance Efficiency = 81.56%**

Theoratical Output = 141 | **Practical Output = 115**

Table 1: Line balanced to target of 115

The following figure provides the flow of garments through the production line. Each stage requires effective balancing for optimal production and efficiency. The components of a garment are separated into preparatory and assembly sections. For example, in a shirt the pocket, cuffs, sleeves, fronts, collar, and back are prepared before if goes to the assembly section.

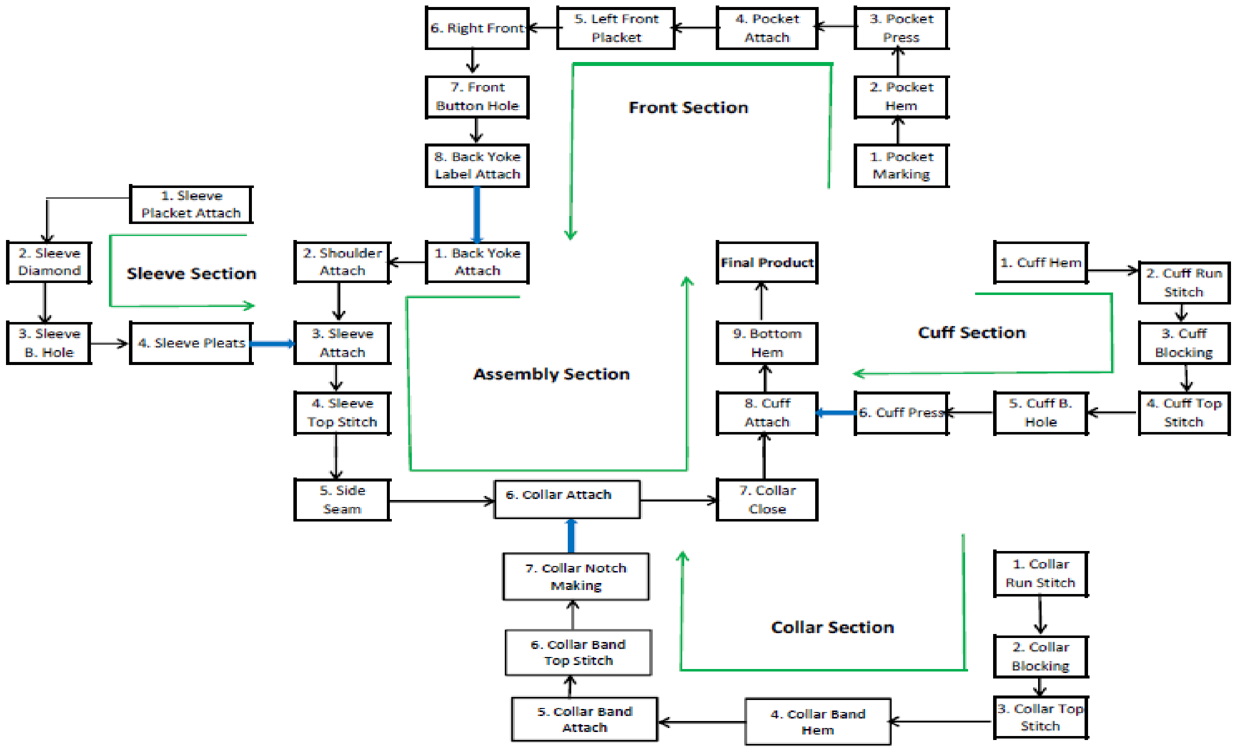

Figure 1: Recommended flow layout

4.2.9 Quality Management

Quality is conformance to customer requirements and quality management on the other hand ensures that product produced are consistent at all times. Quality Management comprises of quality planning, quality assurance, quality control and quality improvement. These four components are key to the recommended process flow layout incorporating Lean Thinking (LT) principles, the activities optimized through line balancing.

5 CONCLUSION

This research study aimed at exploring the impact of line balancing and lean application principles on clothing assembly production. Line balancing conducted on the clothing assembly line and application of lean principles resulted in an optimized process. The results showed that the intervention of line balancing and lean thinking improved overall plant productivity, flow, efficiencies, effectiveness and customer centricity. The foundation of lean is that the customer defines value and meeting customer requirements first time, everytime [13;14;18].

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INVESTIGATING HUMAN BEHAVIOUR IN QUEUES

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ABSTRACT

Queuing theory is the study of waiting, specifically how any type of queuing structure will perform given arrival and service rates. Mathematics and analytical methods have been used but often the human side is often neglected. This study focused on studying the behavioural impact of queues. Two experiments were conducted to test human behaviour in queues; one to test the impact on both the servers and clients in terms of customer's queue length, waiting time and cashiers service time, the other to test perceived waiting times by customers.

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1 INTRODUCTION

It is reported that the average American spends around two years of their life waiting in line [1]. Research by Dutch food retailers found that the most aggravating aspects of shopping is the very long queues [2]. Long waits in a queue more often lead to customers' dissatisfaction, but interestingly for some customers it is not the long wait that leads to the dissatisfaction but the boredom and uncertainty of whether they'll receive service or not and the uncertainty that leads to greater dissatisfaction. This dissatisfaction gives businesses a bad reputation and major losses due to lost business [3]. The solution might be to add more cashiers which will increase cost. However, managers are usually faced with the compromise of keeping customers happy while keeping cost as low as possible in order to maximize profits in their businesses [4].

The theory of queuing systems was first studied in 1908 by AK Erlang, a Danish mathematician through mathematical analysis [5]. Queuing theory measures the performance of the queue which would translate to customer satisfaction based on the following: the average waiting time of the customer, the average expected length of the queue and also the cost of waiting and lost customers. To create queuing models, scientists typically make use of probability distributions such as Poisson distribution for discrete events to simulate the number of arrivals of customers and the exponential distribution for events that are continuous, such as the time between arrivals, and service time [4].

Particular interest has been placed on two queuing structures in the past: single and multiple parallel queues. In a single queue, customers line up and the first in line moves to the next available server (sometimes referred to as an agent or cashier). In a multiple parallel queue system each server has their own queue which they are responsible for, the queueing structure allows customers to jockey in between queues (i.e. to moving between queues if they feel as if their queue is moving slow). The queue length may vary slightly over time as compared to the single queue model where customers cannot jockey however reneging or not joining the queue is a possibility in both systems if the customers are greatly dissatisfied. The two queuing systems are illustrated in Figure 1.

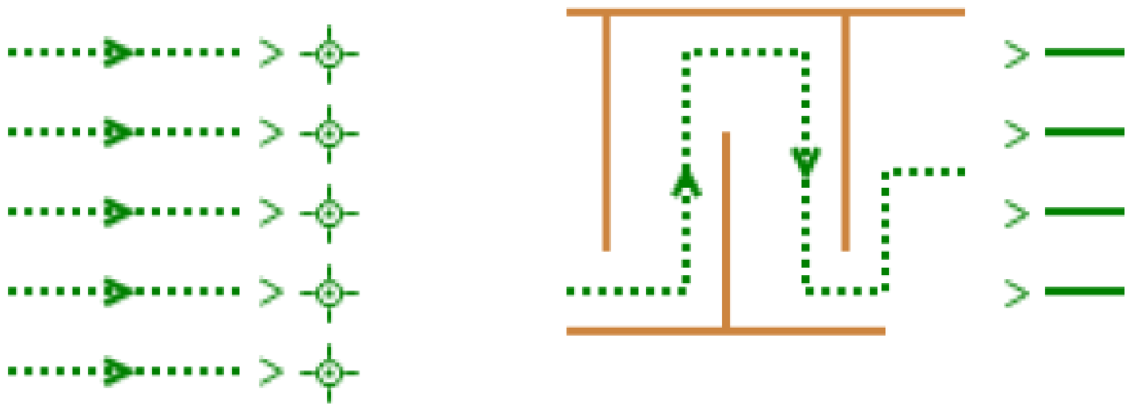

Figure 1: A multiple parallel queuing system (left) versus a single queuing system (right)[6].

The mathematics behind queuing theory has shown that the single queue multiple server system has better utilization and therefore much shorter customer waiting time than that of a multiple queue multiple server system queue i.e. for the same number of customers, one long single queue moves faster than many individuals' queues for each server. Multiple research has been done and proofs of this exist including research by Koka et. al [7] in their article "Single and multi-server queuing models" with derivations of equations and proof that single queues do indeed perform better than multiple parallel ones.

However, over the years, management, scientists, businesses and even engineers have realised that there is a great need to look at the human behaviour side and not just the analytical side when trying to solve queuing problems [8]. This is because there are psychological factors that impact how queues are perceived. Improving the customer experience as they wait is a very important topic that needs more attention and research.

A great example of this is with the increase of high rise office buildings in Manhattan during 1950s. Workers complained about the very long waiting times for the elevators during the morning times, lunch and knock off time. The engineers suggested that there is no way to increase the service rate as the elevators were fixed. Management looked for advice and a suggestion to put full length mirrors from the floor to the ceiling was proposed. After these were installed the complaints of long waiting times reduced to nearly zero. Credit was given to the fact that the experience of the customers while waiting in the line was greatly improved and customers did not get bored while waiting in line [9].

2 LITERATURE REVIEW

Maister [10] proposes that customers experience waiting to be shorter when:

1. they have something to do while waiting;
2. they are actually in the process of service or think that the service has already started while they are in the queue;
3. they don't experience anxiety or worry for what is going to happen (such as food running out while they are in the queue);
4. they know how long the wait is going to last;
5. the reasons for delays are explained to them;
6. rules for queueing disciplines are fair; and
7. the service is considered to be valuable e.g. when patients wait to receive medication.

According to Professor Richard Larson of MIT [11], customers value fairness in comparison to the duration of the wait since queues often work as social systems. This also results in customer experience and satisfaction being much better in a single queue compared to a multiple queue. This is because in a multiple queuing system one queue might be moving faster and customers that arrive later in that queue might be served first.

He also states that another type of queue that is usually experienced is the celebratory queue, where customers would instinctively join a very long queue for a certain product [11]. A great example is with the yearly release of new iPhone and customers wake up early to join very long queues that would extend for kilometres. This shows that the experience of waiting in a queue or the end-product can sometimes be more important than the waiting time itself as this is a celebratory experience.

While customers wait in the line, they experience a trade-off between two psychological forces namely the urge to abandon the queue as the wait continues (waiting disutility) vs the urge to continue when the end comes into sight (completion commitment). Janakiraman et. al [12] concluded from experimental studies that the relative weight of these two factors is affected by i) the number of queues ii) the knowledge that comparative progress in these queues and iii) the presence of external aids such as clocks to measure the awareness of elapsed time.

Companies have developed ways of improving customer satisfaction especially with the use of the aforementioned distractions. Disney World one of the largest entertainment companies, experiences some of the longest queues compared to any other company where customers waiting up to 3 hours for a popular 10-minute train ride [13]. Most popular attractions generate very long queues and in order to improve the experience as mentioned before, the queues for the rides have been turned into an interactive experience using interactive shadow effects and sounds. This means that while customers wait for a certain ride they are kept distracted from the long line and the queuing experience improved which reduces complaints of the long waiting times.

A study by Pruyn et al. [2] aimed to identify psychological factors that were involved in the reactions towards queuing and customer satisfaction. Three studies were conducted and the following findings were made:

- In the sample population tested, people go through an average of 2.1 waiting situations per day with an average wait of 14.5 minutes per wait during the mornings in traffic and purchasing food, exceeding half an hour per day on average.
- Customers evaluate a service based on the perception of the waiting time and the speed of the service.
- The waiting time and the environment were the most influential factors when comparing customer reactions for single versus multiple queues, while the actual queuing systems had minor effects on customer satisfaction. They also concluded that cashiers actually work faster in a multiple parallel queuing system compared to a single queue.

Shunko et. al [14] studied the impact of queue design on worker productivity. They considered single and multiple parallel queues and queue length visibility, with fully visible and blocked queues. Their research was conducted in controlled environment where human cashiers served customers on a computer through a virtual grocery store, with a total of 729 participants that acted as cashiers.

A cashier would serve virtual customers by operating a virtual till by doing non-discretionary tasks to reduce the trade-off between quality and speed of work. The human cashier’s co-workers were automated on the computer in order to reduce social bias from interpersonal group dynamics. The digital customers were set to arrive at a fixed rate as a varying arrival rate would affect the cashier’s behaviour.

Their tests showed that [14]:

- The single queue structure causes cashiers to slow down. In a multiple parallel queuing environment, workers feel that they are responsible for their queues’ progress. In a single queue system, cashiers work together in order to move the queue and each cashier is less motivated to work quickly as there is dispensability in effort as supported by Karau and Williams [15] in their article “Social Loafing: A meta-analytic review and theoretical integration”.
- Blocked / poor visibility of the queue also causes cashiers to slow down. For cashiers to see the impact of their working speed, they need to have a full view of the queue. Workers become motivated to work faster when they have immediate feedback on the queue length i.e. as they watch their queue shrinking, known as feedback saliency.

The research received criticism because it was in a controlled environment. Other researchers stated that it is realistic since the role of the cashiers can be fulfilled by anyone and the learning curve is relatively low. Further research is to be done through experiments of changing the queue structure to determine whether or not cashiers actually work faster in a multiple parallel queue scenario compared to a single queue. Other human impact factors the affect service rates and waiting times are also to be determined.

3 METHODOLOGY

Two experiments were conducted to observe waiting time and human perception of queuing on university students waiting in line for food. In the first experiment the effect on waiting and service times of a single versus multiple parallel queues were measured at a fast-food restaurant on campus. In the second experiment a distraction was placed near the queue of the campus dining hall to measure the difference in customers’ perceived versus actual waiting time with and without a distraction.

The steps of the two experiments were as follows:

1. Identify the queue to study.
2. Observe the current as-is state of the queue for one day.

3. Do the intervention to observe the change in queue and human behaviour.
4. Observe the new state of the queue for another day.
5. For the first experiment, discussions were held with the cashiers at the end of the second day,
6. Analyse and interpret the collected data.

The two experiments are described in further detail below.

3.1 Single versus multiple parallel queues

The first two days, the waiting and service times of single queue and multiple parallel queue systems were recorded and compared at a university fast-food counter with two cashiers. Queueing barriers were used to arrange single and multiple queue formats. Customers would queue to place their orders and after the order was ready they could collect it. Discussions were held with the cashiers at the end of the two days. Initially only a questionnaire was intended to be handed out to the cashiers however due to their busy schedules a discussion with the majority of them proved to be feasible where they could freely express their opinions. A total of 5 out of 6 workers took part in the discussion.

Customer's arrivals were observed from 9:30 am. to 12:30 am, then again from 14:30 pm to 16: 30 pm. The arrival times were captured as well as the times when orders were placed and when the orders were received. The lunch period from 12: 30 to 14: 30 was not captured due to the very high congestion which made it difficult to accurately capture data.

On the first day, a sample size of 352 customers was captured for the single queue with two cashiers experiment. The multiple parallel queue with two cashiers experiment was conducted the following day at similar times and time study data was captured. It was also important to usually direct customers to join the second queue from time to time as the queuing barriers wouldn't be as visible at the back of a very long queue. The multiple parallel queue would usually shift back to a single queue and this would cause slight bias in the processing of the multiple parallel queue and this was usually the case during high congestion of people. A sample size of 459 customers was captured for the multiple parallel queue experiment.

3.2 Customers' perceived versus actual waiting time

A second separate experiment was conducted to compare customers' perceived vs actual waiting time. In this experiment the available distraction that was used was a television that was in the direct path of the queue. The television was turned on for one hour and then off for another hour to test whether customers perceive waiting times to be shorter when there is a distraction i.e. when the television is turned on.

The actual customer arrival time (when joining the queue) and time which the order was placed were captured to calculate the queueing time. Their response of how much time the customers thought they spent in the queue was also recorded and compared to the actual waiting time. In this experiment, a sample size of 63 customers was captured with the distraction and a sample size of 72 was captured without the distraction.

4 RESULTS

The results of the two experiments are given below:

4.1 Single versus multiple parallel queues

Arrival rate is the rate at which customers arrived into the queuing system. Arrival times of customers for both the single and multiple parallel queue experiments were captured. The arrival rates were calculated using Eq. (1):

$$\text{Arrival rate} = \frac{Number\ of\ customers\ arrived\ in\ \Delta t}{\Delta t}; \qquad (1)$$

where *Δt* is the time period interval. Figure 2.a and 2.b illustrate the arrival rates of the single and multiple parallel queues using a *Δt* of 5 minute intervals. The dashed line shows the regression line used to project the arrival rate during lunch times. Arrival rates for the single and multiple queues were found to increase from 1.3 up to 4 customers per minute when approaching 12pm. For both graphs the regression lines displayed similar size and curves and was determined as comparable.

