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PREFACE

The vision of the Southern African Institute for Industrial Engineering (SAIIE) states: "We are a vibrant, learned society, representing and promoting Industrial Engineering in Southern Africa". SAIIE's annual conference epitomizes this vision by bringing together academics and professionals from all over the country and abroad to share best practices and new knowledge concerning Industrial Engineering.

The first call for papers was sent out almost a year ago. About 10% of the initial 163 responding authors opted from the onset for the *Abstract and Presentation Only* track, which does not require a full paper. The remaining 90% of submissions were made to the *Abstract and Full Peer-reviewed Paper* track. These papers were provisionally approved on the basis of an abstract, followed by a double-blind peer review process.

Of the 163 initial abstracts, 68 full papers successfully passed the double-blind peer review process. Of these 68 papers, 52 papers appear in these proceedings. The remaining 16 papers were diverted to a special edition of the *South African Journal for Industrial Engineering* (SAJIE).

All review comments and editorial decisions taken during the process have been recorded and can be traced by means of the online conference management system used for this conference. In an effort to avoid any possible conflict of interest, the reviewers were usually not from the same institution as the author to whose papers they were allocated. When the reviewers recommended minor improvements, the final checks were performed by only one of the two reviewers and the programme director. When major improvements were required, both reviewers were involved in a second (and in some cases, a third) review round. All papers published in these proceedings passed this double peer-reviewed process.

This conference has culminated in three outputs:

1. The **conference proceedings** (this document) is an electronic document that will be distributed on USB Flash drives to all delegates. It contains the full-length papers that were submitted, reviewed and approved for the "Full Peer Reviewed Track", excluding those diverted to the special edition of SAJIE. The proceedings are also available online to ensure that it remains accessible and indexed by scholarly search engines.
2. An abstract of each conference presentation is printed in the **conference programme and abstract book**. This includes papers printed in these proceedings, those diverted to the special edition of SAJIE, as well as all the other non-peer-reviewed submissions (presentations, workshops and keynote speakers).
3. Sixteen papers from this conference will be published in a **special edition of SAJIE**.

We trust that you will enjoy interacting with the authors of the papers that appear in these proceedings and other delegates of the 27th Annual SAIIE Conference, and, in doing so, being part of this "vibrant and learned society, presenting and promoting Industrial Engineering in South Africa".

Prof Liezl van Dyk
Faculty of Engineering, North-West University
Proceedings Editor
October 2016

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RESOURCE EFFICIENT PROCESS CHAINS TO MANUFACTURE PATIENT SPECIFIC PROSTHETIC HANDS USING OPEN SOURCE DEVICES

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ABSTRACT

The success of 3D printed prosthetics over the last few years has made way for further research and development within the field to improve the functionality and aesthetics of low-cost prosthetics. An opportunity now exists to develop a product, similar to that of Robohand and e-Nable, but which uses myoelectric control rather than mechanical control. Online open source projects such as the Open Hand Project, e-Nable, Robohand and various other projects have, to date, successfully supplied low-cost prosthetics to thousands of users and enabled hundreds of people to make their own prosthetics. The next step in the 3D printing revolution is to create the same type of platform, but to improve the designs and their functionality by incorporating myoelectric technology and more lifelike aesthetics into the process chain. This study suggests a process chain that can be used to produce patient specific prosthetic hands with myoelectric control, a 3D printed skeleton structure, and silicone fingers. A time and cost analysis was also performed.

1. INTRODUCTION

Affordable healthcare is one of the needs in South Africa and there are an increasing number of prosthetics required, most of which are not very affordable for the masses [1]. In 2013, the International Society of Prosthetics and Orthotics estimated that, of the 32 million amputees in the world, 80 percent live in developing countries, and only 5 percent have been fitted with a prosthesis [2]. Medical prosthetics are devices that are located either inside or outside of the patient's body to perform a function either aesthetically or practically or both [3]. After the face, the hands are reported to be the principal representation of the self-image which is received by other individuals [4], [5]. Research [1] indicates that an individual's tendency to conceal an affected hand, due to embarrassment, makes them as functionally disabled as a scapula-thoracic amputee. Further research [4] indicated that improved aesthetic prostheses advocate greater psychological well-being. Due to limited funds and available skill in developing regions, people do not have access to quality and aesthetically appealing prostheses. If one had access to affordable prostheses, a life-like passive prosthesis is preferred in order to promote better psychological well-being [6].

Three dimensional printing has become a popular area of manufacturing and medical science. Institutes are now looking into the applications in the medical fields for 3D printers and scanners [7]. Currently the focus is on organ printing where a robotic bio-printer applies tissue, layer upon layer to a print bed where the organ constructs using self-assembling tissue [8]. There is also focus on the 3D printing of prosthetics and whether or not it is feasible to create low cost prostheses that can be donated to underprivileged amputees [9]–[12]. The success of 3D printed prosthetics over the last few years has made way for further research and development within the field to improve the functionality and aesthetics of low-cost prosthetics [9], [10]. The current traditional method of prosthesis fabrication is very costly and not very time efficient [11]. In order to be a worthwhile venture the benefits of the new technology should outweigh that of the traditional methods. The benefits of 3D printing is that the machines can print a prototype or mould in just a few hours and the machines can run nonstop if they have to [13]. This means less waiting time for the patient and less skills required to fabricate the prosthesis.

Open source technology is freely available to download and does not require one to buy the product or expensive licences. The mentality behind this technology is to create a platform for rapid development and to do so using minimal or shared resources [14]. Multiple online databases, or 3D warehouses as they are called, could be accessed to download designs, upload new models or collaborate. The idea of open design platforms is to change the way we construct knowledge around manufacturing, to be able to generate new designs and then be able to share it with others for improvements [15]. This new mentality is providing a new competitive edge to the manufacturing paradigm shift and has also resulted in the uprising of collaborative open source projects. Open source projects are generally crowd funded, collaborative projects where communities of people contribute to a specific cause in the form of finances, knowledge, design, ingenuity, feedback, or experience in order to create awareness and to make the project a success. Several open source projects for the development of prosthesis exist, such as e-Nable, Robohand, and the open hand project.

The 3D-printed prosthetic hands offered by open source projects e-Nable and Robohand are designed for users who still have a section of palm and a movable wrist or elbow. This type of disability can either be a birth defect similar to the user as shown in Figure 1(a), or a partial amputation due to an accident as shown in Figure 1(b). The movement or control of a mechanical prosthesis relies on the upward movement of the palm, section of palm by the wrist, or the elbow in order to bring about movement of the fingers.

(a) (b)

Figure 1: (a) Infant hand showing birth defect where fingers are not developed [16] and (b) user with amputated fingers after accident [17]

The objective of this research was to develop a resource-efficient process chain for the manufacturing of aesthetically appealing patient specific prosthetic hands using additive manufacturing technologies with open-source myoelectric control.

2. LITERATURE STUDY

2.1 Open Community Manufacturing and Online open source prosthetic projects

Open community manufacturing (OCM) is a concept described by Oosthuizen et al. [18]. OCM uses open design platforms to create value in developing communities or the base of the pyramid (BoP). The BoP represents a socio-economic group of four billion people who live on less than US$ 2.50 per day [10]. In South Africa more than half of the working population falls into the BoP category [18]. The OCM model could be used to manufacture prostheses in developing communities in order to grow the formal economy and mobilize entrepreneurs within the communities.

Organisations such as Open Hand Project, Enabling the Future, and Robohand operate open source projects in order to develop low cost prostheses for people in developing countries or for people who cannot afford the traditionally manufactured prostheses. These organisations use a similar model to the OCM model but they do not assist with the incubation of entrepreneurs. A design challenge is presented on a public forum by one of the organisations. The community of designers then collaborate in order to achieve the design goal. The intellectual property (IP) does not belong to anyone as it was a collaborative effort over a public forum. The designs and models are then uploaded onto the Internet of Things (IoT) where anyone can freely download and manufacture the final product. The public and each of these organisations makes use of the FDM technology in order to manufacture the major components of the prostheses [19]–[21].

In order to simplify the prostheses the three organisations designed prosthetics that make use of mechanical control. Mechanical control requires the user to have either a wrist or elbow that is functional. This requirement limits the application of these designs to only a specific group of amputees and the mechanism used for mechanical movement limits the functionality of the prosthesis.

The Robohand prosthetic shown in Figure 2(b) brings about movement using a similar mechanism as the Cyborg Beast in Figure 2(a), but Robohand makes use of only one set of cords. The cords are tightened just enough to keep the fingers straightened when the wrist is in the normal resting position. For users who do not have a palm or section of palm, but who has a functional elbow, some projects provide an adapted design to use the extending motion of the elbow to facilitate the opening and closing of the fingers.

(a) (b)

Figure 2: (a) Movement mechanism on the Cyborg Beast by e-Nable [20]. (b) Robohand prosthetic showing the movement mechanism [21]

2.2 Myoelectric control and Arduino controls

Myoelectric control uses electromyography (EMG), electronic components and motors to bring about movement of the fingers. EMG is a diagnostic procedure used to assess the health of muscles and the nerve cells that control them. These nerve cells are called motor neurons and they transmit electrical signals from the brain that cause muscles to contract. Surface electrodes placed on the skin over a muscle sense the myoelectric activity within the muscle. For the application of myoelectric prosthetic hands, the sensors are placed on a muscle of either the lower or upper arm, depending on the severity of the amputation. The surface electrodes transmit the sensed myoelectric activity to a processor. The processor is configured to interpret the myoelectric signals and then give relevant commands to the motors to close either one, multiple, or all of the fingers [22], [23].

Myoelectric control is more complicated than mechanical control for various reasons. Firstly, the specific myoelectric activity within the muscles differs from user to user. This issue is partially overcome by complex programming and signal processing techniques that enable the processor to correctly interpret a whole range of myoelectric activity as the command for a specific movement of the fingers. Each myoelectric prosthesis thus requires some extent of user specific calibration.

The second issue with myoelectric control is the limited processing capabilities of the electronics used in the prosthetics. The human body has an extremely complex and sophisticated network of nerves that respond to commands sent by the human brain, which is a very complex and powerful processor. Muscles and limbs are created to respond to the commands that travel through the nerves in real time and with extreme precision. The processors, motors and actuators used in the application of myoelectric prosthetics are unable to read, interpret and respond to each and every command that travels through the nerves. It is thus necessary to develop a series of recognisable commands that the components can recognise and interpret successfully. The added functionality of myoelectric control does however strongly outweigh the complexity of its application [22]. In order to keep the costs of the prosthesis low, open source electronics such as Arduino hardware was used for the myoelectric control system.

2.3 Additive manufacturing technologies

Gibson, Rosen, and Stucker [24] define additive manufacturing as the process of joining material layer by layer to make objects from 3D model data, as opposed to subtractive cutting processes (e.g. milling, turning). In order to lower the production costs of prostheses, a fused deposition modelling (FDM) machine was used in the process chain for this experiment. AM is a simpler process to produce 3D objects where very little skill is required compared to other manufacturing processes. With other manufacturing processes a detailed analysis of the object's geometry is required in order to determine the different features that can be fabricated and the different machines and tools needed to do so [24]. An entire process chain needs to be developed in order to produce just one part. With AM the process chain is considerably shorter and less complex than other traditional manufacturing methods. There are many different types of AM technologies and each can be classed into four categories which are separated by the phase in which the component material is used. These four categories are liquid phase material, filament or paste materials, powdered materials, or solid sheet materials [25]. Some of the different AM technologies are classed into their categories and displayed with the years of significant development in Table 1 below.

Table 1: The types and development years of additive manufacturing technologies [26]

Name	Acronym	Category	Development years
Stereolithography	SLA	Liquid Phase	1986 - 1988
Solid ground curing	SGC	Liquid Phase	1986 - 1988
Laminated Object Manufacturing	LOM	Solid Sheet	1985 - 1991
Fused Deposition Modelling	FDM	Filament or Paste	1988 - 1991
Selective Laser Sintering	SLS	Powder	1987 - 1992
3D Printing (Drop on Bed)	3DP	Powder	1985 - 1997

Each AM technology has its advantages and disadvantages. The most cost effective and popular AM technology is fused deposition modelling. The FDM process builds parts layer by layer, where each layer is constructed by depositing a filament of material in a point-wise fashion. The thermoplastic filament is fed into a heating chamber and melted. A set of rollers pushes the material into the heating chamber, and it is this flow of material into the constant volume heating chamber that then produces the required pressure for extrusion. Once a layer has been completed, the build platform or the extrusion head will shift, either one layer down or up, depending on the machine setup, and the next cross-sectional layer is then deposited according to Gibson, Rosen, and Stucker [24].

3. RESEARCH METHODOLOGY

Firstly, a process chain that could be used to produce a fully functional, patient specific prosthetic hand with myoelectric control had to be developed. Once the process chain was developed and refined the prosthesis had to be manufactured following the process steps. The times and costs were recorded throughout each step in the process chain. The research methodology can be observed graphically in Figure 3 below.

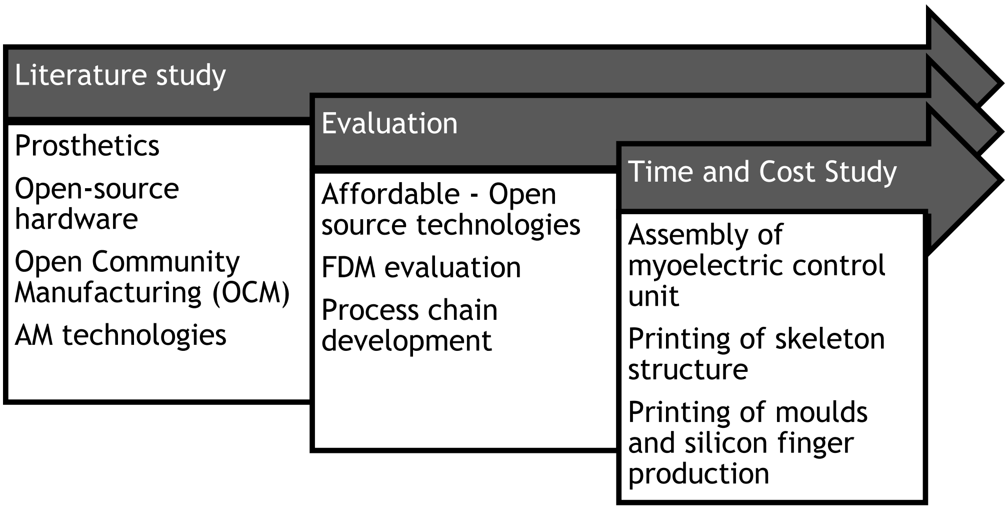

Figure 3: Research Methodology

4. RESULTS AND DISCUSSION

The results from this study are presented and discussed in this section. The process chain that was developed can be observed as well as the finished prototypes and the costs to manufacture the prosthesis at each step of the process chain.

4.1 Open source process chain

The process chain that was developed in order to produce an aesthetically appealing patient specific myoelectric prosthetic hand can be observed in Figure 4 below.

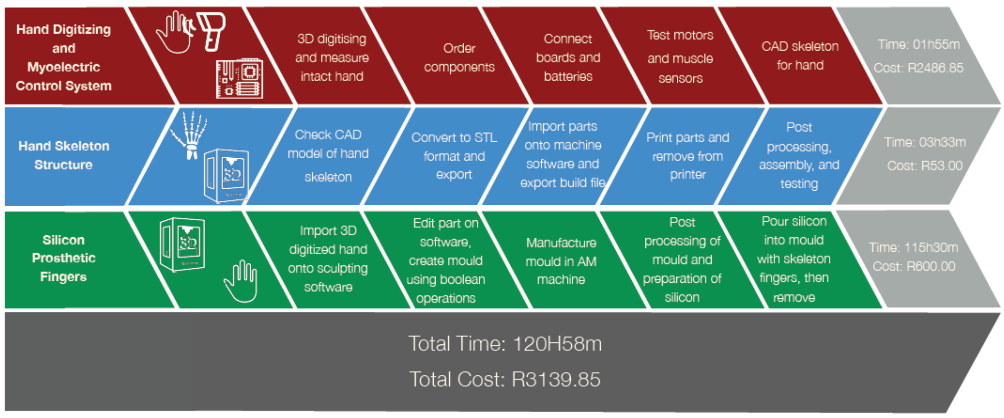

Figure 4: Process chain to develop a patient specific myoelectric prosthetic hand

Each step of the process chain is elaborated on in the following sections.

4.2 Hand digitising and myoelectric control system

Firstly the patients hand needed to be scanned in order to replicate their intact functional hand. In this study a Kreon KLS51 laser line scanner attached to a Zeiss coordinate measurement machine (CMM) was used to scan the hand. The integrated system combines the advantages of a CMM and a laser scanner, for a faster and non-contact method of surface digitisation that allows for very high scan resolutions [10]. Once the hand was scanned and digitised into CAD software format the myoelectric system could be manufactured.

In order for the prosthetic hand to function, similarly to the E-Nable and Robohand, without wrist movement, an open source electronic myoelectric control system needed to be used. One of the best suited open source hardware systems is the Arduino system. The hardware component configuration that was used to create the myoelectric control system is displayed in Figure 5 below.

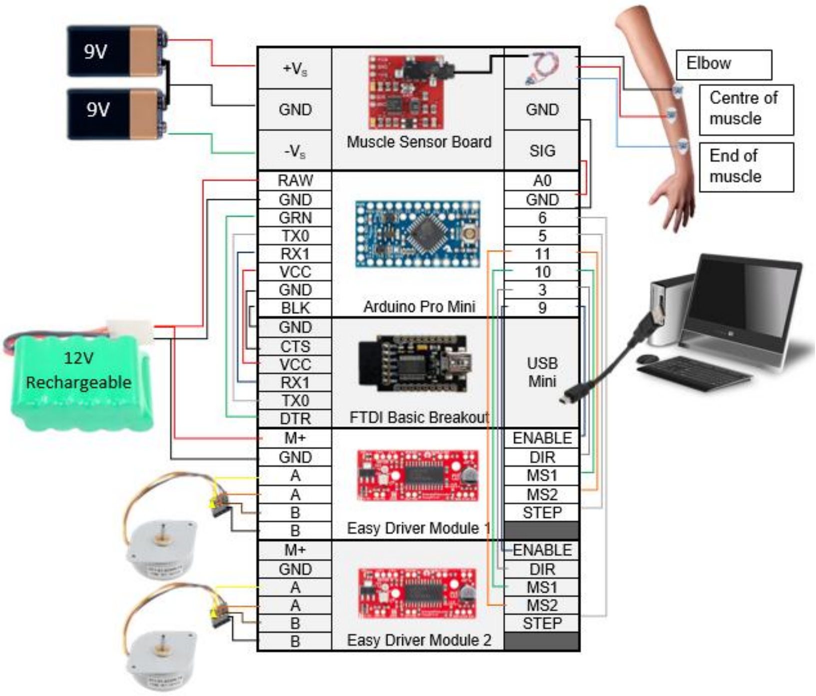

Figure 5: Pin connections and interfaces of electronic subsystem.

Once fully assembled the components were tested and a trial run was performed in order to determine whether the system was functioning properly before moving on with the next step in the process chain.

4.3 Hand skeleton structure

Firstly the dimensions of the designed skeleton structure had to be edited in order to match the dimensions of the patient's intact hand. Once the design was edited the different parts were converted to an STL file format and uploaded onto the machines build software. The skeleton structure was printed on an UP Mini FDM printer. The printing parameters were as follows: the layer thickness was 0.25 mm with an 80% fill density. The material that was used was ABS. The final printed hand skeleton structure can be observed in Figure 6 below.

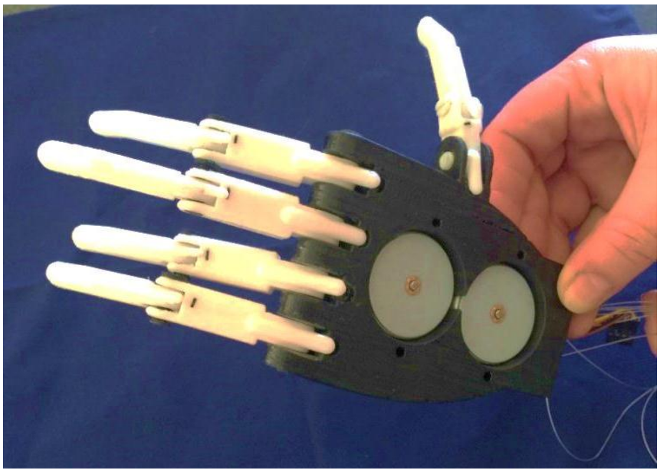

Figure 6: Hand skeleton structure to house all of the myoelectric components

To increase the patient's confidence and psychological well-being the prosthesis needs to look lifelike. So the next step in the process chain is to replicate the patient's intact fingers and mirror them in CAD software and mould them out of medical grade silicon.

4.4 Silicon prosthetic fingers

The aesthetic look of the prosthesis needs to be lifelike and in order to achieve this; the patient's intact hand was scanned in the first step of the process chain. The 3D digitisation of the patient's hand can then be mirrored with the CAD software and edited on an open source sculpting software like Sculptris Alpha or Blender. Once the digital hand is to the patient's satisfaction, each finger can be separated from the model. Once this is performed a Boolean operation needs to be done on each finger in order to create a mould for each finger. Once the moulds are in STL file format they can be loaded onto the 3D printers build software. The mould is then printed and post processing is performed as displayed in Figure 7 below. The fingers from the skeleton structure are then set into position in the moulds. The silicon is mixed, along with the correct colour dye in order to match the patients existing skin colour. The silicon is then poured around the skeleton structure until the mould is filled. The silicon is left to cure for 23 hours and then the fingers are removed and attached to the skeleton structure. The final silicon fingers can be observed in Figure 8 below.

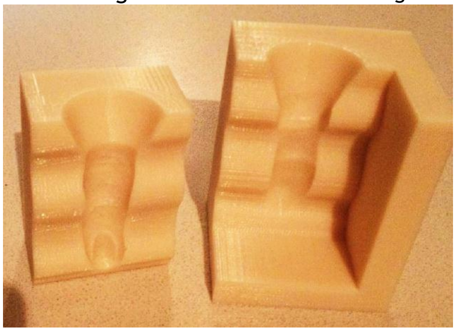

Figure 7: Mould produced using an UP Mini FDM printer [10]

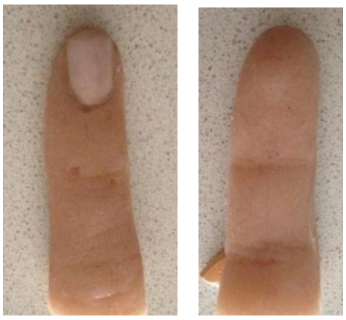

Figure 8: Top (left) and bottom (right) view of the final silicon fingers [10]

In order to not interfere with the motor and other features on the skeleton structure, a latex glove is used to cover the rest of the hand. The glove is dyed the same colour as the patients skin and then cut to allow the silicon fingers to show.

4.5 Time and Cost Study

Tables 2, 3, and 4 display the times and costs for each process chain.

Table 2: Time and costs of 3D digitising and the myoelectric control system

ITEM	COST	TIME
3D Scanning of Hand	R550.00	01H00
Arduino Pro Mini Micro Processor 5V	R144.95	00H05
FTDI Basic Breakout Module 5V	R194.95	00H10
Advancer Technologies Muscle Sensor Kit	R749.95	00H12
Sparkfun Stepper Motors x2	R296.00	00H13
Servo Motor	R148.00	00H09
Easy Drive Stepper Motor Driver	R403.00	00H06
Total	R2486.85	01H55

Table 3: Time and costs to print the hand skeleton structure

PART	COST	TIME
Palm of the hand	R24.00	01H37
4 Fingers with Joints	R24.00	01H36
Thumb with Joints	R5.00	00H20
Total	R53.00	03H33

Table 4: Time and costs to produce the silicon fingers

PART	COST	TIME
Printing of Mould	R50.00	22H36
Post Processing	R10.00	00H30
Silicon Work	R60.00	23H00
Total	R120.00	46H06
Total for 5 fingers	R600.00	115H30

The total time take to produce an aesthetically appealing, patient specific myoelectric controlled prosthetic hand was 120 hours and 58 minutes. The majority of the time is spent on the last step of the process chain with the printing of the silicon moulds and the curing of the silicon in the moulds. The total cost of the hand was roughly R3139.85 which is very affordable in comparison to a professionally manufactured myoelectric controlled prosthesis.

5. CONCLUSION

A process chain to manufacture a patient specific prosthetic hand with open source myoelectric control was successfully developed. The myoelectric control system operated correctly and the hand could open and close as it was designed to do. The skeleton structure would need to be redesigned in order to allow the silicon fingers to bond better to the finger structure. The aesthetic appearance of the silicon fingers were up to the standards of a prosthetic sculptor.

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LEAN MANAGEMENT IN THE HEALTHCARE INDUSTRY

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ABSTRACT

Lean management began in the manufacturing industry as a strategy for increasing efficiency and reducing costs of manufacturing. This strategy proved very successful for Toyota Motor Company and other manufacturing companies. Consequently, based on the success recorded, the service industry embraced it. This study seeks to explore the effects of implementing Lean methodology in the healthcare industry and explore its strategy. A qualitative approach was utilised to evaluate what sets apart lean from other popular strategies. The study focused on the prominence that Lean healthcare management is gaining momentum as a preferred approach to healthcare service delivery in the 21st century. It identified the differences between lean and other popular strategies utilised in healthcare. Management's responsibilities and steps to Lean Management were deciphered and five basic steps developed to better determine the lean journey in simple terms.

1. INTRODUCTION

[12]"Heavy investment over the past 30 years has made the health care sector the largest expenditure category of the health system in most developed and developing countries". Harding and Preker [16]. This is because health care sector is responsible for servicing, repairing and assisting with most human beings health problems. Besides the importance of this sector "There are still significant inefficiencies in the health system stemming from poor quality of care". David Harrison [9]

"The relatively high healthcare expenditure coupled with poor outcomes speaks to weak management" Kleinert and Horton [19]
meaning management is the key needed to be enhanced to get better service delivery in the healthcare sector. "Striving to achieve a process without non-value-added time, monetary waste, and product waste has been a long-standing tradition in manufacturing, but the healthcare industry has been slow to adopt these principles". (Benfield et. al, [6]concurs "clearly it shows that the evolution of the healthcare sector has been slow as compared to the manufacturing sector".
This is because the healthcare sector was focused on developing new technology and better processes to improving healthcare neglecting the basis of its day to operations.

There are many approaches to improve healthcare that have been explored but one in particular has picked up in recent trends in developed countries which is lean in health care. Waldhausen, John HT, et al. [37]
concluded that Lean methodology can be used to improve clinic efficiency as well as patient and staff's experience.

From the manufacturing industry, Toyota motor company developed the Toyota Production System known as lean manufacturing which has now migrated to the service industry Arlbjorn [4] and Kanakana [18] concur.
Healthcare organizations have been one of the latest services settings adopting Lean principles, tools and techniques feeding a crescent stream of literature. Guimaraes & Carvahlo [14]

Why lean in health care one might ask?
"The core competence of Toyota Motor Corporation is its ability to produce automobiles of great quality at best prices, thereby providing a value for money to the customers" Nkomo 2014, [34]. Nkomo [34] further states:" Toyota's distinctive competence is its production system known as the "Toyota Production System" or TPS.

TPS is based on the Lean Manufacturing concept furthermore Nkomo [34] states that "Overall, Toyota has outperformed the industry over the past five years and its 8 times more profitable than the industries average" which shows that lean manufacturing is one of the best if not the best approach to adopt if you want to be competitive in the market.
Furthermore, Nkomo [12] states that "Toyota has outperformed the industry over the past five years". Critics note that alternatives to lean production have not gained much acceptance Dankbaar, [7] and stipulate that ''lean production will be the standard manufacturing mode of the 21st century'' Rinehart et al. [12].

With the increasing pressure on healthcare providers to reduce costs and improve quality, an increasing number of organizations are looking to Lean tools and techniques as a breakthrough solution for performance improvement" White Paper on Lean Healthcare, Philips, [27]

Lean identifies gaps, waste and opportunities for improvement and eliminates or reduces those through continuous improvement. Furthermore, Philips white paper [27] expresses that "Over the last four decades, Lean has emerged as one of the most impactful approaches to help increase an organization's competitiveness through improvements in process efficiency and a reduction in operational waste".
Today, Lean is used in most global industries and virtually all organizational sectors including healthcare. (Kanakana [18] concurs.
Lean begins with driving out waste so that all work adds value and serves the customer's needs. *Institute of health Improvement* 2005, p.2, Innovation Series [17]

To eliminate the 7 waste only a human can influence change so which brings us to the 8th waste which is a lack of creativity or waste of none improvement in lean terms by employees.

Lean aims to tap into this 8th waste in every employee in an organisation to create a culture of continuous improvement using lean tools for solving problems (in lean terms opportunity for improvement) by eliminating waste and coming up with better ways to provide the service or produce a product.

Lean production in healthcare is mostly used as a process improvement approach and focuses on three main areas: Poksinska [28]

- ❖ Defining value from the patient point of view,
- ❖ Mapping value streams and
- ❖ Eliminating waste in an attempt to create a continuous flow.

Lean healthcare is still in an early stage of development if compared to the same process in the automotive industry, Souza [33]. Kanakana[18] quoted Burgess and Radnor[2013] in their study on evaluating Lean in healthcare, claiming that Lean in English National Health Service is being successfully implemented in many cases and continuous to gain momentum in English hospital trusts and also continues to spread throughout the world.
This study aims to show how lean management is one of the best strategies to adopt in order to increase quality in the health care sector by comparing it to PDSA and Six Sigma.

2. LITERATURE REVIEW

The primary target for lean principles in Healthcare is to improve quality healthcare where quality healthcare is defined by Agency for Healthcare Research as:

- ❖ “Doing the right thing at the right time in the right way for the right person, and having the best possible results” **Varkey and Kollengode**[36]
- ❖ “Lean is a systematic approach to identifying and eliminating waste (non-value-added activities) through continuous improvement by flowing the **product at the pull of the customer in pursuit of perfection.” Lockwood [24].

Most of the definitions focus on eliminating waste but lean focuses on increasing the quality of the product or service to the customer by having the following conditions in mind when producing products and delivering a service according to the Levantar organisation. www.levantar.co.uk [44]

1) The customer must be willing to pay for the activity.
2) The activity must change the product making it closer to the end product or service that the customer requires and is willing to pay for.
3) The activity must be done right the first time.

To achieve these three conditions lean looks at increasing the efficiency of its resources to attain the most efficient process to develop a quality product or deliver a service with the aim of being competitive, making the profit and staying in business.

Instead of the old traditional 7 lean wastes lean has identified the 8 waste and a lot of literature has been written to validate the 8th waste under lean Six Sigma by Dr. Pat Hammett, 2008 and The Lean Enterprise Institute and more. This is Waste of none creativity (e.g. Nurses with ideas to improve procurement but withholding it since it’s not their department) because between all the resources required to produce a product or service the only resource that can influence change and solve problems is the people (management and employees).

According to Zameer [43] “Many authors regard the respect for people as fundamental to Lean implementation and **acknowledge the value of staff input in creating improvements**”. Lean aims to **develop employee’s creative thinking** so that they come up with ways to improve the processes, products, eliminate waste; solve problems and come up with improvements in order to produce a quality product or service. Liker[23] concurs by stating that “the more I have studied TPS and the Toyota Way, the more **I understand that it is a system designed to provide the tools for people to continually improve their work**” this is made possible by employees trained and equipped with tools to take initiative through the leadership of management.

Kollberg et al. [20] cited *(Miller, D., et. al., 2005).*"“Adoption of Lean management strategies while not a simple task can help healthcare organizations improve processes and outcomes, reduce cost, and increase satisfaction among patients, providers, and staff” . Balle [5] states that: “the adoption of lean in healthcare is very young it started in the late 90s but started to gain a little bit of momentum in the last decade and now in this decade many health organisations are looking at lean principles since it has been proven to be very successful in many cases around the world”.
However Vinodh et al. [37] states that “a Lean method is a good option for optimizing clinical workflow, because it focuses on detailed process components, such as workflow and problems, and then redesigns the processes by removing waste”. Andersen on the above statement basically wants to show that each organisation will have different lean solutions although they will be driven by the same lean principles. According to Wu [41]moving from theory to practice may be challenging as lean thinking requires a deep change of operating mentality, which frequently collides with embedded mind-set”.

3. METHODOLOGY

The methods of evaluating change and improvement strategies are not well described, **Eccles** et al. [12]
A systematic review of the literature was done in order to establish quality management strategies that are been adopted from the manufacturing sector and applied in healthcare in the 21st century with the aim of comparing them with lean Management in Healthcare; and PDSA and Six Sigma were chosen.
A qualitative method was used in order to determine the effects of lean implementation in the health care industry and the differences it has as compared to other strategies reviewed in order to identify the critical element that sets apart lean from the two strategies. "A primary goal of qualitative research is to produce knowledge that is transferable from one context to another" Goodridge et al. [13]From the available literature relevant literature was reviewed in order to investigate lean health care strategies mainly to establish what sets it apart from other management strategies adopted from manufacturing implemented in healthcare recently.

4. RESULTS

4.1 PDSA

Table 1: Positive PDSA implementation in Healthcare industry

Reference	Year	Country	Study based on	Results
Zack	2008	USA	Zero tolerance for central line-associated bacteraemia.	Positive
Torkki et al. 2	2006	Finland	Managing urgent surgery as a process: case study of a trauma centre.	Positive

Torkki et al. used the PDSA cycle to improve Hospital efficiency and reduce waiting times and the results showed a positive outcome:

- Waiting times decreased by 20.5 percent (p<.05)
- None operative times in the operating room were reduced by 23.1 percent (p<.001)
- efficiency was increased by 9.7 percent (p<.001)
- Overtime hours decreased by 30.9 percent after re-engineering of the care process.

PDSA cycle was introduced by Edward Deming as a strategy for implementing change management. This is an often used process to help management and technical teams improve the quality of care in healthcare. Basically, the strategy is mostly used for addressing long-term strategic change but can also be used for short-term objectives.
PDSA is a tool for *"developing, testing and implementing changes leading to improvement"* Langley et al. [22] which has four stages. Langley et al. [22] furthermore state that "they developed a quality improvement program to reduce patient waiting times in the Hospital Management System using Plan-Do-Study-Act (PDSA) methodology" which proves that this methodology is being adopted in healthcare.

Luther, Hammersley and Chekairi, A.,[25]established the key feature of the PDSA cycle is that it recognizes that the objectives of a project are rarely accomplished first time round, and encourages learning from the errors of the first attempt.

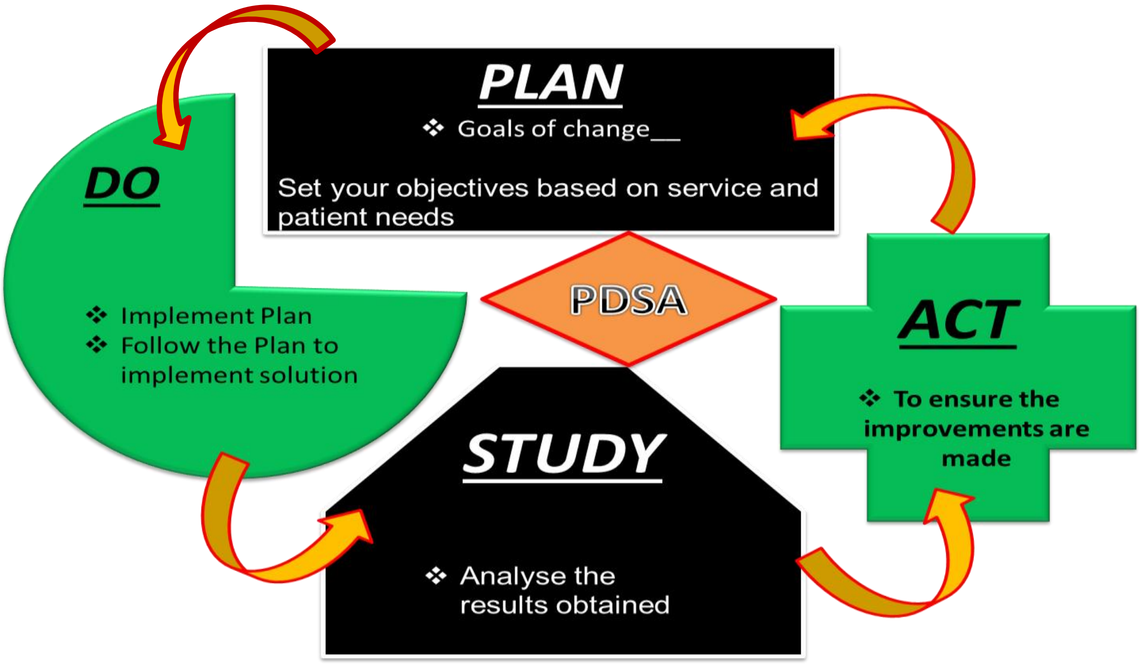

Diagram1: PDSA cycle

4.1.1 Plan

Objectives are placed based on e.g. (in a health care institution service and patient needs) key important questions asked at this phase.

- Mainly what is the Aim or objective of what u trying to achieve? Donnelly and Kirk [45] this is called the *aimed statement*.
- Underpinning this is the question ... What is the problem? You then have to formulate an answer to the question.
- How do you know it is a problem? To answer this, baseline measurements must be acquired.

Donnelly and Kirk [45] "These inform the understanding of the problem and its scale. It is also important to acquire data which informs the likely or actual cause of the problem". Donnelly and Kirk [45] furthermore they state that "The points above naturally lead toward producing a description of the solution"

4.1.2 The second step is DO.

Donnelly and Kirk [45] "This is where you carry out the change, test or intervention and record what has happened. It is important to do this from a particular point in time and to take measurements over a period of time to record the pattern of data"

4.1.3 The third step is STUDY.

Langley GL et al. [22] "In essence, this is about studying or analysing your data and the process itself". Some Important questions in this step are:

- What was the outcome based on what we planned?
- Did things go according to the implemented plan?
- How the experience was and what was gained from the experience (lessons learned)?

4.1.4 The next step is ACT.

Donnelly and Kirk [45] "Act is an important element in that you have to consider what measures and procedures are in place to ensure that whatever solution or solutions you have realised remain effective",
Key questions such as:

- What changes are needed to improve the process?

- Justification of improvement changes?

Such questions lead to a plan which in turn generates the next PDSA cycle.

According to the Authors PDSA is a strategy that seeks perfection by continuously improving the processes (continuous Improvements serves as the key to ingredient that drives the PDSA cycle).

4.2 Six Sigma

Table 2: ***Positive Six Sigma implementation in Healthcare industry***

Reference	Year	Country	Study based on	Results
Frankel et al.	2005	USA	Performance-improvement strategies to reduce incidence of catheter-related bloodstream infections in a surgical ICU.	Positive
Does et al.	2009	Netherlands	Reducing start time delays in operating rooms.	Positive

Ian et al. (2010) stated that "in business the term **Six Sigma** refers to a set of tools and methodologies developed by Motorola to improve the business by eliminating defects". Pandi, Sethupathi and Rajesh [46] concur by stating that "the core concept of **Six Sigma** is to reduce the defects in the process".

"**Six Sigma** has been proved as an effective approach for quality improvement in service sectors, especially at healthcare and financial services" Schroeder et al. [31] and also in the table above the researcher shows two success stories in healthcare.

This means that it is an approach that is suitable to be used in eliminating defects in healthcare. Nicolay et al. [47] states that quality in six sigma is "measured in terms of defect (error) rates and the aim is to reduce this to six standard deviations (sigma or σ) from the process mean" furthermore Nicolay et al. [47] expresses that Six Sigma translates as 99·99966 percent defect free or error-free or 3·4 defects per million opportunities (DPMO).

Six Sigma uses the DMAIC methodology basically divided into 5 steps.

4.2.1 Step 1: Define

Define is where the opportunity for improvement or problem is defined in detail to understand its details and constraints. (Hikmet Erbiyik and Muhsine Saru [15] express key questions to ask at this stage

- What is the source of problems causing to failure?
- What are the relations?
- Between cause and effect of the problem?

Furthermore Hikmet Erbiyik & Muhsine Saru [15] state that "By searching the answers for above questions the relevant problem is defined".

4.2.2 Step 2: Measure

Is when the current situation is measured to evaluate its impact and contribution.

4.2.3 Step 3: "Third, the capability

The capability of the process needs to be analysed in order to determine if it is delivering what is required (accurate stability predictions or estimates), and if not, improve". De Vore [49]

4.2.4 Step 4: Improve

This is divided into 3 steps according to (Alexandra, Carneiro & Pinto [3]

- Step 1: Solution Identification
- Step 2: Solutions Prioritization
- Step 3: Solution Implementation

4.2.5 Step 5: Karl De Vore(2008) state step 5: control as "the stability testing process by ensuring that the improvements that have been implemented are maintained through time".

Six Sigma mainly deals with eliminating problems in a process by eliminating its short comings in simple terms the authors express that (six sigma seeks design perfection in the process)

4.3 Lean.

Table3. Positive Lean implementation in Healthcare industry

Reference	Year	Country	Study based on	Results
Waldhausen et al.	2010	USA	Application of Lean methods improves surgical clinic experience.	Positive
Muder et al.	2008	USA	Implementation of an industrial systems engineering approach to reducing the incidence of methicillin.	Positive

Lean management in healthcare has been discussed and evaluated in many ways and many frameworks developed mostly discussing the tools. From the literature reviewed by the researcher thus far and personal experience, the Researcher developed five basic steps to Lean management.

4.3.1 Control your territory

- Basically, this means to control your working area and know its limits
- Identifying your resources and know what you have and what they can achieve and their costs to run, cost to maintain, what is useless and etc. (Preventative Maintenance concept)
- Create a clean working Area which will able you to spot any anomalies immediately
- Also, this stage, is mainly concerned with Housekeeping (A place for everything and everything in its place defined). This is done by using a lean tool called 5s Method.
- In this initial stage the manager must do regular field visits spotting anomalies and encourage employees to iron them out.
- Lastly to reduce or eliminate the risks of mistakes from happening this is known as Error Proofing outlined by Womack, jones, and Ross, [39]

4.3.2 Establish meaning to actions

- In this step, you Identify ~~your~~ all your customers and what they expect from you.
- Then design performance indicators based on your customers' expectations that you can measure on a daily basis. It's then easy to study the processes and clearly indicate what is required to process and what is not necessary for the processes.
- In this step tools like value stream mapping, Kanakana [18] stated that it provides a graphical representation of the process activities and provides a scope of the project by defining the current and future states of the system.
- Evaluating your suppliers because without the supply of raw materials nothing can be produced. This is done by creating continuous flow in the process.
- Daily activities should be aligned according to customer needs and Tools for monitoring established (Visual Management) which assists in exposing anomalies immediately to the day to day activities.

4.3.3 Training your employees in the lean culture and giving them a platform to express challenges, problems and solutions.

- This will be done by assembling your team around a central location where you will have a visual management board where the performance will be evaluated.
- It must be done in the morning for 15 minutes (sort of a ritual)at least weekly and employees must indicate what they have done, their challenges, discoveries, problems to be solved, lessons learned, opportunities for improvement, actions in progress, update the visual management board and etc.
- This should become a daily ritual and you must acknowledge achievements by your team and always motivate during this time.

4.3.4 Delegating problem-solving

- Problems or opportunities for improvement discussed in the daily or weekly ritual can't all be solved immediately. Delegating a team (including Management if possible) to analyse the problem and stamp out the root cause of the problem discuss the solution and give responsibility employees to implement the solution.

- In this stage method known as Kaizen is used; basically if the solution is simple it will be implemented immediately but if a study needs to be done a team will assess the problem develop a solution and implement.

4.3.5 Managing the progress plan…

- Instead of Kaizen day to day improvements here is when the organisation is running smoothly now breakthrough solutions to meet the strategic challenges are needed.
- This is done by many ways but the cycle is the same evaluate the state of the company's current situation and where you want it to be and set up steps to reach those goals and implement them.

Table 4: Key differences of PDSA, Six Sigma and Lean.

Criteria	PDSA	SIX SIGMA	LEAN
Methodology main focus	Reengineering Processes	Eliminating Defects	Eliminating waste
Tools used	Changing the process to a better more efficient one	Reduce variations in the process	Reducing none value adding processes according to the customer
level of employee involvement	Exploring options to improve the system	Exploring the causes of defects in the process and eliminating them	Making sure the activities of the process add value to the end service or product
Implementation approach	Normally by Management and technical stuff	Mostly Quality experts, Management and technical employees	**Every employee can influence change**
Feasibility	Meduim	Expensive	**Low in most instances**

Discusion

There are Hybrids of improvement strategies in the healthcare sector being applied to complement for the weakness of the other strategy e.g. Lean Six Sigma but for the sake of these study original strategies where evaluated.
The PDSA cycle is driven by the nature repetition of the cycle to seek perfection from the lessons learned in the previous cycle and it's echoed in the DMAIC process of Six Sigma and apparent in the Kaizen continuous improvement methodology of lean. Which one can argue that it can fall under Lean as a tool for continuous improvement? Although unlike Kaizen which uses baby steps (small improvements) to arrive at its goal PDSA completes a goal and re-evaluates the new strategy and sets a different course of improvement.
Six Sigma, however, uses statistical analyses which are very accurate in spotting and eliminating the root cause of defects and process variations all through the DMAIC process defines and improve its application to business re-engineering is very farfetched. Instead of statistical analyses Lean uses value stream mapping and GEMBA (which stands for go observe for yourself) and kaizen which are similar to six sigma but are less complex and anyone can adopt them easily.

Lean seems to embody the two processes in its culture although it's in a different form. To be able to fully integrate Lean into healthcare isn't an easy task because it incorporates a lot of tools from the production industry which might not necessarily be applicable to the service industry e.g. In manufacturing when a defect occurs in any process a lean factory stops and solves that problem but for a hospital it's impossible if a defect occurs in admin we can't expect the doctors to stop operating a patient in theatre.

Nicolay et al. [47] express clearly that methodologies such as Six Sigma require trained employees in Six Sigma (ideally people with statistical background) because it requires a lot of data collection and statistical analysis. This leaves the sustainability of the program in the hands of the Six Sigma specialists.

PDSA is a re-engineering model this process although doesn't require much training the researchers express that it needs at least technical staff and management to execute this process on the other hand although advance lean integration needs specialist the basic form of lean which is termed lean thinking developed by Womack and Jones refers to the spotting and elimination of waste is easy enough to be integrated into the whole organisation easily at a low cost.

From the analyses, Lean is mostly set apart from the other strategies because its continuous improvement methodology known as lean thinking can be easily trained to every employee at a low cost which makes Lean the most viable strategy to adopt in healthcare in the 21 century.

5. CONCLUSION

Dobrzykowski, McFadden, and Vonderembse [11] "To improve patient safety and financial performance, many healthcare organizations have implemented quality initiatives such as lean process improvement".
Mainly this as a result of other studies in other industries provides evidence on the effectiveness of lean in reducing lead times, improving space utilization, increasing throughput, improving quality, and increasing financial performance Shah and Ward, [48].

"It should also have become clear for the readers, that quality improvements and waste reduction require a systematic and well-planned process, where all employees are involved in identifying the problems, route causes ~~behind~~ the problem and the needed action for eliminating the problem". (Dahlgaard, Pettersena and Park[21]
And from the strategies that are common in the 21st century only Lean can achieve that (if we exclude hybrid strategies like Lean Six Sigma).

The researcher expresses that **Lean** is mostly set apart from the other strategies because **it equips all employees in an organisation with tools, principles, and philosophies to influence change and also provides them with a platform to make those changes**. Womack and Jones [40] concur by expressing that Lean seeks to reconfigure organisational processes to eliminate waste and enhance productivity based upon the application of specialist analytical tools and techniques coupled with creating a culture of continuous improvement.

Based on the above the Lean management in healthcare although it was adapted from the manufacturing sector seems to work for the service industries including health care.

Lean's uniqueness of being able to engage management to promote growth in the organisation through making sure that every employee is equipped with a continuous Improvement ideology, from the shop floor operator to the CEO or Director of the organisation sets lean apart from other methods and the researcher expresses lean management in healthcare as the most viable approach to adopt in healthcare.

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VALUE STREAM MAPPING APPLIED TO A TYPICAL THREE YEAR HIGHER EDUCATION QUALIFICATION

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ABSTRACT

Given the challenges that higher education institutions are facing in South Africa due consideration needs to be given to efficiencies associated with the current processes. This article focused on the use of value stream mapping as a means to identify waste in a typical three-year national diploma course in its current format. Statistics and timelines associated with students enrolled for an industrial engineering national diploma at a comprehensive university were analysed and transferred to a value stream map. A comparison of total lead time and value added time revealed ratios that would be totally unacceptable in any other environment. Taking note of these issues could guide academics in the process of re-engineering the entire academic value stream.

1. INTRODUCTION

The current higher education (HE) landscape in South Africa is characterised by unusually high levels of change, a significant component of which, is emanating from forces linked to affordability and efficiency. In the midst of calls for change academics at many universities are in the process of re-designing curricula in line with the the new HEQSF framework and a unique opportunity therefore exists to radically change the way in which qualifcations are structured.

Existing methodologies for offering three-year diploma type engineering courses have been largely unchanged for several decades and have become the de facto blueprint for the new qualifications. In effect, the same content is being re-packaged under new module names and outcomes with no fundamental change to learning process and the associated duration. This article endeavours to bring proven industrial engineering and lean techniques to the diploma value stream with the aim of exposing waste and highlighting current inefficiency. Exposing the levels of waste and the constraints that are crippling flow throughout the process has revealed that there is an obvious and urgent need for a major re-think on the way in which qualifications are offered.

The sections that follow include a brief review of the situation prevailing in HE and an overview of the lean tools used in the analysis of the current three-year engineering diploma. An analysis of the diploma at a selected comprehensive university is conducted and the results discussed.

2. HIGHER EDUCATION IN SOUTH AFRICA

As is the case globally, higher education institutions in South Africa are experiencing a bewildering array of forces aimed at bringing about significant change. The main sources of these forces include reductions in state funding, competition from private learning organisations and a growing resistance to increasing fees [1]. The manner in which they respond to these forces will in many ways determine their future success and in some cases ability to survive. Current responses, to a large extent, depend upon the way the university in question views itself. These views range from the traditional monastery world of careful reflection to the modern marketplace mind-set anchored in quick response to changing requirements. Kirp [2] provides interesting arguments supporting a policy (for U.S. institutions) that includes both viewpoints, the aim being to retain academic integrity with a commitment to need and ability rather than the ability to pay whilst simultaneously recognising the forces of commercialisation. Whether this lofty goal can be achieved or not remains to be seen but it is also evident that South African universities face challenges that are more urgent emanating as they do from a polarised population desperate to gain access to higher education as a means of realising economic freedom. Adding to the complexity of the problem in South Africa is the relatively small tax base [3] where less than two percent of the entire population pay more than fifty percent of the total personal income tax collected. Growing tax revenue to further subsidise higher education is clearly going to be a challenge. Ironically, evidence suggests that national economic growth is dependent upon increased investment in education and training [5].

Although it could be argued that financial challenges are the major force contributing to change in the global higher education landscape there are other challenges that include [4]:

- higher public expectations
- increased parental concern about quality of education
- greater emphasis on university ratings, and
- demographic changes to the student population.

The development of new technologies has also stimulated thought around new ways to organise and deliver programmes. Competition from online learning and the awarding of credits for prior learning has become common practice in private learning institutions [1]. As is the case with most service industries, customers are demanding better quality at a lower cost and those universities that do not acknowledge this trend may do so at their own peril. Social media is believed to be an increasingly important factor in the development of higher academic service quality transparency [6]. In addition, increased student mobility gives students the freedom to choose a university based on the factors discussed in this section

Addressing all the forces that are currently exerting an influence on the higher education sector is beyond the scope of this paper as the final solution will undoubtedly be multi-faceted. Given that funding is unlikely to increase, this paper seeks to address the factor that is arguably the most important and urgent namely that of cost reduction. A number of options for reducing costs exist but for reasons that will be discussed in the following section the lean option of waste reduction and increased flow has been selected.

3. LEAN

Reducing manufacturing costs per unit can be achieved in two ways, either cut costs and maintain output or keep costs static whilst increasing output. In reality most organisations try to realise cost per unit reductions using both methods. Lean is a well-known philosophy associated with waste reduction (and by association, cost reduction) and increased output which is generally referred to as flow [7]. Although developed in the manufacturing sector, lean has since proven effective in a number of other fields such as the service sector and health care. Of particular relevance to this paper are the recent successes achieved by lean in the higher education sector [4].

Lean can be described [4] as a philosophy "intended to reduce cost and cycle time significantly throughout the entire value chain while continuing to improve product performance". As such it clearly focuses on cost reduction and faster throughput, both factors that are relevant and sought after in the context of higher education. A number of scholarly articles have been published that describe successes achieved through lean applications related to administration functions in higher education institutions [1,4,5,8]. Examples of lean applications related to the design and delivery of actual academic programmes are less common. Reasons for this phenomenon are not clear but may reside in the logic that administrative functions are not the core function of a university and are not therefore afforded the almost untouchable monastery status of the academic programmes. Whatever the reason, it is clear that the building pressure to reduce costs and increase throughput will erode this status.

One of the notable exceptions to the trend of neglecting programme design is the work done by Emiliani [9,10, 11] where he outlines the process of redesigning courses using lean principles. This paper seeks to address the topic of course design in a similar fashion but using different lean tools. Kaizen, which has been utilised for more than three decades now, was the tool of choice for Emiliani whereas this paper describes the use of the value stream mapping (VSM) tool.

4. VALUE STREAM MAPPING

Value stream maps are diagrams, usually drawn on A3-size paper, that provide an overview of how a group of processes produce a product or service [12]. According to Emiliani [13] the technique was developed by the Operations Management Consulting Division of Toyota Motor Corporation in the late 1980's with the aim of improving information and material flow. Used almost exclusively in manufacturing for many years the technique has since gained popularity in service industries where it is used to map processes such as order entry, procurement and design [14]. The purpose of doing a value stream mapping exercise is to identify and eliminate waste or non-value adding activities in a series of processes. In the case of conventional value stream maps the waste is normally expressed in terms of time although hybrid versions have been developed that focus on other resources such as energy and water [15].

The procedure for carrying out a value stream mapping exercise can be divided into three stages that include:
- drawing the current state depicting the value stream as it *is*,
- an analysis phase where waste is identified, and,
- developing the future state which reflects an improved value stream.

The diagrams are completed using a standardised set of icons where possible augmenting these with personalised icons where one does not already exist. Any set of processes can be mapped using this technique with the key being to ensure that the current state truly reflects reality and not someone's perception of reality.

5. MAPPING A TYPICAL 3-YR ENGINEERING DIPLOMA

The mapping exercise that constitutes the main body of this paper was conducted at a comprehensive university in South Africa that offers a range of engineering diplomas that are designed to take three years to complete. Consisting of a planned two-year period where theory is taught in a conventional classroom setting and one year of experiential learning in industry the process appears fairly simple and logical yet almost everyone involved in the system including academics, students and sponsors (parents or students themselves) are aware that it is inefficient. The raison d'etre for this study is to highlight inefficiencies in the diploma value stream using lean tools, or more specifically value stream mapping, whilst the importance of the study is highlighted by the discussion surrounding the need for meaningful change in the way higher education institutions design engineering programmes.

The mapping process was divided into three distinct phases including the drawing of a map depicting the desired current state, amendments to the map to depict reality and an analysis of areas where problems occur.

5.1 Desired current state

Although it goes against accepted procedure, the point of departure for the value stream mapping exercise was to map the process as it was *meant* or *planned* to transpire. The reason for the deviation (the first map is usually an actual current state) was that this step would show the interested parties just how removed from reality the desired state had become.

The desired current state map is shown below in figure 1. The map shows 55 students entering the system annually and the same amount graduating three years later. A two-year period is set aside for students to complete 24 main modules with the goal of passing six every semester (six months). In the original course design each of the six modules was afforded the same amount of time per week in a timetable that had six keys. This has been mapped by numbering each module (1 to 24) and adding a prefix letter (A to F). The industrial engineering department was responsible for the programme, offering the bulk (14) of the modules, while service departments offered the balance.

For reasons of simplification, the timeline focuses on the two-year period containing the theory component of the programme. A total of 474 days were deemed available over this period of which 280 days were value-adding. The balance of the days was either non-value adding (134) or set aside for assessment in the form of exams (60).

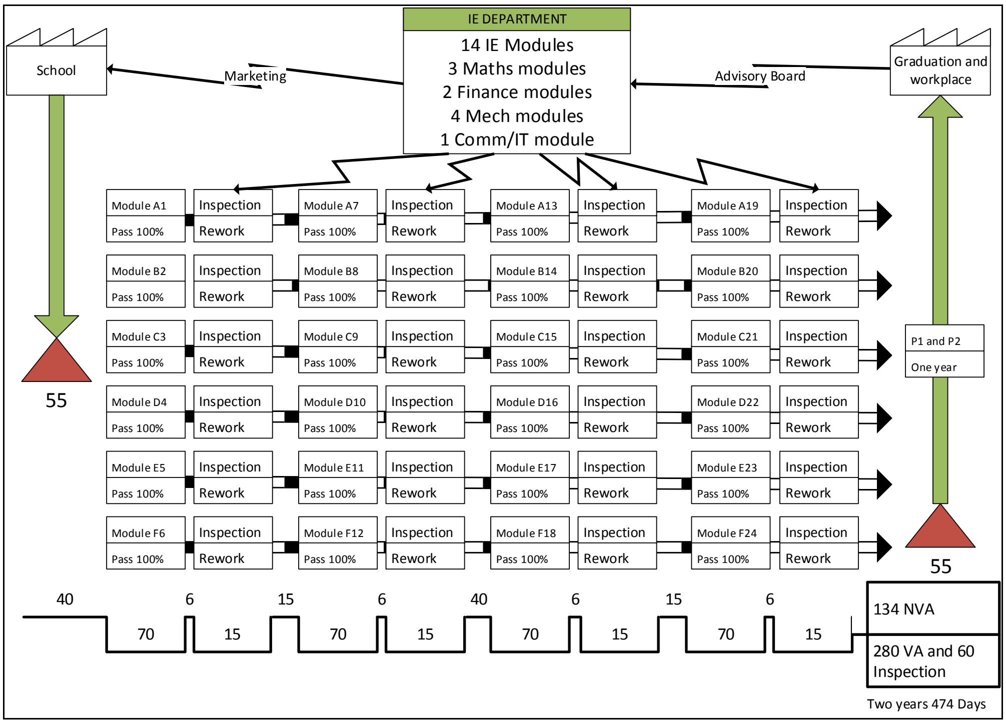

Figure 1: Desired state map (own construction using MS Visio)

This scenario represents the original planned programme and even so results in a fairly dismal picture where non value adding activities (or inactivity) account for almost thirty percent of planned time. To anyone intimately familiar with the entire process it will also be evident that these timelines err on the conservative side. Available academic time (planned) has been eroded by administrative functions over the last two decades.

5.2 Actual current state

Experts in the field of value stream mapping advocate that a mapping team should walk the entire process collecting data as it is observed [12]. This type of approach creates a “snapshot” of the value stream at a specific point in time which is fairly meaningless when a two-year process is being mapped. Developing a map to cover this type of event requires that the mapper bases the current state on a typical (or average) student flow. Doing so results in a map that is clearly very different from the desired current state. The complete actual current state map is shown in figure 3.

Although there is considerable variation, the average student takes approximately four years to complete the required 24 modules of theory and 35 percent of each intake drop out altogether. The experiential learning component of the programme takes just over the planned year – revealing that this is not a major factor in the lengthy throughput time. It may, however, be an important factor contributing to the high drop-out rate. Another significant difference between the two current state maps is that the average student fails six modules during the entire process.

It is also worth noting the addition of a seventh module key was introduced since the original plan in order to help students overcome scheduling issues resulting from timetable clashes

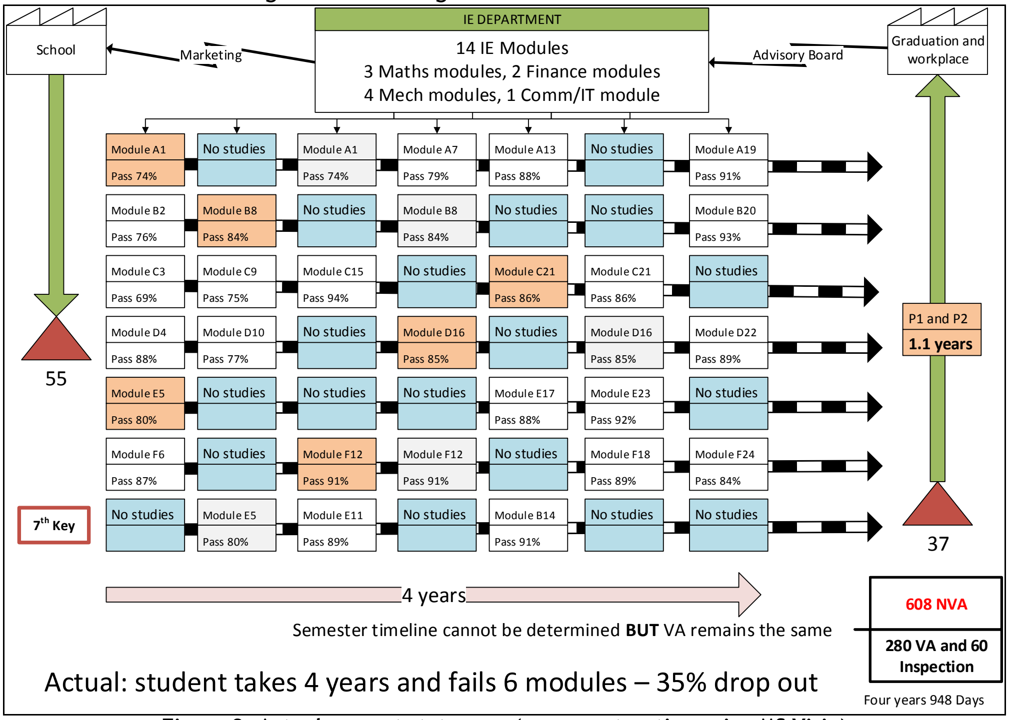

Figure 2: Actual current state map (own construction using MS Visio)

Again using a conservative approach, the value adding time remaining the same, it becomes evident that the non-value adding time is more than four times larger than originally planned.

5.3 Value stream map analysis

The actual current state map shows that students are taking significantly longer to complete the two-year theory component of the engineering diploma in question. There are, of course, repeats where students failed a module and analysis of the map reveals that there are a number of occurrences of "no studies" where the student did not register for a module on a particular key. Eight students were questioned to find out why they do not use all the available keys. In nearly all the cases (only one indicated finances as an issue) they indicated that they were not able to register because of clashes and precedence rules. Verifying this response required that a network diagram be constructed to show the flow of modules and the associated precedence rules. The resulting diagram is shown in figure 3.

Two obvious types of constraints were found to reduce the options available to a student when selecting modules every semester. The first of these factors is linked to the timetable; each module is offered on a certain key (depicted by colour) every semester and therefore the choice is limited by clashes in the module key allocations when two required modules are held in the same time slot. The second factor is as a result of the precedence relationships between certain modules; Work Study 1, for example has to be passed before the student can register for Work Study 2. In total, the programme in question contains sixteen of these precedence rules.