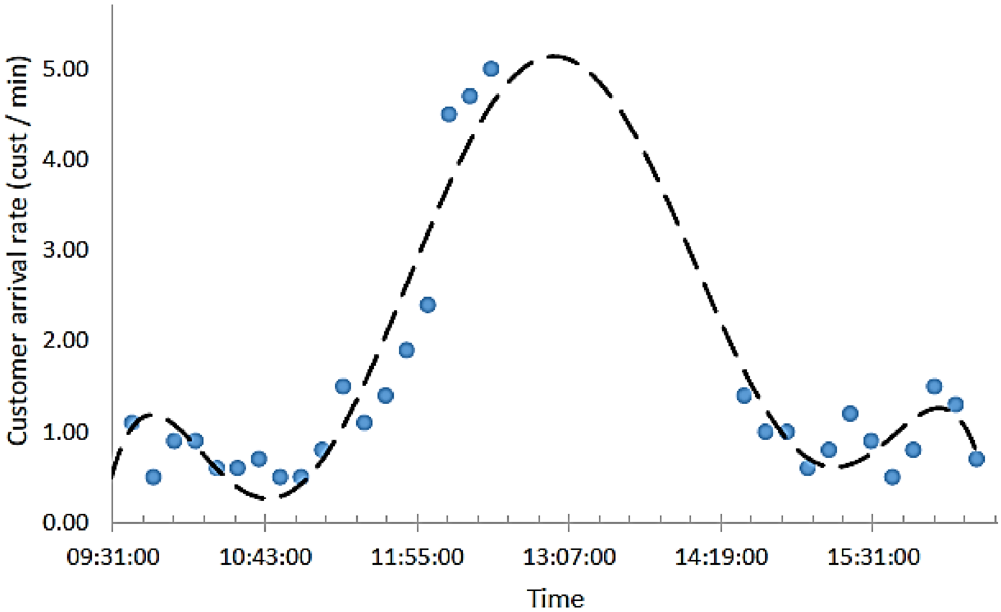

Figure 2.a: Arrival rate over time (with projected rate for lunch time) for a single queue.

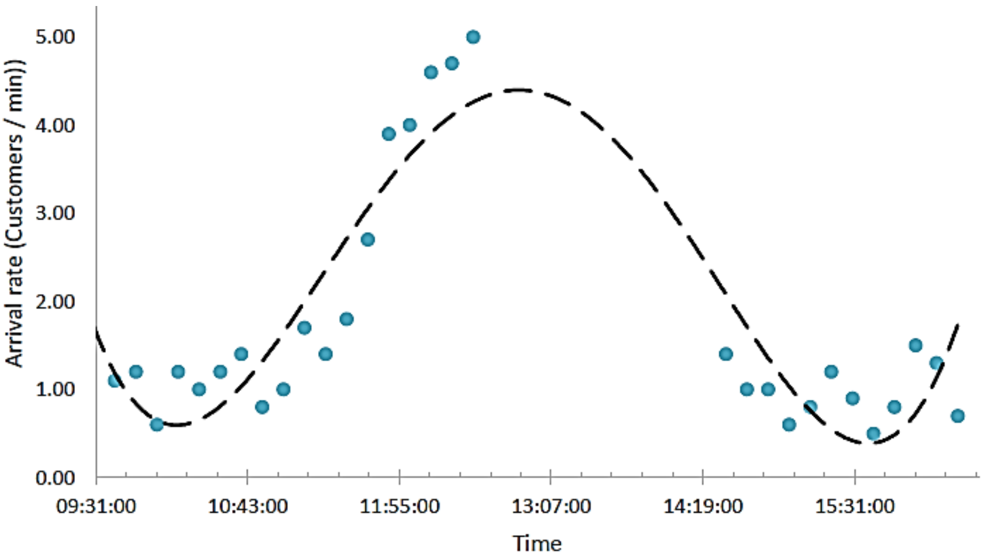

Figure 2.b: Arrival rate over time (with projected rate for lunch time) for multiple parallel queues.

For the time studies in both single and multiple parallel queues, the customer queue time and service time were plotted over time. The queuing time was calculated as using Eq. (2):

Queuing time = Service timestamp – Arrival timestamp; *(2)*

Figures 3.a and 3.b illustrate the time customers spent in the queue before being serviced for the single and multiple parallel queuing systems. Outliers resulted from customers who had to return as they would have received an incorrect order.

When comparing figures 3.a and 3.b, it is clear that the multiple parallel queues had lower maximum queuing times, indicating that the mathematical proof from Koka et. al [7] apply for this experiment as well.

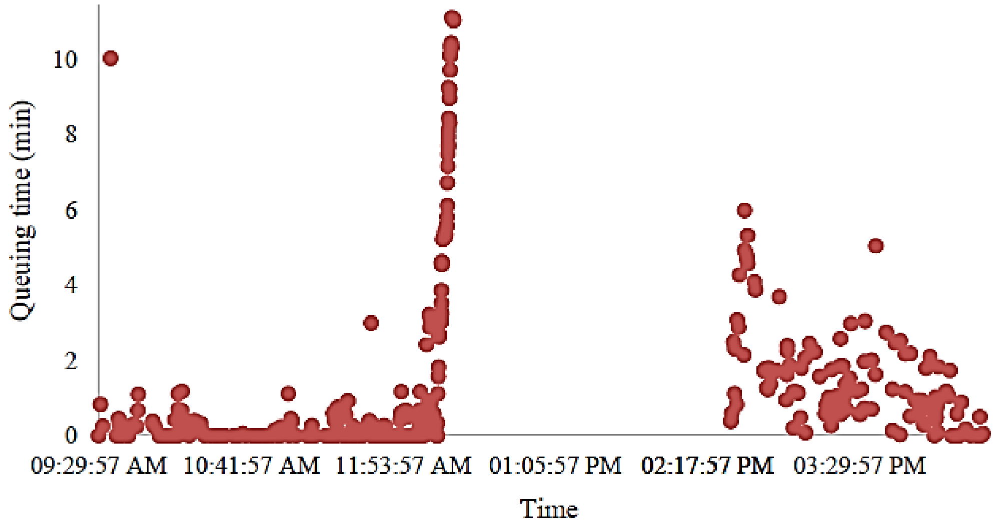

Figure 3.a: Queue waiting time for a single queue.

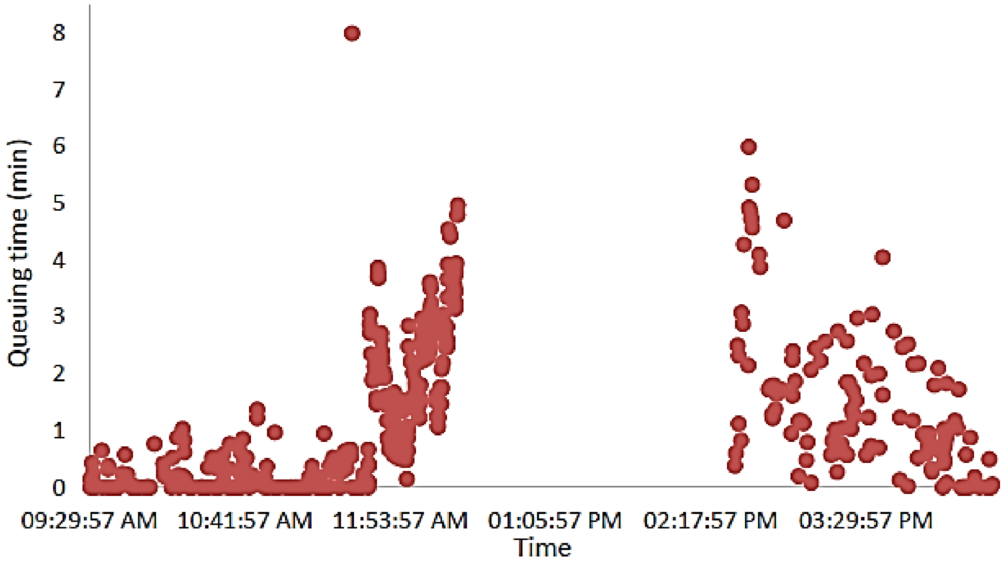

Figure 3.b: Queue waiting time for multiple parallel queues.

The service times for the queuing systems were also recorded. The objective is to compare the service times of cashiers to observe if single queues service times are actually slower than multiple parallel queues as claimed by Shunko et. al [14]. Figures 4.a and 4.b illustrate the service time of cashiers for both the single and multiple parallel queuing systems.

Average service rates were calculated using Eq. (3):

$$\text{Average service rates} = \frac{Total\ number\ of\ customers\ served}{Total\ time\ in\ minutes}; \qquad (3)$$

The average single queue service rate was found to be 3.55 customers per minute. The average multiple queue service rate was found to be 3.84 customers per minute. This confirms that the service time of cashiers were slower for the single queue.

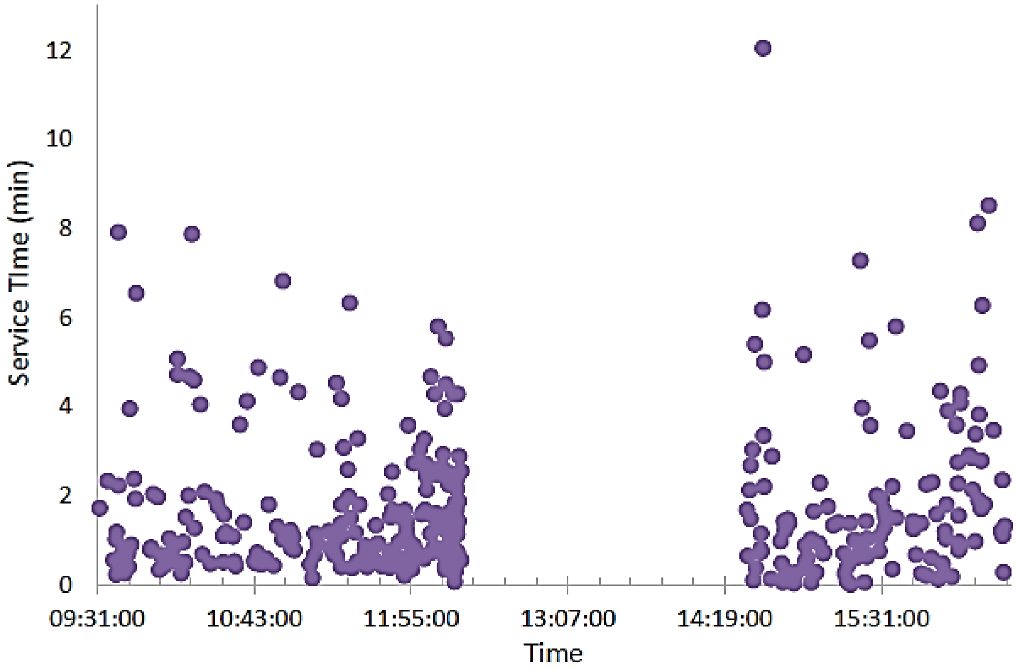

Figure 4.a: Cashier service time for a single queue.

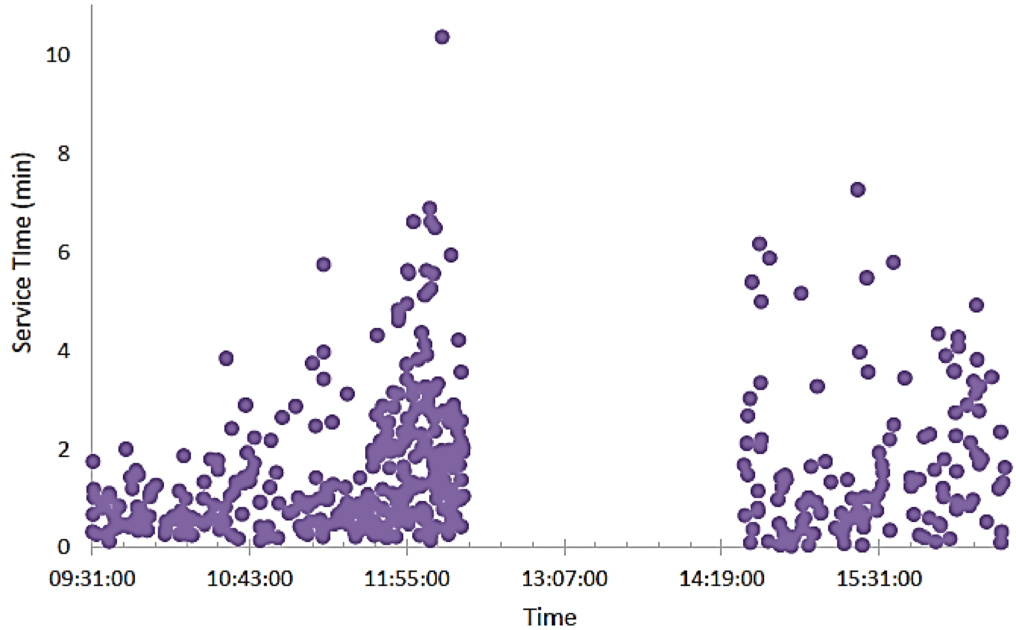

Figure 4.b: Cashier service time for multiple parallel queues.

During multiple parallel queuing, customers were often hesitated to join the second shorter queue since the notion of fairness came into play [11]. They would prefer to join the back of the long queue than to be labelled as “cutting in line” by other customers. This further increase in the queue length would lead to further lack of feedback (feedback saliency) for the cashiers and they intrinsically work slower as the number of customers increases as shown in Figure 23 for customer service time and arrival rates.

Comments from the cashiers suggested that queuing barriers made customers more orderly and caused good flow of people. This allowed for cashiers to easily track orders and ensure that the orders are given to the correct customers. Cashiers also commented on other factors that influenced their service rate. These factors included orders that have to be shouted to kitchen staff when the noise levels become too high during peak times. Slow tills that do not print receipts cause frustrations while capturing orders. Lastly the workplace environment in summer can become very warm due to cooking equipment being on all the time in a small space, causing non-ideal working conditions.

4.2 Customers' perceived versus actual waiting time

Figure 4.a shows that when the television was off, 68% of customers thought their waiting time was actually longer than what it actually was. Customers would often check the time and look at the front of the queue as they were in a rush, therefore they would be time conscious about the wait.

As shown in Figure 4.b, 76% of customers perceived their waiting time to be shorter than it actually was when the television near the queue was on. This is because their attention is drawn away from the long queue and they did not pay attention to the actual time that has passed.

This can be used to a business's advantage as sometimes the physical attributes of the queuing system such as the number of servers and service rate can be difficult to change as in the example of the Manhattan elevator scenario. However, the perception and mind set of the customers' waiting time can be changed which improves they are customer satisfaction [9].

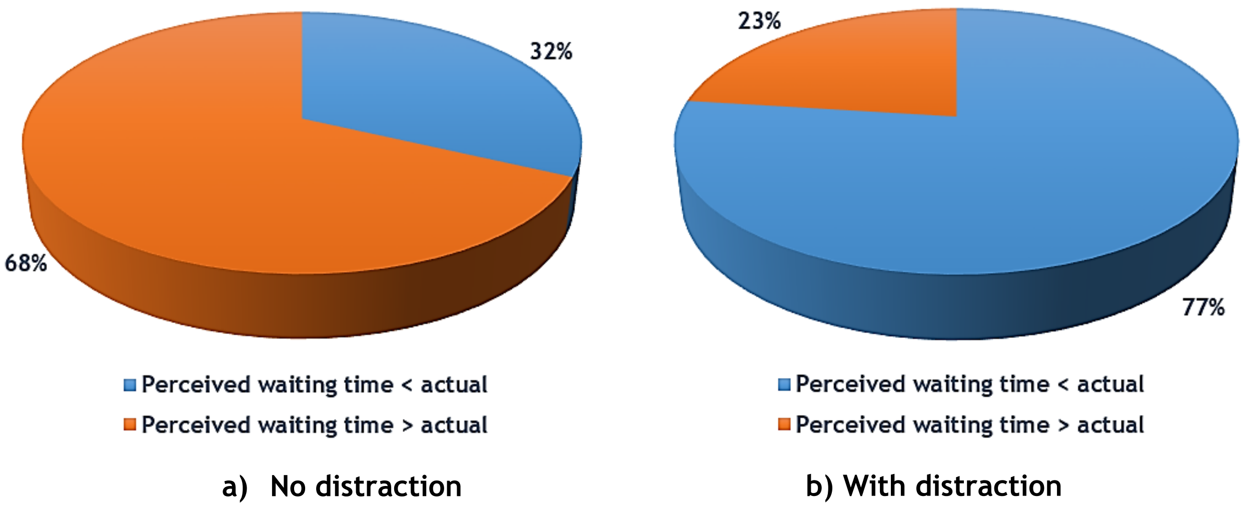

Figure 5: Perceived versus actual waiting times

5 CONCLUSION

In the first experiment, time studies for both queuing systems were conducted and it was found that the overall cashier service rate were lower when serving in one of multiple parallel queues. The rate would increase slightly when there were fewer customers in the queue. It was also found that cashiers tend to work slower when they are serving many customers, similar to the results perceived by Shunko et. al [14]. This could be due to the lack of queue length visibility as suggested by Shunko et. al [14].

The impact factors on the cashier service rate had in turn an effect on queuing time and queue length. The cashiers identified impact factors that could influence their service rate negatively to include: communication, equipment and the working environment.

Despite having structures such as queuing barriers to form different queues, once the queue capacity becomes too saturated, human behaviour will naturally let people form a single queue and their value of fairness motivates this behaviour within the queue.

In the second experiment, customers perceived their waiting time to be much shorter when there was a distraction such as a television near the queue. Impact factors that affected customers waiting time included: value for fairness in the queue and the presence of distractions such as television.