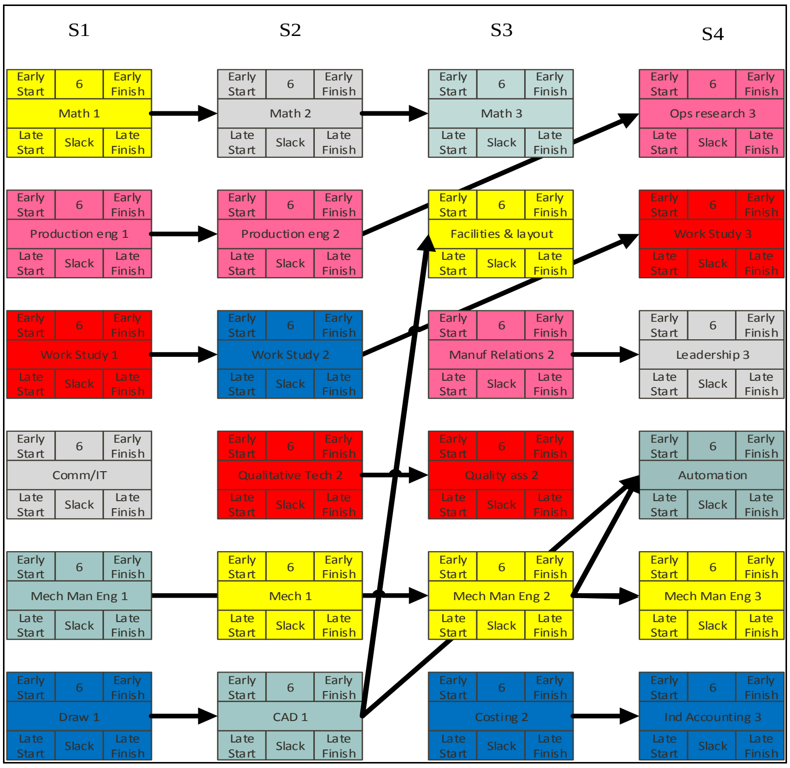

Figure 3: Programme network diagram (own construction using MS Visio)

Timetable and precedence factors, particularly combined, make it very difficult for a student to fill the available keys on his or her timetable. Making this situation even worse is the fact that module keys occasionally have to be changed by the department in order to accommodate lecturer availability changes.

The abovementioned analysis prompted further thinking on the current methodology associated with the design of the three-year diploma (or any diploma for that matter). Leaving aside the reluctance of most academics to consider academic programmes in industrial terms the following anecdotal comparison was made by the mapping team.

> *"Raw material in the form of students enter the system. Variability among the raw material is certainly high but is also largely unmeasured (except for a system we know is flawed). Virtually every unit is re-worked and approximately 35 percent of the work-in-process is scrapped. When exactly, and for what reason we do not know. The majority of the work-in-process takes roughly twice as long to process as the production plan originally intended. We spend somewhere between 10 and 20 percent of our time inspecting roughly half of the attributes each unit should have. Approximately 60 percent of our time is allocated to either re-working the work-in-process of leaving it in storage. We are also completely unaware of the cost per unit."*
> The mapping team (2016)

Whilst the narrative above is obviously anecdotal it nature it is also cause for concern.

6. CONCLUSION

Global reports [16] would indicate that the non-continuation rates of students studying engineering diplomas in South Africa is not unusually high. Contact programme design is fairly similar around the world and it is reasonable to assume that institutions see no cause for alarm because of this commonality. Cost pressures are certainly being experienced in the higher education sector in other nations but in light of South Africa's unique history and uneven society it is also evident that innovation in programme design is required. The amount of constraints and variability inherent in the system would suggest that there must be a better way, not only for the students but also for academics (who are constantly switching between teaching and research throughout the day). In closing, the system in use is a classic example of an outdated system that was designed to suit the education service providers of yesteryear.

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ENGINEERING MANAGEMENT AND BUSINESS INTELLIGENCE: THE IMPORTANCE OF PLANT DESIGN BASE

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ABSTRACT

Most popular business improvement models center their framework and approaches around ***business process*** improvement – thus on people, process and technology aspects of the business. They tend to drive business process improvement cycle elements, and seldom evaluate the impact of not using high quality critical plant design and control data effectively. As a result, these business models generally struggle to quantify their value proposition as they lack the plant and process data needed to demonstrate/prove value. This paper highlights the importance of understanding and using the plant design base as a primary input to process plant business improvement models and initiatives.

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1. INTRODUCTION: THE IMPORTANCE OF THE PLANT DESIGN BASE

Most of the popular business improvement models centers their framework and approaches around ***business process*** improvement. Very few of these models, if any, evaluate the impact of not using critical plant design and control data effectively. Limited focus is therefore placed on the ideal set of plant data and information required for business improvement and analytics. As a result, these business models generally find it difficult to quantify the value proposition sold to the business as it lacks the supporting plant and process data that can be used to demonstrate and prove the value proposition.

According to Biehn[2], data scientists believe that as little as 5% of the "big data" gathered results in 95% of the value contribution of the data. And herein lies one of the biggest problems with data in business today – ***effectively identifying, modelling and analysing the 5% critical data to improve business operations***. Many companies gather vast amounts of data, but rarely take the effort to analyse the data or even asking the basic question of *WHY* they are gathering the data. Although data storage costs have significantly reduced, the impact of analysing critical business and plant data when it is buried in 95% of "low value data" has a significant impact on productivity, situational analysis capability, incident response and decision times.

The research study has developed an integrated plant information (IPI) framework and Business Improvement Model (IPI-BIM) depicted below in Figure 1. At the core of this model is the Plant Design Base Data contained in an IPI system environment, with the design base content supported by the required engineering processes and advanced analytics capability to manage it.

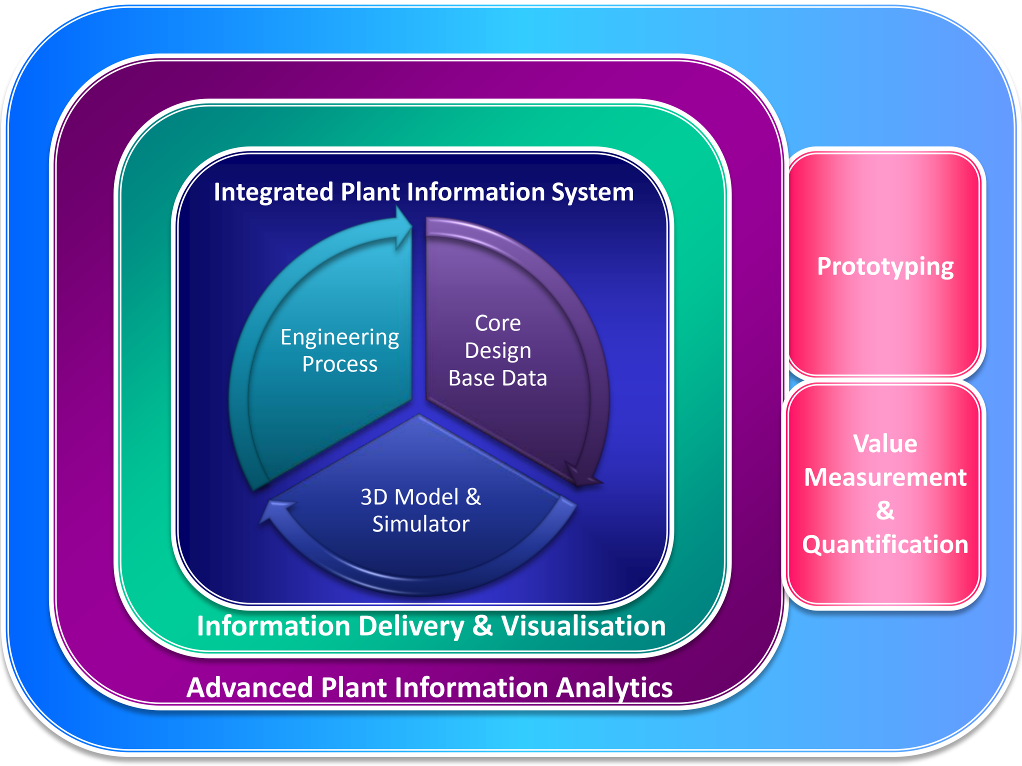

Figure 1: The Integrated Plant Information Business Improvement Model (IPI-BIM)

The research study scope included the identification, sourcing, validation and information management requirements of the most critical and core design base content needed for advanced analytics and decision making. Although the research study was focused on the Power Utility environment, any process plant owner would be able to identify with the core design base content listed in Table 3.

Most of the current Power Utility Generation fleet are either mid-design life or post this midpoint in terms of the asset lifecycle (Figure 2). The research scope is thus of great interest to the Utility that is currently undertaking a process of Validating and Verifying (V&V) their plant design base and implementing more extensive configuration control capability for the management of the plant design base. V&V of the entire potential design base can come at significant cost to the Power Utility, so if a reduced critical and core design base can be identified, there is significant cost saving potential for the Power Utility in a very funding-constrained environment.

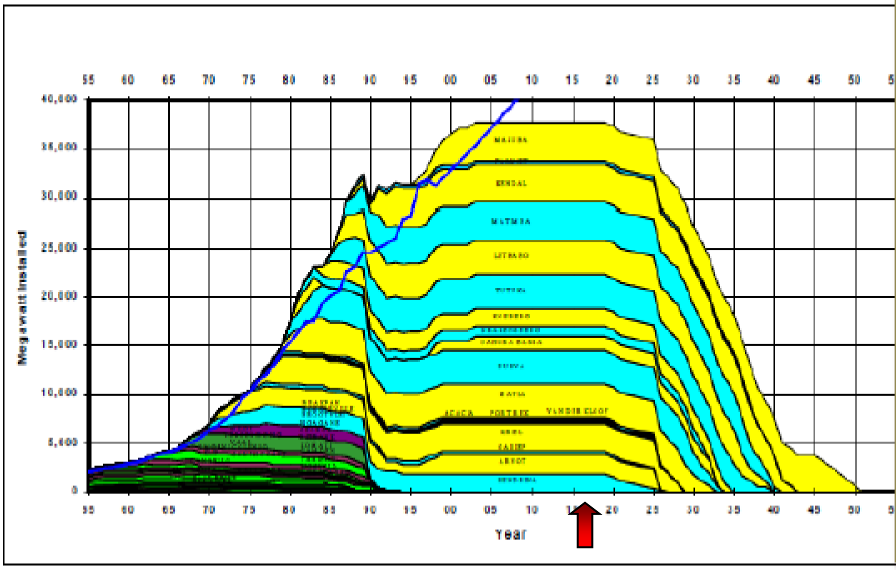

Fig 2: Shows the current age profile of the Eskom Power Generation fleet, red arrow indicates current year (2015). The utility face a significant decline in generating capability in the next 10-15 years due to ageing plant, making it more crucial to improve reliability and prediction of performance risks.

Figure 2: Eskom Generation Fleet Age [4]

The operational research and prototyping further evaluated whether the identified core design base proposed for the IPI-BIM would support predictive analysis of plant behaviour in order to increase reliability of plant. Proposed system integration, core design base identified, the required data interaction, validation and visualisation capability, all formed part of the operational research effort to prove the IPI-BIM elements and implementation approaches suggested.

The research included an evaluation of information delivery options and technology within the Power Utility to define the most cost efficient, intuitive and effective/productive way to make the information available. More integrated design base data management would also support business improvement by supplying consistent, validated and verified design base data in one central information repository. This paper focuses on a sub-set of the overall research undertaken to build and prove the IPI-BIM Model and Approach. It specifically covers the core design base definition and operational prototyping/research undertaken to prove that it is sufficient to support business improvement initiatives in process plant environments.

2. PLANT DESIGN BASE AS THE FOUNDATION FOR ADVANCED ANALYTICS

The IPI-BIM Framework works on the premise that a systematic and integrated approach to configuring and building the required Integrated Plant Information (IPI) infrastructure and architecture can set up the organisation for success in driving more informed decision making and improved business operations (Figure 3).

Research into the building of Artificial Intelligence (AI) capability and algorithms clearly indicated that it is a research study field in its own right, and the aim of this study was not to build or establish this AI capability and was thus excluded from the research scope. The research aimed to establish the framework capability stack to enable predictive analytics capability level, with the premise that AI would be a natural outflow from the initial predictive analytics frameworks and fault models built during the research prototypes.

Figure 3 indicates how the Plant Design Base ***is the most fundamental requirement for advanced plant analytics***. The challenge is to define the core design base data set, specifically on plants that were built before the electronic information era, and confirming that what has been sourced is sufficient to support the advanced analytics capability required for business improvement using plant information.

Searches of the Electrical Power Research Institute (EPRI) research database (www.epri.com) returned very limited information on exactly what is deemed prescribed design base information and scope, and rather focused on actual design examples - confirming the need to define the core design base data set needed for advanced analytics in the proposed Business Improvement Model.

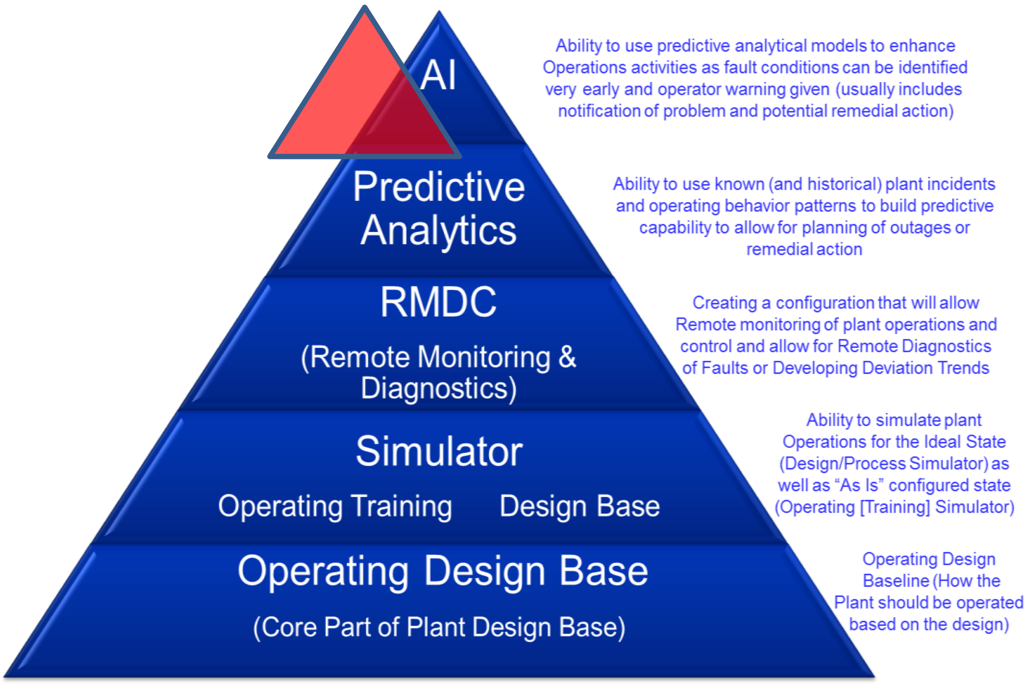

Figure 3: Advanced Analytics Capability Building Blocks [15]

The PAS-55 [10] framework makes it clear that good decisions should be balanced between deterministic ***and*** probabilistic analysis to provide the required insights, perspective, comprehension and balance in the decision making process. **The PAS-55 framework also emphases the importance of a well-managed design base information and data-set to assist in decision making.**

The Nuclear industry study on advanced AI on control systems [18] sees the development of advanced algorithms and fault models as exciting new future trends that can have a major impact on operator efficiency in dealing with plant upsets. **This industry study confirms the crucial importance of a well-managed, integrated plant database where all critical plant design base information is contained.** The study also supports the view that it is key to apply rule sets in the management of information and when dealing with the ordering of large data-sets for analytical analysis.

3. RESEARCH SCOPE AND OUTCOMES

Part of the overall operational research performed aimed to define the scope, effort, establishment methodology and extent of design base information in an integrated plant information system (IPIS) hub for a Brownfields plant. As indicated, it is considered a core capability needed to deploy and use more advanced predictive plant information analytical capability to enhance and improve business efficiency and decision making. It is also a key input to achieve the Power Utility SmartUtility Strategy [8] desired outcomes.

Part of the research process was to understand and characterise the core elements that make up the critical plant design base for a Brownfields power utility plant and investigating whether there is any difference in content and methodology of establishing the critical plant design base between Greenfield and Brownfields Plants.

Although there is obvious benefit with a reduced core design base (reduced validation and verification [V&V] effort and cost if only the most critical information has to be subjected to this process), it remains important to ensure that the scaled down design base information set is still sufficient to support asset management, advanced analytics and Business Intelligence (BI).

The research effort further included an investigation into the viability of reverse engineering data and plant process design base content. This was required in cases where original design base data-sets could not be sourced with conventional data mining/sourcing processes. Reverse engineering results were subjected to a three-way process of V&V using Plant Operating Simulator, Engineering Simulator/Flow Simulation and Actual Plant performance data evaluation to ensure its correctness.

Subsequent prototyping was then conducted to confirm that the core design base elements identified in the Plant Information System hub is extensive enough in nature to support efficient asset management and predictive diagnostics.

The research also aimed to identify the most efficient methods of information delivery based on user needs, type of user and specific business requirements. The engineering design base is very data-centric in nature and options for delivering it in a more user-friendly and intuitive manner was prototyped.

3.1 Software System Implementation Methodology

The research developed a templatised, standardised, balanced implementation methodology and system configuration that contains the required elements of data content, workflow, engineering business processes and information integration needed to enable and support the engineering organisation and core engineering processes required across the asset lifecycle (Figure 4).

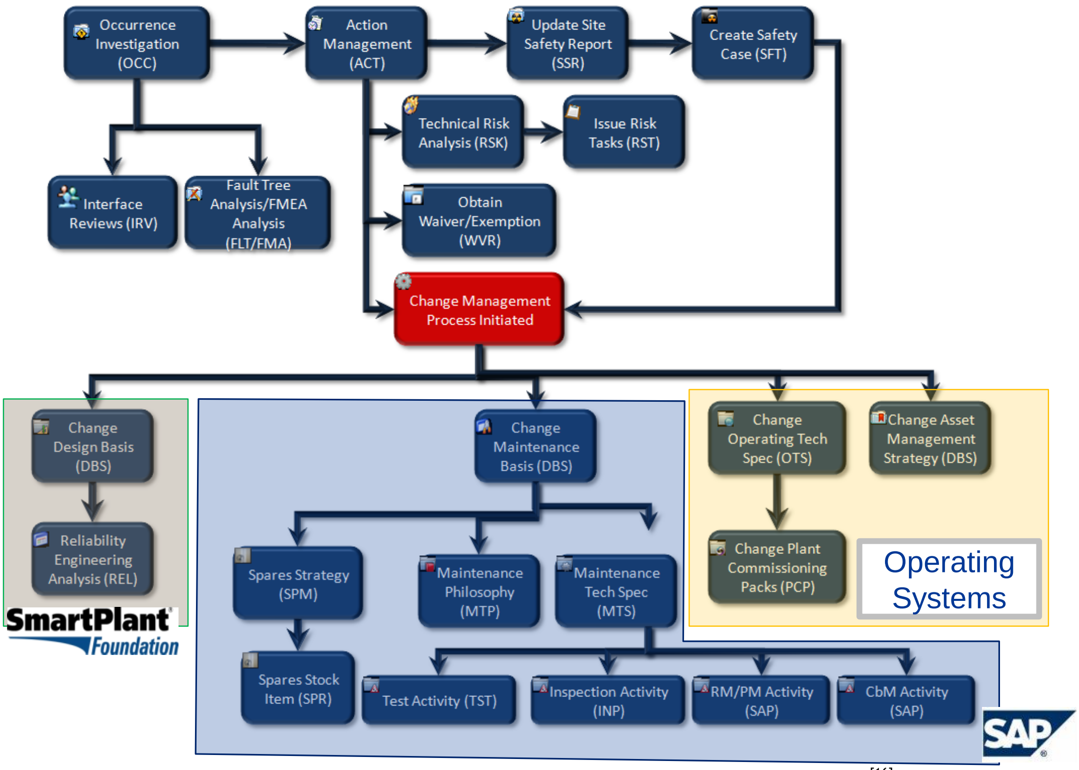

Figure 4: IPI Engineering Business Process Integration [16]

This implemented configuration and capability forms part of the core system framework in the IPI-BIM and acts as the integrated repository for engineering processes (with their associated BI meta-data for analytical purposes), design base data and the 3D plant visualisation platform.

Four Engineering Information Management System Project implementation methodologies were evaluated during the research study (Table 1). The four projects all had the same intent – the implementation of an integrated engineering information management system for the Power Utility that can manage the plant design base and associated workflows.

Although these projects had the same intent and intended outcomes, they followed very different approaches and execution methods. The biggest impact on system implementation timelines are the engineering business process configuration scope and implementation methods. Delays on Projects 2, 3 and 4 were primarily caused by challenges on engineering process workflow configuration. These configurations generally ended up being the critical path items defining/ affecting the project timeline. Enabling a more optimal method to define and configure workflows would therefore add significant value in system implementation scopes of work.

Table 1: Research Findings - IPI System Implementation Methodologies

	PROJECT 1 METHOD	PROJECT 2 METHOD	PROJECT 3 METHOD	PROJECT 4 METHOD
Implementation Timeframe (Planned) {9}	6 Months	24 Months	9 Months	6 Months {2}
Implementation Timeframe (Actual)	6 Months	36 Months	24 Months {1}	42 Months (Still Ongoing) {2}
Deployment Timeframe	4 Weeks	2 Years	8 Weeks (Prototype)	52 Weeks (Still Ongoing)
Number of Eng. Processes Enabled	6	4	22	8
Extent of 2D Intelligence{7}	30%{4}	0%	60%	40%{5}
Extent of 3D Intelligence{8}	25% (Point Cloud, Limited 3D Model) {4}	10% (Only 3D Review models, no intelligence)	60% (Limited 3D use due to reference data availability) 3D-Pact Ops Simulator Implemented	30% (Reference 3D Models only - reference data still an issue to enable full intelligence 3D Models)
Operational Use	Full operational use of all functionalities created – Used at Power Station for 7 years	Partial – 1 New Build Project, no use in Brownfields Generation plants. No 2D/3D deployed in operational use.	Prototype implementation only – SPO OOTB implementation favored and GEDI Project closed out at feasibility study and concept delivery phase.	Limited use as it is still in deployment phase. Partial Implementation at 2 sites. A number of functionality additions still required for full operational use.
Implementation Cost	R9M{3}	R60M	R15M{3}	R120M+{6}

Notes:

{1} Increased timeframe caused by scope creep in number of business processes required. (7 core processes were defined at the start of the project to prove the concept – a total of 22 processes were eventually implemented under the full project scope).

{2} "Out of the Box" (OOTB) Timeframe of 6 months was claimed by vendor. The OOTB implemented solution was not accepted or signed off by business as it did not meet business requirements.

{3} Implementation cost included the proof of concept implementation of 2D and 3D design base deliverables for Project 3. The other 3 projects only focused on ***enabling*** the capability to create intelligent 2D/3D deliverables.

{4} The initial project scope excluded 2D & 3D Deliverables but was added subsequent to initial project scoping.

{5} The 2D/3D design-base related work undertaken in Project 3 was re-used in Project 4's Implementation.

{6} Implementation cost for this project *excludes* extensive design base data migration. The project's scope only covers legacy EDMS system replacement efforts.

{7} Two-dimensional (2D) intelligence implies the conversion of conventional drawings into data-centric "intelligent drawings" where design base content is related to objects on the drawing and available on "query" of the object on the drawing.

{8} Three-dimensional (3D) intelligence implies the use of visual/three-dimensional information datasets to display the plan design base in a visual format. As with 2D intelligence drawings, 3D model "objects" can be queried for design base information like design criteria, specification values, etc.

{9} The engineering process workflow configuration would typically dictate the anticipated project timeframe and on all four projects was the "critical path" scope.

From evaluation, the Project 3 Implementation Method was found to be preferred baseline to establish the IPI System implementation approach for the IPI-BIM. Enhancement of this method and the development of a templatised 6-step implementation methodology in the research study resulted in a well-documented rapid application development (RAD) approach to integrated engineering system implementation.

3.2 Engineering Business Process Implementation Methodology

To prove the methodology developed, the enhanced implementation methodology was used on Project 3 to configure and implement the 15 additional engineering processes identified in addition to the original 6 core processes. Table 2 below demonstrates how the structured and templatised approach and methodology developed by the research significantly reduced business process implementation cycle time and configuration error rates.

Table 2: Engineering Business Process Implementation Method Findings

	COMPLEX ENGINEERING PROCESS	AVERAGE COMPLEXITY ENGINEERING PROCESS	SIMPLISTIC ENGINEERING PROCESS
Target Processes	**1st Pass:** Engineering & Project Change Management (Design & Field Changes) **2nd Pass:** Technical Risk Analysis **3rd Pass:** Technical Documentation Management	**1st Pass:** Occurrence & Incident Management **2nd Pass:** Non-Conformance Management **3rd Pass:** Authorisation Management	**1st Pass:** Action Management **2nd Pass:** Interface Management **3rd Pass:** Spares Strategy Management
No of Workflow Steps	>20	10-20	<10
First Pass Process Configuration & Implementation Cycle Time	42 Days	14 Days	6 Days
2nd Pass Process Configuration & Implementation Cycle Time	29 Days	11 Days	4 Days
3rd Pass Process Configuration & Implementation Cycle Time	21 Days	7 Days	2 Days
Error Rate (UAT/FAT NCR - % rework)	1st Pass: 22% 2nd Pass: 19.8% 3rd Pass: 13%	1st Pass: 15% 2nd Pass: 7.8% 3rd Pass: 4.5%	1st Pass: 11% 2nd Pass: 6.3% 3rd Pass: 2.8%

The projected business process system configuration time for the additional 15 processes was reduced from 9 months to 6 months (with the resulting benefits of reduced project cost and earlier project scope delivery).

3.3 Identifying the Core Design Base

An Intergraph study [3] states the goals of having core design base information available as being:

- Reduced Time-to-Market (TTM)
- Maximised Time-in-Market (TIM)
- Optimised Operating Parameters (OOP)

The study very aptly shows how certain information creates a cascading negative business effect later in the asset lifecycle when it is not available, as well as the inter-relatedness of the TTM, TIM and OOP elements.

Numerous examples were sourced from industry players in the EPC space [3, 6, 11, 13, 14, 17] to establish the typical Design Base Handover scope that Owner/Operators ask for and measure at handover of plant into commercial operation.

The challenges with obtaining a full design base were demonstrated on the Greenfields Power Plant Project as well as the Brownfields Power Station that formed part of the research study. The research study concluded that the ability to source a full-on design base data set is problematic if a proper and extensively detailed handover information specification was not issued to the Design Authorities/Contractors.

Given the analysis of information sourced/available against the full design base, the research study theorised that it will be possible to identify the set of core design base information most needed by the Owner/Operator to manage, operate and maintain the asset for the design asset lifecycle timeframe. And to demonstrate that supply/sourcing and validation of this core design base data-set is both possible and feasible.

The research study also theorised that it may be more difficult to source such design base content on an old Brownfields plant, and that there would be a need to do reverse engineering of missing design base content. To prove this hypothesis, design base sourcing was therefore conducted in both a Greenfields and Brownfields scenario to compare the availability of information and determine the need for reverse engineering.

The research study concluded that the design base elements and content needed for a full C&I control system refurbishment (Figure 5) would be the closest requirements definition of what plant and technical information should be deemed ***CORE*** design base content for a power plant asset (in this case the plant Operating Design Baseline). Further detailed analysis of the typical design artefacts that would define the Operating Design Baseline, is provided in Table 3.

This Operating Design Baseline is typically augmented by a Maintenance Design Baseline for the plant asset, defining the maintenance strategy and tasks for plant equipment based on its criticality classification, operating duty and operating environment conditions.

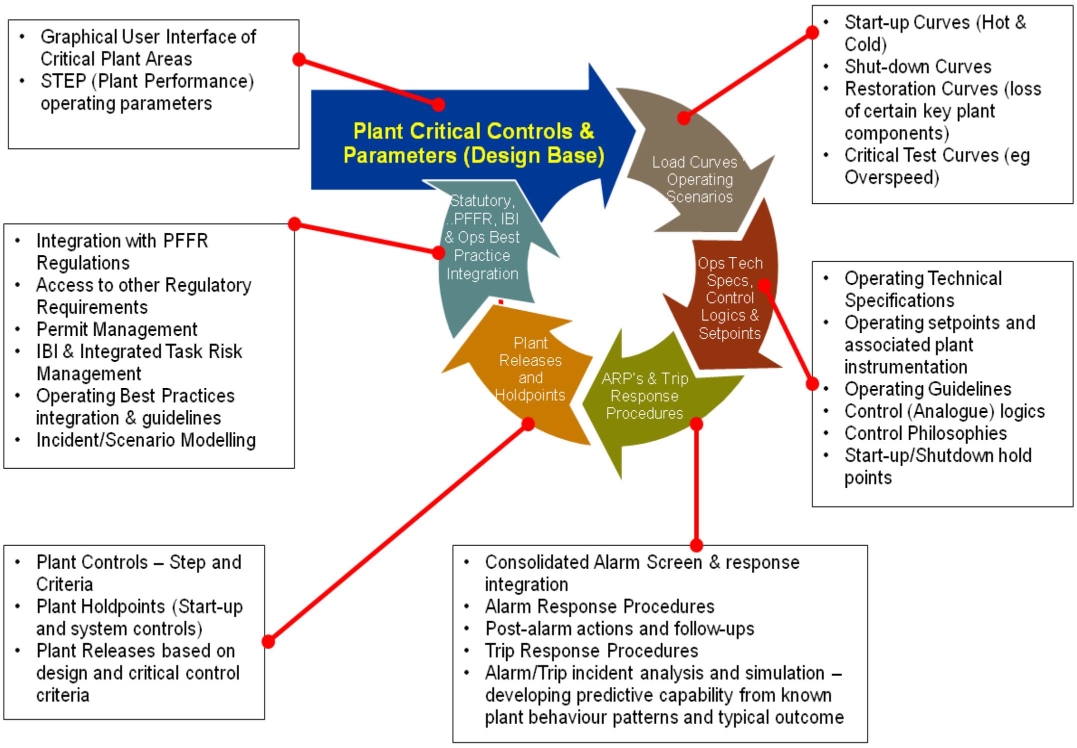

Figure 5: Core Design Base Content needed for C&I Upgrades

The research study focused further data sourcing and evaluation of design base artefacts listed in Table 3. Although the research study was focused in the Power Utility environment, the commonality of these design base artefacts to most process industries should be evident. This view is confirmed in the numerous examples sourced from industry players in the EPC space [3, 6, 11, 13, 14, 17].

Operational research was used to determine completeness and availability of this information in a Greenfields Power Plant Project, as well as an operational Brownfields Power Plant, to confirm that this is a viable hypothesis and design base scope.

Table 3 indicates the actual volumes of design base artefacts sourced for each core design base element. It demonstrates that the information is indeed available, and can be sourced successfully for the Greenfields as well as Brownfields plant scenarios.

Interpretative notes at the end of Table 3 explain anomalies or large differences found with the comparative analysis done in the research study.

Table 3: Core Design Base Content Value - Brownfields vs Greenfields Plant

CORE DESIGN BASE CONTENT	QUANTITIES OF DESIGN BASE ARTEFACTS	
	GREENFIELDS PLANT	BROWNFIELDS PLANT
Process Flow Diagrams (PFD's)	144	122
Process & Instrumentation Diagrams (P&ID's)	4,467	3,198
Material, Mass & Energy Balances	2	4
Plant Process Set-point Lists	95	1{8}
Operating Envelopes	135	13{1}
Operating Curves (Start-up, Shutdown, Specific Conditions)	0	16
Single Line Diagrams	869	1,321
Control & Operating Philosophies	1	7
Control Functional Specifications	272	32
System Functional Specifications	793{9}	42
Operating Manuals	0	135
Process Alarms List – Alarm Response Procedures	2	1,578
Plant Trip & Interlock Schedule	2,817	12,695{2}
C&I Setpoint List	165	55
SIL Report (Safety Instrumentation List)	17	1
Instrument Schedule (Preferably including Locations)	101	304
Plant Control & Protection Logic (Including Interlocking)	0{2}	0{2}
Automation Concepts/Strategy	0	2
3rd Party Control Systems Connectivity to SCADA Systems	0	1
Interface Bus Requirements (IT Level)	0	1
Electrical Settings Documents (Including Protections)	244{3}	373{3}
Drive & Actuator Schedule	38	373
Switchgear Schedules	244	1,696
Equipment Datasheets/Data-lists	2,404	970{4}
Maintenance Philosophies/Strategy	0{13}	8
Maintenance Technical Specifications	0{13}	145
Layout Drawings (Plant Control/Switchgear Rooms)	15,213	4,978
Test & Inspection Plans	723	399{5}
Operating Technical Specifications	0{13}	33
Operating Check sheets	591{11}	202

Commissioning Check sheets (Running, Start-up & Shutdown)	1,750	833
Panel Standby Check sheets	0{6}	0{6}
Control Panel Releases	51{6}	0{6}
Plant Simulation / Simulator Strategy	0	1
Simulator User Requirement Specification	0	1
Technical Procedures – Operating	584	893
Technical Procedures – Maintenance	563	199
Plant Occurrences History	0	6,944
Plant FMECA Analysis (Occurrence Statistics)	90{12}	0{7}
Plant Modifications History & Detail	355{10}	1,726

Notes:
{1} Operating Envelopes are typically described in the OTS and not found as a stand-alone/separate document. Some Operational/Performance Requirements documents were identified that to some extent provided the information needed to define the operating envelope.
{2} Does not exist as unique entities, but part of the set of Logic Diagrams of the Control System.
{3} Some of the information was contained in the electrical load list, and some of it in the Control Logic Diagrams.
{4} Number reflects the unique datasheet entities. This ***excludes*** equipment data contained in MSExcel format spreadsheets extracted from manuals and other sources.
{5} Excludes 177 actual test specifications for the Brownfields plant (content defines test specifics and not just test frequency and high level criteria) and 383 for the Greenfields Project.
{6} Panel Standby checks forms part of the Commissioning Check sheets and not separate entities.
{7} Statistics derived from Occurrence History captured in the Occurrence Management Process. Data mined and analysed on "as/when required basis"
{8} Information exists as "Process Design Criteria".
{9} Delivered as System Descriptions on Greenfields Project
{10} Greenfields Project still under construction, changes handled under Project Engineering Change Notice (ECN) or Field Change Notice (FCN) process. Number reflects the quantities of these registered under the project.
{11} Issued as Operating Instructions.
{12} Safety Study artifacts, feeding into FMECA process.
{13} Normally a document compiled by the System Engineer for the Plant system once all commissioning, maintenance guidelines and operating information is provided and signed off at hand-over.

A low volume of information & data was found on operating envelopes and expected plant process response behaviours on the Brownfields Plant. This design base content was therefore earmarked as the ideal candidates for the reverse engineering scope of the research study.

3.4 Structuring Design Base content

The research study theorised that it is crucial to implement a structured classification system to identify and manage the plant design base and its associated artefacts more effectively. The Power Utility implemented the IEC 61355 Document Classification standard[9] in 2008 and this standard was used to define and group the design base artefacts listed in Table 13. Prior to this standardisation, very little consistent structuring or classification methods were employed in the Power Utility to order engineering design base artefacts and content, making assessment of design base artefact maturity and completeness problematic.

The first pass assignment of design base artefacts to the IEC classification standard was done manually for the research study Greenfields Project. It was found to be very time consuming, and the research theorised that it should be possible to define and utilise data analytics rule-sets to assign IEC classes to the documents automatically. The data-mining would focus on the titles of documents and drawings and sometimes internal content (if Optical Character Recognition [OCR] technology was executed on the documents).

The first data-mining algorithmic rule-set was defined and executed as "Iteration 1" on the Greenfields Project data-set. This was then compared against the manual IEC allocation done previously to determine the accuracy of the automated rule-set. A success rate of 53.7% accuracy on IEC level 4 assignments was achieved.

Table 4 summarises how the data-mining and analytical success rate was improved using further iterations and enhancements to the rule-set (and using both Brownfields and Greenfields plant documentation).

Iteration 2 significantly enhanced the success rate, mostly due to the fact that a mature Brownfields Power Station data set was used to enhance the set developed using the Greenfields Project. Many design base artefacts were not available on the Greenfields Project during Iteration 1, reducing the number of artefacts automated (57 artefact types). With Iteration 2, the IEC artefact types were expanded to 107 instances.

Iteration 3 used data from a second Brownfields plant (with additional new data mining keywords and search terms), which resulted in a further notable improvement.

Table 4: Automated Data Analytics Mining Tool Success Rate

ITERATION 1	ITERATION 2	ITERATION 3*
Greenfields Rule-set	Greenfields enhanced with Brownfields design base data and naming conventions used on older plants	Greenfields enhanced with design base data from 2 Brownfields plants
53.7%	83%	90.3%

**Note: For the final iteration, the remainder of the document types was manually assigned by evaluating the document titles in batches and allocating the correct IEC document classes*

The productivity benefit and thus usability of this automated classification tool in an operational environment was confirmed by the research – a previously labour intensive, manual IEC class assignment process of nearly 9 months was reduced to 2 months by applying the automated data-mining rule-sets on another power plant of the Power Utility.

3.5 Reverse Engineering Core Design Base content

The research study scope included an element of reverse engineering using the Brownfields Plant Operating Simulator content to re-build and validate the missing design base content identified. This allowed the re-creation of the operating envelopes and the expected plant process response behaviours of the Brownfields Plant. The research process and methodology is indicated below, and Figure 6 is an example of the typical process followed by the research study (this process may differ depending on the scope of the reverse engineering exercise).

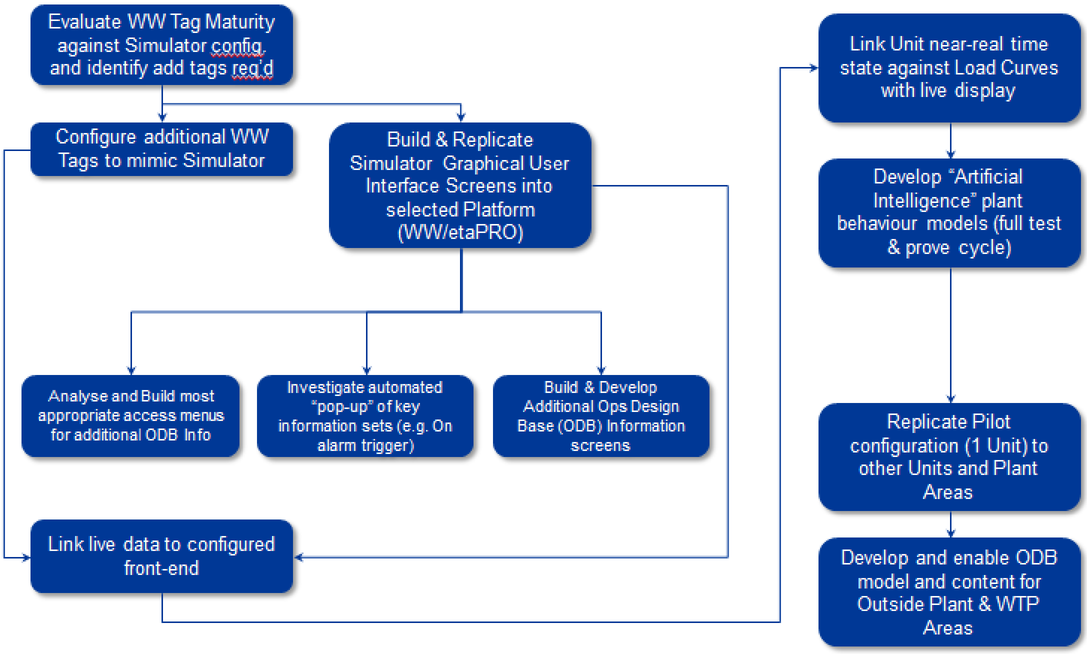

Figure 6: Reverse Engineering Design Base using Plant Operating Simulator

Notes on Figure 6:

1. *WW = Invensys WonderWare technology deployed as Plant Data Historian platform.*
2. *etaPRO = engineering simulation software deployed by the Power Utility at the Brownfields Power Station of the research study.*
3. *ODB =Operating Design Base.*
4. *WTP = Water Treatment Plant.*

Research data analysis also revealed that there was a significant number of missing or mismatched data-points between the 3 systems used in the reverse engineering process (plant control system, the Operating Simulator and Engineering Simulator). Resolving this data quality issue resulted in a notable improvement in the outcome of the advanced analytics (as certain values in the engineering simulator previously used "interpreted" or estimated values instead of real-time data values from the plant).

Research efforts included alignment of the Engineering and Operator simulator systems in terms of design base content, and then comparison to actual plant performance monitoring data-sets to confirm re-engineered datasets and expected behaviour observed in the two simulators.

The research proceeded to evaluate the load curves (that only existed in unverified paper format) and automated these in the Operating Simulator. Using actual plant data-sets and start-up scenarios, the operating curve was evaluated and confirmed against control system data (confirming that the simulated configuration and outputs mimic real life conditions and behavior). This reverse engineered and developed plant operating curve and analytical model can therefore be used with confidence for further analytics and measurement of plant reliability and availability.

The advanced analytics model built of the Brownfields Plant Rankine cycle (and the outcomes achieved running analytical scenarios on this cycle model), created a useful plant process design baseline.

Introduction of transient process analytics using the Flownex™ software platform further enhanced the simulation capability in the research study. A drawback of the etaPRO Virtual Plant system™ is that it provides a static analysis of plant process conditions and does not cover transient conditions and the subsequent process condition normalisation usually experienced when plant process conditions change.

3.6 Reducing Information Delivery Complexity

Gentile [7] states from his research that there are notable benefits from using data visualisation in an effort to reduce perceived and actual information/data complexities.

Typical benefits listed are:

- Understanding and absorbing complex technical engineering concepts when visually described.
- Better visualisation and understanding of relationships and behavior patterns for operational and business activities.
- Emerging trends and patterns can be recognised and acted on faster.
- The ability to directly interact and manipulate data.
- Complex business concepts can be better implemented in a visual format to enable a new business langue or bring about a change in business paradigms.

Part of the IPI-BIM operational research entailed the evaluation of the various information delivery technologies available within the Utility and defining the most appropriate infrastructure to use. Due to funding constraints, the research brief was to contain the research and data sources prototyped within the realm of the Power Utility's approved software technology stack, and as such research was not undertaken into alternative systems or software solutions.

The research study prototyping scope proposed and proved portal technology as a preferred medium of information delivery in a diverse organisation with different needs and uses for the information contained in business systems. The diversity of information covered is depicted in Figure 7.

The research and prototype scope considered both static and dynamic data sources within the Utility organisation. The frequency of data storage in the source systems varied from continuous on-line data capturing systems to systems where data is captured and trended on a monthly (or infrequent/"as and when required") basis.

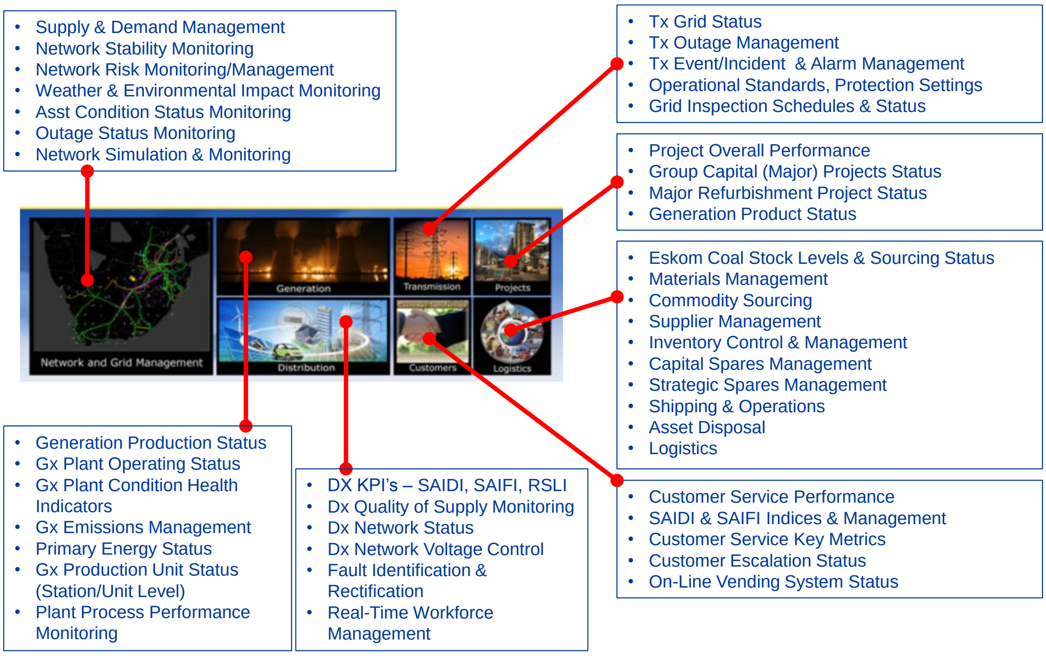

Figure 7: Implemented Portal Technology and Scope of Business Information Visible

Further research undertaken demonstrated the ease with which modern 3D CADD Models could be used to enable 3D visualisation capabilities in a portal environment. Being an integral part of the plant design base, the 3D Model of the plant could be enabled as a prototype research to demonstrate the ease of creating an interactive, virtual plant 3D environment on the Greenfields Project (Figure 8) from where design base information can be interrogated.

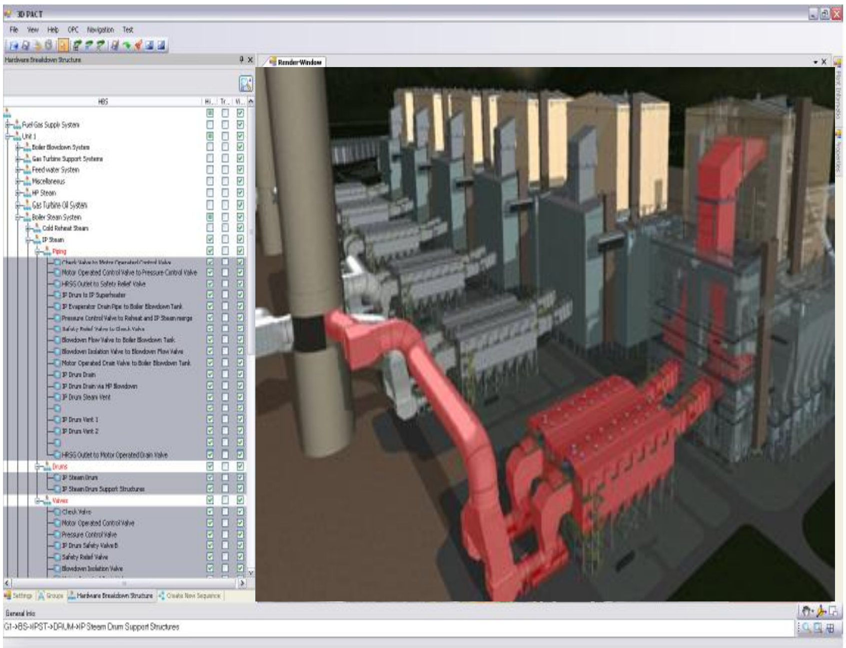

Figure 8: Visualisation of Design Base Content in 3D interactive plant model

As part of the information delivery research portion, a Proof of Concept (PoC) study demonstrating the integration of the 2D advanced analytics Flownex^{TM} capability into the 3D Plant Operating & Engineering Simulator was undertaken. The PoC focused on the Flue Gas Desulpherisation portion of the plant on the Greenfields Project that formed part of the research study. The reason for the choice was two-fold:

- A more mature 3D model of the Plant Design Base existed.
- A business need for Operating Staff to be trained on a very complex and intricate plant process technology that has not been implemented on a power generation plant in the Utility before.

Figure 9 below shows the outcome of this PoC - controllable parameters linked to a dynamic process simulator (Flownex^{TM}) was enabled (on the right hand side of the User Interface) allowing the end user to make changes to these parameters and evaluate the impact on plant performance and outputs. In the same visual interface it also exposed the end user to the integrated design base information system (on the left hand side of the User Interface) where more design base content can be accessed to evaluate the impact of plant control and parameter changes.

The plant breakdown structure of the Plant Design Base becomes the integration lever to expose more design base information and data when required by the operator/user, creating an “information on demand” capability and reducing potential information overload by exposing too much information in one user interface.

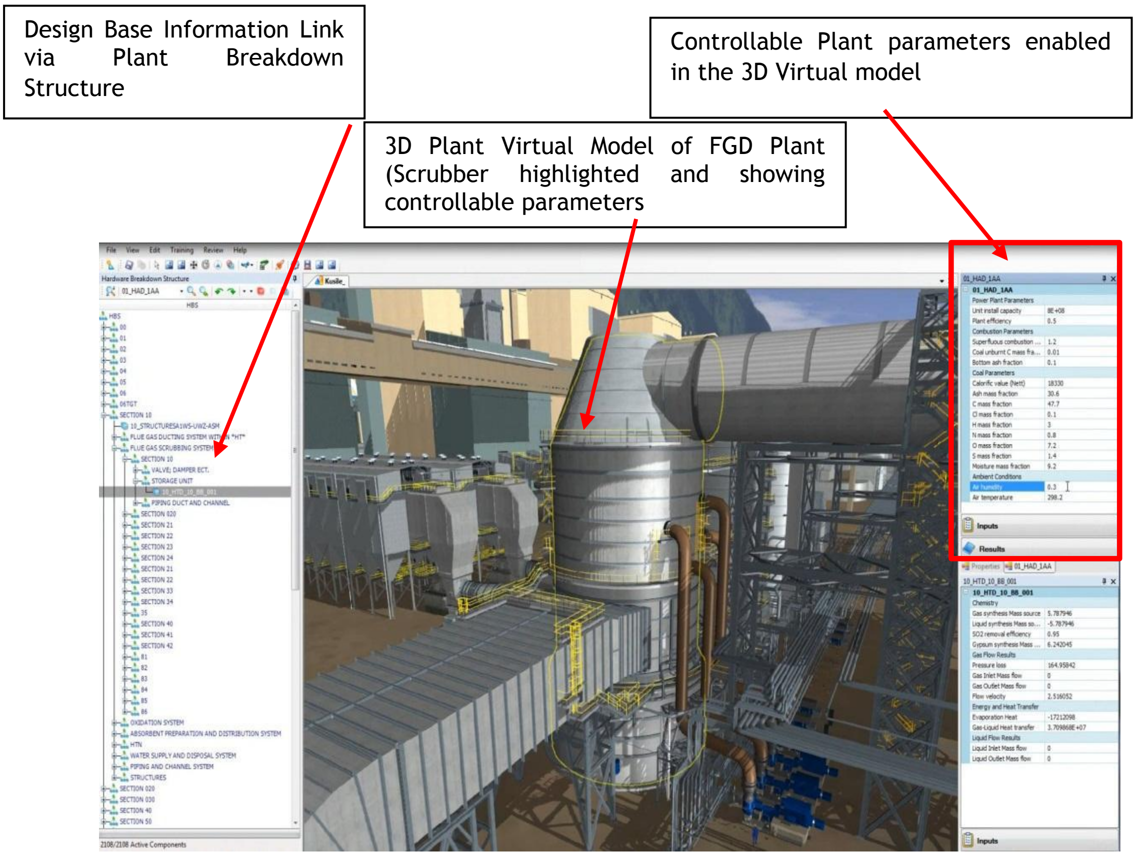

Figure 9: Integrating Advanced Analytics with the 3D Information Delivery and Design Base

It also evaluated of methods to simplify complex plant process models by focusing on core operating design base content known as "Controllable Parameters" in the process plant control environment. Work done in the reverse engineering phase of the research project added significantly to this evaluation.

The research study scope included an evaluation of the viability of creating a similar virtual, interactive and 3D visualisation capability enabled environment for the Brownfields Plant using 3D Laser scanning technology and data outputs.

The research study scope was extended to include a small prototype to prove that the same 3D virtual environment capability can be enabled using 3D laser point cloud scanning technology on top of which design base content can be enabled for a Brownfields plant that does not have access to a modern CADD 3D Model. The prototype outcome confirmed that similar results were achievable and feasible.

4. BENEFITS OF A WELL MANAGED DESIGN BASE

4.1 Better identification of "Plant Hot Spots" and addressing performance issues

The research prototyping showed how effective management, ordering of design base data and analysing plant historical information allowed the Brownfields Plant in the research study to focus on problem plant areas.

The Brownfields Plant could identify the top 10 problem plant areas using improved plant design base data and information classification and management approaches, and it also assisted the research study in the identification of candidate plant areas to use for advanced analytics prototyping.

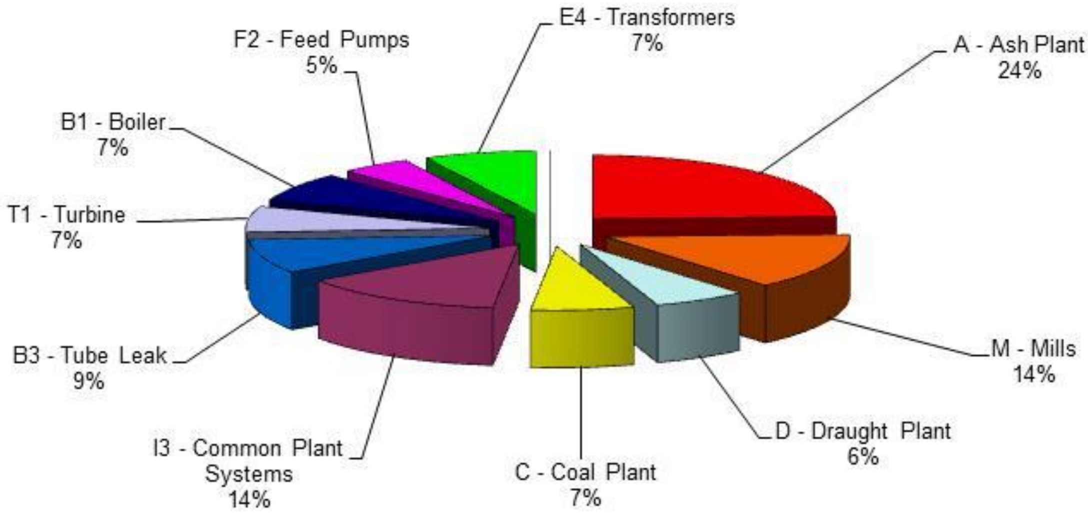

Figure 10: Top 10 Problem Plant Areas (Brownfields Research Plant) [19]

4.2 Improving Plant Abnormal Condition Analytics

The Design Base information contained in the Integrated Plant Information System platform, will enable the organisation to effectively build, test and refine analytical fault models.

An Emerson study [5] confirms that some of the biggest challenges in process plant are overwhelmed operators and complex plant operations that demand a new approach to managing plant more efficiently and predictively. The study confirms that abnormal situation ***prevention*** is one of the biggest potential productivity gains in the Process Plant operating space.

The research postulated that the IPI Design Base content can be used to efficiently and correctly define, build and prototype advanced analytical models that will make it possible to:

- Measure efficiency of current operating practices against operating design base and make recommendations on remedial action where there is room for improvement.
- Demonstrate that improved early warning failure detection is possible using big data and advanced analytics capabilities to analyse plant operating and control data.
- Measure efficiency of operations during abnormal and/or test conditions of process plant.
- Improve operator training outcomes – if training can be integrated with design base simulation capability and predictive capability it will create a highly efficient operator workforce that has the tools and means to timeously act on plant deviations to prevent trips and load losses.

The research outcome confirmed the theory postulated that a combination of analytical methods will most likely be required to provide a holistic plant improvement framework. The analytical methods employed in the overall research study was found to cover all 3 types of analytical techniques - descriptive, predictive and prescriptive[12].

From the research study literature survey, it was suggested that Angeli[1] most aptly describes the basic research methodology and elements that made up the advanced analytics models of this research study.

The researcher could find practical application of this method already employed on the Brownfields Plant that formed part of the research study, so it made sense to leverage the method further when it came to defining more advanced analytical models on the plant.

Several derivations of the plant ideal state with regards to the Rankine cycle were developed and evaluated in the research. This allows an analysis of the impact when plant operations and maintenance do not align with the requirements of the design base.

Identification of controllable parameters in the Plant Operating Design Base further allowed online continuous trending of plant operations to evaluate how well it is operated within this baseline, and identify areas of continuous improvement where further technical training can enhance the Operator's ability to better control and manage plant within the required design base parameters.

Fig. 12 shows an example of how the performance comparison was done and trended in the Brownfield Plant's boiler system area.

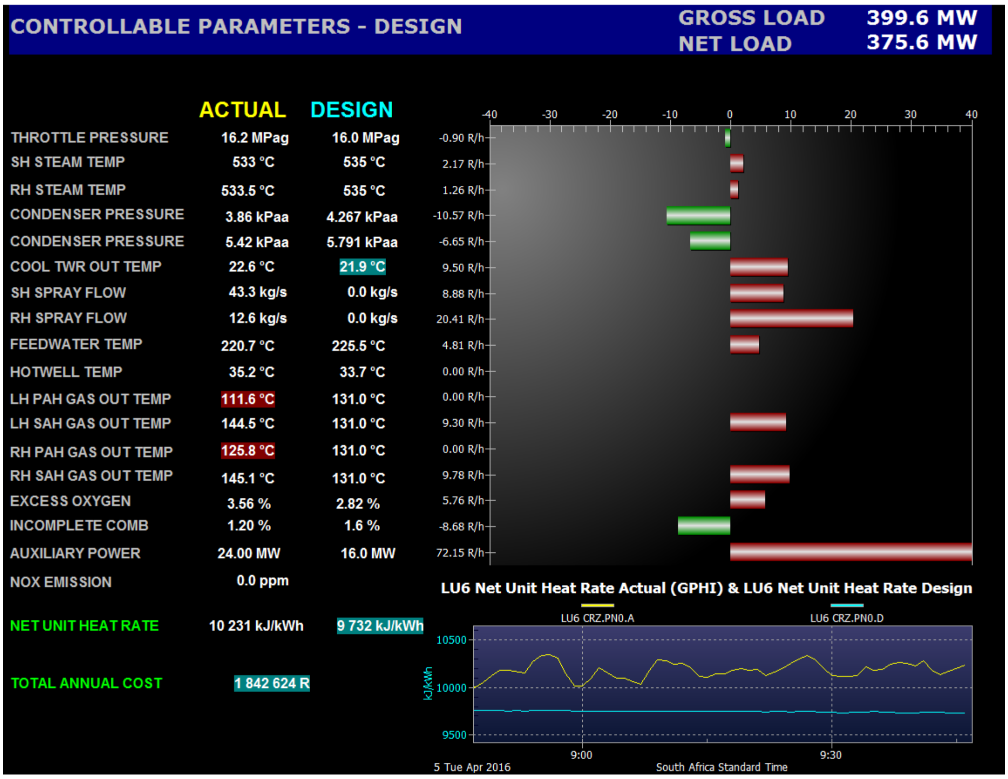

Figure 12: Plant Controllable Parameter Monitoring

The research also successfully demonstrated the impact of design base decisions during plant design, and the long term impact it can have on product output and plant efficiency.

As an example, the original Brownfields Plant design base was one where steam-driven feed pumps formed the basis for both normal as well as stand-by duty. The final implemented design configuration however, was one Steam-turbine driven feed pump with two electrically driven feed pumps as back-up in emergencies when the main pump is not available.

The research prototype evaluated the impact of using the two Electric Feed pumps (EFP) for feed water supply (normally reserved for standby/emergency purposes). This would be contrary to the ideal design base scenario of using the steam-turbine feed pump (SFP) for normal operations.

The impact of this decision on available output generation and GTCHR is significant – higher fuel consumption and heat transfer rate requirements for less MW's output to the electricity grid (Table 5) – which can be a significant impact considering a plant design life of at least 40 years.

Table 5: SFP vs EFP feedwater Supply Impact on Generation and Heat Rate

PROCESS SCENARIO	GROSS GENERATION (MW)	HEAT RATE - GTCHR (Btu/kWh)
BFPT providing feedwater to Boiler	619.384	7,683
EFP's providing feedwater to Boiler	604.309	7,876

5. CONCLUSION

The research has provided a practical and workable methodology and framework within the overall IPI-BIM to identify, source, validate and implement the core design base information data-set required for plant asset management and advanced analytics to improve business efficiency. It confirmed the importance to have engineering business processes to support the management of the design base content over the plant asset lifecycle. The research study further showed that the choice of system implementation methodology can have a significant impact on cost and timelines involved to implement the IPI system and associated design base contents of the IPI-BIM.

The research demonstrated the benefit of design base data and information structuring into a well-controlled classification system. This greatly assisted in evaluation and identification of core design base candidates. Using the research to introduce an effective and very accurate automation document type classification tool sped up the process of this classification exercise significantly. This was shown to significantly improve the productivity of staff involved with any Design Base back-fit or V&V exercise.

The research managed to successfully define a core set of design base information required for advanced plant condition analytics and associated improved business intelligence. The research hypothesis was proven that C&I Control System Upgrade design base requirements make up the core Operating Design Base content. It was shown to be a feasible scope for design base V&V, regardless of whether it is a Greenfields Project or Brownfields Process Plant.

Where identified core design base content could not be sourced, sufficient alternative information was available to reverse engineer and/or re-build the missing information.

The advanced analytics and plant process modelling/simulation portion of the research study further confirmed that the identified core design base set was sufficient for the research scope of work. The data set could be successfully used to identify opportunities for business improvement using the integrated plant information.

By undertaking the design base definition and additional reverse engineering exercise in the research, and enabling it in Portal technology and 3D visual/interactive format, opened up significant value propositions for the business:

- Improved visibility of plant performance and design base data.
- Increased understanding of plant behavior in upset conditions, and the impact of this on plant output and reliability.
- Online and continuous monitoring of performance against design base values.
- Timeous management of performance deviations in cases where the plant deviates from the target or expected operating envelopes.
- Increased usage (and thus better Return-on-Investment) for the advanced analytics software investment made in the Utility.

By bringing together critical business, plant process and design base information into a single integrated plant information platform, a powerful business improvement capability is enabled using integrated plant information. It empowers business users to make plant and process decisions in the fastest and most efficient manner.

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SELECTION, TRANSFER AND ADOPTION OF NEW TECHNOLOGY IN THE MINING INDUSTRY

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ABSTRACT

The mining industry is known for mass production with minimal technology innovations. The mining industry is known for mass production with minimum technological innovations, owing to the capital intensive operations that cannot be easily changed. Nonetheless, various reasons such as government legislation and improvements in process efficiencies prompt the need for innovation within the industry and when this occurs, the success of such endeavours is of utmost importance. One inescapable threat to this success is the risk of rejection of new technology by end users coupled with the potential losses with respect to capital injected into the venture. To encourage successful technology implementation, the development of methodologies pertaining to the selection, transfer and adoption of new technology in the mining industry is vital. The objective of this research is the evaluation of new technology implementation processes and the investigations conducted offered a framework for use within the mining industry.

1. INTRODUCTION

The identification of alternative energy sources as possible substitutes for electrical power has long been a topic of interest and has recently been made a mandate by the Department of Mineral Resources as a result of the large power constraints experienced by Eskom. The mining industry is known for consuming large quantities of power and thus a reduction on the load imposed on Eskom by the industry is both of national and strategic importance. To this effect, various alternative sources of power were considered by the mining industry in order to identify viable options. The switch from electrical power to other alternatives although mandated and some alternatives viable, is capital intensive and as such, success of any endeavor to be taken is vital. One inescapable threat to this success is the possible risk of rejection of the new technology by end users coupled with the potential losses with respect to capital that would be incurred in the event of failure. It is thus important that the selection, transfer and adoption of new technology are investigated in order to gain insight into the many considerations that need to be taken into account when new technology is being introduced.

Technology selection, being the first stage of the process, refers to the choice of technology to be invested in by an organisation; an all-important decision that can catapult an organisation into possessing a significant market share by creating a competitive advantage in its industry [13]. After the selection of technology, technology transfer, which loosely refers to the relay of technological information from one party (transferor) to the next (recipient) [7], is the next step in the technology implementation process that needs to be executed. Lastly, technology adoption, which refers to the acceptance of transferred technology and its continued use in an organization, is the third and final step of the process [4]. The three stages described above are important to the success of any technology implementation programme and thus warrant further investigation across the various industries. Each of the three stages involves a number of steps to be completed to aid success in technology implementation projects.

1.1 Problem Statement

Viable technology alternatives as sources of energy is a relatively new concept in the mining industry aimed at reducing the electricity generation load placed on Eskom. Despite the well documented advantages of various energy options and taking into consideration the fact that the measurable success of any technology lies with its application, successful selection, transfer and adoption of the new technology is not guaranteed. Failure to successfully select, transfer and adopt new technology places into jeopardy efficacious integration of forthcoming technologically advanced concepts scheduled for implementation in the near future. It is thus imperative that all possible stumbling blocks to the successful integration of new technology are identified and a viable model developed.