This ties in with the theme of the conference. Alternative realities can be a matter of perception. This can impact human behaviour when humans believe that their perceptions are facts. Management of perception is a key concept in Industrial Engineering that should always be kept in mind when trying to improve processes or queues, as highlighted by Swanson [9] and Larson [11].

Recommendations for further studies include repeating the experiment with the two queuing systems for a longer timeframe to get a bigger range of data. An experiment of redesigning how to get customers to understand how to form multiple queues can also provide more insight into human behaviour. For example the perception of fairness as the reason for the human behaviour, provided by Larson [11], is not always clear in this experiment. More queueing barriers or assistant(s) could be used to aid this experiment.

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PROACTIVE SERVER ALLOCATIONS IN SINGLE QUEUING SYSTEMS

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ABSTRACT

This study investigated methods to decrease the waiting times for customers standing in line to pay for groceries at a local supermarket by using forecasting techniques to predict the amount of servers needed ad hoc. The aim of the study is to better control the queuing time of a customer being serviced in a single queue multiple server system with the use of AnyLogic software. This was done by allowing an algorithm to assign capacity to the service stations automatically after a specified time frame. The most optimal model was one that used the exponential smoothing formula to predict the next waiting time for the next period. In doing so, the model became proactive in assigning service station capacity.

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1 INTRODUCTION

Queuing theory has become a popular field of interest in Industrial Engineering because of the huge frustration associated with long waiting times in queues. In retail, this could have a cost implication for a store if the waiting time becomes so excessive that it impacts the number of customers reneging (leaving the store without buying anything due to the long queues) as well as the number of returning customers [1],[2].

This study focused on decreasing the waiting times for customers standing in line to pay for groceries at a local supermarket. The supermarket was already using a single queue multiple server system. Comparing the current single queue multiple servers queuing system with multiple queues for parallel servers were considered impractical as there is not enough space in the store for this. It was therefore clear that the store would not benefit from studying the use of different queuing systems. While there are many forms of queues and services, this study deals with the improvement of the single queue multiple server queuing system. The study of queuing theory pertains to any situation in which waiting is involved.

Data was then gathered to consider other possibilities of process and/or customer waiting time improvements. A trend was found that certain times of the day was busier in the supermarket than other times. Management had catered for this by assigning a different number of tellers to be available at certain times of the day. The assignment schedule started off with a single teller at 6am, growing to 6 tellers in the middle of the day and decreasing back to a single teller at day end before the store closes at 9pm. The schedule limited the amount of other work employees could be utilised to perform while the queues were short. It was then decided to investigate more effective methods to predict how many tellers should be available ad hoc at certain intervals of the day based on past data.

Of all the methods and concepts used in queuing theory, the idea of assigning service points to be available based on predictive future waiting times seems to not have received much attention in the past to the authors knowledge. This aspect makes up the foundation of this study.

2 LITERATURE REVIEW

2.1 Queuing theory

Koka et. al [3] describe the differences between the parallel queue multiple server queuing system and the single queue multiple server queuing system. Comparing alternative queuing systems is a good place to start when investigating ways to reduce waiting times in queues. Based on the mathematical formulas from Little’s Law, the single queue multiple server queuing system has shorter average waiting times than the parallel queue multiple server queuing system if the service rate remains the same and can therefore be considered more effective [4].

Currently, methods of reducing wait times vary. Applications where the entity can wait in a virtual queue has enabled entities to perform other tasks during the waiting period [1]. Some retail stores have replaced manual service stations with automated machines [5], while there are concept algorithms that automatically decide which customer to serve first [6].

2.2 Cost trade-offs in queuing theory

If the waiting time associated with the queuing system becomes too long, it results in a loss of profit due to non-returning customers [4]. This loss of profit can be quantified by management as a waiting cost. In order to optimise a queuing system, a balance trading-off the waiting cost and the cost of the service has to be undertaken. This trade-off is displayed in Figure 1. On the one hand, as more service stations are added, the service costs will increaser while on the other hand, the less the amount of service stations available, the more the waiting cost associated with dissatisfied customers will increase [7]. The optimal service level is calculated as the number of open service stations that will minimise the total cost including the cost of providing the service and the waiting cost due to the loss of profit.

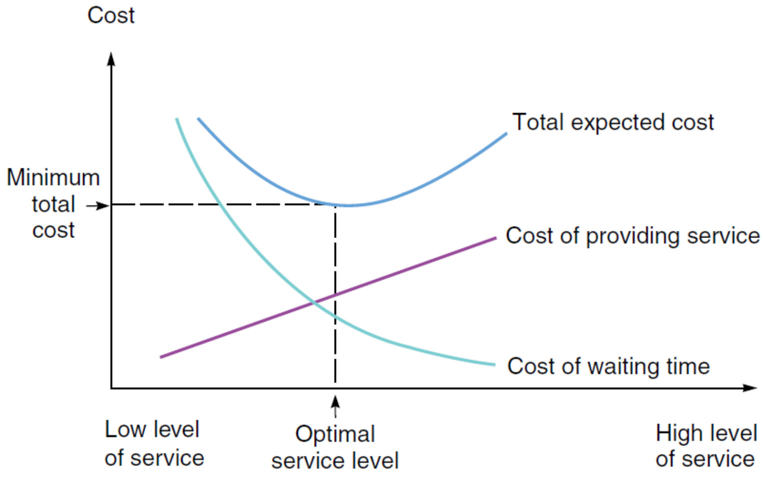

Figure 1: Cost trade off for service levels [7]

The graph in Figure 1 assumes that the arrival rate of the queuing system remain the same throughout the opening times on the queuing system. In actual real life situations, this is rarely the case. The decision regarding the cost trade off does not have to result in a constant number of open service stations that have to be open throughout the day. Different numbers of stations could be open during different times of the day based on the amount of traffic. This option is especially useful if employees could also be utilised to do other duties, like packing of shelfs, price checking, inventory stock keeping and cleaning.

2.3 Forecasting

Forecasting predicts how a future trend will act and in what direction that trend will run. This is used in industries to predict the demand for a certain period so that a business can produce enough supply to satisfy the demand [8]. Demand can vary over time and can be broken down into 6 areas; average demand, cyclic demand, demand according to a trend, seasonal fluctuation demand, random variations and autocorrelation.

Seasonal, average and trend demands are the easiest to predict. These different components of a forecasting line follows a predictable pattern that can be used in the foreseeable future. There are also random variations as a result of unpredictable events such as cold weather, political changes and wars that cannot be modelled by seasonal, average or trend demands. These variations are not linked to anything and are regarded as outliers in the system.

An autocorrelation is where a future value is highly correlated with past values [9]. This relevant to queueing theory, where one can assume that if a queue contains a large number of people, the queue will continue to contain a large number of people until the system changse due to the arrival rate slowing down, service time increasing or extra service points coming online.

For forecasting based on previous data, time series forecasting models are used. The period in which forecasts are made is broken down into short, medium and long term. Short term uses observations or data points amounting up to 10 points to forecast events happening up to a week. Medium term uses from 10 to 20 data points to forecast events happening within a month. Long term uses 20 data points or more to forecast events happening in a time frame larger than a month.

In this study, the focus fell on short term forecasting and the following forecasting models were investigated: simple moving average, weighted moving average and exponential smoothing.

2.3.1 Simple moving average

A simple moving average is used when there are no major fluctuations in the data and the data is not influenced by seasonal changes. The simple moving average is used to smooth out the trend while ignoring the random outliers that may occur. The simple moving average is primarily the average demand over a defined period[9].

Eq. (1) shows the formula used for the simple moving average model [8]:

$$F_t = \frac{(A_{t-1}+A_{t-2}+A_{t-3}+\cdots+ +A_{t-n})}{n}, \qquad (1)$$

where: $F_t$is the upcoming period forecast,n is the number of data points in the time series and A_{t-1} is the actual data point value in the previous period.

2.3.2 Weighted moving average

The weighted moving average follows a similar model to the simple moving average, but does not give equal weighting to the data points as with the simple moving average. Each data point, or element, is given an individual weighting. All weightings applied have to add up to 1. Using this method, more importance can be given to the latest data points with less importance on the earlier points [9]. The forecasting line will just be closer to the latest data point at the end of each period of calculation.

The equation to calculate the weighted moving average model is as follows [8]:

$$F_t = w_1 A_{t-1} + w_2 A_{t-2} + w_3 A_{t-3} + \cdots + \ + w_n A_{t-n}, \qquad (2)$$

where $w_1$is the weight associated with the data point value for time period t-1, $w_n$is the weight associated with time period n.

2.3.3 Exponential smoothing

For the simple moving average and the weighted moving average, large amounts of data are needed to develop a reliable model. In the case of exponential smoothing, the biggest weights of the prediction is proportionally assigned to the latest data and older data can be discarded, similar to the weigthed moving average method, but a smooting parameter, called the response rate, is used to determine the weights of the data for each time period [9].

The equation used to determine the average queuing time for the next cycle is as follows [8]:

$$F_t = F_{t-1} + \alpha(A_{t-1} - F_{t-1}), \qquad (3)$$

where F_t is the forecasted data via exponential smoothing; F_{t-1}= Previous forecasted data via exponential smoothing; A_{t-1}= Actual data point value in the previous period; and α is the response rate.

3 METHODOLOGY

On a day to day basis, many different queues are formed where people or objects may be serviced in one way or another. In the study of queuing theory using simulation techniques, these people or objects are called agents. Queuing theory is subsequently defined as the study of agents waiting to be serviced in various guises [4]. The simulation software, AnyLogic, was used to model the different scenarios. AnyLogic is an agent-based, object-orientated modelling software. The animation capabilities of AnyLogic enable the user to visually validate the model [10].

3.1 Current model

The data from the current state of the supermarket was used to create a current baseline model in AnyLogic. Figure 2 illustrates an AnyLogic simulation model where agents are being fed through a single queuing multiple server system to the next available service desk.

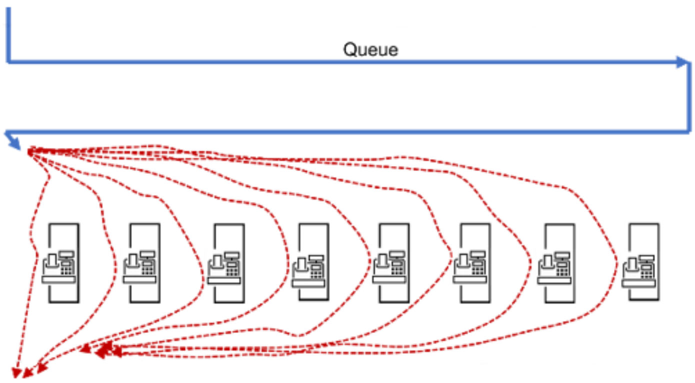

Figure 2: A single queue multiple server model in AnyLogic

The current model within AnyLogic was set up as shown in Figure 3.

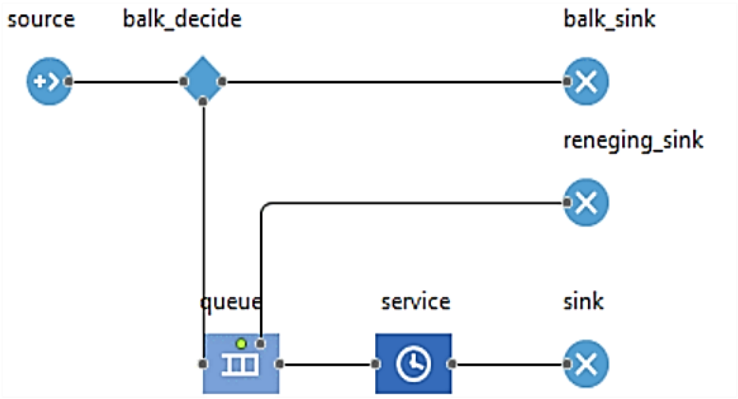

Figure 3: Current model AnyLogic screenshot

Once the model in Figure 3 was built, the logic shown in Figure 4 was applied to the current AnyLogic model.

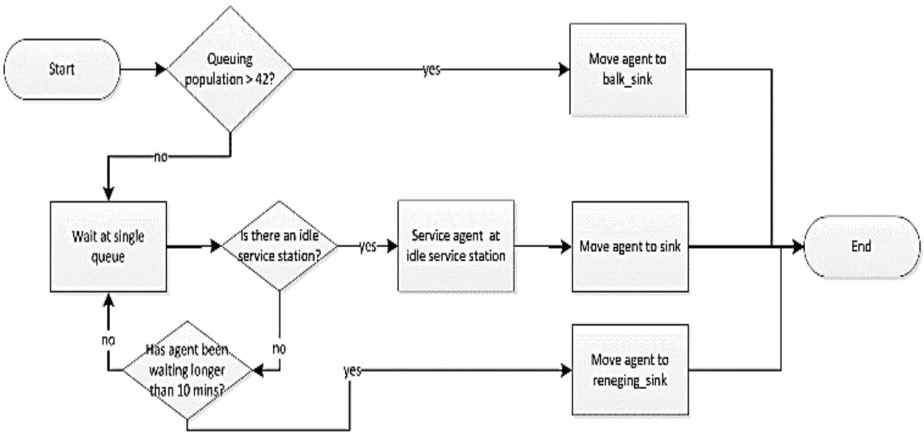

Figure 4: Current model logic flow chart

Data was collected from historical transaction data at the supermarket for the months of November 2016, December 2016, January 2017 and February 2017. These months were chosen as they represented holiday months as well as working months. The data was in the form of transactions per month per hour of the day. The data was manipulated to display the average number of transactions occurring per day within each time interval. The time intervals represented each hour from the opening time at 6am to closing time at 9pm. Figure 5 shows the average arrivals per time period over the 4 months for the supermarket.

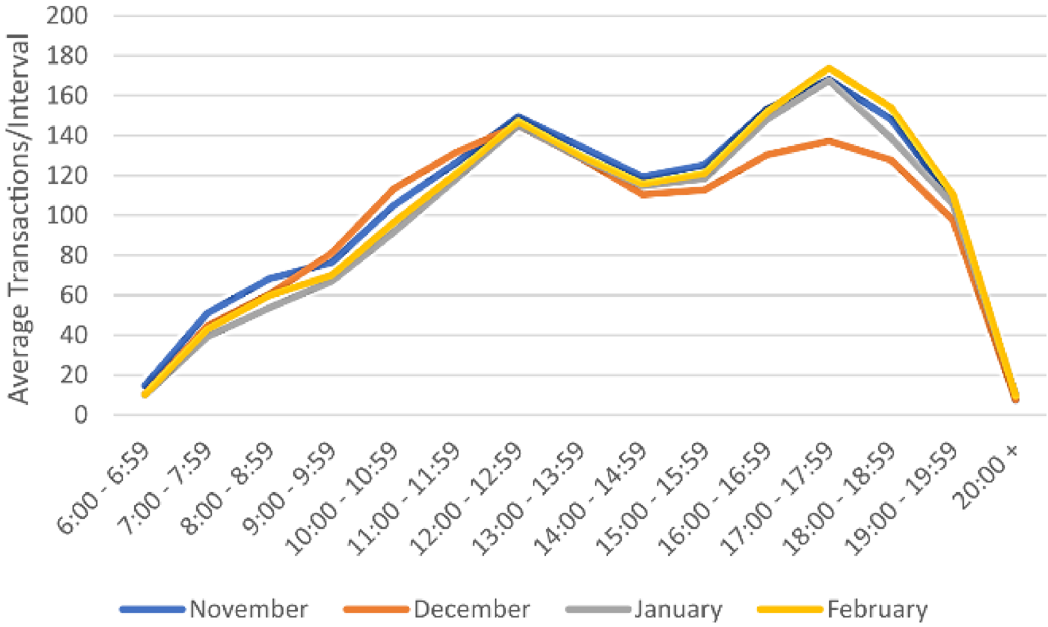

Figure 5: Average arrivals per time interval per month

Along with a fixed arrival rate, the number of servers manually assigned per time period is shown in Table 1. This current schedule for teller availability was dictated by past experience from the manager of the store.

Table 1: Current supermarket teller assignment

Time Period	Tellers Available
6h00 – 6h59	1
7h00 – 9h59	3
10h00 – 19h59	6
20h00 – 21h00	1

This resulted in allocating the same number of servers per hour of each day. This static server allocation model presented the following problems:

- The model was not flexible to change should there be an unexpected influx of customers. It also could not cater for random occurring events like a rainstorm, electricity outage in the local suburb or a nearby school requesting items for a charity event.
- The model risked servers being idle during unexpected times where the arrival rate was lower than usual.
- The model did not predict the waiting times of customers for the next period. It therefore was not able to prepare itself for more customers in the following period.

These problems could be mitigated by introducing a queuing system that predicts the demand for servers in the next time period. This would enable the system to dynamically allocate servers to the system based on the random changes in arrival rates.

Other aspects of the current model were based observations from the current supermarket data and confirmed by management. These parameters were kept as constant parameters in all variation models and are listed in Table 2.