1.2 Research Objectives

The various factors governing the selection, transfer and adoption of new technology are investigated to encourage the worthwhile implementation of new technology while also indirectly making headway for future projects. The objective of this research is the evaluation of new technology with regards to the three stages namely selection, transfer and adoption. Ultimately, the goal is the development of a framework for the mining industry that rallies the success rate of technology implementation projects by taking into consideration the factors that affect effective selection, transfer and adoption of new technology. In addition, highlighting the pitfalls that retard the successful implementation of technology projects is also valuable. The research topic will attempt to answer the questions:

- What factors need to be considered for effective technology selection?
- What factors need to be considered for effective technology transfer?
- What factors need to be considered for effective technology adoption?
- What pitfalls risks need to be avoided?
-

2. A CONCEPTUAL THREE-STAGE FRAMEWORK BASED ON LITERATURE REVIEW

Based on an analysis of relevant literature, the following steps in the execution of technology selection, -transfer and –adoption activities were structured to form the basis for a proposed three-stage framework:

2.1 Technology Selection steps

Identification of relevant stakeholders: The identification of relevant stakeholders is the initial step before any other action can be taken [12]. Stakeholders describe all parties who have vested interests in the organisation. Having all stakeholders present during the technology selection phase ensures that due diligence is conducted by all affected parties who will remain accountable for the final decisions taken.

Definition of systems requirements: From a systems engineering point of view, the transferor and the transferee of the technology must, where possible, work together [2] as early as the research phase of the technology's life cycle. This will ensure that all requirements are filtered through to the design, development, production, maintenance and the usage phase of the technology. Ideally, the end user must be present at all stage gates to give approval to proceed with the technology development process so that all dissatisfactions are addressed as and when they occur rather than waiting until towards the end of the life cycle where the costs of the change are astonishing.

Analysis of technology alternatives: All of the possible technology alternatives are selected from a variety of technologies available in the market. It is imperative that the list of possible alternatives is exhaustive and also explores foreign technology that would be beneficial to the organisation [11]. This mandates the organisation to conduct extensive research into current trends and to also obtain free lessons learnt from other organisations that have attempted similar endeavours.

Evaluation of core competencies: Core competency evaluation is pivotal to the selection process [10]; the technology to be selected needs to build on these competencies i.e. enhance the current capabilities. Any of the alternatives identified in the preceding step that complement current competencies must be considered first based on what the organisation perceives to be its core capabilities that provide a competitive advantage against its competitors.

Development of selection criteria: Development of selection criteria will provide a system upon which the various alternatives can be weighed for evaluation against each other [13], thereby ensuring that the same rigorous and fair set of principles are applied at all times. The criteria to be used must include cost implications, opportunities and threats; market trends as well as the existing skills level of the workforce.

Appraisal of alternatives: Appraisal of viable alternatives is the last step in the technology selection process. The employment of the requirements and adoption filters [11] which ensure that issues pertaining to the risk, strategy alignment, government regulations and payback periods are addressed is ideal for this purpose.

2.2 Technology Transfer steps

Core competency zone partnerships: Stemming from the selection of technology that complements existing core competencies, zone 1 category relationships are the most ideal. Zone 1 relationships refer to the employment of cooperative R&D agreements that allow for mutual beneficiation between parties [1]. This type of collaboration is more productive stemming from the initial involvement of the technology end user at the research phase of the technology life cycle. Collaborations also make way for long term relationships that do not just end when the technology is transferred but rather extend to other R&D projects that the end user organisation may be involved in.

Technology transfer environment: Involvement of the transferee at the initial stages of technology development awards the end user the opportunity to describe the type of environment that the technology will be used in [5]. This in conjunction with the intrinsic knowledge of their workforce allows for adaptation of the technology for the receiver's environment. It is thus important that existing conditions are taken into consideration and the technology designed to fit into this environment.

Selection of transfer mechanism: Once again, due to the knowledge of the workforce and challenges faced by the organisation, the technology transfer mechanism must be chosen by the recipient of the technology who is privy to the best possible transfer environment and processes [5]. The chosen mechanism must adequately address the expected reactions, some of which will have been communicated by the various stakeholders identified during the selection process.

Iterative training: Training of the technology end user should not be a single event but rather designed as a recurring process. Employee training by the technology inventor must be planned carefully and aimed specifically at bridging the gap in the capabilities of the organisation's employees with respect to the use of the new technology being introduced. The continuous training will allow end users to learn all aspects of the technology with the aim of reaching a stage where, with thorough extensive knowledge, the end users can identify further opportunities for improvement [9].

2.3 Technology Adoption

Communication of selected technology: Personnel in the organisation must be made aware of the decision to introduce new technology and must be informed of the technology selected as soon as a decision has been made [3]. Reasons behind the choice and decision (inclusive of government endorsed/legal compliance) to implement the technology should be communicated as early as possible. This step goes a long way in addressing minor issues which, if left unattended, may result in major resistance to the technology adoption process.

Targeted personnel training: Literature revealed that age plays a major role in the adoption of technology [8] and to this effect; the age distribution of employees in the organisation should be taken into consideration. Training facilitators must be made aware and assigned to particular age groups for targeted training sessions. Highly skilled facilitators are thus required for this change management exercise.

Selection of technology ambassadors: Stemming from the targeted training interventions that are aimed at curbing the technology knowledge gap for all employee age groups, ambassadors for each age group [8] must be selected. It is advised that the selected ambassadors be trained as “super users”, a process which entails rigorous training of the super users prior to the introduction of the technology to the remainder of the workforce. The super users can then be positioned as change agents during the targeted training workshops where they will endorse the technology and serve to encourage sceptics on the benefits of the technology.

Selection of transfer mechanism: The best decision pertaining to the transfer mechanism can only be made by the end user [5] who is privy to the most knowledge about its employees i.e. the transferee. The transferee can choose from transfer mechanism options which include training of end users at the developers site, training at the final destination/ end user’ site or a combination of the two options.

Continuous technology exposure: This goes hand in hand with the iterative training process discussed during the technology transfer phase. Constant exposure to the new technology will help break down all defence barriers [6] as the employees interact with the technology thus dissolving the fear factor. With time, all fears pertaining to the change will be alleviated and the technology gradually adopted by the workforce.

2.4 Proposed Hypotheses

Based on the development of the three-stage framework for the selection, transfer and adoption of new technologies, the following sets of hypotheses are stated for each of the three stages:

2.4.1 Technology Selection

H1: Government regulations and improvement of existing core competencies drive new technology implementation in an organisation.
H2: An exhaustive list of stakeholders and a variety of technology alternatives aid informed technology selection decisions. (PM)
H3: Existing core competencies are the primary consideration during technology selection.

2.4.2 Technology Transfer

H1: Recipient involvement at the design phase of new technology allows for retrofitting of new technology for the recipient’s environment which favours technology transfer. (SE)
H2: Collaborative contractual agreements increase the success rate of technology transfer.
H3: Practical training sessions favour successful technology transfer.
H4: Iterative training sessions ensure maintenance of the skills and capabilities required to utilise the new technology.

2.4.3 Technology Adoption

H1: Early communication of selected technology to the workforce assists technology adoption.
H2: Targeted training interventions at the recipient’s site promote successful technology adoption.
H3: Technology ambassadors accelerate the process of technology adoption.
H4: The duration of exposure to new technology favours technology adoption.

3. RESEARCH METHODOLOGY

As a first step, a literature study relating to the selection, transfer and adoption of technology was conducted. The review covered relevant definitions, existing models and methods employed in previous studies. This was done for all three stages i.e. selection, transfer and adoption of technology in order to provide the background for the conceptual model to be tested and analysed. Stemming from the literature study conducted and the conceptual model developed, hypotheses for technology selection, transfer and adoption to be tested and either proved or negated by the data collected were formulated.

The data was collected by means of survey questionnaires sent to various respondents within the mining industry. For the purposes of external validity, the framework was tested in other industries as well (see Figure

1). The results of the survey in the other industries are not reported here since the focus of this paper is on a framework for the mining industry. To this effect, two electronic survey questionnaires were developed, one for the mining industry (platinum refinery) and the other for external organisations. The questions included in the surveys were extracted from the proposed hypotheses such that each hypothesis could either be distinctly proven or negated. The survey developed for distribution to multiple industries was identical to the one distributed within the refinery with an additional question that required respondents to indicate the industry within which they operated. Responses from the mining industry were utilised to developed a framework for each of the three stages i.e. selection, transfer and adoption of technology to be tested for validity. Descriptive statistics were applied to the data gathered.

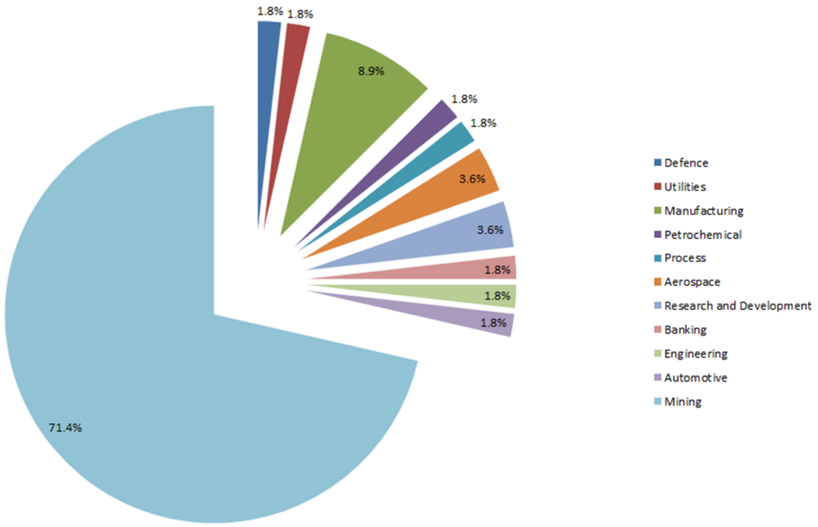

Figure 1: Distribution of respondents

4. RESULTS

Descriptive analyses were conducted on the data collected from a total of 18 responses received within the refinery and the 58 responses obtained for the survey distributed to various industries. Of the 58 responses, 96% of the respondents stemmed from the mining industry and thus the results of the survey were dominated by the mining industry owing to the significant percentage of respondents from this sector.

4.1 Descriptive Analysis

The following section summarises the conclusions from the descriptive analysis for each step of the three stages of selection, transfer and adoption.

4.1.1 Technology Selection

Years of experience: The years of experience of respondents ranged between 15 months and 36 years within the refinery and between 5 months and 37 years in the various industries, thus vast experience from the respondents of the survey.

Motives for new technology implementation: The most common reason for the implementation of technology in the mining industry was found to be the improvement of process efficiencies as this translated to lower running costs and higher metal recoveries thus the generation of income for the business.

Identification of relevant stakeholders: Stakeholders involved were found to be based on internal structures, the importance of the project and the disciplines (knowledge field) involved. The finance department was found to be involved in all decisions made and what stuck out however was the absence of labour union representatives in the list generated by the respondents.
Definition of systems requirements: Mining organisations were found to be involved as early as the design phase of the technology life cycle owing to the value of seeing the technology right through its entire life cycle (cradle to grave) in order to prevent failures which are as a result of avoidable matters.
Analysis of technology alternatives: The respondents explained that the number of alternatives considered was dictated to by the purpose of the project; geographical source of the technology; patented/ novel technologies, availability of suppliers and the intended application of the technology.

Evaluation of core competencies: Existing core competencies were found to be a secondary consideration for technology selection. The cost of the new technology was the primary consideration above core competencies in decision making processes.
Development of selection criteria: Decision making criteria reported included strategic intent; SHEQ aspects; financial aspects; risks appetite; current vs. future needs; alignment of the new technology with existing infrastructure and maturity of the technology.
Appraisal of alternatives: Appraisal methods in use included financial benefits; SWOT analysis; supplier reputation; technology life cycle and ease of use of the new technology.

4.1.2 Technology Transfer

Core competency zone partnerships: Zone 1 partnerships i.e. collaborations and partnership contractual agreements were entered into during technology transfer due to the new era of information sharing and dissemination that in turn gives birth to powerful long term relationships.

Technology transfer environment: It was found that new technology was retrofitted to suite the organisation. The results were considered to be sound when taking into consideration that all operations differ from one section to the next. In line with getting involved at the inception/design phase of the technology life cycle, retrofitting was considered to be the most effective transfer tool because the technology could be tailor made for a specific use within the organisation.

Selection of transfer mechanism: Practical and modular training of employees were the most favoured technology transfer mechanisms. This was found to be in line with the retrofitting of technology to an organisation as discussed above. In addition, it was offered that the type of training intervention employed depended mostly on the type of technology to be implemented.

Iterative training: In line with the modular training discussed above which incorporated changes and improvements in the new technology recently implemented, continuous/iterative training processes were found to be most favoured.

4.1.3 Technology Adoption

Communication of selected technology: Communication of technology implementation was found to be mostly done when the selection process was concluded however, communication upon delivery was also found to occur quite often as well. It was considered that communication of technology implementation upon delivery accompanied by the absence of labour representatives in the technology selection stage was bound to generate feelings of ambush and uncertainty amongst employees.

Targeted personnel training: It was found that combined training sessions were the most common training intervention employed. Age targeted training intervention were rarely used thus all employees were subjected to the same training methods regardless of age. It is believed that this could be the result of the costs associated with age specific training since combined training sessions were found to be the most common, cheaper and more convenient.

Selection of technology ambassadors: Data gathered showed that the use of technology ambassadors was the second most common method for stimulation of technology adoption. The most common method employed was the promotion of the technology's benefits to the intended recipients as well as financial incentives. From the results above, it was found that faith was placed on acceptance of the new technology by placing emphasis on the technology's benefits with regards to improved efficiencies and improved productivity offered by the new technology.

Selection of transfer mechanism: Training interventions were reported to occur at a combination of both the developer's and recipient's sites. Rarely was technology transferred at the developer's site. It was considered that this was because this translated to major costs owing to the large number of employees who would have to be transported to the developers' site for possibly long durations. An alternative offered entailed training of an organisation's employees at another organisation's (third party) site/premises. The third party organisation would ideally be one that had perfected the use of the technology and had gathered enough experience and knowledge to share with other organisations.

Continuous technology exposure: Technology exposure was reported to be based on:

- The rationale that for personnel (operators) who were required to operate the new technology on a frequent (daily) basis, exposure accounted for more than 75%. For employees trained to understand the mechanisms for troubleshooting purposes, exposure accounted for more than 50%. For employees who required background and basic understanding of the technology, exposure accounted for less than 50%.

- The level of interest and commitment conveyed by the employee; complexity of the technology and the employee's level of responsibility.

Impact of duration on technology exposure: Almost unanimously, it was found that the duration of exposure to the new technology had a positive effect on technology adoption. This was considered to be a logical result because familiarity with the new concept eventually resulted in comfort and ultimately reception and acceptance of the new technology. It was explained that in light of the fact that change was intimidating, constant exposure eliminated the unknown, eradicated resistance and replaced all of the fears with excitement and passion to learn more about the new technology.

4.2 Hypotheses Testing

4.2.1 Technology Selection

Hypothesis 1 offered that government regulations and improvements to existing core competencies drove new technology implementation in an organisation. From the data gathered, it was found that this was not the case and that improved process efficiencies were the main driver for technology implementation within the mining industry. The second and third reasons were found to be cost saving initiatives and government regulations respectively.

Hypothesis 2 offered that a holistic list of stakeholders ensured that all avenues were explored and that all possible scenarios were discussed and resolved. Data gathered generated a comprehensive list of stakeholders involved in the selection process. It was also found that the purpose of the technology (strategic vs. incremental innovation) informed the list of shareholders involved. Irrespective of the scale of the technology innovation project, the finance department was however always involved. It was thus concluded that a holistic list of stakeholders varied from one project to the next and that it also differed from one organisation to the next.

Hypothesis 3 offered that existing core competencies were the primary consideration during technology selection. From the data gathered, it was found that in the mining industry, costs of new technology were the main driving factor in technology selection. Existing core competencies were found to be a secondary consideration. The conclusion was made that the proposed hypothesis does not hold true for the mining industry.

4.2.2 Technology Transfer

Hypothesis 1 offered that recipient involvement during the technology development phase allowed for retrofitting of new technology for the recipient's environment which favoured technology transfer. The data gathered validated the offering within the mining industry and it was found that involvement of the recipient organisation during the design phase ensured all requirements were taken into consideration. This also ensured that retrofitting of the technology for the recipient's environment was also incorporated into the design phase.

Hypothesis 2 offered that collaborative contractual agreements increased the success rate of technology transfer processes. From the data gathered, this was indeed found to be the case. Collaborations between the developer and recipient organisations were the most common type of partnerships as these symbiotic relations are maintained throughout the years.

Hypothesis 3 offered that practical training sessions favoured successful technology transfer by bridging the gap between current capabilities and those required to operate the new technology. The data collected substantiated the proposition in that practical training interventions were the most common and effective form of training employed in mining organisations.

Hypothesis 4 offered that iterative training sessions maintained the skills and capabilities required to utilise the new technology. From the data gathered it was found that a combination of iterative training, as per need training and once-off training sessions was employed and that the type of training intervention chosen was informed by the type of technology (retrofit vs. plug and play) that was being implemented. Iterative training albeit most common, was thus not the only type of effective training employed to promote technology transfer.

4.2.3 Technology Adoption

Hypothesis 1 offered that early communication of selected technology to the workforce assisted technology adoption by allowing employees sufficient time to adjust to imminent changes. Data obtained revealed that communication of the selected technology in the mining industry was mostly done after the selection as proposed; however it was also found that the remainder of the time, communication was conducted during the commissioning stages of the technology life cycle. It could thus not be conclusively stated that the proposition was completely proven and thus remains an area open for further investigation.

Hypothesis 2 offered that targeted training interventions allowed for interaction between the transferor and transferee organisations thereby developing a trust relationship which in turn facilitated the adoption process. Data obtained to test the hypothesis was found to be inconclusive as most mining organisations seldom used targeted training sessions but rather opted for the conventional combined training sessions. The hypothesis was thus neither substantiated nor negated due to inconclusive data obtained.

Hypothesis 3 offered that technology ambassadors accelerated the process of technology adoption. Data collected was found to be inconclusive due to the fact that most mining organisations rarely used technology ambassadors. Instead, the promotion of the technology's benefits was the main stimulant used to encourage technology adoption.

Hypothesis 4 offered that the duration of exposure to new technology favoured technology adoption. Data collected attested to this proposition serving as proof that prolonged exposure greatly encouraged technology adoption.

5 CONCLUSIONS AND RECOMMENDATIONS

An amendment of the conceptual model offered above as informed by the findings of the research is set below. The model is considered to be valid within the confines of the mining industry as informed by the respondents of the surveys who stemmed mainly from mining organisations.

5.1 Technology Selection in the Mining Industry

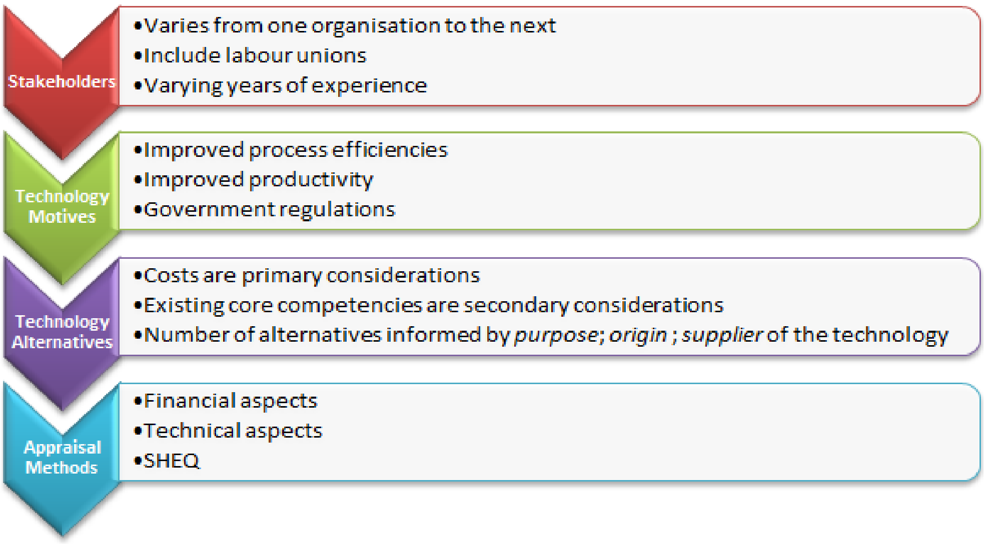

Figure 2: Revised Technology Selection in Mining Industry

Stakeholders involved in the process will vary from one organisation to the next but it is imperative that labour unions are involved at the early stages in order to prevent labour unrest due to feelings of exclusion. Stakeholders with varying years of experience should be selected to draw from past experiences (seasoned employees) while at the same time taking advantage of current industry trends brought forth by younger employees who keep abreast of technology trends. Improvements in process efficiencies and productivity are the primary motives for technology implementation followed by government regulations. Cost considerations are the main criterion used for selection purposes followed by existing core competencies of the organisation. The number of alternatives for consideration is informed by the purpose, origin and the availability of suppliers of the technology respectively. Appraisal methods employed include financial, technical and SHEQ consideration that are prevalent in the organisation.

5.2 Technology Transfer in the Mining Industry

Figure 3 shows the proposed steps found to be effective in the mining industry.

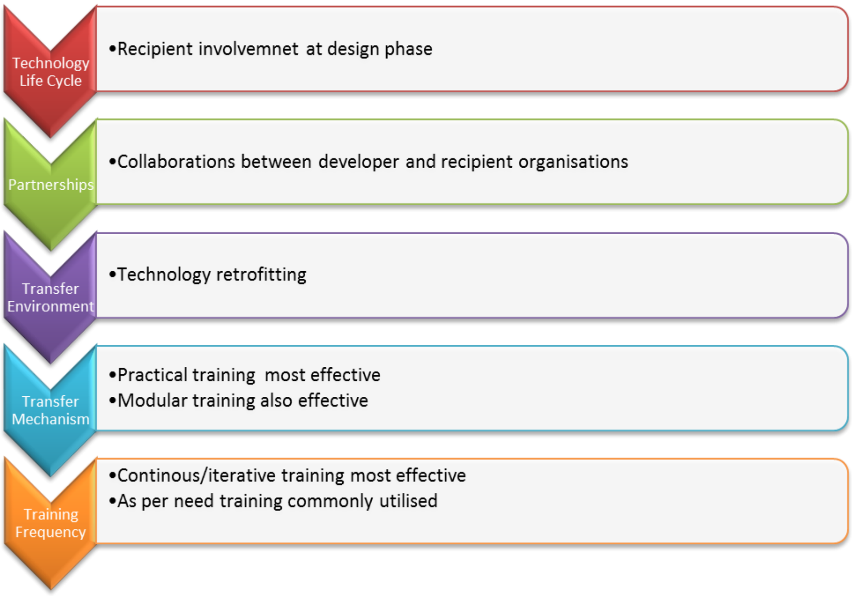

Figure 3: Revised Technology Transfer in Mining Industry

Involvement of the recipient organisation at the technology design phase is most beneficial and this in turn paves the way for collaborations between the transferor and transferee organisations. Involvement at the initial stages allows for technology retrofitting and ensuring that the new technology is designed to align with the existing systems within the recipient's organisation. Practical training as the most effective (followed by modular training) enables employees to possess the skills required for operating the new technology. Practical training is complemented by continuous training interventions aimed at retraining employees on an agreed upon basis. As per need training is also an effective training mechanism that is conducted as and when required.

5.3 Technology Adoption in the Mining Industry

The technology adoption steps in the mining industry are as described in figure 4.

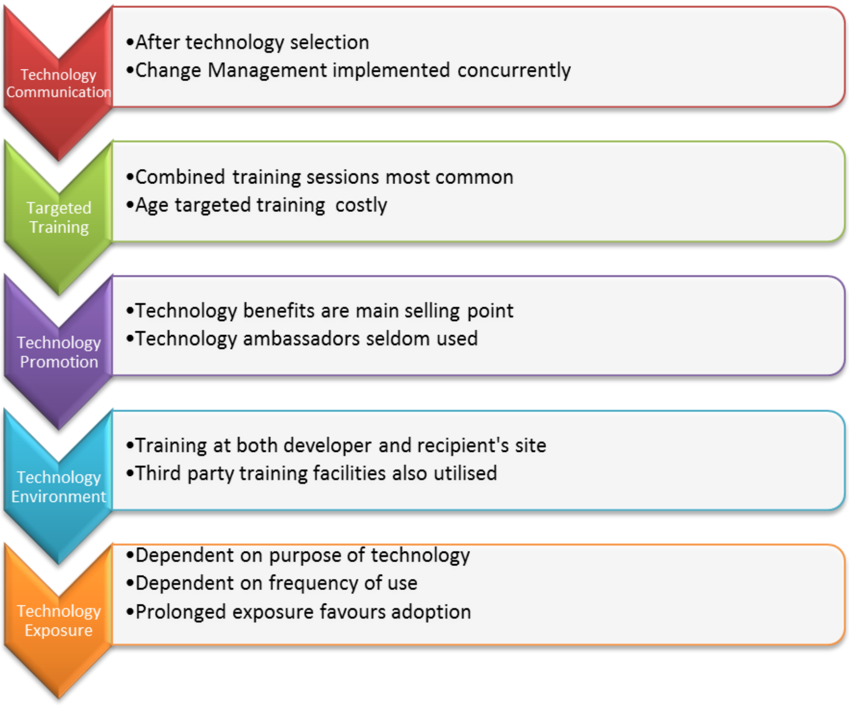

Figure 4: Revised Technology Adoption in Mining Industry

The communication of impending changes must be conducted immediately after the technology selection step; change management processes must also be kick-started at the same time in order to address employees concerns and fears. As was the case with technology transfer, targeted training is seldom used in favour of combined training sessions that are less costly than age specific training sessions. The benefits of the technology must be highlighted and where deemed necessary, ambassadors must be selected to endorse the new technology. Training of employees at both the transferor and the transferee's sites allows for effective training sessions and where possible the use of third party training facilities can be utilised. The duration of technology exposure is informed by the purpose and frequency of use of the technology, which for direct end users warrants prolonged exposure in order to obtain the skills required and to also enable troubleshooting abilities which favour technology adoption.

5.4 Recommendations

5.4.1 External Validity

As a result of a significant number or respondents to the surveys being from the mining industry, the findings of the current research cannot be generalised to other industries and thus could not be externally validated. The findings are therefore limited to the mining industry and it is proposed that the modified model be tested for external validity outside the confines of the mining industry.

5.4.2 Technology Ambassadors

The use of technology ambassadors to encourage technology adoption was not completely verified during the current study and as such, the benefits (if any) of technology ambassadors need to be investigated further.

5.4.3 Age Targeted Training

Owing to the fact that targeted training sessions were seldom used in the mining industry, it was not established whether or not the employment of various training techniques per age group provided any benefits. Further studies into this aspect of technology adoption need to be conducted in order to obtain conclusive data on the subject.

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CONCEPTUALISING GLOBAL MINERAL VALUE CHAINS: A TOOL FOR MINERAL POLICY DESIGN

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ABSTRACT

This paper presents a model by which policy makers can conceptualise the shape and impact of mineral value chains (MVCs) and how their decisions influence the local footprint and value capture of mineral related activities. The model combines a high-level value chain perspective with the triple bottom line dimensions of sustainable development. The proposed model aims to stimulate increased discourse surrounding a more holistic view of value capture from mineral value chains. This is done by investigating the role of productive actors, government and civil society and how each of these players' roles interlink.

1. INTRODUCTION

The last fifty years have seen the metals producing and consuming nations moving into different camps, with the major consumers no longer being the major producers. This has led to consumer countries increasingly moving to adopt policies that ensure the supply security of critical minerals. On the other hand, producing countries have increasingly become prone to resource nationalism and the adoption of policies that aim to maximize the benefit achieved from the extraction of their resources [1]. However, this is often a difficult task where there may be trade-offs between short to medium term value for the nation and the long term sustainability of their resource activities [2].

In some cases, this resource nationalism has found expression in policies that are aimed at localising the downstream processing of minerals to the mineral producing countries. The reasoning behind this usually being that the local processing of minerals will result in greater economic value add, an improved balance of trade and the creation of more jobs [1–5].

Academia has also been investigating several aspects regarding the increased sustainable value capture from mineral resources in support of the drive to ensure more benefit from mineral endowments for mineral producing countries and to combat the so called “resource curse”. This has included research on aspects ranging from the role of corporate social responsibility (CSR) in development [6, 7], managing small scale and artisanal mining (ASM) for improved regional outcomes [8], trust between different stakeholders in promoting sustainable development [9] and incentivising the recycling of minerals [10].

However, there appears to have been limited recent attempts to collate the research into a conceptual framework to enable policy makers to consider the wide ranging impacts of their resource policies in a holistic manner. This is particularly important due to the increased emphasis on localising mineral processing activities where multiple factors need to be considered. The nearest to such a framework that the author is aware of is the conceptualisations suggested by Franks et al. [11] for representing cumulative impacts in resource regions, presented in their introduction of the special issue of the journal, *Resources Policy*, on ‘Understanding and Managing Cumulative Impact in Resource Regions’.

This paper aims to address this gap by proposing a model conceptualising mineral value chains (MVCs) with a focus on the downstream processing of extracted minerals, the value capture from the local MVC footprints and the factors that influence both the location of and value capture from mineral processing activities. The framework combines a high-level value chain perspective similar to that used by authors such as Gereffi and Lee [12] and Barrientos et al. [13] with the triple bottom line (TBL) dimensions of sustainable development (economic, social and environmental) that has become increasingly important in various areas of research [14].

From this dual perspective, the conceptual model was inductively constructed through reviewing 304 articles published in the journal *Resources Policy*. These articles were selected by reviewing all the articles published in this journal since the start of 2010 up until the 12th of July 2015. The identification of these articles was based on a Scopus® search on the latter date for all articles from this journal, filtered by the requirement of being published in or after 2010. Instead of delivering the final word, the proposed model aims to stimulate increased discourse surrounding a more holistic view of value capture from mineral value chains, particularly for mineral rich countries and to provide policy makers with a starting point from which to consider their mineral related policies.

The first element of the conceptual model, presented in Section 2, focuses on the elements of a mineral value chain. The second element of the conceptual model, presented in Section 3, is the national value capture from mineral value chains. The third element of the conceptual model, presented in Section 4, focuses on the factors that influence the shape of the mineral value chain.

The final element of the model focuses on the factors that influence the value capture from mineral value chains, presented in Section 5. In Section 6, these four elements are collated into a single conceptual model. Finally, Section 7 provides concluding remarks to the article.

2. CONCEPTUALISATION OF THE MINERAL VALUE CHAIN

There are various ways in which to conceptualise a mineral value chain. The specific focus of a study, the mineral considered and the types of policies being investigated will dictate which of these conceptualisations may be more applicable. This section presents a typical conceptualisation of the MVC for the investigation of the location mineral processing activities. Thereafter, other considerations that might be important in the current mineral related policy environment are discussed.

In order to analyse the location of downstream mineral processing activities, the proposed conceptualisation integrates the theoretical work of Humphreys [1] focussing on the tension between producing and consuming countries for control over the processing steps of the mineral value chain and the GVC conceptualisation work of authors such as Gereffi and Lee [12] and Barrientos et al. [13]. This proposed conceptualisation is shown in Figure 1.

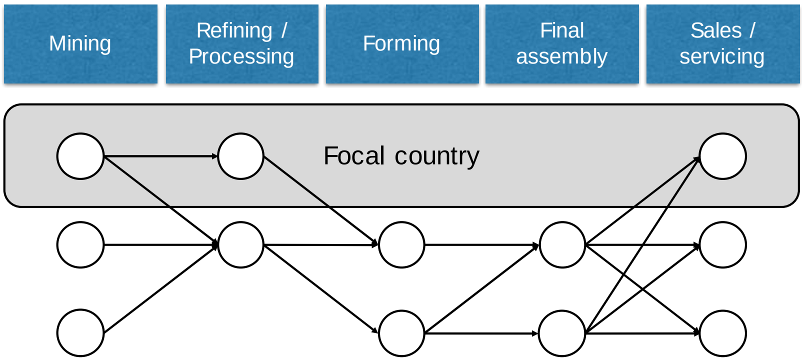

Figure 1: Proposed conceptualisation of the local footprint of the mineral value chain within a global context.

This conceptualisation allows for the evaluation of the structure of MVC by distinguishing between the extraction source of the mineral and the market where the products using this mineral are eventually used or consumed. Between these two poles, the model allows for the evaluation of where manufacturing takes place - in the focal country or not. It could be expected that the refining and processing takes place close to the extraction activity in order to minimize the costly transport of unprocessed ore. It could also be expected that the final assembly might take place close to large final markets in order to minimize the transport cost and lead times to the final consumers. The manufacturing, forming and assembling might take place somewhere in between, though this need not be the case, and different factors play a role in determining where these activities are located.

By conceptualising the MVC in this way, it is possible to glean new insights regarding the location of MVC activities and the drivers of this location. This high level conceptualisation will have to be adapted for different minerals depending on the different and possibly parallel processing steps, the importance of recycling and other mineral specific properties.

Other considerations that might be important in the current mineral policy environment include the distinction between large scale and artisanal mining (ASM), the clustering of activities, linkages and the mineral life cycle. These are briefly discussed here in turn.

Recent literature emphasises the distinction between and consideration of both large scale conventional mining and artisanal and small scale mining (ASM). The failure to distinguish and accommodate both can lead to sub-optimal outcomes, particularly on the local social level [8, 15–27].

Another important consideration is the clustering of activities. Activity clusters can generate critical mass and unlock positive feedback loops that generate additional growth and activities. They can also assist in overcoming constraints through the pooling of resources. However, due to the often observed mining revenue flow to cities, abroad to shareholders and to fly-in fly-out employees and the flow of royalties to national governments, these clusters are often not allocated sufficient resources and underexploited. This can lead to the suboptimal development of mining regions [24, 28–36].

Related to clusters is the consideration of linkages. Linkages (both upstream and downstream) are also important in terms of the shape of MVCs. Increasing them allows governments to increase the local footprint of MVCs and the value capture from them [37]. Fessehaie [30], Morris et al. [37] and Hanlin and Hanlin [38] emphasise the importance of “deeper” upstream linkages that stretch beyond the first tier to ensure that the maximum local activity footprint is achieved.

Toward better environmental management, Fleury and Davies [39] conceptualises the MVC as part of a wider life cycle. This life cycle starts with the societal demand for minerals and includes the disposal, reuse and recycling of minerals. By conceptualising minerals in this way, policy makers can consider the effects of minerals after extraction to the point of disposal.

This section presents a generic conceptualisation of the MVC to analyse the location of mineral processing activities. Thereafter, other considerations that were identified during the literature review that may be important to incorporate into a MVC conceptualisation for other policy related studies were identified. The following section extends the proposed view of the MVC by incorporating the sustainable value capture dimensions of the triple bottom line.

3. NATIONAL VALUE CAPTURE FROM MINERAL VALUE CHAINS

The value that is captured from the local footprint of MVC activities can be conceptualised according to the three sustainability dimensions of the *triple bottom line* (TBL) concept, popularised by Elkington [40]. Each of these dimensions can also be conceptualised as entailing gain and cost, as the complex impacts of mineral related activities can have both positive and negative effects on the host nations. This is illustrated in Figure 2.

The triple bottom line, consisting of an economic, social and environmental dimensions, has been increasingly used in supply chain literature and provides a useful conceptualisation of the aspects related to the sustainability of a variety of activities and how these activities translate to value [41-44]. The distinction between gain and cost is somewhat problematic, as choosing in which category certain impacts fall might be a matter of perspective. However, the goal of distinguishing between the two categories is to support decision-making by ensuring the consideration of both positive and negative aspects. A number of aspects can be identified to form part of each of these dimensions of value capture. These are each considered in Section 3.1 through 3.3.

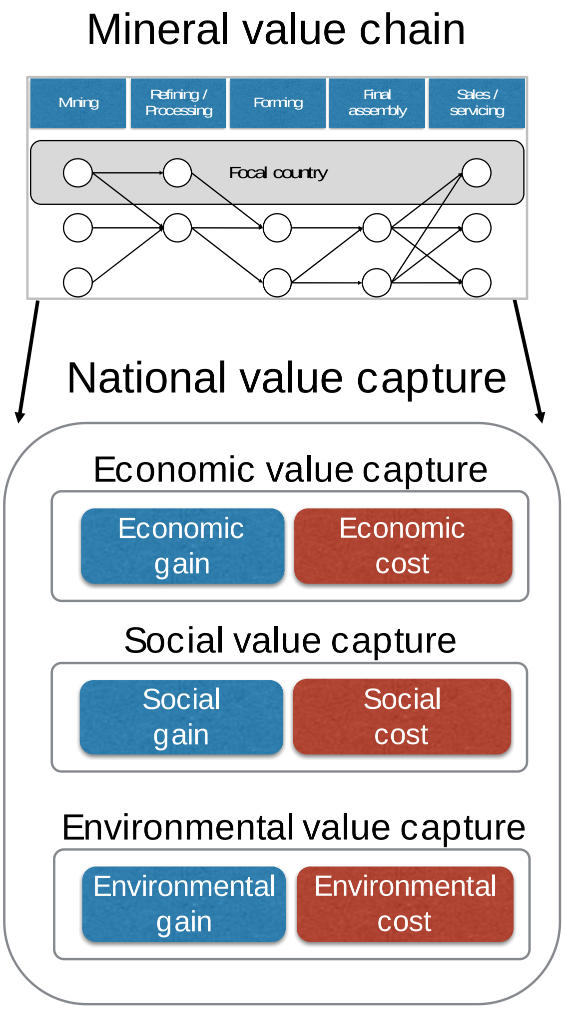

Figure 2: The national value capture from the local resource value chain footprint.

3.1 Economic value capture

Some direct economic benefits from mineral related activities cited in literature include capital investment [32, 45, 46], employment sustained [1, 29, 32, 46-48], economic growth [32], improved income levels [1, 32, 46, 48, 49], local development, lower inequality [48, 50], shareholder returns [32], tax revenue [1, 21, 32, 51, 52] and local value added [47]. Indirect economic benefits include the appreciation of the national currency [32], a diversification of exports [53], the stimulation of downstream activities, employment in other sectors, particularly in transport, rental and accommodation [1, 29, 36, 54], infrastructure development [37, 45] and other linkages [4, 5, 32, 37, 38, 45, 46, 55-62].

There may also be several economic costs related to the exploitation of minerals that should be considered. These have been identified to include the opportunity cost, which is particularly important due to the relatively capital intensive nature of mining and thus might translate to fewer jobs for the equivalent investment [32, 54], the exhaustion of minerals [32], the outflow of revenue to foreign investors [28], low job spill-overs into manufacturing and agriculture [54], poorer financial development [63], regional economic problems such as low entrepreneurial activity, pressure on local services and infrastructure, specialisation on minerals and unaffordable housing [32, 35, 64], resource dependence of the economy which may lead to the crowding out of other sectors, instability and insecurity due to the dependence on the fluctuating external demand [32] and possible slower national economic growth [65].

3.2 Social value capture

Some of the potential factors related to the social gain from resource related activities include better education [49], a reduction in poverty [66], improved communication access [49], an increase in disease prevention initiatives [67], improved income levels [1, 22, 32, 49], lower unemployment [48] and a more equitable distribution of income [1]. Some of the social problems that have been associated with resources related activities include conflict [21, 65, 68], corruption [65, 69], the displacement and relocation of communities [21, 70, 71], the disruption of traditional cultures [72], risks to human health such as deaths through contamination, mine injuries, the increased spread of sexually transmitted diseases, mental health issues, addiction, family stress, increased violence towards women and the intake of toxins through contaminated water [73–75], the aggravation of societal issues through the white washing effect of corporate social responsibility [72, 76], poor working conditions [35], poorer education [32], inequality [65], rentier states [65], stranded regions [32] and human rights suppression [75].

3.3 Environmental value capture

As far as minerals and the environment is concerned, the focus in literature and elsewhere is generally on minimising the negative impacts on the environment. However, positive impacts such as man-made habitats for protected birds have been reported [77]. Some of the reported negative effects include deforestation [35], degraded recreational resources [78], general environmental degradation [35, 69, 75], erosion [35, 78], the loss of fauna [72], the loss of habitats for fauna [78], the introduction of non-native species [78], the pollution and contamination of the environment leading to air quality degradation [11, 73], ecosystem degradation [73, 78] and heavy metal contamination [75], toxic spills [75], risks to clean water supplies [11, 35, 78] and visual degradation [11]. There has also been an increasing trend towards the cumulative assessment of impacts as to not view impacts in isolation [11, 75, 79, 80].

4. FACTORS INFLUENCING THE SHAPE OF MINERAL VALUE CHAINS

The factors that influence the location of mineral processing activities and thus the shape of mineral value chains can be conceptualised as enabling and constraining factors that influence the context for stakeholder decisions that ultimately determine the shape of mineral value chains. These decisions again impact on the enabling and constraining factors. This is illustrated in Figure 3.

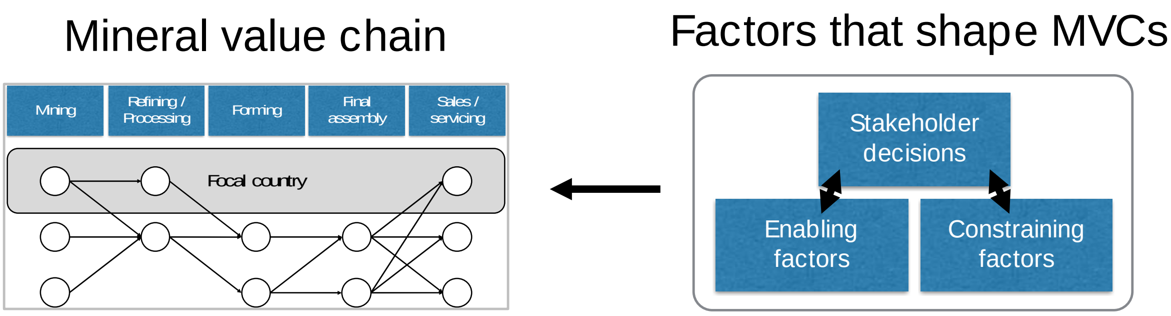

Figure 3: Factors influencing the shape of mineral value chains.

The enabling factors identified include access to capital [30, 53], expectation of sustained demand [81, 82], clusters and corridors [11, 29], sizeable domestic markets [57], improved technology and processing techniques [30, 53, 83, 84], infrastructure [30, 81], local suppliers [29, 38], competitiveness supported by labour productivity, management practices and quality ore [85], supportive policies [29, 30, 38, 70], continued research and development [33, 60, 86], the regulation and formalisation of industries [21], local skills [30], subsidies [10], tax breaks [1, 21] and trust [38].

The constraining factors identified in the literature review include demand and price volatility [32, 87], competition [32, 81], environmental concerns [83], exhaustion of resources [32], increased cost of production [32], land acquisition difficulty [53], a restrictive and uncertain legislative environment [82, 88, 89], logistical costs [47], physical infrastructure [29, 57], a decrease in investor confidence brought on by resource nationalism [1], substance restrictions [39], supplier readiness [38] and the availability of water [83].

In the environment of the enabling and constraining factors at a given time, different stakeholders make decisions that impact the shape of the mineral value chain. These include end-users making product choices determined by a variety of factors. These may also include their perceptions on the sustainability of the products that they are buying [39].

Governments also influence the shape of mineral value chains through policy stances, which may vary from neoliberal to resource nationalistic [90] and may directly interfere through, for example, the nationalisation of mines or the protection of specific industries [3, 91, 92]. Company decisions also influence the shape of mineral value chains through supplier decisions and procurement policies [38, 39]. Other influencing stakeholders may include employees, NGOs and local communities [21].

5. FACTORS INFLUENCING THE VALUE CAPTURE FROM MINERAL VALUE CHAINS

Similar to the impact drivers suggested by Franks et al. [11], this section presents a conceptualisation of the value capture from mineral value chains as being determined primarily by the actions of productive actors within the context created by government and other stakeholders as illustrated in Figure 4.

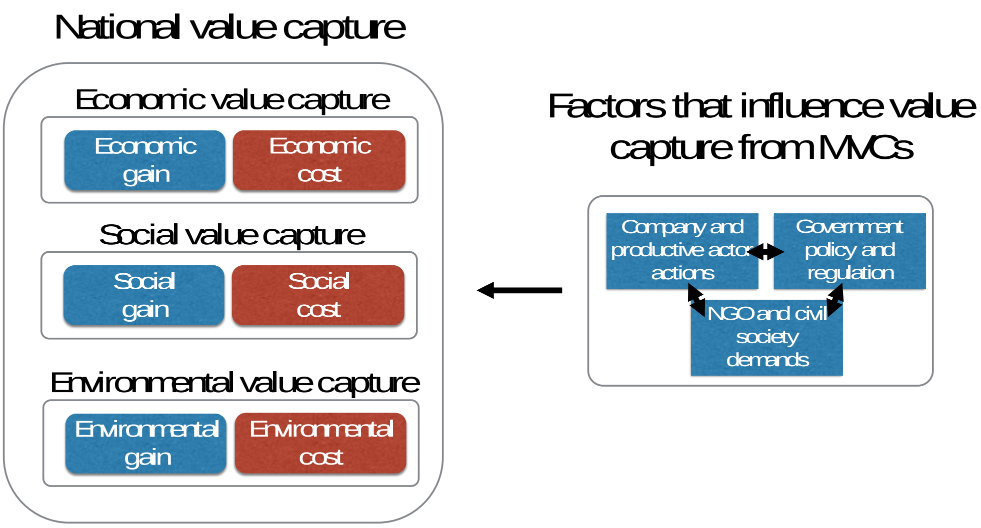

Figure 4: An illustration of the factors influencing the value capture from mineral value chains.

The actions of companies and other individuals and entities involved in productive activities play a predominant role in the value capture outcomes of mineral related activities [7, 11, 72, 90, 93]. These actions may be influenced by the boundaries set by government [11, 28, 36, 70, 73, 89, 90, 94– 101], the business model and values of the companies or individuals involved in productive activities [93], NGO's [21] or civil society and local communities [11, 90, 99].

These non-productive actors fulfil a crucial role by influencing the actions of government and those involved in productive activities. This goes some way in explaining the increasing emphasis in literature on the so called "social licenses to operate" [96, 102–115] and multi-stakeholder forums and collaboration to achieve better outcomes for all the stakeholders involved [72, 80, 103, 116].

6. COLLATED CONCEPTUAL MODEL

The four conceptual aspects presented in Section 2 through 5 can be collated into a single conceptual model, as shown in Figure 5.

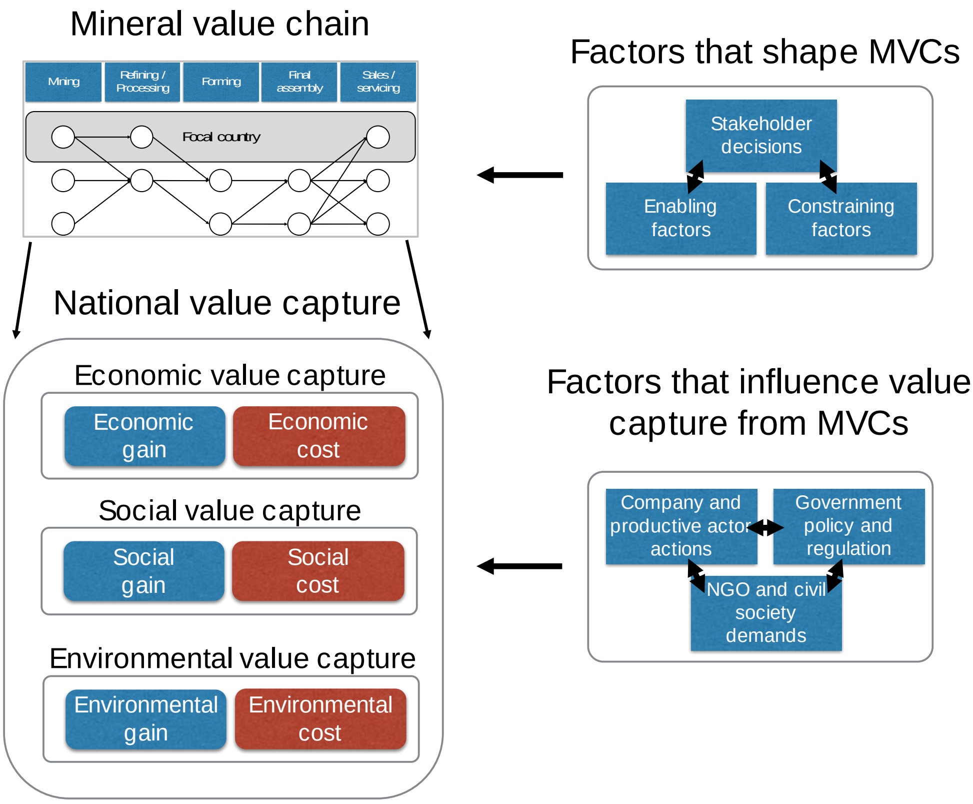

Figure 5: Collated mineral value chain value capture conceptual model.

The proposed model is a major simplification of all the dynamics at play. In particular, there may be factors that influence the shape of MVCs and the value capture from them. For example, a policy of higher mineral taxation may increase the short to medium term income from minerals for the country, but may lead to less investment in the host nations over the medium to longer term.

The model also does not explicitly account for feedback loops that may exist in the system. For example, the level of national value capture achieved from minerals may influence the expectations and demands of civil society, which may, in turn, influence how they interact with other stakeholders to influence the national value capture.

By simplifying the dynamics at play the model aims to provide a starting point for mineral policy discussions that ensure a sustainable development agenda and a best practice perspective. It also serves to support an appreciation of the important roles of different role players in the MVCs within host countries. This is achieved by providing a clearer conceptualisation of how policies might impact the local footprint of and national value capture from mineral resource value chains.

7. CONCLUSION

This paper aimed to address the need for a conceptual model by which policy makers can conceptualise the shape and impact of mineral value chains and how their decisions influence the shape of and value capture from mineral value chains. The model combines a high level value chain perspective with the triple bottom line dimensions of sustainable development. From this dual perspective, the conceptual model was inductively constructed by reviewing 304 articles published in the journal *Resources Policy* since the start of 2010 up until the 12th July 2015. Instead of delivering the final word, the proposed model aims to stimulate increased discourse surrounding a more holistic view of value capture from mineral value chains, particularly for mineral rich countries and to provide policy makers with a starting point from which to consider their mineral related policies.

The first element of the conceptual model focuses on the elements of a mineral value chain. Although various possible dimensions are identified, the proposed conceptualisation focusses on the producer-consumer dimension of the value chain. The second element of the conceptual model is the national value capture from mineral value chains. It explores the positive and negative value capture aspects of the economic, social and environmental sustainability dimensions from mineral related activities identified in the literature review. The third element of the conceptual model focuses on the factors that influence the shape of the mineral value chain. It explores the role of stakeholders decisions and how these are influenced by local and global enabling and constraining factors. The final element of the model focuses on the factors that influence the value capture from mineral value chains. It emphasises the role of productive actors in bringing about the different aspects of local value capture, while illuminating the role of government and civil society to influence the actions of these productive actors.

The proposed model captures the current thinking on mineral value chains and how they translate to value for host nations. The model also highlights the tensions between ensuring a greater local value chain footprint, while ensuring a more positive value attainment from this footprint.

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EVALUATION OF ELECTRICAL ENERGY CONSUMPTION BY A HOT-DIP GALVANISING PLANT

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ABSTRACT

The galvanising industry is generally characterised by significant consumption of energy. Over 75% of South African plants in the galvanising sector use electric furnaces, an approach was originally prompted by the previous low price of electricity. The biggest challenge now is that from year 2008, electricity prices have risen considerably. It is against this background that an energy assessment was conducted on a batch hot-dip galvanising plant in order to identify potential opportunities for the reduction and more efficient use of electrical energy. The methodology which was adopted commenced with an evaluation of the organisation in terms of its awareness to energy management and commitment to improving on energy efficiency. The methodology also entailed compiling a detailed electrical energy balance and identifying the most significant energy users of electricity. An assessment of the results revealed that the galvanising kettle was the most significant energy user. A heat loss calculator was then used for evaluating energy saving initiatives for the significant energy users after which recommendations were made for reducing the energy consumption by the galvaniser.

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1. INTRODUCTION

The operational environment of manufacturing plants is characterised by increasing pressure to reduce their carbon footprint, motivated by trepidations associated with high energy costs and climate change, with energy as one of the most vital resources for manufacturing. Increasing the Energy Efficiency (EE) of production processes and management approaches have a greater potential of reducing energy costs and avoiding high carbon footprint [1] [2]. It has been generally acknowledged that hot dip galvanising (HDG) is a cost-effective and adequate protection system for components and fabrications required to operate with minimum or zero maintenance for extended periods of time in any environment [3]. The subject of energy optimisation is vital in any industry, especially in hot dip galvanising processes which are used to fabricate a wide variety of steel products such as large pre-fabricated items, structural steel, small washers, threaded parts and so forth. About half of the zinc produced world-wide is used to protect steel from corrosion by a through galvanising of steel and iron [4]. The dearth of energy sustainability is continuously posing major challenges to the South African government and globally. Galvanising furnaces are the predominant consumers of energy in the galvanising industry. The key factors that contribute to large energy consumption by the galvanising furnace is heat losses through convection, conduction, and radiation through pot components as well as the galvanised products. This paper evaluates the electrical energy consumption by a hot-dip galvanising (HDG) plant, against the backdrop of rising energy costs. This evaluation assisted the galvaniser to quantify its significant energy users and identify potential opportunities for the reduction and more efficient use of energy within the plant.

2. LITERATURE REVIEW

2.1 Background for Galvanising

Rahrig (2002) cited batch hot-dip galvanising and inline-continuous galvanising as two most common methods of applying zinc metal to steel. Batch hot-dip galvanising is characterised by immersing the parts or jobs as a discrete "batch" into the zinc bath [5]. Pertaining continuous galvanising, molten zinc is applied on a continuous ribbon of steel sheet as it passes through a bath of molten zinc at high speeds and the process may operate for days without interruption. The duration for the steel in the zinc bath is about two to four seconds and in spite of the favourably faster galvanization rate, continuous galvanising is limited to very thin, flexible sheets of steel [6].

Galvanising plants may also be further sub-categorised according to the type of fuel used to heat the surface preparation and galvanising tanks. Gas-fired furnaces can be categorised in terms of whether they heat the zinc directly or indirectly. Furnaces that heat the zinc directly use immersion burners while those that heat the zinc indirectly have a combustion gallery between the furnace and its exterior to facilitate the transfer of heat from the combustion gases to the zinc. Flat-flame, forced-circulation and high-velocity furnaces are the major types of indirect gas-fired furnaces prevailing within the galvanising industry [7].

Hot dip galvanising is a complex metallurgical process in which steel material is rapidly immersed into a zinc alloy bath whose temperature is normally between 450°C and 480°C [8] [9]. The hot dip galvanising process is characterised by massive heat losses and with regard to heat transfer. Cook (2005) presented basis data for calculations for heat lost at zinc-air interface for "open" and "enclosed" furnace [10]. Thereafter, Blake and Beck (2004) modelled the effect of combined radiation and convection on hot dip galvanising furnace wear [11] and Depree *et al.* (2010) used a three dimensional model to investigate temperature distribution due to radiative heat transfer in three dimensions [12].

Electrical heating is preferred for a galvanising furnace since the radiant heat produced by resistance elements is very uniform, though the high cost of electricity usually precludes the use of electrical heating [7]. There are three steps to the galvanising process which include preparation, galvanising, and post-treatment, with the preparation step being divided into degreasing, pickling, and fluxing [6].

2.2 Surface Preparation

The initial process tank in the galvanising plant is the degreasing tank which usually contains a caustic soda solution used to get rid of organic contaminants such as oils and dirt from the surface of steel. The tanks is generally heated to a temperature of about 80° C and can be agitated to hasten the cleaning process [7]. These surface contaminants need to be eliminated prior to pickling so that the surface can be "wetted" by the pickling solution.

The second surface preparation step is pickling where the degreased steel is immersed into a tank containing acid solution. This tanks either contain sulphuric or hydrochloric acid solution which is used to remove any mill scale or other oxides that may have developed on the surface of the steel [13]. Hydrochloric tanks may be used at ambient temperatures without heating since the cleaning action of the hydrochloric solution is sufficient at room temperature. Conversely, in order to increase the cleaning action, sulphuric acid must be heated to a temperature of about 60˚C.

The third surface preparation step is fluxing which involves the application of a fluxing chemical coating, usually zinc ammonium chloride, onto the surface of the steel part [6]. The fluxing chemical would chemically remove the last

vestiges of oxides prior to steel immersion into the molten zinc, and allows the steel to be wetted by the molten zinc. There are two types of fluxing which include “dry” and “wet” fluxing. Dry fluxing is characterised by immersing the

steel part into an aqueous solution of the zinc ammonium chloride flux, of which upon removal, the flux solution is dried prior to immersion into the zinc bath. The amount of flux deposited on the components is a function of the flux concentration, and the cleaning performance is a function of the drying time and temperature conditions [3]. On the other hand, in wet fluxing, a blanket of liquid zinc ammonium chloride is floated on top of the molten zinc bath so that the steel part to be zinc coated first passes through the molten flux as it is being immersed into the zinc bath. Zinc ammonium chloride is less dense and has a lower melting point than molten zinc and thus floats on the bath surface. Wet fluxing is preferred for workloads that consists of small fasteners, mixes of shapes and sizes, and when centrifuging is executed [3].

2.3 Galvanising

Hot dip galvanising is the application of the zinc coating whereby cleaned steel is immersed in molten zinc usually at a temperature of between 445˚C and 450˚C [14]. A metallurgical (chemical) reaction results when perfectly cleaned steel is immersed into molten zinc, forming a thick coating comprising of a series of zinc or zinc iron alloy layers. Generally, the duration for the steel to reach bath temperature and to react with the zinc is usually less than ten minutes [6]. The adhesion of the resultant coating to carbon steel is therefore determined by means of metallurgical laws and forms a chemical bond to the substrate. Chemical bonding is considered to be far superior to that of a mechanical bond. The galvanised steel product is withdrawn slowly from the galvanising bath once the coating growth is complete, and the left-over zinc is removed by draining, centrifuging or vibrating.

One key by-product of hot dip galvanising is dross which is formed inside or on top of the molten zinc as floating (galvanising ashes) or bottom dross. The intermetallic compounds of the floating and bottom dross develop when the concentration of elements of iron oxides and zinc ammonium chloride exceed their solubility limits in the zinc furnace. The floating dross is characterised by a mixture of oxides and chlorides. Despite perfect control of the zinc bath and the deliberate addition of elements such as aluminium to reduce the iron dissolution, the temperature gradient between the immersed objects and the zinc bath necessitates the crystallisation of dross [15]. The temperature at which the zinc bath is maintained has a direct effect on the galvanising furnace life since at galvanising temperatures, the partially soluble iron from the furnace wall dissolve in the liquid zinc and form dross [11]. The equation for the reaction can be indicated as:

$$\mathrm{Fe} + 13\,\mathrm{Zn} \rightarrow \mathrm{Fe\,Zn_{13}} \qquad (1)$$

The composition of the dross layer is therefore about 4% Fe and 96% Zn.

2.4 Post Treatment and Inspection

Post galvanising treatment can be characterised by air cooling or quenching into water. Generally, quenching is the last step in most HDG processes used to promote passivation of the zinc surface and to control the growth of the zinc-iron alloy layers, with chromium-free passivating technology being preferred to toxic hexavalent chromium passivation [16]. The inspection of hot-dip galvanized steel is less complex, given that zinc does not adhere to contaminated steel, and thus, a visual inspection of the galvanized steel provides adequate evaluation of the quality of the coating [17].

A variety of simple physical tests can be performed to determine thickness, uniformity, adherence, and appearance. The duration to first maintenance of HDG products is directly proportional to the thickness of the zinc coating, given any operational environment. This is a function of the coating thickness which is a critical parameter in the specification and effectiveness of hot-dip galvanising as a corrosion protection system. Thus, inspection of the coating thickness is a key feature of hot-dip galvanized products since thicker coatings yields enhanced durability and decades of maintenance-free performance [18]. Salt-fog tests are generally used for a relative comparison with respect to service condition in order to relate the extent to which various coatings provide protection against corrosion [5]. These tests produce quick results and are less costly although the correlation between the duration in salt spray test and the expected life of some HDG coatings is generally weak [19].

2.5 Benchmarking and Energy Consumption

Energy consumption benchmarking is an energy consumption indicator as a function of the raw materials, process and product output [20]. It can be used for comparison of the energy performance of a number of plants within the same industry, to compare the dynamics in energy performance of one plant at different time periods, with the view to improve energy performance [21]. Energy consumption benchmarking can also be useful for estimating the energy-efficiency improvement potentials within a particular sector whereby the results are compared against best practice technology currently in operation [22]. According to Phuong (2010), energy consumption varies with different raw steel materials and each item has its own product and process parameters which determine the extent of energy consumption [23].

One of the key performance metrics in energy consumption benchmarking is specific energy consumption (SEC) which is an indicator of the amount of primary energy consumed by a process to produce one physical unit of product [24]. Blake and Beck (2004) presented a set of equations that describe the energy efficiency of a galvanising furnace in order to emphasise the need for energy optimisation. These equations could be used for comparing furnaces of different designs

and fuel types in a completely objective fashion [4]. Cook (2005) elaborated that future furnaces will have to operate using less energy and have higher production capabilities to be competitive [10].

3. STUDY AREA

The case-in-point galvaniser provides hot dip galvanising solutions to a wide range of products using a functional jobbing production mode. The plant has a maximum capacity of 40 tonnes per day and the bath size for degreasing, pickling, fluxing and galvanising tanks is 14m x 1.3m x 2.5m, with cranes having a lifting weight capacity of 4 tonnes. Figure 1 shows the flow diagram for the hot dip galvanising process at the company.

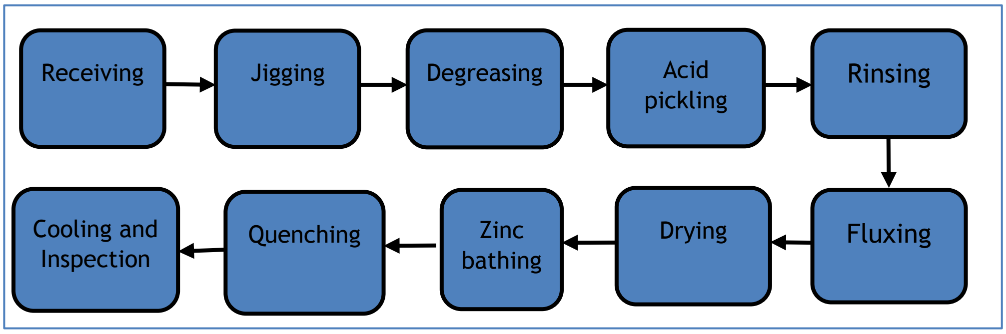

Figure 1: Flow diagram for hot dip galvanising process

The final surface preparation step in the galvanising process is fluxing, where a zinc ammonium chloride solution is used to remove any remaining oxides and deposits a protective layer on the steel to prevent any further oxides from forming on the surface prior to immersion in the molten zinc. The dimensions of the tank are 14 m x 1.3 m x 2.5 m and this 30 000-litre tank has no insulation on the side walls and no covers at the top. The galvanising kettle is powered by 24 rows of chromium heating elements sectioned into 4 zones and furnace temperature is generally set at 600^0C.

4. METHODOLOGY

The methodology which was adopted commenced with an evaluation of the organisation in terms of its awareness to energy management and commitment to improving on energy efficiency.
The questionairre for assessment of company's energy management had the following questions:

- Does the top management know that significant energy cost savings can be achieved by simple low cost measures without necessitating financial assessment?
- Is the top management committed to energy cost reduction and is there an approved energy policy in place?
- Have roles, responsibility and authority been identified for all persons having an influence on significant energy use and is this documented?
- Have the significant energy uses been quantified and documented?
- Has a baseline of energy performance been established against which progress can be measured?
- Have indicator(s) or metrics been identified to use in measuring progress against your baseline?
- Have the organisation's energy objectives and targets been identified and documented?

- Have energy action plans been established?
- Is the energy management system evaluated at least once a year and are improvements made based on the results of the evaluation.

The methodology also entailed compiling a detailed electrical energy balance and identifying the most significant energy users of electricity. A heat loss model was then developed for evaluating energy saving initiatives for the significant energy users which include the galvanising and degreasing tanks after which recommendations were developed for reducing the energy consumption of the galvaniser.

5. ASSESSMENT OF ELECTRICAL ENERGY CONSUMPTION

5.1 Assessment of Galvaniser's Energy Management

An initial evaluation of the company's energy performance was conducted. Figure 2 shows the results for assessment of the organization in terms on its awareness to energy management and commitment to improving its energy efficiency. Although there was no energy policy in place, top management was committed to energy cost reduction. However management was also generally unaware that significant energy cost savings could be achieved by simple low cost measures without huge financial investment.