Table 2: Current model parameters

Parameter	Value
Arrival Rate	Average rate set by supermarket data.
Service Rate	Exponential (λ,x_{min}) λ=4.0 minutes, x_{min} = 2.5 minutes
Reneging Period	10 minutes
Balk Limit Size	7 people per queue (42 people)
Simulation Run Time	6h00 to 21h00 (900 minutes)
Maximum number of servers	10

A simulation model of the current single queue multiple server in the supermarket was created to use as the baseline model for further enhancements. Figure 6 shows the results from the base model simulation. In this model the average number of transaction per hour was used to simulate arrival rates of customers throughout the day.

Although Kimes et.al [11] comment that they could not find any research conducted on the consumers' perceptions of acceptable duration as a function of wait and service times, Strange [12] reports the maximum acceptable waiting time for retail customers to be between 5 and 10 minutes in a queue management blog from InfraRed Integrated Systems Ltd.

In this study the target time was set to 5 minutes. As seen in Figure 6, the waiting time fluctuates below and above the target time. The upper and lower bounds set at 50% above and below the acceptable time were chosen. These bounds were set to prevent too many service stations being open (low waiting times) and to prevent customer dissatisfaction (high waiting times).

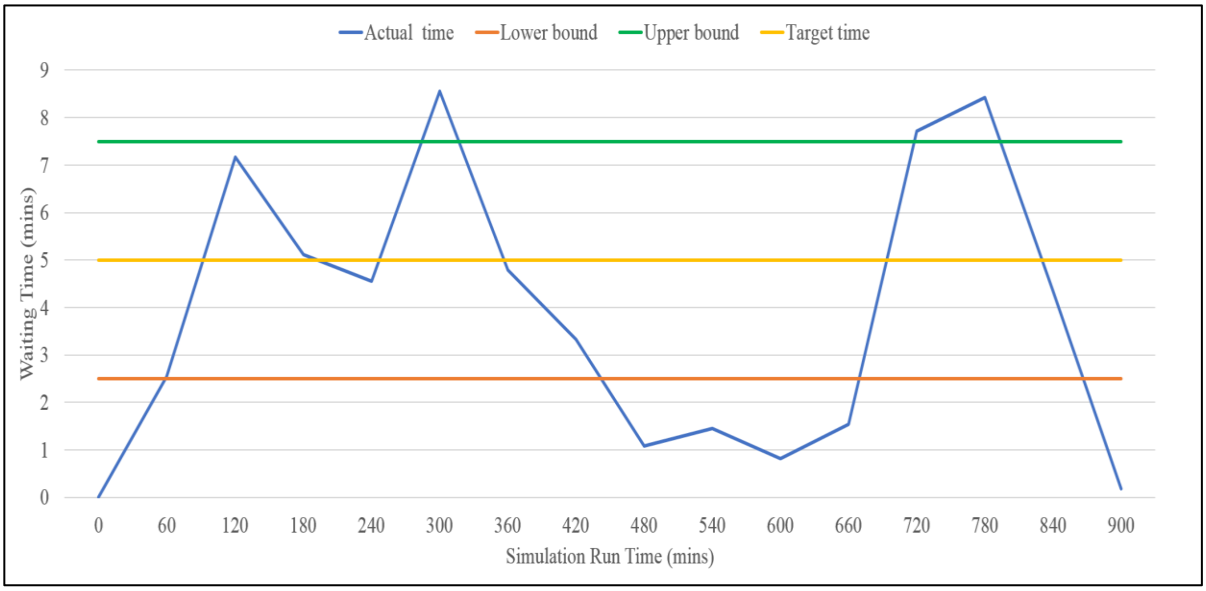

Figure 6: Current model average waiting time per hour

3.2 Model variations

From the current model and algorithm, an opportunity to alter the queuing time of an entity was investigated. This was achieved by developing an algorithm that would alter the number of service stations online during a given period.

Based on the fluctuations observed in Figure 6, three models were developed that would dynamically change the number of service stations open in a given cycle (time frame). The cycle time and the ideal waiting time could be set by the user of the system. To test each model, the different model codes where entered into the algorithm shown in Figure 7. These model codes were run each time the cycle time came to an end. At the end of each cycle, the model code would assign a number of servers to be online for the next cycle. The maximum number of servers that can be assigned were set to ten.

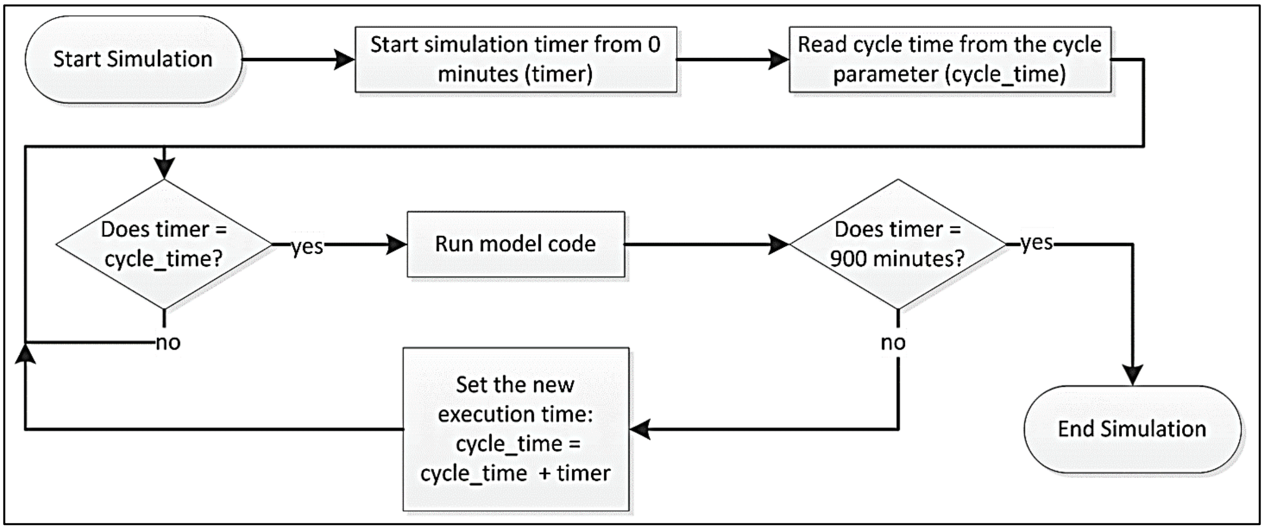

Figure 7: The simulation algorithm used to compare different models.

To compare the different model concepts, the following metrics were used: service income, reneging entities, processed entities, average queue time, maximum queue size and server utilisation. The service metric comprised of cost per service station per hour (R20.00 per hour) and the revenue per transaction of R500.00. No other costs such as overheads were taken into account. The metric was used as a tool to compare the cost for the number of tellers versus the amount of revenue generated by customers being processed. Reneging entities are those that join the line but leave based on waiting too long in the line [2]. Processed entities is the number of entities that successfully moved through the system without reneging.

The following model concepts were developed to predict how many service stations would be required to be online in the following cycle. For each model, the cycle times of 5, 10, 20, 30, 40, 50 and 60 minutes were tested. This meant that, should the cycle time have been 30 minutes, the model code was run every 30 minutes to determine how many service stations to assign for the next 30-minute cycle. A satisfactory model would be a model that produced an average waiting time that was within the defined waiting time bounds (see Figure 6). The number of regening agents as well as the total server working hours were used to compare the different models against one another as well as against the base model.

4 RESULTS AND ANALYSIS

The results and analysis for the different forecasting models are as follows:

4.1 Model 1 - The Average Time Model

For Model 1, a simple moving average was used to smooth out the waiting time data. Should the simple moving average trend be moving towards an upper or lower bound, the number of servers online would be adjusted to attempt to get the average waiting time as close to the desired time as possible. Figure 8 shows a screenshot of the output from the 30-minute cycle test.

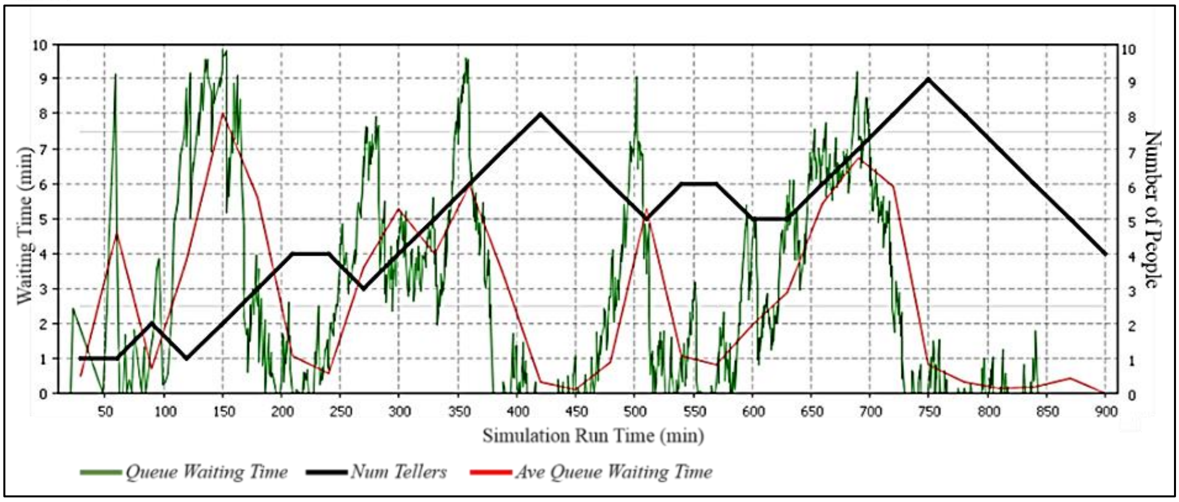

Figure 8: Model 1 with cycle time of 30 minutes

From the results, the number of reneging customers decreased as the cycle time decreased. However, as the cycle times decreased, the frequency at which the number of service stations were being changed at was far too erratic to be used in a supermarket environment. The 30-minute cycle time was therefore chosen as the optimal for Model 1.

4.2 Model 2 – The Gradient Method

Model 2 analyses the graph's direction of travel. The algorithm for the gradient model (Figure 4.6) was based on the gradient of the waiting time graph or in which direction the graph was heading. The gradient method was divided up into four different scenarios, shown in Figure 9. Scenarios 1 and 3 handled waiting times that were on the upper and lower bounds respectively. If a waiting time fell within these regions, more than 1 service station would be added or removed based on the direction of travel of the waiting time graph. A negative gradient would indicate that the graph was heading downwards while a positive gradient indicated that the graph was heading upwards. Scenarios 2 and 4 followed the same principal laid out for scenarios 1 and 3. Where scenarios 2 and 4 differ is that 1 or 0 extra service stations will be added in the various scenarios.

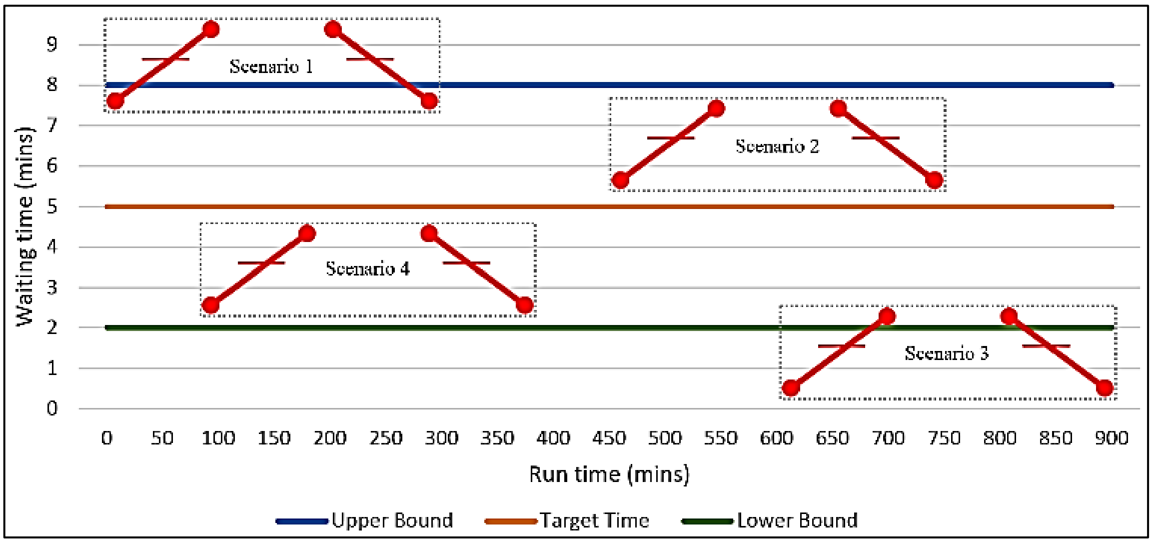

Figure 9: Model 2 gradient method

All scenarios determined where the average waiting time was in relation to the upper bound, target and lower bound times. From here the gradient of the graph was looked at to predict in which direction the graph was heading.

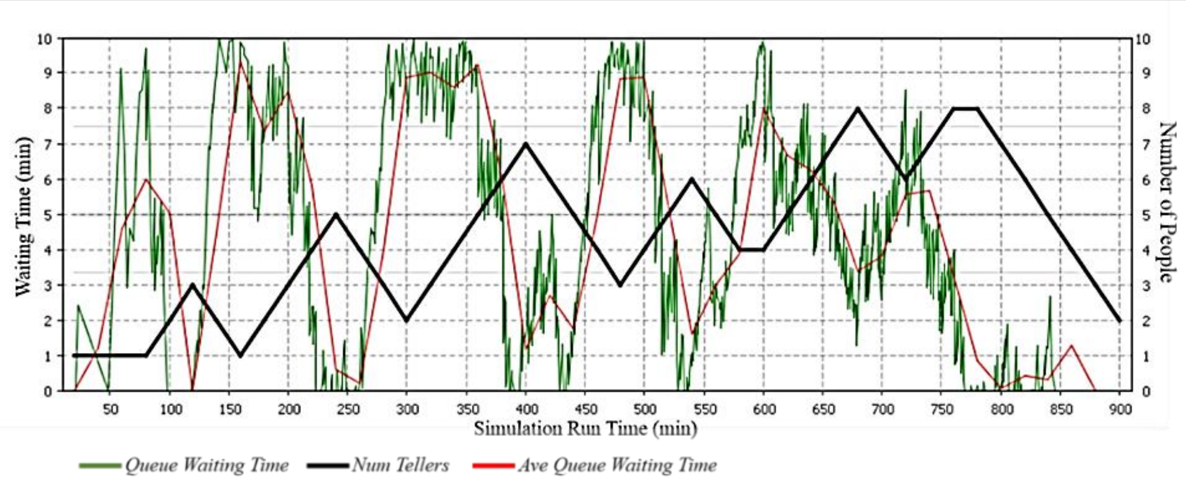

Figure 10: Model 2 with a cycle time of 20 minutes

4.3 Model 3 – The Exponential Smoothing Method

In Model 1, the simple moving average method works best when there is a large amount of previous data available, whereas when the exponential smoothing method, only the most recent transactional data and older data can be forgotten.

From the exponential smoothing equation, Eq. (3), the response rate ($0.0<\alpha<1.0$) determines how quickly or slowly the forecasted average time adjusts based on the difference between the actual average time and the forecasted time from the previous calculation. A low α value would result in a slow response rate and a smooth forecasted average time curve. A high α value would result in a faster response rate with a more volatile forecasted average time curve.

After running multiple instances of the simulation using Model 3's algorithm, 0.3 was chosen as the optimal α value. Using the exponential smoothing method, the simulation was able to accurately predict the next period's average queuing time using a cycle refresh time of 5 minutes (Figure 11).

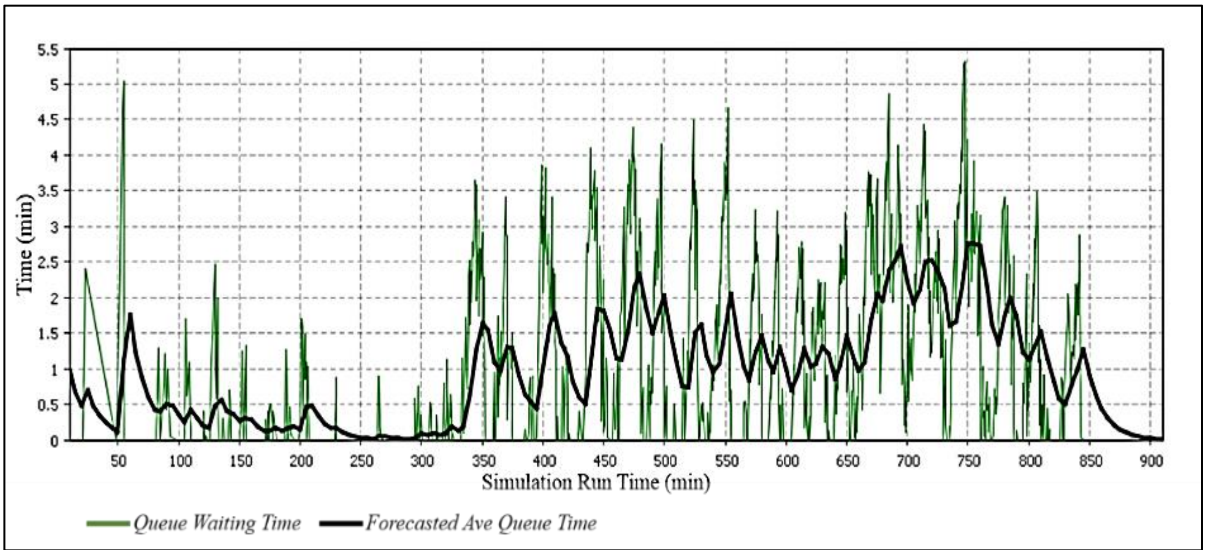

Figure 11: Model 3 forecasted time with a cycle refresh rate of 5 minutes

While the cycle time of 5 minutes resulted in an accurate forecasted average time, realistically, this cycle time could not be used to change service station numbers in a real-world environment. A cycle refresh rate of 30 minutes was deemed more viable to operate in the real world. Figure 12 shows the results from a cycle time of 30 minutes. This cycle time also produced an accurate average time forecast.

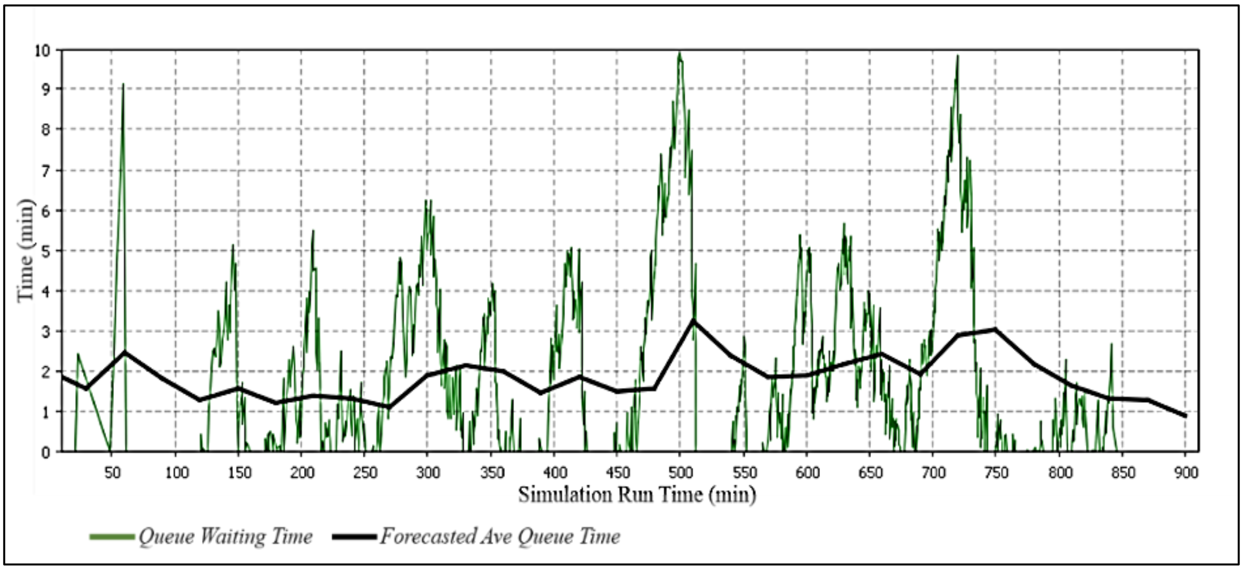

Figure 12: Model 3 forecasted time with a cycle refresh rate of 30 minutes

Following the accurate forecasting method shown in Figure 2, the results of how many service stations to add or remove for any of the cycles are shown in Figure 13.

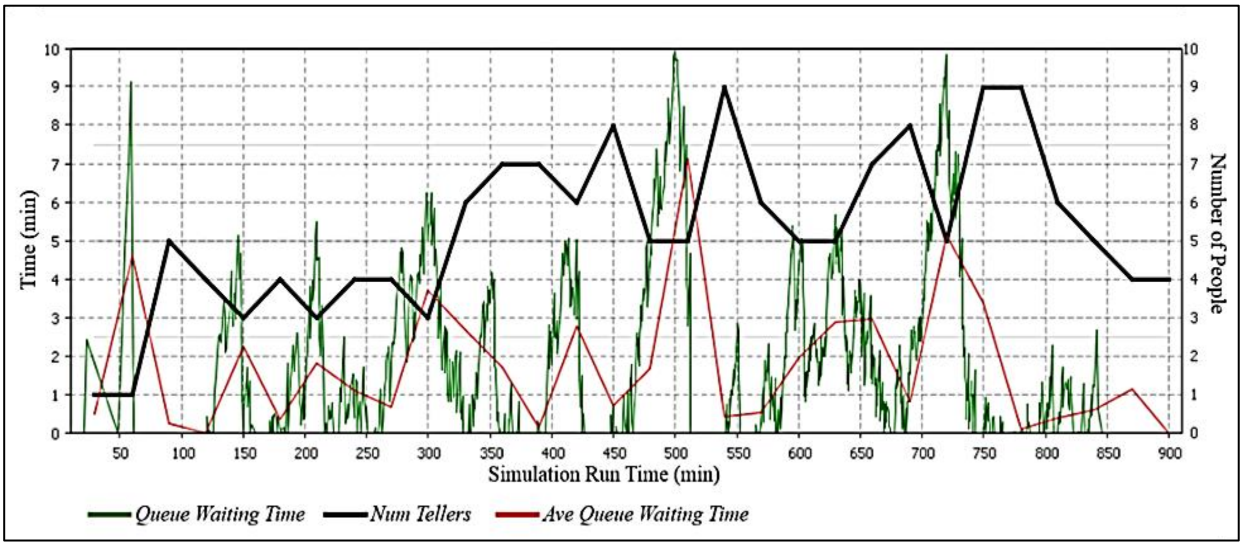

Figure 13: Model 3 with a cycle time of 30 minutes

The unique aspect of Model 3 was that the average queue time for the next cycle was predicted. In doing so, the model was able to add or remove service stations for the next period based on this prediction.

While the trend in Figure 13 was erratic in its number of service station assignments, Model 3 did give results that surpassed those of Model 1 and 2 (see Table 3).

Table 3: Model simulation results

Model	Service income (R)	Cycle time (minutes)	Reneging entities	Processed entities	Average queue	Max queue size	Server utilisation

					time (minutes)		
Model 1	739 990	30	13	1483	2.794	25	82%
Model 2	678 700	20	136	1360	4.233	29	85%
Model 3	742 920	30	7	1489	1.884	24	78%

Using Model 3 as the preferred model, the service station allocation during the day would be allocated as shown in Figure 14. This allocation chart could be used in real time and would adjust itself based on changes in its environment.

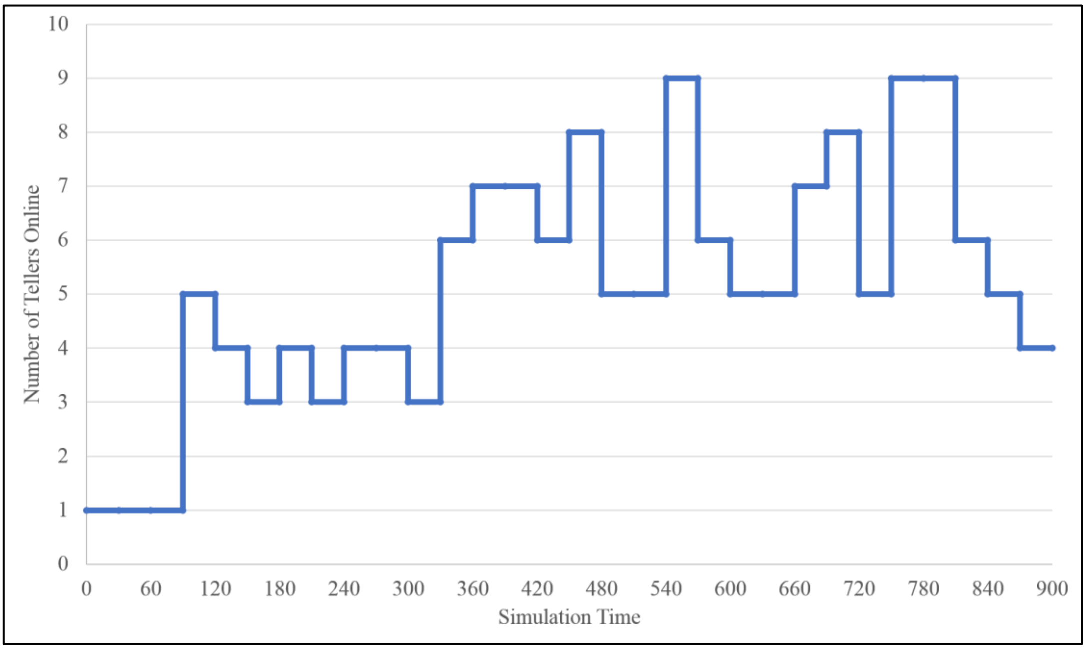

Figure 24: Service station allocation for Model 3 (cycle - 30 minutes)

5 DESIGN SPECIFICATION

Using Model 3 and its exponential smoothing methodology, queueing times for the next cycle could be predicted. In doing so, unacceptable waiting times (long or short times) could be mitigated by altering the number of service stations online during a cycle. Given the dynamic and flexible nature of the model, the model is not limited by the size of the supermarket store or even by application. Where a single queue multiple server system is used, Model 3 can be implemented. In order to implement this model into a new environment, the following input parameters would need to be decided on:

- maximum single queue size;
- maximum time in the queue;
- acceptable queuing time (mean queue time);
- maximum number of service stations allowed; and
- the cycle time or frequency in which the service station number would be changed.

The response rate of $\alpha = 0.3$ was used for the application of a supermarket. Depending on the application and the ideal cycle time for the application, α would have to be determined to be optimal for the specified environment. As an example, a higher service station capacity change rate would be achieved with a smaller cycle time.

6 FURTHER IMPROVEMENTS

In this study, only the most recent data points were used. For a more accurate model, data could be stored in a database and error values can be recorded for each cycle. The error value could be determined as follows:

$$error = WaitTime_{actual} - WaitTime_{predicted} \qquad (4)$$

When the next day comes around, service station number allocations can be changed based on previous error values in order to reduce the size of the error.

The database can also be used to record seasonal trends. The system can adjust itself to cope with a busy Christmas period and would enable managers to forecast how many more or less workers to employ during certain periods. In turn, this allows for more accurate financial preparation for the year as well as when opening a new store.

Using a weighted neural network or a metaheuristic algorithm to make service station capacity decisions based on waiting time predictions, past seasonal data and past error data could be used to create a more accurate prediction model.

7 CONCLUSION

This study investigated the effects of using an online forecasting model that could predict the number of tellers needed for the next timeslot. Three forecasting models were tested and various timeslot lengths were considered. According to this model, employees could be assigned to tellers if the forecasting model predicted peak times of the day. The objective of the study was to propose a simple generic forecasting simulation model that can be used in different queuing system environments to assist with the online assignment of employees to tellers.

Moving away from a reactive service station capacity assignment to a proactive capacity assignment method will enable supermarkets to plan their business day better. Having the predictive waiting time model that tells the manager when to add service station capacity and what quantity to add will free up the manager to concentrate on other aspects of the supermarket. Using the methodology laid out in this study can also be implemented into any environment where a single queue multiple server configuration is used.

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THE EVOLUTION OF BUSINESS MODELS FROM SUPPLY CHAIN TO AGILE DEMAND NETWORKS THROUGH ADDITIVE MANUFACTURING

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ABSTRACT

Disruptive technologies had been the drivers for each of the first 3 industrial revolutions. These technologies shaped the evolution of the supply chain. As customers became more demanding, business models had to adapt from focus on supplying customers with goods, according to forecast, to a demand driven business model. The dynamics required to fulfil customer demand required more dynamic thinking and agility. It was also requested that companies leave behind linear chain thinking and participate in flexible agile networks.

As with all previous industrial revolutions, disruptive technology also plays an important part in shaping 4IR. In order to survive and thrive in 4IR, organizations will have to transform their business models from a supply chain model to an agile demand network. The most disruptive technology of 4IR is additive manufacturing. This paper discusses key requirements of an agile demand network and also the role additive manufacturing plays with the transformation from a business model based on supply chain principles to a business model based on an agile demand network.

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1 INTRODUCTION

The world has experienced a number of significant step-changes that changed the way people conduct business, and ultimately their lives, which we know as industrial revolutions. According to the Collins dictionary an industrial revolution can be described as: "the change in social and economic organization", while the Longman dictionary indicates that revolution indicates a change in ways of thinking and methods of working. Each one of the industrial revolutions started with the invention of a new technology (see table 1) and also demanded a change in the required ways of working and thinking that can be called a change in business models.

Table 1: First three industrial revolutions - [33]

Industrial Revolution	Started	Technology
1st	Mid 1700's	Steam engine
2nd	Mid 1800's	Electricity
3rd	Mid 1900's	Computers - Mainframe, PC's, Laptops

According to Schwab [1], the 4th Industrial Revolution (4IR) will be the most disruptive of all revolutions to date due to the way in which it will change everything we know, do, and relate to others. This revolution is, as with prior revolutions, earmarked by disruptive technologies and will have a significant impact on existing business models. In 4IR, emerging technologies and broad-based innovation are diffusing much faster and more widely than in previous industrial revolutions.

The impact of 4IR on business leads to an inexorable shift from simplistic digitization, which characterized the third industrial revolution, to a much more complex form of innovation based on the combination of multiple technologies in novel ways. Intense competition, a changing world, complexity, and increased risks demand a new approach to enterprise management to optimize enterprise performance and agility. This is forcing all companies to re-examine their business models.

1.1 The research question

What will be the impact of Additive Manufacturing on the spare parts provisioning business model?

1.2 Objectives of the research

The objectives of the research are:

1.2.1 Research the business model evolution

1.2.2 Define the requirements for success in the fourth industrial revolution

1.2.3 Define an industrial component supply business model and the required attributes based on the business model evolution and the requirements for success in 4IR

1.2.4 Define the role of additive manufacturing in shaping the new business model

1.3 Final Output

The final output of this research paper will be a proposed conceptual frame work for a new business model for spare part provisioning based on additive manufacturing

1.4 Approach used and structure of the paper.

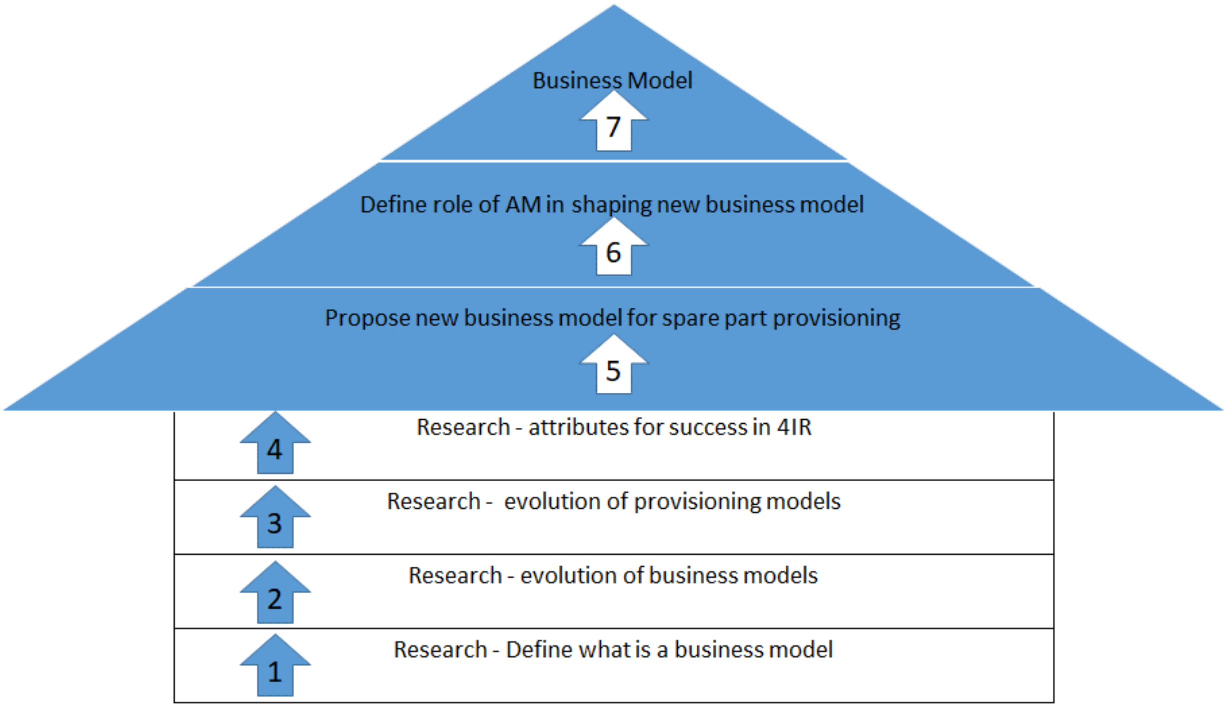

Figure 1: Approach for defining business model

2 BUSINESS MODEL EVOLUTION IN INDUSTRIAL COMPONENT SUPPLY SYSTEMS

2.1 Business model definition

According to Linder [2] a business model can be divided in business that is fundamentally concerned with creating value and capturing returns from that value, and a model that is simply a representation of reality. Magretta [3]. Linder [2] indicates that while a business model facilitates analysis, testing, and validation of a firm's strategic choices, it is not in itself a strategy. In some cases, organizations might consider a set of business models representing different strategic choices before drawing a conclusion about the best business model for their organization. A business model embodies a set of choices, digital or not, where executives must make decisions about changes to their business in four key categories, namely (i) value proposition, (ii) customer, (iii) capabilities and lastly (iv) finance Basilirie [5](reference). Csik [4] indicated the following key components that should be part of a business model design. See table 2 for the key components. This was also echoed by Linder [2], Basiliere [5].