There was no documentation of the roles, responsibility and authority for all persons who could have an influence on significant energy use (SEUs) and the significant energy uses have not been quantified and documented. No baselines of energy performance indicators (EnPIs) had been established against which progress can be measured and there were no metrics for measuring progress against baselines. The organisation's energy objectives and targets were neither identified nor documented and there were no energy action plans.

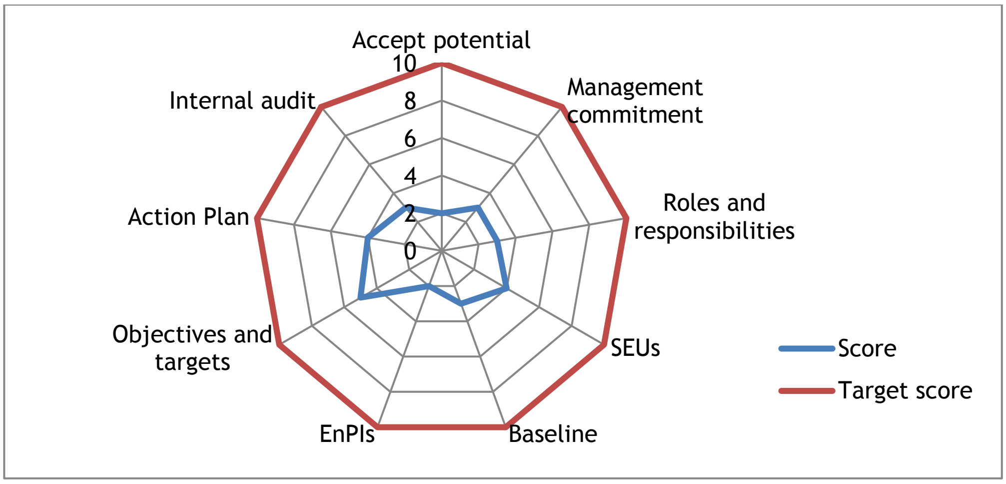

Figure 2: Assessment Chart for awareness to energy management and commitment

5.2 Assessment of Consumption Data

An average of 33 tonnes of metal was galvanised per day from an average of 45 dips per day. Total monthly tonnage sat at around 62 7921 tonnes of steel material using about 49 757 tonnes of zinc. Average monthly electricity consumption sat at 270779 kWh and charged at an average rate of R1.49/kWh but higher figures were noted for June (R3.00/kWh), July (R2.95/kWh) and August (R2.95/kWh). The average rate of R1.49/kWh was computed as a mean of the energy standard, energy peak, and energy off-peak as derived from the municipality monthly bills.

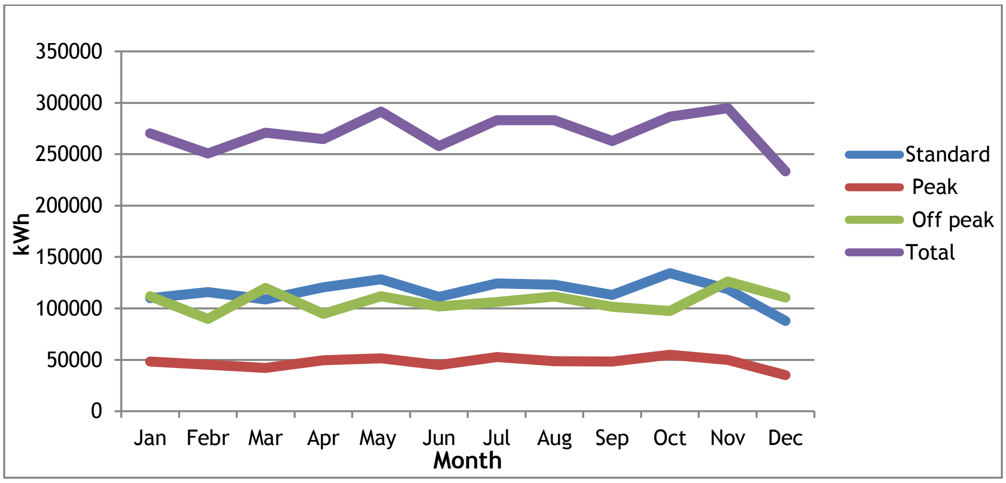

Figure 3: Electricity consumption profile

Active energy data for standard usage time, peak usage time and off peak time is shown in Figure 3. The galvaniser utilised a high percentages of both standard time and off-peak times and lower amounts of peak time. It was noted that plant loading during peak periods was lower than for off-peak periods, sitting at around 50 000 kWh per month. A key

recommendation would be to further schedule as much production as is feasible during off-peak times or standard times as energy usage for peak times are billed at a rate of almost double that of off-peak time usage. Peak, off-peak and standard energy usage were fairly constant over the year, albeit that a few peaks could be noted as production and factory usage fluctuated in some months. As shown in Figure 4, it was also noted that the notified maximum demand is far greater than the average monthly network demand consumption by the company.

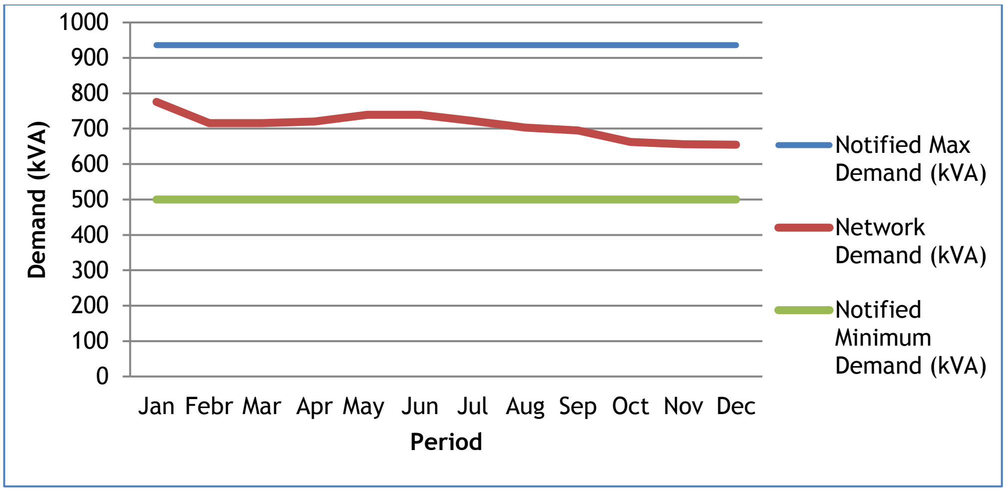

Figure 4: Monthly network demand versus notified demand

Figure 5 shows percentage contributions of the appliances for the consumption of electrical energy. It was revealed that the galvanising tank consumes the bulk of the energy, followed by the flux and degreasing tanks.

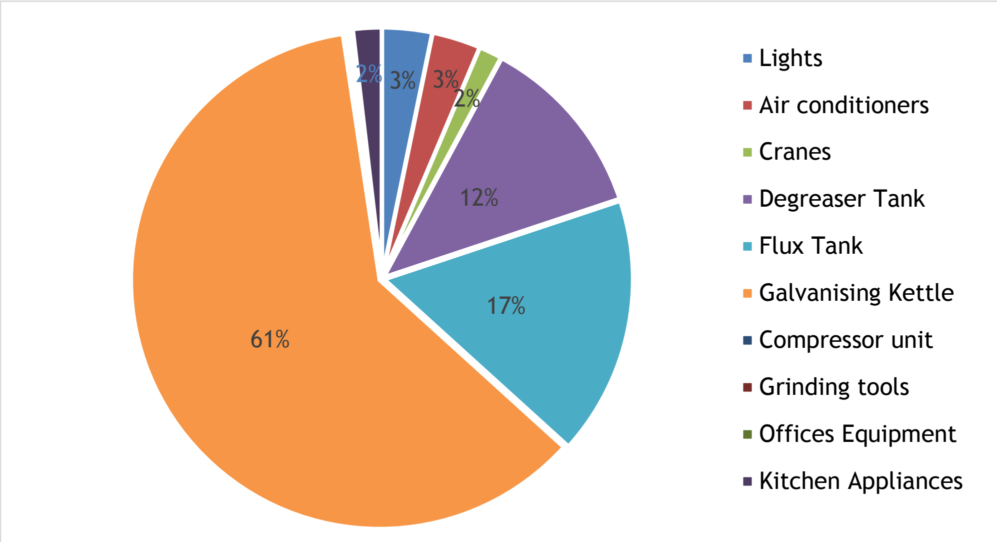

Figure 5: Pie chart for distribution of electrical energy consumption

Figure 6 shows the average current drawn by each of the heating zones and the spot temperature of the galvanising fluid surface. It is worth mentioning that only the side walls of the tank can be heated, not the bottom. Heat was lost from the tanks primarily through convection and evaporation from the surface of the liquid. The spot temperature at molten zinc surface was slightly less than the galvanising temperature since dross formation at the top act as a partially insulating blanket because of its lower thermal conductivity. Since the tank was not covered at the top, heat was lost over an area of 18.2 m^2 i.e. from 14 m x 1.3 m. This is equivalent to a 14 m horizontal bare pipe with a diameter of 41.3 cm. It was recommended to cover the tank during non-production hours to reduce surface losses. The rate of loss was dependent upon the differential temperature between the zinc fluid and the surface exposed to air movement.

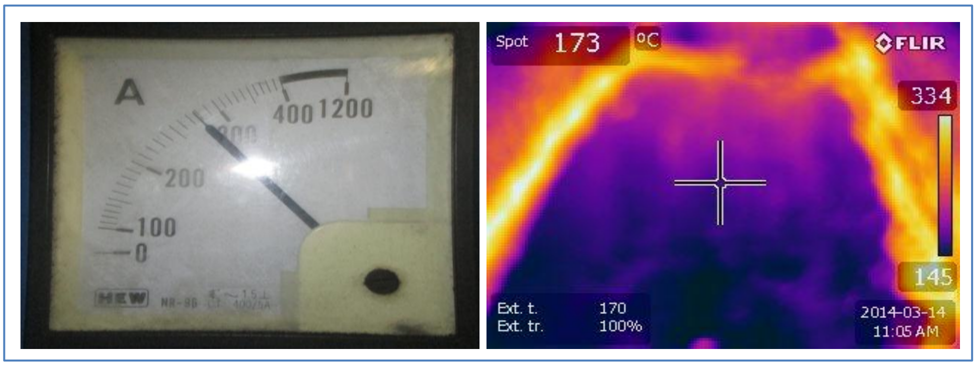

Figure 6: Current drawn by heating zones and the spot temperature at zinc surface

5.3 Evaluation of energy saving initiatives

5.3.1 Galvanising tank

An online calculator from CheCalc was used to compute the heat loss from the galvanising tank and estimate the saving that would be derived from insulating it [25].

Table 1: System parameters used to minimise heat loss on galvanising tank

Process Temperature	173^0C
Ambient Temperature	28^0C
Wind Speed	0.0 km/hr
Fuel Cost	R1.48
Efficiency	90%
Hours Per Year	4224
Nominal Pipe Size	400 mm diameter
Bare Metal	Steel
Bare Surface Emittance	0.8
Outer Jacket Material	All Service Jacket
Outer Surface Emittance	0.9

Using the previously stated calculator, the results from Table 2 show that covering with a 40 mm thick insulating material will prevent an estimated heat loss of the difference between 12640 kWh/m/yr and 998 kWh/m/yr thus saving R19143.64/m/yr. Given that the tank is 14 m long, and is idle about 50% of the time, 81494 kWh/yr i.e. from (11642 x 14 x 0.5) will be saved annual savings will be about R134 000. About 80.67 tonnes of CO_2 emissions will be avoided, i.e. from (81494 x 0.99/1000).

Table 2: Summary of the savings from variable insulation thickness

Variable Insulation Thickness (mm)	Cost (Rand/m/yr)	Heat Loss (kWh/m/yr)	Savings (Rand/m/yr)
Bare	20784.35	12640	
15.0	4274.99	2600	16509.36
25.0	2350.32	1429	18434.03
40.0	1640.71	998	19143.64

5.3.2 *Flux Tank*

The dimensions of the tank are 14 m x 1.3 m x 2.5 m and this 30 000-litre tank has no insulation on the side walls and no covers at the top. Since the tank is not covered at the top, and has no insulation on the side walls, heat is lost over an area of 94.7m^2 i.e. from (2 x 14 x 2.5 + 2 x 1.3 x 2.5 + 14 x 1.3). This is equivalent to a 14 m horizontal bare pipe with a diameter of 200 cm. Figure 7 shows the spot temperature for the side wall of the flux tank.

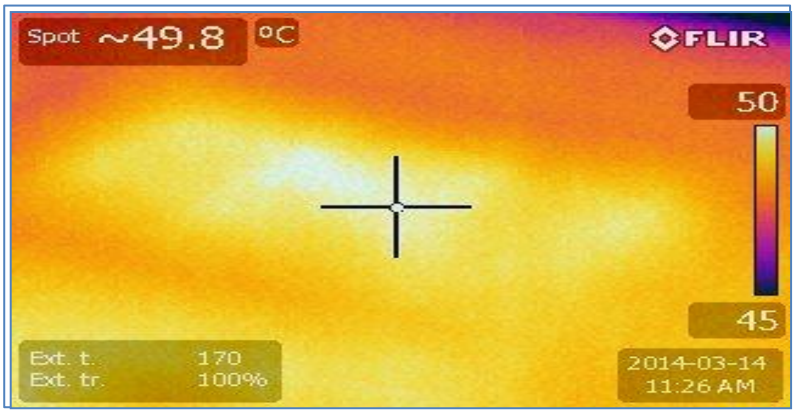

Figure 7: Spot temperature for the side wall of the flux tank

Using the CheCalc calculator, Table 3 shows the system parameters that were used to minimise heat loss on flux tank. Covering with a 40 mm thick insulating material will prevent an estimated heat loss of (2925 - 269) kWh/m/yr to give 2656 kWh/m/yr.

Table 3: System parameters used to minimise heat loss on flux tank

Process Temperature	49.8^{0}C
Ambient Temperature	30^{0}C
Wind Speed	0.0 km/hr
Electricity Cost	R1.48
Efficiency	80%
Hours Per Year	4224
Nominal Pipe Size	2000 mm diameter
Bare Metal	Steel
Bare Surface Emittance	0.8
Outer Jacket Material	All Service Jacket
Outer Surface Emittance	0.9

Given that the tank is 14 m long, and that part of the top will be open, of which its total surface area contributes about 25% of the total surface area, 27888 kWh/yr i.e. from (2656 x 14 x 0.75) will be saved. Annual savings will be about R68 787 and about 27.6 tonnes of CO_2 emissions will be avoided, i.e. from (27888 x 0.99/1000).Table 4 shows a summary of the savings from insulation layer which is 40 mm thick.

Table 4: Summary of savings from insulation of 40mm thickness

Variable Insulation Thickness	Cost (Rand/m/yr)	Heat Loss (kWh/m/yr)	Savings (Rand/m/yr)
Bare	5410.93	2925	
Layer 1 (40.0)	497.57	269	4913.36

5.3.3 Degreasing Tank

Figure 8 shows the spot temperature for the side wall of the degreasing tank. The dimensions of the tank are 14 m x 1.3 m x 2.5 m and this is equivalent to a 14 m horizontal bare pipe with a diameter of 200 cm.

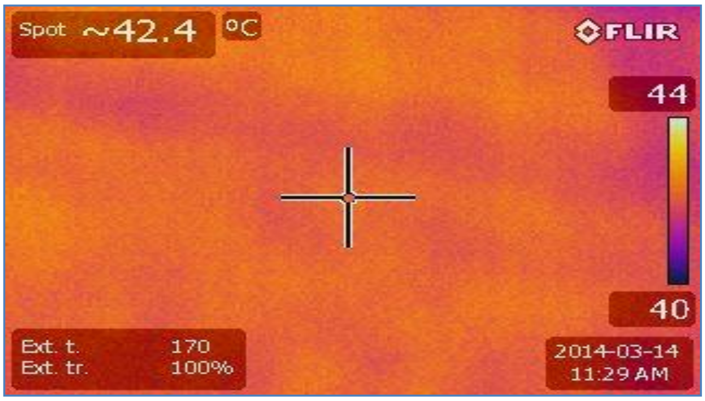

Figure 8: Spot temperature for the side wall of the degreasing tank

Using the previously stated calculator, covering with a 40 mm thick insulating material will prevent an estimated heat loss of (1698-166) kWh/m/yr thus saving R1750.87/m/yr. Given that the tank is 14 m long, and that part of the top will be open, of which its total surface area contributes about 25% of the total surface area, 16086 kWh/yr i.e. from (1532 x 14 x 0.75) will be saved. Annual savings will be about R39 694 and about 15.92 tonnes of CO_2 emissions will be avoided, i.e. from (16086 x 0.99/1000).

5.3.4 Geyser

The 200-litre geyser with its current manufacturer's insulation has a standing energy input of 4 kWh over 24 hrs irrespective of use because the hot water is maintained at the set point temperature. In order to calculate the total amount of energy dissipated by the geyser the heat losses in W/m^2 were multiplied by the surface area of the geyser, using the conductivity as 0.055 W/m.K and a surface heat temperature coefficient of 6.3 W/m^2.K. The ambient temperature was considered to be 25°C and the cost of electricity at R1.48 per kWh. This loss could be reduced by adding an external insulating blanket over the geyser. The analysis revealed that the insulating blanket would reduce the heat loss from the geyser by 3.2 kWh/day, resulting in a saving of 292 kWh/yr for the geyser. This cascades to saving

R432 per year and avoiding 0.289 tonnes of CO_2 emissions. i.e. from (292 x 0.99/1000). The additional insulation would cost R2 000, and thus simple payback period would be 4.6 years.

Alternately, a better solution will be retrofitting the geyser with an instant water heater. This heater has an in-line water heater utilizing electrically conductive polymer structures for electrodes and by varying the area of electrodes that confront one another would yield variable temperatures to which the water is heated. The heat is by the resistance of the water to the electrical current flowing between the electrodes [26]. Their advantages include better energy efficiency, minimised space utilisation and longer life expectancy. The efficiency of tank-less hot water heaters range from 85 to 97% as opposed to conventional tank-style hot water heater systems which are characterised by efficiencies of less than 70%.

After observation for a period of month, the time taken to heat the water from using the 4 kW element was 1 hour. A day heating profile therefore consisted of eight 1 hour intervals. One can consider retrofitting the present 4 kW geyser with a 7kW instant water heater with a flow rates ranging from 1 to 6 litres per minutes and save ((4 kWh x 8h) – (7 kWh x 3 h), i.e. 11 kWh per day or 2640 kWh per year if we consider 20 working days per month. The resultant saving would be equivalent to R3 900. A 7kW instant water heater costs about R3 000 and installation costs about R2 000 to give R5 000, and simple payback period would be 1.2 years.

5.3.5 Summary for estimated energy and cost savings

Table 5 shows a summary for estimated energy and cost savings from energy minimisation options. It reveals that covering galvanising kettle would yield huge energy savings followed by insulation of the flux tank. Further insulation of the geyser does not realise much energy saving. A total of 125 760 kWh of electricity at an estimated cost R242 913 would be saved by implementing the stated four energy minimisation opportunities.

Table 5: Summary for estimated energy and cost savings

Energy Minimisation Opportunities	Estimated Savings (kWh/Annum)	Estimated Savings (Rand/ Annum)	Investment (Rands)	Estimated CO_2 emissions avoided (Tons/yr)	Simple Payback Period
Covering galvanising kettle	81 494	134 000	100 000	80.67	0.7
Insulation of flux tank	27 888	68 787	80 000	27.6	1.2
Insulation of degreasing tank	16 086	39 694	80 000	15.92	2.0
Insulation of geyser	292	432	2 000	0.289	4.6
Retrofitting with instant water heater	2640	3900	5000	2.61	1.3
Total	125 760	242913	267000	124	

5.3.6 Scheduling Production Dips

Scheduling influences the energy consumption behaviour of the whole system, and by integrating energy efficiency criteria into scheduling, a reduction of energy costs may be realised. It was noted that about 50% of the dips utilised about half the full length of the galvanising tank. Figure 9 shows a galvanised product coming out of a dip, of which the product uses less than half the size of the galvanising tank.

Figure 9: Galvanised product coming out of a dip

It was advised to schedule dips for the long products in batches separate from shorter products to reduce to labour cost of covering and uncovering the tanks between dips. The energy saving to be derived are aligned to the covering of the galvanising, flux and degreasing tanks. The aspect of developing scheduling a scheduling algorithm with the view to save energy is a potential area for future research.

6. CONCLUSION

The aim of this paper was to evaluate the electrical energy consumption by a hot-dip galvanising plant and the evaluation assisted the galvaniser to quantify its significant energy users. The estimated savings which arise from the energy savings initiatives lie at around 125 760 kWh per annum and the payback periods range from 0.7 to 4.6 years. The results from the paper also assisted the galvaniser to identify potential opportunities for reduction and more efficient use of energy within the plant. It is recommended that management should run an appreciation course on energy efficiency for all the employee since the survey conducted revealed that there is no energy policy in the company. It is also recommended to cover the galvanising tank in between dips, insulate the fluxing and degreasing tanks as well as the geyser. Although lights were not consuming a substantial amount of electricity, retrofitting the administration block would also reduce electricity consumption at the company by a small magnitude. Future work in this area will embrace development of algorithms for optimal schedules to save energy in these non-continuous galvanising plants. It was also noted that it may be difficult to assess the reliability of an online calculator, and thus it is recommended to develop energy models using tools such as Microsoft Excel or MATLAB where the researcher can have full control of the modeling parameters.

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A PROPOSED MODEL FOR SOUTH AFRICA TO EFFECTIVELY RECYCLE AND DISPOSE WASTE ELECTRICAL AND ELECTRONIC EQUIPMENT

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ABSTRACT

In South Africa there are daily occurrences of dumping of Waste Electrical and Electronic Equipment (WEEE), also called e-waste, at municipal refuse sites. WEEE is hazardous and comes from households and businesses and these unhealthy and unsafe practices can lead to permanent damage of the soil and water resources of areas. It can cause humans and animals to acquire different kinds of cancers and illnesses which could ultimately lead to deaths. WEEE contains valuable materials that can be recycled and there is thus loss of potential extraction of these valuable materials. South Africa has a limited WEEE infrastructure to collect, refurbish, recycle, and disposal capabilities to handle e-waste and need a management model to address WEEE effectively.

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1. INTRODUCTION

The retirement stage of any product, namely decommissioning and disposal, is of vital importance due to the increased awareness of environmental issues all around the world [1]. WEEE contains valuable materials and there is thus an opportunity for extraction of valuable materials. South African legislation regulating WEEE is vague and not specific causing confusion, hazardous practices, and minimal disposal and recycling. A country's infrastructure, geography, legislation, social challenges, individual knowledge, etc. are drivers that necessitate a "custom made" model to dispose of e-waste effectively. There is a need for a model that suits the unique circumstances of the South African environment and a model to address the effective recycling and disposal issues will be proposed in this paper.

According to [2], South Africa is a signatory to the Basel Convention, an international **treaty** designed to reduce the movements of hazardous waste between nations. It is stated in [3] that South Africa is not a signatory to the Bamako convention which implies that South Africa can import e-waste legally. In [4] it is stated that in South Africa"…only a fraction of the discarded EEE (estimated 10%) finds its way to recyclers." Authors [5] estimate that South Africa generates around 100,000 tons of e-waste annually of which only 20% is recycled by formal recyclers. Figures from [5] also indicate that that the South African average e-waste recycling is around 0.39 kg per capita per year, far below European countries. It is estimated by [6] that South African households have between 1,129,000 and 2,108,000 tons of potential e-waste which includes white goods, consumer electronics and IT. It is also estimated that around 70% of South Africa's e-waste is in storage [7].

2. IMPORTANCE OF MANAGING E-WASTE EFFECTIVELY

In a study conducted by [8] a mathematical calculation concluded that the best methods for treating e-waste are *reuse* and *recycling*. A summary by [4] indicate that e-waste is an emerging problem as well as a business opportunity due to the value of materials. E-waste components are diverse and some are classified as "hazardous" because they go beyond the threshold quantities mentioned in the Material Safety Data Sheet (MSDS) [9]. The environmental and health effects such as asthmatic bronchitis and other allergic reactions, DNA damage, abdominal cramps, vomiting, diarrhea, nausea, decreased red and white blood cell production, abnormal heart rhythm, difficulties in breathing, increased or decreased blood pressure, numbness around the face, muscle weakness, and paralysis are highlighted by [10]. Some of the substances are known human carcinogens causing cancer and possibly death. Chlorofluorocarbons (CFC's) used in refrigeration equipment also causes stratospheric ozone depletion and global warming [11].

3. METHODOLOGY

For <u>this</u> paper the following methodologies were implemented: The researcher did a literature review of e-waste practices in different countries. This included collection initiatives, recycling practices, legislation, extended producer responsibility, financing of e-waste, etc. The scenarios in South Africa were also investigated through a literature review. The researcher visited European recycling facilities and also visited South African entities such as municipal refuse sites, e-waste recyclers, government officials, environmentalists, etc. Observations were made at the different sites and informal discussions contributed to the development of a proposed e-waste management model as is discussed further in this paper. This proposed model is a first draft and will be adjusted where needed after scientific research data has been collected. The methodologies that will be implemented to collect the future data are: <u>Quantitative data</u> will be collected from South African <u>*consumers*</u> by using a survey questionnaire. <u>Qualitative data</u> will be collected from <u>*producers*</u>, <u>*retailers*</u>, <u>*recyclers*</u>, <u>*municipal refuse*</u> managers, <u>*government*</u> officials and <u>*environmentalists*</u>. Semi structured interviews will be conducted with knowledgeable representatives at these entities. The data will be analysed and a <u>final</u> e-waste management model will be proposed together with proposed legislation for South Africa.

4. GENERIC E-WASTE MANAGEMENT FRAMEWORK

This paper will continue the discussion under the following headings:

- Mechanisms to co-ordinate and drive the management processes
- Legislation
- Collection arrangements of e-waste
- Financing models for recycling e-waste

The framework will be expanded and discussed to highlight the important e-waste management points and to pave the way for a South African framework.

4.1 Mechanisms to co-ordinate and drive the management processes

Basic drivers-The conclusion from the literature is that different European countries have different levels of success with e-waste collection rates ranging from just above 1 kg/capita/year to 3.75 kg/capita (Switzerland) collected per year [12]. Switzerland is a world leader in effective e-waste but [13] states that although a system appears to be successful in some country the success of one system does not necessarily indicate success in another country due to different cultures, attitudes, social problems and behaviors, economic drivers, etc.
EXTENDED PRODUCER RESPONSIBILITY-Extended Producer Responsibility (EPR) is a strategy widely used around the world. EPR as a policy strategy was proposed by Thomas Lindhqvist and introduced in 1990 [14]. EPR is defined as an "environmental protection strategy to reach an environmental objective of a decreased total environmental impact from a product, by making the manufacturer of the product responsible for the entire life-cycle of the product and especially for the take-back, recycling and final disposal of the product. EPR is implemented through administrative, economic and informative instruments. The composition of these instruments determines the precise form of the Extended Producer Responsibility." [14]. According to [15] policies on EPR had been introduced in European countries to achieve waste minimization.
EPR in South Africa-The ultimate responsibility of e-waste management must lie with the producers as it is the view of the researcher that the SA government should have the role as overseer and enforcer of legal action and that the SA government do not have the capacity, capabilities, or the knowledge to ensure the effective operation of a system of this magnitude. The Waste Act, [16], entered into force on 1 July 2009 and required the Minister of environmental affairs to draft a National Waste Management Strategy. The Framework for the National Waste Management Strategy specifically mentioned e-waste, and stated that it "should be prioritized for further investigation and implementation for extended producer responsibility". In [2] it is stated "The responsibility of processing of e-waste in South Africa is not under the Extended Producer Responsibility (EPR) as what is now a practice in Europe." The ***goal*** of EPR in South Africa should be on waste prevention (pollution reducing and preventing).

STAKEHOLDER RESPONSIBILITY-According to [17] the Japanese law on WEEE clearly stipulates the roles of each participant in the e-waste recycling chain. The Environmental Protection Administration of Taiwan (EPAT) created the 4-in-1 recycling program which consisted of community residents, private collectors and recyclers, municipal collection teams, and a recycling fund [18]. In [13] it is shown that in South Korea the EPR law came in effect in 2003 and local manufacturers, distributors and importers of consumer goods such as air conditioners, TVs and PCs are required to achieve official recycling targets or face financial consequences. Stakeholders are thus identified in WEEE management programs.
Stakeholder responsibility in South Africa-A statement by [6] declares "a practical e-waste management solution which has the buy-in of all stakeholders" is needed.

SYSTEMS COVERAGE AND ENSURING COMPLIANCE-In [19] it is indicated that countries such as Belgium, the Netherlands, Sweden, Norway, and Switzerland had some form of legislation on e-waste even before the implementation of the WEEE Directive and made use of a Single National Compliance system covering all WEEE types. In a report [19] it is shown that at the time there were 76 compliance schemes in EU countries. In South Africa there is no systems coverage in place where e-waste is concerned. Compliance of effective recycling can thus not be ensured.

REGISTRY-Producers are defined on European, national and local levels due to the fact that sometimes manufacturers are or are not in the EU and producers could be wholesalers, distributors, retailers etc. depending on their status and position in the retailing chain [19]. In [2] it is suggested that "A single Registry would need to be set up and funded by producers". At present no registry exists in South Africa.

4.2 Legislation

In a research survey conducted by [20] it was concluded that industrialists and academics perceived legislation to have the biggest industrial influence when designing environmentally conscious products. In a focus group study [21] point out that from the literature, legal and economic drivers have been identified as the strongest drivers.

Some Asian countries-It is pointed out in [4] that the Japanese Specified Home Appliances Recycling Act 1998 was published in 1998 and came into effect in April 2001. The act covers only TVs, refrigerators, washing machines and air conditioners and recycling is the responsibility of producers. A report [22] warns that India has tried to implement e-waste legislation without success. The Chinese WEEE legislation measures taken were summarized by [23] as well as some successes after implementation. In [24] mention is made that Indonesia has no regulation for managing the e-waste generated at homes. The Act on the Promotion of Saving and Recycling of Resources (APSRR) which regulates four types of home appliances in South Korea is mentioned in [25]. Personal computers were added to the program in 2003 followed by mobile phones and audio equipment (2005), and printers, copying machines and fax machines (2006). APSRR was replaced in 2008 with a new system called the Eco-Assurance System or EcoAS [25]. According to [18], Taiwan has EPAT that regulates and ensures effective recycling of e-waste. According to Article 18 of the Waste Disposal Act, WEEE collection, storage and recycling must follow EPAT's environmental and safety standards. These standards were issued in 2002 and revised in 2007 [18].

Europe-Legally, e-waste management was introduced in 1998 by the Swiss Federal Office for the Environment (FOEN), by way of the Ordinance on "The Return, the Taking Back and the Disposal of Electrical and Electronic Equipment (ORDEE)" [26]. Directives were drafted in Europe which required an environmental approach to all designs. The first one was the RoHS Directive 2002/95/EC. The second important directive is called the WEEE Directive 2002/96/EC and this directive (European Union, 2003b) requires producers in the EU member states to take back their products and dispose them using environmentally sound methods. A new Directive (2012/19/EU) requires the member states to achieve the collection rate of 45% by weight of weight of EEE put on the market in the three preceding years by 2016 [25].

America-Legislative activity in the US has rapidly increased [27]. According to [25], although no national law exists in North America, states, provinces and cities have implemented various measures to address the WEEE problem. According to [28] 25 states in the USA have some form of recycling program.

Developing countries-The 1989 Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal (into force on 5 May 1992) is an international initiative to prevent the dumping of hazardous materials in developing countries, [29]. America is the only industrialized country in the world that is not a signatory to this convention [4]. To address shortcomings in the Basel Convention, African countries created the Bamako Convention for complete banning of hazardous substances such as e-waste. Referring to the Bamako convention [3] states that "these instruments share the common goal of controlling the movement of hazardous wastes across national borders". The key issues of effective management of e-waste in developing countries are a change in attitude by governments, WEEE legislation, control of WEEE dumping, implementation of EPR, and the transfer of technology on sound recycling of e-waste [30]. A comment is made by [28], "There is currently no country in Latin America with a comprehensive e-waste management system".