Table 2: Key business model concepts

Business model architecture	Cisk [4]	Linder [2]	Basiliere [5]
Who	Who is the customer?	Strategic choices	Customer
What	What does the customer consider to be value?	Create value	Finance
How	To build and distribute a value proposition through the firm's value chain	Value Network	Capabilities

Why	How to create revenue in business	Capture value	Value Proposition

2.2 Business model transformation

Business model transformation involves many elements of an organization, and its success relies on the support and execution of an array of functions. The emergence of new digital technology and the disruption it brings to customer preferences, market dynamics and competitive advantage, fundamentally alter how companies must approach business model change Gartner [6].

If companies become complacent and think that they are sustainable by following a traditional business model, they risk losing out to more flexible competitors. Industry is changing rapidly, and soon, an industry may cease to exist. The path to profitability is different from traditional paths and opportunities for raising capital have changed. The capabilities upon which you build your business and your customer base may not appeal to customers in the future Magretta [3].

In 4IR, companies regularly explore a far broader set of options tied to potential future states and opt to run initiatives simultaneously with broad organizational involvement. According to Schwab [1], 4IR has four main effects on businesses across industries: (i) Customer expectations are shifting; (ii) products are enhanced by data that improve asset productivity; (iii) new partnerships are transformed into new digital models; and (iv) operating models are being transformed into new digital models.

While the third industrial revolution saw the emergence of purely digital platforms, a hallmark of 4IR is the appearance of global platforms intimately connected to the physical world. Platform strategies combined with the need to be more customer-centric and to enhance products with data, are shifting many industries from a focus on selling products to delivering services and total solutions focussing on the total cost of ownership. Product vendors will focus on their core strengths and build better products relying greatly, or even totally, on ecosystem partners to provide additional services like maintenance, repair and other support functions Schwab [1].

New business and organizational models promise innovative ways of creating and sharing value, which in turn leads to whole system changes that can actively benefit the natural world as much as our economies and societies. 4IR will enable firms to extend use cycles of assets and resources, increase asset utilization and is not only changing what assets do, but what they are. At a strategic level, organizations must ensure that the challenges that technology pose are properly understood and analysed. Only in this way can organizations be certain that 4IR will enhance, rather than harm, their health and business models.

It is evident that companies will have to reconsider their business models to align with the disruptive changes of 4IR Rojas [34]. In future, competition will take place between business models, and not between products and technologies. Managers consider business model innovation to be more important for achieving competitive advantage than product or service innovation. Csik [4]

The convergence of additive manufacturing (generally known as 3D printing) with developments like open source licensing, repositories to share 3D data and files, and platforms to access manufacturing capacity has created an environment where innovation is highly supported, but also where current regulatory schemes and business models are ill-equipped to deal with this changing landscape.

In an increasingly nonlinear world, only nonlinear ideas will create new wealth. To thrive in the age of revolution, companies must adopt a radical new innovation agenda. The future operating environment will be more hostile and far less forgiving than that which we have experienced in the past Gattorna [7]. The fundamental challenge companies face is reinventing themselves and their industries not just in times of crisis - but continually and therefore they will require agile business models that are based in true customer demand Hamel [8].

3 EVOLUTION FROM SUPPLY CHAIN TO DEMAND DRIVEN BUSINESS MODELS

Gattorna [8] states that:

> "Supply chain management never was a good term because it immediately conjured up in one's mind the "supply" side of the enterprise. The "chain" descriptor doesn't help either, as it implies we are dealing with linear chains or strings of enterprises, when in fact the real world involves three-dimensional arrays of enterprises".

Authors such as Vollman [9] and Hugos [10] suggested that a better term than supply chain management would be necessary to emphasize the shift from efficient supply to meeting the need of the customer. In Beers [11], it is indicated that since consumers should be the focus of a chain's existence, consumer demand should be at the core of a chain's business strategy. In doing so, the supply chain transforms itself into a so called demand-driven chain or simply a demand chain.

Freughtwanger [12] indicates that the change from "supply" to "demand-driven" rightly suggested that all network activities should ultimately be aligned, planned and executed in pursuit of enterprise demand imperatives. Therefore it is important that we move from a linear chain perspective to a dynamic demand *network* perspective. A demand-driven network is a system of technologies, processes, and organizations that senses and responds to signals across a value-driven network of customers, suppliers, and employees. According to Barret [13] Soliman, & Youssef [14], to survive in today's volatile business environment with increased complexity, organizations have to transform traditional supply chains to *outside-in* demand-driven value networks that focus on creating customer value.

According to Gattorna [15], the convergence of the Internet as a communications medium, and the coincidental development of a myriad of new software applications, will require the internal and external integration of processes and demolition of silo's prohibiting real-time information sharing with all the partners in the network to create customer value.

According to Cecere [16], demand networks are adaptive structures that can quickly align organizations, market-to-market, to focus on a value-based outcome. They sense and translate market changes bi-directionally with close to real-time data visibility and integration to better optimize and align. More mature companies are managing multi-tier networks with strong visibility and agility to support rapid change in demand or disruptions in supply Cummins [18]. Therefore the functional specialization and fragmentation of activities that are part of the supply chain will need to be revised and a new business model will have to be created to survive in 4IR.

4 REQUIREMENTS FOR SUCCESS IN 4IR.

4.1 Disruptive technology as catalyst

A disruptive event is an event that suggests the occurrence of an enterprise threat or opportunity. An agile enterprise recognizes, analyses, and responds to disruptive events that occur in the enterprise ecosystem Cummins [18]. Since the first industrial revolution, technology has played a crucial role in transforming industries and fuelling growth. These technologies disrupted and changed older ways of thinking and conducting business, thus rendering old skills and organizational approaches irrelevant.

As before, disruptive technology will transform how we connect, learn, share and innovate in the future, with broad implications on organizations, workforces, and customers. Unrealistic expectations, fears of job security, and decision uncertainty due to options are ways in which technology challenges leaders to reconsider how future value will be created and protected.

Numerous new technologies surface daily that will impact the future, but there are only a handful that will have critical impact on business models. These have the potential to significantly disrupt the *status quo* so that we have to rearrange value pools and make use of entirely new products and services.

Table 3 indicates the criteria to determine the disruptive potential of a technology obtained from Aghina [20].

Table 3: Technology disruption criteria Aghina [20]

Criterion	**Characteristic**
The technology is *rapidly advancing* or experiencing breakthroughs	Demonstrate a rapid rate of change in capabilities and experience… (incomplete) see page 12 table 6 the duplicate
The potential *scope of impact* is broad	Must have a broad reach, touching companies and industries affecting a wide range of machines, products, or services.
Significant *economic value* could be affected	Will have massive economic impact
Economic impact is potentially disruptive	Can change the *status quo* dramatically

Figure 2 shows examples of technologies that will have a disruptive impact on business going forward, as identified by Schwab [1].

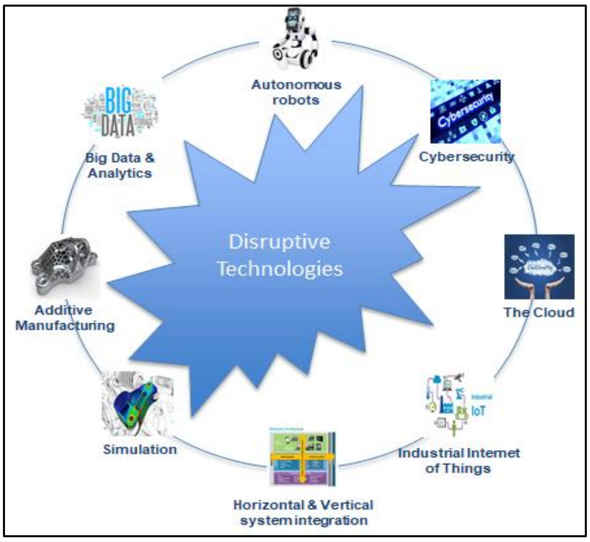

Figure 2: Disruptive Technologies of 4IR [1]

4.2 Agility in a changing environment

A view of the world – a paradigm – will endure until it cannot explain new evidence. The paradigm must then shift to include that new information. 4IR, with all its disruptive technologies, forces a shift in business paradigms from linear, fragmented models to new agile integrated models Ganguly [20]

An agile enterprise breaks silos down into relatively autonomous service units. Enterprise agility requires access to shared knowledge about how the enterprise works as well as knowledge that provides the basis for competitive advantage. The agile enterprise must have a culture of constant change. Models are essential for understanding the current state of the enterprise as well as evaluating potential future states. Models that reflect the state of the business in the future will have to include the interaction of the eco-system and all its components Cummins [37].

An "agile" organization thus reacts quickly to change, recognizes both internal and external customer and supplier change, perceives the need for change in the future, and accepts that need as a cost of doing business Meier [36]. Agility is an essential quality of the enterprise of the future. It continuously improves to optimize cost, quality, and speed of delivery. It enables top management to quickly implement new strategies and control key business parameters to gain competitive advantage. Agility resolves some common business challenges faced by many enterprises. But the agile enterprise does not fit current business models. It requires a new business paradigm — a new way of thinking about the business and new ways of planning, organizing, operating, and controlling the business Cummins [18].

In a world characterized by persistent and intense change, institutions rich in leaders with high emotional intelligence will not only be more creative but will also be better equipped to be more agile and resilient – an essential trait for coping with disruption. A capacity for agility will be much more about employee motivation and communication as it will be about setting business priorities and managing physical assets Meier [36]. A digital mind set, capable of institutionalizing cross-functional collaboration, flattening hierarchies, and building environments that encourage a generation of new ideas is profoundly dependent on emotional intelligence. Forward-thinking strategy leaders recognize that the secret to creating a growth-focused organization is not by further improving the planning calendar and templates, but by challenging operational mind sets that keep the organization in short-term firefighting mode.

Companies are at the threshold of a radical systemic change that requires human beings to adapt continuously. As a result, we may witness an increasing degree of polarization in the world, marked by those who embrace change versus those who resist it. Agile organizations mobilize quickly, are nimble, empowered to act, and make it easy to act. They respond as a living organism in the business eco-system Bisson [19](reference). Table 4 is a summary according to Aghina [20] of the key trademarks of agile organizations.

Table 4: Trademarks of an agile organization – Aghina [20]

	Trademark	Organizational Agility practice
Strategy	North star embodied across the organization	• Shared purpose and vision • Sensing and seizing opportunities • Flexible resource allocation • Actionable strategic guidance
Structure	Network of empowered teams	• Clear, flat structure • Clear accountable roles • Hands-on governance • Robust communities of practice • Active partnerships and eco-system • Open physical and virtual environment • Fit-for-purpose accountable cells
Process	Rapid decision and learning cycles	• Rapid iteration and experimentation • Standardized ways of working

	Trademark	Organizational Agility practice
		• Performance orientation • Information transparency • Continuous learning • Action-orientated decision making
People	Dynamic people model that ignites passion	• Cohesive community • Shared and servant leadership • Entrepreneurial drive • Role mobility
Technology	Next-generation enabling technology	• Evolving technology architecture, systems, and tools • Next-generation technology development and delivery process

These trademarks play an important role for any organization that wants to become truly agile. Only when all the trademarks are part of a company's business model, will that company be able to embrace the opportunities of 4IR. The management philosophy of an agile network should be project- and task-based with processes, resources, tools and techniques drawn from project management principles Atkinson[35] Meier[36]. This supports agility in that organizational restructuring may take place on an "as needed" principle to align with goals and objectives that frequently change.

4IR may be driving disruption, but the challenges it presents are of our own making. It is thus in our power to address them and enact the changes and policies needed to adapt in our emerging new environment. Business organizations that are not agile will fall behind. Agility is fast becoming a key business driver for all organizations as well as a crucial factor to a firm's ability to survive and thrive in uncertain and turbulent markets Chatzopoulos[22].

4.3 Demand driven provisioning

Markets are becoming more and more demanding. Customization is required to solve a specific problem or to enhance a process. The new markets will be small with highly unpredictable demand and price elasticity. It will be based on digital demand. The traditional business culture of handling one big market with mass produced goods will struggle to handle the forthcoming niche-markets of customized products Chatzopoulos[22].

4.4 Network and eco-system integration

Fast-moving competitors provoke a disaggregation of the more traditional industry silos and value chains, and also disintermediate the existing relationship between businesses and their customers. New disruptors can scale at much lower cost than the incumbents, generating in the process a rapid growth in their returns through network effects.

Hamel [8] argues that neither value creation nor value capture occurs in a vacuum but both occur within a value network, which can include suppliers, partners, distribution channels, and coalitions that extend the company's own resources. The role a firm chooses to play within the value network is an important element of its business model.

In almost all industries, digital technologies will create new, disruptive ways of combining products and services – and, in the process, will dissolve traditional boundaries between industries. Not all industries are at the same point of disruption, but all are being pushed up a curve of transformation by the forces driving 4IR. In a world characterized by uncertainty, the ability to adapt is critical – if a company is unable to move up the curve, it may be pushed off it. The companies that survive and prosper will need to maintain and continually sharpen their innovative edge and derive value from their eco-system integration Schwab [1].

At the core of this ideal is the opportunity to shift businesses and consumers away from the linear source-make-dispose model of resource use, which relies on large quantities of easily accessible resources, and toward a new industrial model where effective flows of material, energy, labour and information interact and promote, by design, a restorative, regenerative and more productive economic system Rojas [34].

Successful organizations will move from hierarchical structures to more networked and collaborative models. Motivation will be increasingly intrinsic, driven by the collaborative desire of employees and management for mastery, independence and meaning. This suggests that businesses will become increasingly organized around distributed teams, remote workers and dynamic collectives, with a continuous exchange of data and insights about the things or tasks being worked on Atkinson [35].

Companies able to combine multiple dimensions – digital, physical and biological - often succeed in disrupting an entire industry and their related systems of production, distribution and consumption. These combination-based business models illustrate the extent of the disruption that occurs when digital assets and interesting combinations of existing digital platforms are used to reorganize relationships with physical assets. The latest advances in additive manufacturing introduce powerful disruptions to manufacturers in the areas of design, customer engagement and production location. These disruptive features require an entirely new way of engaging with the outside world Kleer [28].

In a recent survey conducted, 76% of all the business leaders participating in a survey agreed that current business models will be unrecognizable in the next 5 years and that ecosystems will be the main change agent Lyman [24].

5 A SPARE PART PROVISIONING BUSINESS MODEL FOR SUCCESS IN THE FOURTH INDUSTRIAL REVOLUTION

From the research it is clear that new dynamic business models are required to participate in 4IR. These business models require agility to understand the dynamics of the market demand from the networked eco-system. As technology played an important part in the past to start an industrial revolution, so will the disruptive technologies available in the market also play an important role in transforming 4IR. One of the most disruptive technologies of 4IR is additive manufacturing Campbell [40]. Figure 3 indicates the impact of technology on the provisioning business models.

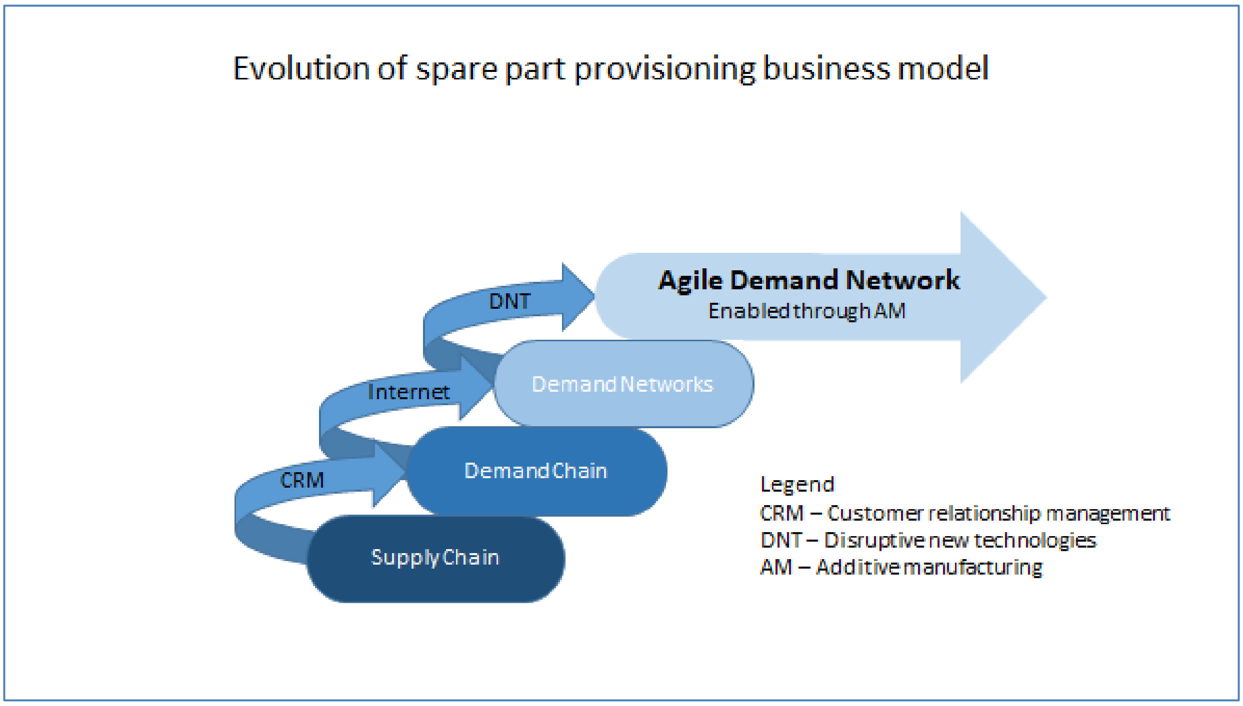

Figure 3: Impact of technology on the creation of spare part provisioning business models

. A supply chain is focused on the supply of product to the customers. It became more important to understand and service the customer according to the customer's requirements. Customer relationship management systems were implemented and paved the way for new demand driven business models. The internet linked more entities and created improved visibility throughout global networks. 4IR created disruption with new technologies as previously indicated in figure 2. This necessitated a new business model based on agility with participation in the network/eco system.

6 THE ROLE OF ADDITIVE MANUFACTURING IN CREATING THE AGILE DEMAND NETWORK BUSINESS MODEL

6.1 Define Additive Manufacturing and the disruptive nature on the business

Generally, additive manufacturing refers to

> "the process of joining materials to make objects from 3D model data, usually layer upon layer" ASTM International 2012 [25].

There is a variety of manufacturing processes behind the general term "additive manufacturing". These processes largely differ in the available choice of materials, build rates, mechanical properties of produced parts and other technological constraints. The main benefit of additive manufacturing is that it enables the flexible production of customized products without cost penalties in manufacturing. It does so by using direct digital manufacturing processes that directly transform 3D data into physical parts without the need for tools or moulds. Additionally, the layer manufacturing principle can also produce functionally integrated parts in a single production step, hence reducing the need for assembly activities. Thus, additive manufacturing technology significantly affects the cost of flexibility, individualization, capital cost, and marginal production costs Berman [26]. Additive manufacturing will also change the way in which we conduct business and will transform every day consumers into manufacturers in the future.

Additive manufacturing's impact ranges from incremental capability and finance improvements to radically new customer value propositions. Astute managers and technology planners use business models to assess the impacts and prepare their organization for the threats and opportunities brought on by additive manufacturing. Like the printing press, additive manufacturing printers have the potential to cause quite a stir from both business and legal standpoints Wilbanks [27] Bassiliere[5] Campbell [40].

Additive manufacturing will largely influence the locus of innovation and production, enabling the design of new value chains and business models Crane [28]. The impact of the eco-system will play a significant role in the development of the business models in future Kleer [29].

This is especially true with the mass-complexity business model, which allows the company to create new versions of products with fewer parts and different materials. A supplier with additive manufacturing capacity can consolidate the manufacture of many low-volume parts and therefore reduce the number of items that have to be kept. A similar logic applies to distribution, because additive manufacturing allows a company to build smaller factories close to customers Campbell [40]. Some companies even have mobile additive manufacturing factories — printers in trucks that can quickly move to a customer in need. Because AM makes factories and suppliers' more flexible, it generally works to reduce supply chain complexity D' Aveni[30].

Economic consequences of additive manufacturing can hardly be discussed at a single user level. In an interview with Jennifer Lawton (president of Makerbot) she indicated that3D printing is an ecosystem, not a device Conner [31]. Thus it is important to develop an understanding of the different elements that constitute this ecosystem that extends beyond sole manufacturing resources and industrial users. Additive manufacturing will revamp the economics of manufacturing and revive industries with creativity and ingenuity. People tend to overestimate the impact of new technologies and thereby lose sight of the long-term impact and how additive manufacturing will change the way companies operate and conduct business Bronberger [32]. Table 5 is an indication why additive manufacturing will have such a disruptive nature on business models in the future.

Table 5: Disruptive nature of Additive manufacturing Manyike [39], Campbell [40]

Criterion	Characteristic	Additive Manufacturing
The technology is rapidly advancing or experiencing breakthroughs	Demonstrate a rapid rate of change in capabilities and experience breakthroughs that drive accelerated rates of change.	New materials, new printing technologies, increase in size of components, technology can be operated on desktops.
The potential scope of impact is broad	Must have a broad reach, touching companies and industries affecting a wide range of machines, products, or services.	Impacting all manufacturing, repair and maintenance activities. Change culture of organizations.
Significant economic value could be affected	Will have massive economic impact	Eliminate warehousing, capital requirements are low, print components close to point of consumption. Reduction in components due to part consolidation. Improve Overall Equipment Effectiveness and reliability of equipment. Extend life time of assets.
Economic impact is potentially disruptive	Can change the status quo dramatically	Numerous suppliers in the eco-system. Patent reverse engineering. Change of materials i.e Steel with polymer.

The key area that will be impacted by spare part provisioning is equipment availability. Two of the main causes of equipment failure continue to be (i) human intervention and also (ii) operation of equipment outside of operating conditions Snider [33]. This will require the redesign of the equipment to improve the functionality of equipment that in some cases was limited by design constraints from traditional manufacturing. With Additive Manufacturing and the new design for Additive Manufacturing principles where complexity is free, the functionality of equipment can be improved significantly. Additive Manufacturing is not just another disruptive technology but is a strategic disruptive force. Figure 4 is a summary of all aspects of a business that will be disrupted by implementation of additive manufacturing.

Figure 4: Business impact of additive manufacturing

6.2 Key attributes of proposed new spare part provisioning business model

Table 6: Attributes of the evolution of the spare parts provisioning business model

	Business model attributes for spare part provisioning			
	Supply Chain	**Demand Chain**	**Demand Network**	**Agile Demand Network**
Culture	Ego Centric/Consistency	Inspirational	Inclusion/Innovation	Agile - Eco centric
Leadership	Directive	Transformational	Servent	Agile
Change	Top down	Cunsultation	Team inclusion	Agile change
Processes	Linear - push based	Linear - pull based	Network integrated	Agile Network integrated
Structure	Silo's	Cross functional	Team based	Agile
Finance	Lowest cost	Cost to serve	System cost	TCOO
IP/Legal	IP internal	IP Internal	IP Internal/External	IP ecosystem
Safety	Enforce	Enforce	Engineer safety out	Way of life
Procurement	Category Managed	Category managed	Network managed	Eco-procurement
Storage	Multiple warehouse	Warehouse/ VMI	System Kanban	E-storage
Inventory	Obsoleccense	Obsolessence	Obsolessence	On demand
Maintenance strategy	Reactive	Preventative	Predictive	AIM (Asset integrity management)
Asset strategy	Replacement	Replacement	Renewal	Optimized renewal/design
Manufacturing	Lean	Lean	Lean/Additive	Additive
Customer	Push/ Product centric	Pull/Product centric	Pull/Demand driven	Interactive demand - Customer centric
Design philosophy	Design for manufacturing	Design for manufacturing	Design for maintainabiliy	Design for functionality
Spares management	Manage various components	Manage various components	Basic part consolidation	Consolidation of components
IT	ERP systems	Maintenance support systems	Some IR 4 technologies	Enbrace technologies of IR4
Environmental	Compliance	Cradle to grave	Cradle to grave with some recycling	Cradle to cradle
Quality assurance	Adhere to set standards	Adhere to set standards	Build quality in	Imbed quality in process
Riskmanagement	Risk averse	Improved understanding of risk	Learn how to manage risk	Understand and manage risk

Table 6 is a summary of key attributes that will have an influence on shaping the business model for spare part provisioning and how the proposed new spare parts business model evolved based on the research and the role that additive manufacturing will play in shaping the proposed new business model.

7 CONCLUSION

Disruptive technologies played a major role in all the industrial revolutions. Although the previous industrial revolutions were started by a key disruptive technology (refer to Table 1), 4IR is characterized by a multitude of disruptive technologies. These technologies require totally new business models to ensure companies are sufficiently agile to manage the speed of change and ensure they understand how to add value to new demand networks.

New business models, based on agility and demand, will also ensure that the spare parts provisioning business model is transformed from a traditional supply chain view to an agile demand network perspective where creativity and innovation Campbell [40] are part of the business model. The agile demand network business model for spare parts provisioning will also be fuelled by Additive Manufacturing. There is not a single part of the organization that will not be transformed once a company starts implementing additive manufacturing. Hence, Additive Manufacturing is not simply a disruptive technology, but a strategic force that must be embraced by an agile demand network business model.

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COMPARATIVE ANALYSIS OF OPTIMIZATION MODELS APPLICATION IN HOUSEHOLD WASTE MANAGEMENT SYSTEMS

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ABSTRACT

Optimization also known as mathematical programming has been introduced and used since the beginning of the 20th century. Since then, many techniques and algorithms have been developed and applied in various fields. The past overviews of optimization modelling applications have been grouped in nine sections based on the solution to the theme-based real world problems, including Solid Waste Management (SWM). The aim of this research is to provide a comparative analysis of linear programming (LP) techniques application in SWM and to determine their applicability in waste management. The method used is an extensive literature survey conducted based on the type of LP techniques used, the problems solved and the computer software's used to complement the optimization process. Although other parameters such as environmental and social concerns cannot easily be modelled in the optimization process, it has been found that mathematical programming, along with simulation techniques, has been extensively used and has provided substantial benefits for the optimization of solid waste management systems around the world. The paper concludes by determining the optimization approaches that have been mostly used to optimize Solid Waste Management System (SWMS) by minimizing the total design and operations cost of different waste management infrastructures and resources. The paper also describes the pros and cons of these methods, and identifies the gaps that exist in the application of optimization techniques and simulation in waste management. The novelty of the research is the grouping of LP techniques based on the type of problems solved.

Keywords: Solid waste, Mathematical programming, Modelling, Optimization, Simulation

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1 INTRODUCTION:

Municipal Solid Waste Management (MSWM) is a major responsibility of local governments, typically consuming between 20% and 50% of local government revenue in developing countries [1].

Waste management is one of the major health and environmental concerns of every large human community, because if not managed properly, the produced wastes can contaminate surface and ground water, soil and air on a grand scale and very rapidly [2]. Collection and transportation of municipal solid waste is a huge contributing factor to the total cost of waste management in any country. More than 60% of the costs in SWMS in different countries are due to the collection and transportation process including labour cost, the high price of fuel and machinery and equipment maintenance [3].

Based on the fact that humans as well as all the other living creatures consume all sorts of natural and manmade products for their survival, waste will always be produced in communities, and the production of waste always brings about environmental and health concerns. Hence, waste management has been and will always be a major issue for countries.

1.1 Definitions of Key Terms, Concepts and Variables

The South African National Environmental Management: Waste Act [4] defines waste as any substance, whether or not that substance can be reduced, re-used, recycled and recovered –

i. That is surplus, unwanted, rejected, discarded, abandoned or disposed of;
ii. Which the generator has no further use of for the purposes of production;
iii. That must be treated or disposed of; or
iv. That is identified as a waste by the Minister by notice in the Gazette, and includes waste generated by the mining, medical or other sector; but –
i. A by-product is not considered waste; and
ii. Any portion of waste, once re-used, recycled and recovered, ceases to be waste.

Although not inclusive, here are some of other key terms and concepts that are mostly used throughout optimization in waste management and their conceptual and operational definitions:

i. **Solid Waste**: Solid or semisolid, non-soluble material (including gases and liquids in containers) such as agricultural refuse, demolition waste, industrial waste, mining residues, municipal garbage, and sewage sludge [5].
ii. **To Haul**: to pull something heavy slowly and with difficulty [6];
iii. **Knuckle boom crane**: A knuckle boom crane looks similar to the traditional straight boom crane, but the knuckle boom crane has two booms; a main boom and an outer boom. These two booms have a knuckle between them, which allows more options for the loader crane operator [7];
iv. **Optimization**: the process of finding the best possible solution to a problem;
v. **Multi-objective Optimization**: the optimization problem that has more than one parameter to optimize;
vi. **Pareto sets**: a set of optimal solutions to a problem that cannot be improved upon without altering one of the constraints;
vii. **Heuristic optimization**: optimization techniques that might not result in the best solution but which can be necessary to apply in some practical cases.

When the issue of waste management is raised, it is noteworthy to emphasize that different cities in the world face different kinds of problems regarding their waste management systems. Waste management is even a major problem in developing countries because developing countries do not always have institutions enforcement at municipality level to regulate waste management systems [8]. On the other hand, these developing cities usually find themselves in a state whereby the density of the population keeps on growing and the local governments do not usually have sufficient data about waste management.

Mathematical optimization has been extensively used in various solid waste routing problems, as well as in Municipal Solid Waste Management Systems (MSWMS).

Researchers from around the world have developed various techniques to solve different optimization problems. The past reviews of optimization modelling applications have been grouped in nine sections based on the solutions to different theme-based real world problems. These sections include the use of optimization modelling for conjunctive use planning, groundwater management, seawater intrusion management, irrigation management, achieving optimal cropping pattern, management of reservoir systems operation, management of resources in arid and semi-arid regions, solid waste management, and miscellaneous uses [9].

Applying mathematical modelling and simulation has proven to be a very good tool in order to optimize the MSWM systems in different countries and with different constraints and perspective.

MSWMS involves three crucial factors that include the Cost, the Environment and the Social impacts. Different cities or countries face different types of economic, environmental and social constraints and challenges regarding waste management. Given this fact, it is necessary for every city to do an analysis of its geographical, economical and demographical situation to be able to determine the means and the requirements for an optimal design and operation of its waste management system.

Given the above mentioned reasons, it is not surprising to see how different researchers around the world have applied optimization modelling and simulation to address SWM in different perspectives.

Primitive optimization problems were mainly single objective problems, where only one function needs to be either minimised or maximised. However, with the evolution of science and the increase of challenges and constraints in the global optimization problems, it is usual to be faced with a multi-objective optimization problem, where more than one function have to be optimized, and these functions are in most cases conflicting. This reality has made the development of multi-objective optimization techniques, also called intelligent optimization algorithms, imperative.

The term optimization comes from ancient world, and its foundation has been created by great ancient mathematicians and philosophers by defining optimum over several fundamental domains such as numbers, geometrical shapes, optics, physics, astronomy, the quality of human life, state government, and several others. This era started with Pythagoras of Samos (569 BC to 475 BC), a Greek philosopher who made important developments in mathematics, astronomy, and the theory of music [9]. In the same book, the authors have classified optimization techniques in the following categories:

1. Deterministic or Analytical, which includes Gradient descent Methods, Newton – Raphson Methods and Nelder – Mead Search Methods.
2. Stochastic Methods. This category includes Simulated Annealing (a Monte Carlo – based technique), and Stochastic Approximation (SA).
3. Evolutionary Algorithms. Two techniques exist in this last group, based on the evolution theory, namely genetic Algorithm (GA) and Differential Evolution (DA).

Given the fact that most of multi-objective optimization problems have two or more conflicting objective functions, it is not always possible to determine one exact optimal solution. As a result, most of these techniques strive to find a set of optimal solutions with the best possible solutions to the problem; and these optimal solutions define what is called the Pareto sets. When these optimal solutions are plotted with one objective function with respect to another, it defines a curve that is called the Pareto Frontier, and the optimal solution whose distribution is the closest to the Pareto Frontier is usually selected.

It has to be noted here that, some of these optimization techniques are heuristic methods; these methods develop optimization algorithms that are not mathematically guaranteed to provide optimal solutions, but are nevertheless useful in some practical situation.

An overview of the Optimization Modelling applications, by Singh [9], has revealed that researchers around the world have developed techniques to solve optimization problems in different fields. This paper has described various articles that have been published on the application of optimization techniques and simulation to improve the effective use of resources in the waste management sector, and these studies have produced positive results. According to this same study, the rapid urbanization poses a serious environmental threat of SWM. The problem is particularly serious in the developing countries.

The concept of selecting intermediate points for transfer of materials in order to minimize transportation costs was first utilized in a Ph.D. dissertation by Marks in 1970 [12].

But according to Chang & Lin [13], on overall, the mixed integer programming models have been extensively used in the siting issues of recycling centres, transfer stations, treatment plants, and disposal facilities.

Different optimization techniques have been extensively used throughout the world to optimize the SWMS of different cities. Optimization techniques mostly applied in waste management can be classified in nine groups, which include: Linear Programming (LP), Non – Linear Programming (NLP), Mixed – integer Linear Programming (MILP), Multi – Objective Optimization (MOO), Capacitated Vehicle Routing Problem (CVRP), Non-Linear Integer programming (NLIP), Integer Linear programming (ILP), Mixed – Integer Programming (MIP), and Particle Swam Optimization (PSO). These techniques as depictured in Figure 1 have been applied in various studies to optimize the waste management systems around the world, and these studies are described in subsequent sections in this paper.

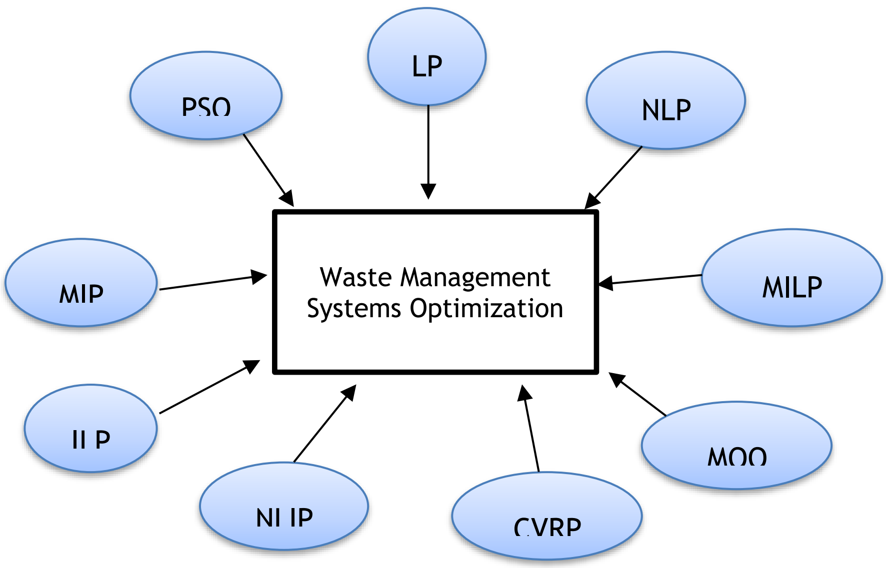

Figure 1: Mathematical programming approaches applied in waste management systems optimization

2 METHODOLOGY

The method that has been followed for the purpose of this research is an extensive literature survey and comparative analysis of different optimization techniques with a focus on the final goal of the optimization process. In this perspective, the application of optimization in SWM has been be categorised in three groups namely Transportation problems, Facility location problems, and a mixed of transportation, facility location and resource utilisation problems. This categorization was based on the fact that these are the main problems that one can be faced with in waste management; grouping LP techniques in this manner will assist researchers and waste management stakeholders to easily identify which techniques will be more suitable for the problem in hand.

2.1 Transportation Problem

Transportation problems are very common in optimization processes. These problems refer to the use of various optimization techniques to reduce the traveling time and the overall cost of transporting resources or any material from one point to another. In SWM, transportation problems refer mainly to the application of optimization techniques to minimise the total cost of collection and transportation of MSW from the households to their final destination sites, which can be material recovery facility, incineration centres, or landfills.

The following are the summary of different studies that have applied optimization techniques to solve transportation problems in waste management.

Talebbeydokhti et al. [3] have conducted a study on the optimization of solid waste collection and transportation using TransCAD software, which is a Geographical Information System (GIS) based software for the solid waste routing and transportation optimization. The research included a case study of the city of Marvdasht, in Iran. The study resulted in an optimised system that showed a decrease in distance travelled and time of 15.7 % and 29.43 % respectively. TransCAD application has deficiencies such as the Arc Routing routine does not consider the place of unloading in the collection vehicle routing.

Apaydin and Gonullu [14], have conducted a study in the city of Trabzon, in Turkey to optimize the routing of municipal waste collection and transportation. The objectives of this research were to create MSW Collection data recorded by a video camera by riding in collection vehicle cabined; to use data gathered by observing the collection of MSW in 39 districts in the city; to form a GIS database on the route map of Trabzon; and to compare the cost and time of present and optimized route.

The methodology followed in this study was twofold, first, it made use of a GIS software to record all data; and second, it used the shortest path model to optimize the routing of waste collection and transportation from the households to their final disposal facility. The results in this research show that a decrease of 24.7 % in the total expenditure will be obtained by implementing the optimized routing, this is achieved by decreasing the total collection time by 44.3 % and the total distance by 24.7 %.

While most studies on WMS optimization have focused on the applications of conventional, heuristic and Meta – heuristic optimization techniques to improve the efficiency of MSWMS, the study conducted by Hannan et al. [15] has made use of computer software to optimize the collection and routing of solid waste systems. In this research, Particle Swam Optimization (PSO) algorithm, Capacitated Vehicle Routing Problem (CVRP), have been used together with the implementation of smart bins to optimize the collection and routing in a solid waste collection system. The research suggest that smart bins can be used to send information about waste level and weight in the bins to a PSO – based CVRP system that coordinates the scheduling of waste collection vehicles. In this way, the system is able to only send vehicles to full bins and to optimize the routing in the system.

The last item in this category is a study conducted by Nguyen-Trong et al. [16]. This study has proposed a model for the optimization of MSW collection. The methodology followed in this research was as well twofold, it first applied the conventional Vehicle Routing Problem (VRP) to optimize the collection, and second it integrated GIS system with agent-based modelling to provide the analysis with a dynamic consideration. The final result was a system that reduced the distance and travel time of waste collection vehicles.

2.2 Facility Location Problem

Identifying the right position for a facility is not as easy as it might sound; different critical factors have to be addressed to ensure that a facility is placed at the optimal position to get the most benefits out of it. Facility location problem in waste management perspective is even a more complicated problem as locating waste handling facility involves not only economic factors, but also environmental and social factors. Because waste generation and management is a reality for all the countries on planet, a myriad of studies have been conducted for the optimization of waste facility location in different cities of the world. Some of these studies are described in this section.

In the study *a Model for Optimal Operation and design of Solid Waste Transfer Stations*, University of California [17], optimization techniques have been used to optimize the waste management system of cities.

In another study conducted by Chang and Wang [18], a multi-objectives optimization has been applied to optimize the solid waste management system of a metropolitan. In this study, four objectives functions have been taken into consideration, namely the economic impacts, characterized by operational income and cost for waste management, air quality impacts from discharges of target pollutants due to waste incineration, noise impacts from various types of facilities operation, and traffic flow increments by garbage truck fleets. After collecting all relevant data, the first step of this study was the mathematical modelling of these specific objectives functions, then all these conflicting objectives functions have been incorporated into one optimization process using LINDO Software package to determine the most optimal solution. A case study of the Kaohsiung City, in Taiwan was conducted, and the study has proved that the inclusion of environmental quality constraints in a single objective optimization, may result in a very different optimal solution for the waste management system.

Chang and Lin [13] have made use of GIS and the mathematical programming to optimize the citing of a solid waste transfer station in the city of Taipei, in Taiwan. This study has demonstrated that the application of GIS techniques together with mathematical optimization can help to ensure systematic economies of scale and reduce the total transportation cost of a metropolitan Solid Waste.

In the same stream of thought, Chatzouridis and Komilis [19] made use of the non-linear integer programming and the GIS system to optimise the collection of municipal solid waste. The methodology followed by this research consisted of 4 parts. The first part consisted of excluding areas unsuitable for WTS siting. In the second part of the study, the author sited all candidate waste transfer stations in the remaining suitable areas using a siting approach. The third part was the development of an objective function (OBF) that minimizes total solid waste collection cost. Finally, the fourth part consisted of a development of the model in a user friendly environment, such as an Excel spreadsheet.

The result of this research was a model to minimise the cost per unit of municipal solid waste collection. A case study was conducted in the Hellenic region, in Greece, and the minimum collection cost of €42.4 t^{-1} was determined for the city.

The novelty of this study was that, the model developed could be applied in a situation where the number and locations of candidate transfer stations are not determined.

Another study in the optimization of municipal solid collection and transfer has been conducted by Yadav *et al*. [20]. In this study, a non - linear integer programming in conjunction with a geo-spatial database system have been used as methodology to develop a model for the optimal siting of waste transfer stations. As it has been the case with different other studies, a number of transfer stations have been proposed and the aim of the model was to use GIS and mathematical modelling to find the best sites that will minimise the overall cost of municipal solid waste collection and transfer to their final disposal facilities. The novelty of this study was the fact that, it has considered a scenario with on – roads distance between waste production nodes and transfer stations (landfills), instead of taking Euclidean distances as in other studies. The other difference in this research is that, one of the constraints was every waste production node could only transfer its waste to a transfer station, and not directly to a landfill or processing centre. A case study on the city of Nashik, in India was conducted, and it's been found that, implementation of waste transfer station in this city was not economically feasible.

Let us end this section with a study for a master's degree in Industrial Engineering conducted by Begen [21] in the University of Bilkent, in Turkey. In this study, the author has developed a new optimization model to optimize the collection and transfer of solid waste. In the first part of the study, it was a subject of reducing the excessive time and cost required to conduct the feasibility analysis of waste landfills location by waste management Decision Makers (DM). The method proposed the use of the p-Median methodology to first find the economically optimal landfills sites, before applying the conventional time consuming and subjective analysis that looks at social, environmental, political and demographical factors. In the second part of the study, the author developed a model for the optimal siting of waste transfer stations and landfills. The model was then applied for the city of Ankara, and the optimal solution for three different scenarios were found. The last section describes different studies that have applied linear programming to solve a mixed of transportation, facility location and resource utilization problems.

2.3 Mixed of Transportation, Facility Location and Resource Utilization Problem

This last section describes researches that have applied optimization techniques to solve a combination of transportation, facility location and/or resource utilisation problems.

In the University of Greece, two conceptual mixed-integer linear optimization models to optimize the haul and the transfer of municipal solid waste prior to landfilling have been developed [22]. The first being the time minimization, and the second one being the cost minimization. It has been found that the time optimization is easier to use since it uses readily available time data such as distances between wastes production nodes, intermediate nodes (transfer stations) and final destinations nodes (landfills). On the other hand, the cost optimization, though not easy due to availability of cost data, is more reliable than the time model, provided that accurate cost data is available. The author made use of mathematical modelling to model the system and then used "What's Best" software to perform the optimization process. This study has demonstrated that time optimization is ideal for optimizing the haul and transfer of municipal solid waste given that transfer station is not included in the system, since this model does not consider the cost of construction and operation of the station.

In the same study, it also has been found that cost model can be used to determine the optimal location of waste transfer stations and can aid the communities to determine the threshold distance from the landfill above which the construction of transfer stations becomes economically beneficial.

Key input variables that are used in such models are the queue time at landfill and at transfer stations and transfer stations ownership and initial cost data.

In another study conducted by Lee et al. [23], a mathematical modelling has been used to develop a MSWMS for the city of Hong Kong. In this model, an integer linear programming and a mixed – integer programming have been used with the objective function to improve the utilisation of solid waste infrastructures. Researchers in this study have highlighted that mixed integer programming can handle a problem with constraints that the variables can be integers or non-integers and that mathematical models provide useful information for decision makers to select appropriate choices and save cost.

This study was limited to a specific waste management model which includes four nodes - waste collections points, waste incinerators, landfills and trucks warehouses. The model has suggested the number of incinerators and trucks that the city of Hong Kong should have to optimize its waste management system.

Among various studies that have used multi – objectives optimization techniques is the study conducted by Habibi et al. [8]. The objective of this study was to improve the MSW system of the city of Tehran by optimizing the site – selection and capacity allocation of waste facilities. Although there are a lot of similarities between this research and other researches conducted in the same field, the novelty of this study is the fact it has combined the three factors of sustainability in waste management, which includes the cost, the environment and the social aspect.

With the use of robust and multi - objective optimization methods, this study has proposed a model able to minimize the cost of MSW management system, its greenhouse gas emission, and visual pollution due to construction of MSW handling and processing facilities.

Finally, the *Optimization of waste collection and disposal in Kampala city* by Kinobe et al. [24] has made use of the GIS system to optimize the collection routing of MSW in Kampala city, Uganda. The objective of this study was to reduce the total cost of MSW collection by reducing the total distance and travel time of waste collection vehicle, and it has been showed that GIS has provided a model that improved the efficiency of Kampala MSW system and also has provided an optimal location of a new waste landfill. After optimization and changing the visiting orders, the system has resulted in a decrease of 19% and 17% of traveling distance and time respectively.

3 RESULTS AND DISCUSSION

As described in the previous sections, optimization techniques have been applied in different studies and for different objectives. Table 1 provides a summary of the literature discussed above, with the different optimization techniques and simulation or computer tool used in the waste management field.
Optimization methods can be categorized based on various perspectives. Considering the nature of the equations involved in the objective function as well as in the constraints expressions, optimization methods can be classified as linear (If the objective function and all constraints are linear functions of the design variables), nonlinear (If any of the functions among the objectives and constraint functions is nonlinear), geometric (one in which the objective function and constraints are expressed as polynomials in x), and quadratic programming problems which is Considered as the best behaved nonlinear programming problem with a quadratic objective function and linear constraints and is concave [25]. As it can be seen from the literature, the most used methods in this perspective are Linear and Non-linear programming. But due to their simplicity and less computation, Mixed-Integer Linear Programming and Heuristic Methods are the most commonly used approaches [20].
However, the same source has highlighted that other authors like Chatzouridis and Komilis have made use of Mixed-Integer Non Linear Programming to solve similar problem in the optimization of municipal solid waste management systems.

Although MINLP is considered as difficult to solve by many, it paves the way for much precise research; and today's computational advancements have made possible to solve these nonlinear models and hence precise research.

As far as the computer simulation is concerned, the Geographic Information System seems to be the most used tool in these studies. In fact, a GIS software is designed to store, retrieve, manage, display, and analyse all types of geographic and spatial data.

GIS software lets you produce maps and other graphic displays of geographic information for analysis and presentation [26]. This software can be used to get geographic data that constitute the main inputs data for any waste management system planning.

Table 1: Comparative Overview of Optimization methods application in Solid Waste

Author & Year	Paper Title	Optimization Methods	Computer and/or Simulation tool	Research problem
Chang & Wang 1996	Solid waste management system analysis by multi-objective mixed Integer Programming Model	Multi-Objective Optimization	-	Transportation and Facility Location
Chang & Lin 1997	Optimal siting of transfer station locations in a metropolitan solid waste management system	Mathematical Optimization	Geographic Information System	Facility Location
Yaffe 2001	A Model for Optimal Operation and design of Solid Waste Transfer Stations, University of California, Berkeley	Physical model	-	Facility Model Section
Nilufer 2002	Optimal locations of Landfills and Transfer stations in Solid Waste Management	P-Median Method	-	Facility Location
Apaydin & Gonullu 2007	Route Optimization for Solid Waste Collection. Trabzon, Turkey: case study	Vehicle Routing Problem	Geographic Information System	Transportation
Komilis 2008	Conceptual modeling to optimize the haul and transfer of municipal solid waste	Mixed-Integer Linear Programming	-	Transportation and Facility Location
Chatzouridis & Komilis 2012	A methodology to optimally site and design municipal solid waste transfer stations using binary programming	Non-Linear Integer programming	Geographic Information System	Facility Location
Talebbeydokhtia 2013	Optimization of Solid Waste Collection and Transportation Systems by Use of the TransCAD	-	Transcad	Transportation
Yadav et al. 2015	A feasibility study for the locations of waste transfer stations in urban centres: a case study on the city of Nashik, India	Non-Linear Integer programming	Geographic Information System	Facility Location

Kinob et al. 2015	Optimization of waste collection and disposal in Kampala city	Conventional Optimization techniques	Geographic Information System	Transportation and Facility Location
Lee et al. 2016	A mathematical model for municipal solid waste management - A case study in Hong Kong	Integer Linear Programming	-	Infrastructure Utilisation
Habibi et al. 2017	A multi-objective robust optimization model for site-selection and capacity allocation of municipal solid waste facilities: A case study in Tehran	Multi-Objective Optimization	-	Facility Selection and capacity Allocation
Khanh et al. 2017	Optimization of municipal solid waste transportation by integrating GIS analysis, equation-based, and agent-based model	Vehicle Routing Problem	Geographic Information System	Transportation
Hannan et al. 2018	Capacitated vehicle-routing problem model for scheduled solid waste collection and route optimization using PSO algorithm	Particle Swam Optimization & Capacited Vehicle Routing Problem	Smart Bins	Transportation

4 CONCLUSION

In conclusion, this review has demonstrated that optimization techniques and simulation software's have extensively been used in municipal solid waste management around the world.

Although the list of researches on optimization techniques applications in SWM described in table 1 is not exhaustive, a thorough literature review on this matter has been conducted. And based on this review, it can be concluded with certainly that mathematical modelling and simulation can be used to optimize the SWMS by minimizing the total design and operations cost of solid waste infrastructures and resources. Regardless of its complexity and long computation, MINLP together with heuristic methods are the most commonly used approaches in solid waste management systems optimization, thanks to the advancement in computation technologies. GIS systems happened to be the most used computer tool in data collection and storage; and this software proved to be very helpful as a support tool in the optimization process. Another fact that this paper entails is that, researchers around the world have applied optimization techniques in different perspectives and for different objectives. This is because waste management in different cities involve different constraints and priorities level. Given this fact, it can also be said that, although different cities can apply the same optimization models or waste management system frameworks, it is ideal for every city to do an analysis of its waste management system to determine the most appropriate model and framework that will help to optimize the collection, transportation and disposal of its solid waste. Another aspect worth mentioning is that, with the expansion of Industry 4.0, big data is becoming more and more available, and LP is a very good tool that can be used to make use of available data to drive decision-making.

This study has focussed mainly on the comparative analysis of optimization approaches based on the nature of equations involved in the objective functions and constraints; a comparison based on other factors should form the basis for future researches.

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