Legislation in South Africa-In 2007 (Updated in 2009) a report was compiled and released by Dittke, an attorney from Cape Town, to review the e-waste legislation in South Africa. The report stated that "Unlike many other countries, South Africa currently does not have any dedicated legislation dealing with e-waste. As such a whole range of environmental, as well as health and safety, laws must be examined to provide answers. Such investigation will have to cover national, provincial and local legislation. Needless to say, this is an arduous and unsatisfactory situation, and certainly does not help to clarify matters", [31]. In [16] it is stated that mandatory Industry Waste Management Plans (lndWMPs) must be prepared for the lighting industry for mercury containing lamps e.g. compact fluorescent lamps (CFL's). It also states that "Over the course of the next five years, lndWMP's will be required for different forms of e-waste and batteries, and other waste streams that are best managed through an lndWMP." Towards the end of 2013 a news release on the eWaste association of South Africa (eWasa) website stated: "As you may be aware e-waste has not been deemed a priority in terms of the waste act, therefore it was not mandatory for the sector to submit Industry Waste Management plans."

4.3 Collection arrangements of e-waste

Composition of e-waste-The Directive 2002/96/EC of the European Parliament and of the Council (January 2003) on Waste Electrical and Electronic Equipment (EU, 2002a) defined ten categories of WEEE.

Composition of South African e-waste-A claim is made by [2] that the e-waste recycling systems are not uniform and sustainable solutions for materials such as CRT tubes, brominated plastics and printed circuit boards, have not yet been found.

Collection, number of collection points and efficiency of collection-In table 1 some countries with known collection points and recycling rate numbers per year are analyzed. For Norway and The Netherlands the first recycling rate per year could only be obtained for 2010 and it is assumed that the collection points did not change significantly. When analyzing the figures for the 4 countries (Ireland excluded) a coefficient of correlation of 0.75 was calculated if a comparison is made between the collection points and the total weight of WEEE being collected per year, indicating a very strong relationship.

Table 1: Collection points and recycling data per country

Country	Collection Points (All)	Recycle rate per year (Kg/p/y)	Population in millions	Persons/ collection point	Total weight in Kg per year
Norway (2003)	400	13.41	4.5	11250	60345
The Netherlands (2003)	600	7.5	16	26667	120000

Spain (2007)	600	3.3	44.5	74167	146850
Ireland (2007)	740	6.7	4.313	5828	28897
Sweden(2006)	950	15.8	9.113	9593	143985

In calculating the coefficient of correlation of the recycling rate per person per year compared to the persons per collection point (PCP) in a country the figure is -0.70, indicating that if more collection points are available in a geographic area, the collection rate would increase. By including the four countries (Ireland excluded) in Table 1 a coefficient of correlation of 0.72 is obtained if the collection point numbers and the population of a country are analyzed. Although collection point numbers will not be only the determining factor of collection rate success, the number of collection points should play an important factor in collection efficiency.

Figure 1 shows the number of inhabitants per collection point on the Y axis and the collection in kg per inhabitant on the X axis. From the figure and the curve it can be derived that the less persons there are per collection point, meaning more collection points per persons, the better the collection rate will be. Spain has the least collection points per inhabitants and this is reflected in the collection return rate. From the key figures report released by [32] the data shows that all of the countries mentioned in Table 1 have increased the collection return rate except for Spain that shows a lower number of 2.91 kg/person collected in 2012 as compared to the rate of 3.3 kg/person being collected in 2007 [32]. The fewer collection points compared to the other mentioned countries could be a contributing factor.

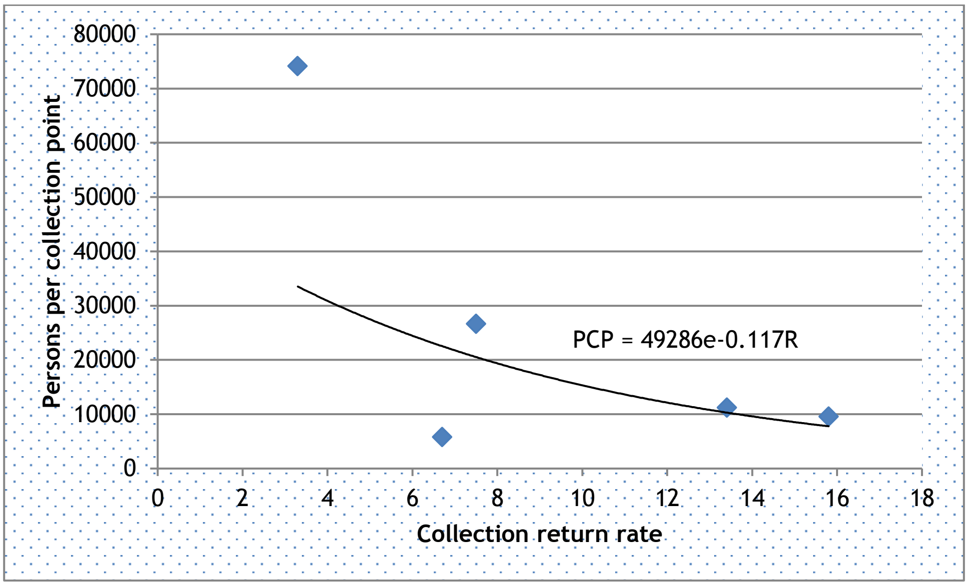

Figure 1: Collection rate versus persons per collection point

Collection and number of collection points in South Africa-South Africa has approximately 51 million people [33]. Mention is made in [2] of some collection points but no exact figure is available. The same document lists a number of E-Waste consumer programs and drop-of points available in South Africa whereby the consumer can dispose of E-Waste responsibly. The researcher has found that some of the mentioned collection points are not collecting WEEE anymore (Pickitup) and that some do not know of collection initiatives (Builders Warehouse). Stores such as Pick and Pay and Woolworths only collect batteries, CFL's and printer cartridges.

4.4 Financing models for recycling e-waste

Mention is made by [19] that even with the EU directives which indicate that producers must finance the costs of waste management there are different interpretations and promulgated legislation on the financing of new WEEE after 13 August 2005. Five financing mechanisms are described by [19] but the authors also state "the examples provided here are not an exhaustive list of possible models used for EPR programs". In Japan the recycling fee and fund is managed by the Association for Electric Home Appliances (AEHA), [34]. It is the opinion of [17] that the majority of Japanese consumers disposes e-waste properly but is concerned that the recycling fee at disposal "may stimulate illegal dumping". The South African environment does not have any financial model to assist with e-waste recycling and the focus of recyclers is mainly on the WEEE which is profitable when recycled.

5. WEEE DESIGN AND TREATMENT SYSTEMS

Since the realization of the hazardous nature of WEEE new measures were introduced in countries, especially in Asian and European countries to reduce the negative effect. Mentions were made of ROHS and design for environment (DfE) as measures to lessen the effects on the environment. In [18] it is explained that in Taiwan the recycling technologies for WEEE were developed using techniques from developed countries. As in many countries, WEEE recyclers in Taiwan focus on dismantling. It is the opinion of [17] that WEEE containing hazardous substances must be managed by accredited recycling plants in Japan. The results of previous research is used by [35] to indicate that vast quantities of e-waste are now being moved around the world for recycling in developing countries using manual processes in backyards of residential properties. South Africa is mentioned as one of the counties.
Where WEEE design and treatment systems for South Africa are concerned problematic practices associated with the environmental protection in South Africa are highlighted by [6]. Examples are one out of ten refurbishers and recyclers were ISO 14001 compliant, ozone-depleting practices, lack of disposal knowledge, etc. The same authors also highlight a key concern in the South African market as the potential threat of backyard electrochemical processes being set up.

6. PROPOSED COLLECTION ARRANGEMENT FOR SOUTH AFRICA

6.1 Suggested collection point numbers for South Africa

Statistical numbers suggest that the more the collection points, the better the success rate will be. The statistical website, [36], was accessed to determine the ten biggest city population figures in South Africa. From figure 1, using the formula $PCP = 49286e^{-0.117R}$ where R indicate the collection return rate in kg/person (assume 4kg/person), it can be calculated that a collection point must be set up for every 30865 persons. For Johannesburg (4434827), Cape Town (3740026), Tshwane (2921488) and EThekwini (Durban) (3442361) the collection points are calculated as 144, 121, 95, and 112 respectively. In the Tshwane metropolitan area the landfill sites and garden refuse transfer sites are 18 [37]. Potential retailers selling EEE are: 13 Pick and Pay stores [38], 9 Builders Warehouse stores [39], 23 Checkers and Checkers Hyper stores [40], 12 Shoprite stores [41], 3 Hi-Fi Corporation stores [42], 4 Deon Wired stores [43], 8 Game stores [44], and 21 Super Spar stores [45]. The minimum stores that can be used as collection points for the Tshwane Metropolitan area are thus 111 and the suggested 95 collection points are possible and achievable.

6.2 Collection point placement

It is proposed that collection initiatives are done at:

- EEE Retailers- Collect similar WEEE of EEE type being sold in the store.
- Public collection points-Municipal refuse sites and garden refuse sites.
- Free Call to collect-Set up in cities and bigger towns to collect large WEEE.
- Containers at apartments-To collect WEEE from tenants.
- Public collection boxes-To collect small WEEE from shops selling EEE.
- Special drop-off events- Bi-annually in rural areas and small towns.
- Corporate collection points (Not for large WEEE)-Hundred or more employees.

6.3 South African collection infrastructure

It is proposed that it must be in three groups, namely: 1-CRT's, 2-all lamps, and 3-any other WEEE. Collection sites must have impermeable surfaces and must have weatherproof covering.

6.4 Voluntary or mandatory program for South Africa

A mandatory system is proposed. Producers have had many years of experience in other countries but have done little to start an effective e-waste management program.

6.5 Take-back requirements in the South African environment

All retailers of EEE should accept any similar WEEE irrespective if a customer buys a new product or not. All retailers selling EEE must accept WEEE with dimensions smaller than 30 cm^3 without any obligation. Large enough shopping malls (> 50 000 m^2) with more than 10% of retailers selling EEE must set up a manned WEEE collection point.

7. ECONOMIC INSTRUMENTS TO FUND AN EPR PROGRAM IN SOUTH AFRICA

The "polluter pays principle", should apply and the South African consumer of EEE should pay for the recycling of WEEE. Currently no disposal fee is levied on any South African EEE item. It is proposed that an advance disposal fees (ADF) is levied on the sale of new EEE products to cover costs that arise from the implementing and administering of an EPR program. It is also proposed that an ADF fees should be levied on imported second hand items. The ADF fee structure must be an uncomplicated system to prevent confusion.

8. THE PRODUCER RESPONSIBILITY ORGANISATIONS (PRO) IN SOUTH AFRICA

The researcher proposes three different PRO's. The *first* is for household appliances and electrical tools, excluding cooling appliances. The *second* is for information technology, telecommunications equipment and consumer equipment. The *third* one is for problematic equipment such as CRT, LED, LCD, cooling equipment, batteries, and different types of lighting equipment. From [46] the "Product structure" is proposed for PRO1, PRO2, and PRO3.

8.1 Detail setup of proposed PRO 1

PRO 1 for ***household appliances and electrical tools***, excluding cooling appliances.

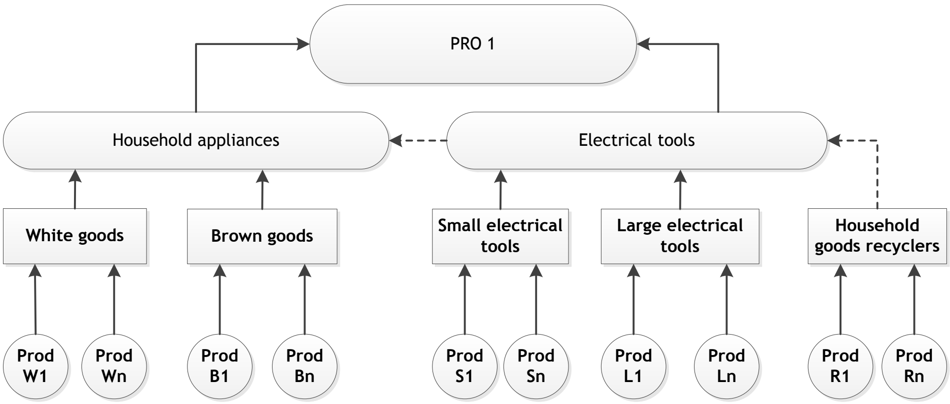

Figure 2: Proposed PRO 1 model

In figure 2 the proposed setup of PRO 1 should mainly focus to extract metals, aluminium, plastics, copper, glass, etc. as this equipment contains a minimum of electronic control parts/boards.

8.2 Detail setup of proposed PRO 2

It is proposed that PRO 2 should be for ***information technology***, ***telecommunications equipment and consumer equipment.***

In figure 3 the proposed setup of PRO 2 should focus on information technology (PC's, notebooks, printers, etc.), telecommunication (cell phones, telephones, answering machines, etc.), and consumer equipment (Video recorders, smoke detectors, electric toys, video games, etc.). The suggested grouping is due to the high content PC boards in the equipment.

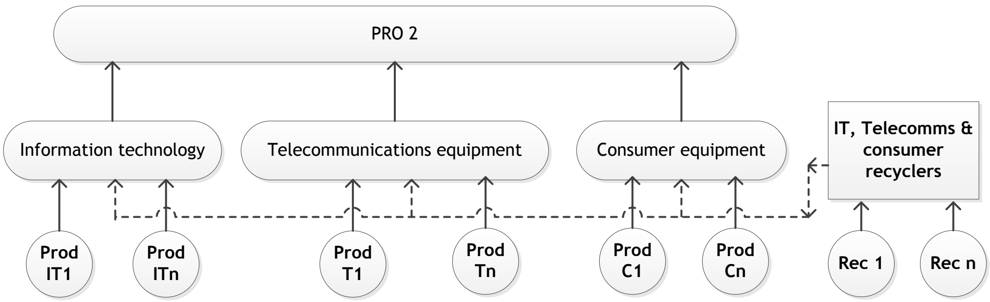

Figure 3: Proposed PRO 2 model

8.3 Detail setup of proposed PRO 3

PRO 3 should be for ***problematic equipment***. Problematic equipment are televisions and monitors such as CRT, LED, LCD, plasma etc., all types of cooling equipment using refrigerants as the cooling medium, all types of batteries, and all different types of lighting equipment used by consumers.

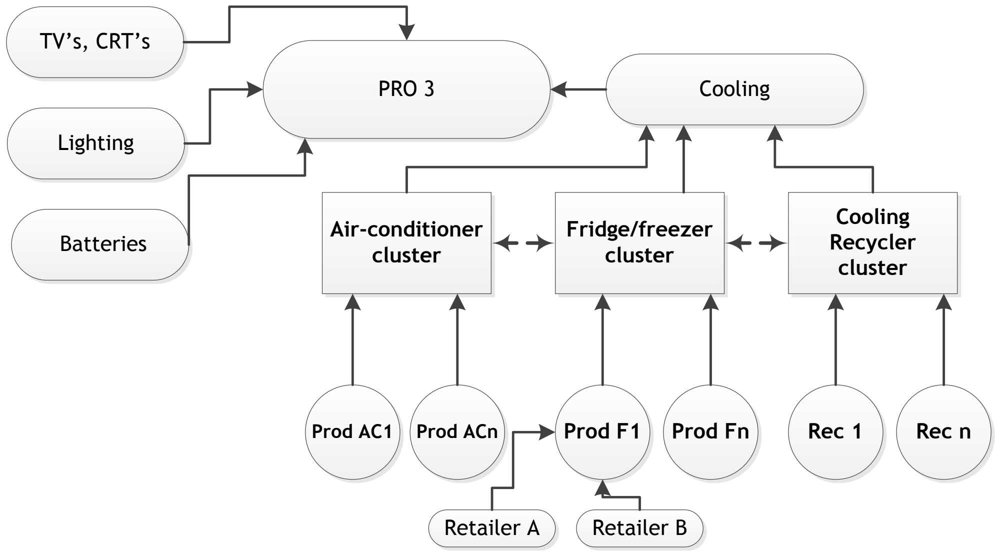

Figure 4: Proposed PRO 3 model

In figure 4 each cluster will consist of producers of the same type of EEE being produced or imported. The products in this case have different applications, but generally they have the same properties. The producer clusters have the best knowledge on recycling of their products and communication from producers to recyclers and retailers (on recycling, handling and storage) is of extreme importance and is indicated by the broken line.

8.4 PRO's and other stakeholders

In the entire proposed PRO models the following stakeholders need to be part of the group: Producers, retailers, recyclers, public representatives such as political party representatives, environmentalists, and government representatives.

9. THE PROPOSED MANAGEMENT BODY

The proposed name of the entity that will manage the WEEE process in South Africa is the South African Waste Electrical and Electronic Equipment Association (SAWEEEA). From [46] the "Functional structure" is proposed for the management body.

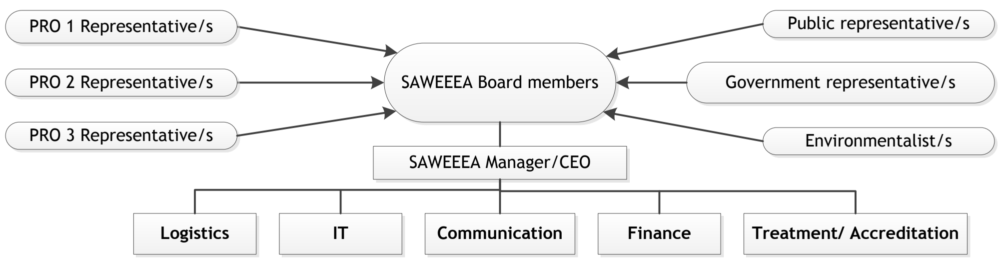

Figure 5: Proposed SAWEEEA management model

9.1 Composition and tasks of SAWEEEA

Figure 5 shows the proposed structure for SAWEEEA which consist of a board of members which are representing and selected by the three PRO's. To prevent corruptive actions no employee of SAWEEEA must have any links to stakeholders which can cause undue influence in the operation of managing the WEEE in South Africa. SAWEEEA should be registered as a non-profit Section 21 company or similar.

9.2 Function of the five groupings under the SAWEEEA CEO

9.2.1 Logistics

This department should be involved in contracts for transporting of WEEE, monitoring of the operation of the auction houses (to be described in section 12), collection of WEEE, ensuring safe practices are applied at collection points, compile statistics (weights collected and of fractions), SAWEEEA infrastructure maintenance and setup, setting up of non-existing recycling facilities, setting up of an administrative system at collection points, etc.

9.2.2 Information Technology

This department should be involved in the design and setting up of a website for SAWEEEA in order to have retailers to report ADF amounts received, to have producers reporting ADF amounts and sales, maintain and upgrade the website, link to auction houses, implementing links on municipal websites, implementing links on government websites, and maintaining all SAWEEEA information technology networks.

9.2.3 Communication

This department should be involved in informing the public of the hazardous nature of WEEE, making the public aware of collection points and initiatives, implementing educational material on WEEE in school programs, provide feedback to stakeholders on the EPR program, communicate the applicable ADF fees to stakeholders, etc.

9.2.4 Finances

The financial department of the SAWEEEA team must be involved in determining the ADF fee in co-operation with all three PRO's, receiving and comparing the ADF fee from producers and retailers, compensate recyclers of negative value items, compensate transport contractors, finance the setting up of collection facilities, finance the setting up of non-existing recycling facilities, payment of salaries of SAWEEEA employees, payment of operational expenses, payment for auditing of entities, etc.

9.2.5 Treatment/Accreditation

This department should issue and retract licenses to recycling facilities, assist in setting up of recycling facilities, audit recycled materials to prevent dumping, implement and upkeep the registry, ensure imported goods are RoHs compliant, etc.

9.3 EEE, ADF and ADF information flow

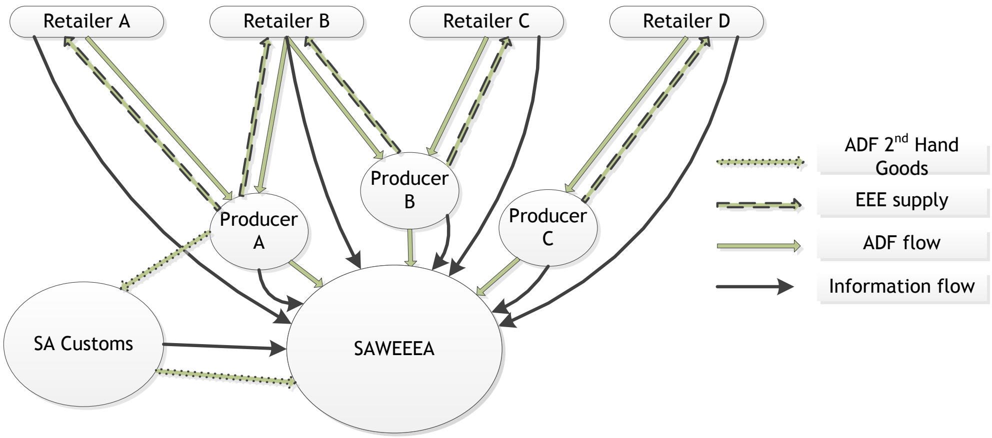

Figure 6: EEE, ADF and ADF information flow in proposed model

Figure 6 depicts the suggested flow of new EEE, the ADF fee, and ADF information flow. New EEE items are sold by producers to retailers. Producers can supply more than one retailer as indicated. The ADF on an EEE item is paid at the point of sale and received by the retailer. The ADF fee collected by the retailer must be paid to the producer/supplier of the item. Payment to the producer/supplier will thus become part of the transaction payment where the ADF fee will be additionally highlighted on the settling documentation. Producers should then transfer the ADF fees to the financial department of SAWEEEA. Retailers should record the ADF amounts received by consumers for specific items, and indicate from which producer the products were. Retailers should also provide this detail to SAWEEEA on a monthly basis as part of information flow. There will thus be a correlation between producers and retailers about ADF amounts received for recycling as well as detail information on the number of items and weight placed on the market. The customs department must also report figures to SAWEEEA on a regular basis. Information that must be supplied include number and dates of items that entered the customs points, the ADF fee received from producers/recyclers for second hand imported goods, and the payment of the ADF fee to SAWEEEA. In figure 6 Producer A represents an importer of second-hand EEE and an importer/manufacturer of new EEE. With all three entities reporting independently to SAWEEEA, fraud and free riding will be minimized due to the audit trail availability.

9.4 ADF and information flow for imported WEEE

South Africa is allowed to import e-waste. It is proposed that a SAWEEEA official must inspect the WEEE upon arrival. If there is uncertainty about the status (WEEE or second hand EEE) the SAWEEEA official must determine the ADF amount for EEE and payment must be done to SAWEEEA before the release of the containers at the ports or border posts. If the shipment is WEEE, a SAWEEEA official (same or another) should inspect the shipment at the recycler premises to ensure that the shipment is

WEEE. The difference between the ADF fee received and the cost to inspect the imported shipment must then be refunded to the recycler.

9.5 Financial (ADF) flow diagram

In figure 6 it has been shown that the ADF that was received from the customers, by the retailers, must be paid to producers which must again pay the ADF to SAWEEEA. In figure 7 below, the further proposed flow of the ADF fees is shown.
In Figure 7 the SAWEEEA head office is a single entity linking to an Auction house. In practice, more than one Auction house will be linked to SAWEEEA. ADF fees collected from the respective producers will be applied as shown in figure 7

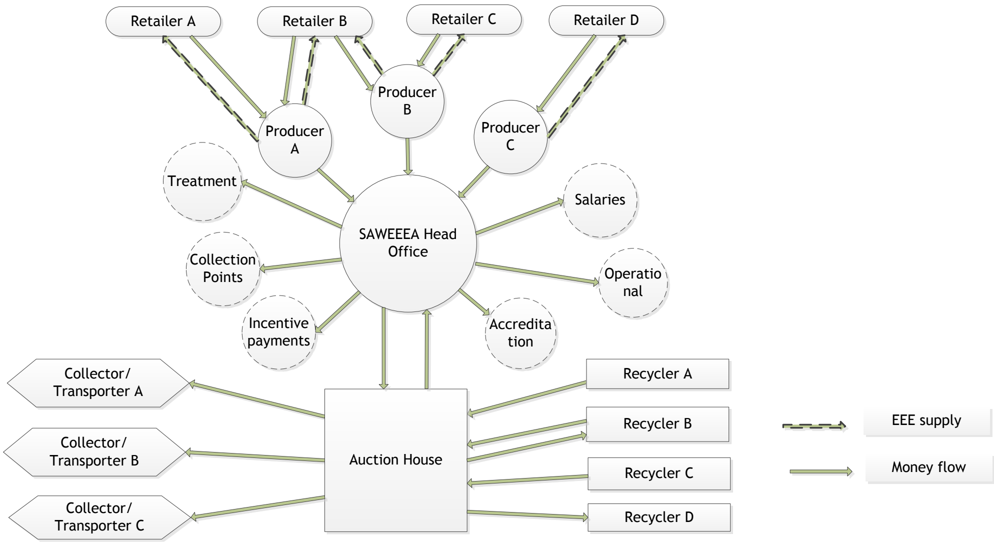

Figure 7: Financial (ADF) flow diagram

9.6 ADF and information flow for second hand EEE goods

Importers of second hand goods will have to pay exactly the same ADF fee as producers of new EEE. As in the case of imported WEEE, a SAWEEEA official should also inspect the shipment and determine the ADF before the items can be released. The costs involved with this inspection must be paid by the importer on top of the ADF amount.

9.7 Setup costs for the proposes model

With the introduction of laws that demand an ADF fee from consumers for recycling it should not be difficult to fund the expenses. The ADF fee will need to be introduced from a specified date after which the setup of Auction houses, collection points, SAWEEEA main office, etc. will commence. The physical collection, transportation, auctioning and recycling will thus follow at a later stage. With the introduction of the ADF fee, private or government loans could be secured to fund the setting up of the entire system.

10. PERFORMANCE STANDARDS – SETTING TARGETS IN SOUTH AFRICA FOR RE-USE, REFURBISH AND RECYCLING OF WEEE

If possible the life of consumable items must be extended through re-use. Refilling a printer cartridge is an example of re-usable consumable items. The refurbishment of equipment is a lucrative and live sector and there is no need to set standards in this sector. For recycling, no targets will be proposed as this is a consultation process between all stakeholders.

11. THE ROLE OF THE SOUTH AFRICAN NATIONAL GOVERNMENT

Government should establish a consultative framework and start by leading the process. Government must co-opt SAWEEEA to co-ordinate and run the day to day operation of the management system and set up a single legal policy framework which guide and support the implementation of an e-waste strategy. Government must set reasonable targets of WEEE collections and government must act as the enforcer of laws if not complied with.

11.1 Additional government/local government measures

The disposal of any WEEE onto landfills and into municipal refuse bins or bags, rivers, dams, any open area, or the sea must be banned in South Africa. The role of local government must be limited to the reception and storage of WEEE at municipal and garden refuse sites and to information communicated to the public.

12. CONSUMERS AND INCENTIVE SCHEMES

South Africa is a relatively poor country and it would be wise to incorporate incentive schemes to motivate consumers to hand in WEEE. Incentive schemes could possibly be the receiving of talk time or data bundles on cellular phones or data devices, points on reward card systems such as FNB's eBucks points, Pick a Pay's smart shopper cards points, Woolworths's WRewards points, ABSA bank's Rewards points, Standard bank's UCount Rewards etc.

13. PROPOSED AUCTION HOUSE

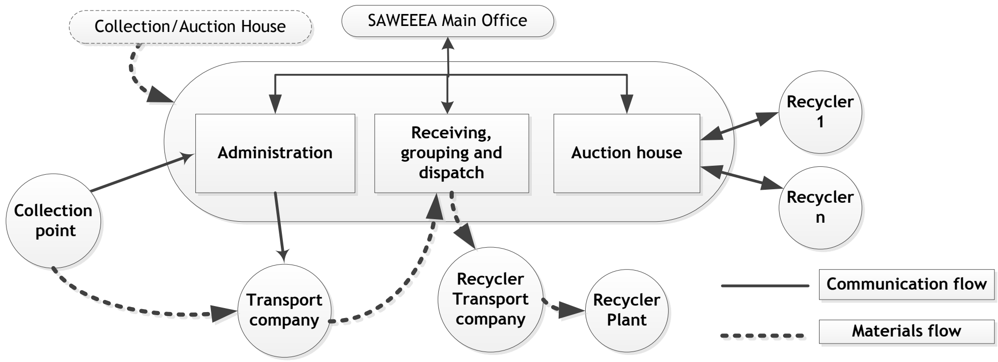

Figure 8: Proposed Auction house

In figure 8 the researcher is proposing an "Auction house" for WEEE recycling. An auction environment has benefits and fit into the proposed model. Klemperer (1999:227), state that "…auctions are such simple and well-defined economic environments". The auction houses should be placed in the bigger cities/towns in South Africa close to recyclers. Johannesburg and surrounding areas, Cape Town, and Durban/Ballito/Pietermaritzburg area are proposed. Due to the fairly large distances between cities in South Africa the solution would be to have collections done at remote areas ones or twice per year using larger trucks to ensure single trips and economy of scale.

From [46] the "Process structure" is proposed for the auction house. Figure 8 shows two different flows namely that of information (the solid line) and material flow (the dotted line). The ***administrative section*** should be the center point of information. Collections, call-to-collect, and transport arrangements are done from this section and the number/weights of received WEEE and the income generated must be reported to SAWEEEA. Auction details must be published through the administration department. The ***receiving, grouping and dispatching section*** must receive the collected WEEE from the transport companies, group the WEEE in different categories, separate items that can be refurbished and dispatch auctioned items. The ***auction section*** should deal with the auctioning of the WEEE. On auction days this section must ensure that bidders are registered, auction deposits are collected, terms of the auction are communicated, an auction list with available items are distributed and details of buyers of lots are captured.

14. PROPOSED ACCUMULATION STATIONS

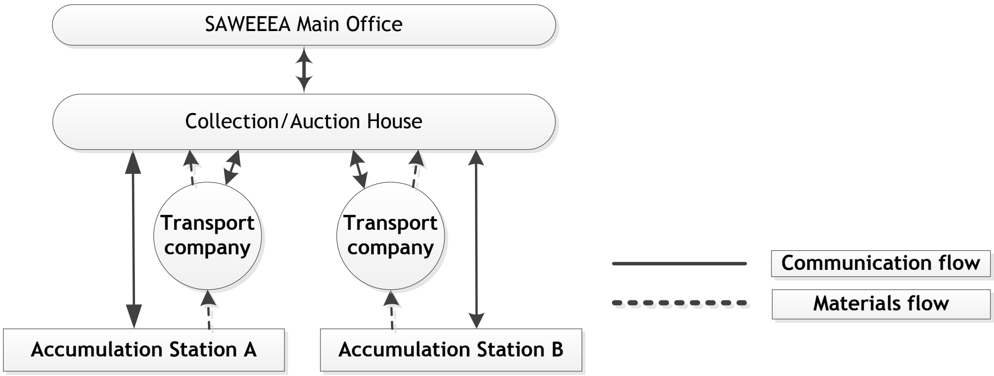

Figure: Proposed Accumulation Stations

In figure 9, accumulation stations must be located in areas (Polokwane, Nelspruit, Bloemfontein, Kimberley, George, etc.) where relatively large WEEE quantities can be collected but where very few recycling facilities can be found. Although rural areas are not seen as towns, there are some areas where large communities exist and the proposed Accumulation station could also be set up in these areas. The operation of the Accumulation station will be similar to the auction houses in the sense that the public and collection points will communicate with the Accumulation Station when WEEE must be collected. When enough material is available the WEEE will be transported to the auction houses. In rural areas the municipal refuse site, schools, community halls, etc. could act as the Accumulation Station to centralize collections. If recycling facilities are established near accumulation stations the selling price of WEEE items can be negotiated by using the market prices received at the auction houses. From [46] the “Process structure” is proposed for the accumulation stations.

15. FREE-RIDERS AND MEASURES TO PENALIZE FREE-RIDING

According to [47] “Free-riders” are actors, individuals or businesses, in an EPR system that does not pay for the benefits they receive. Free riders will always be part of any system but the existence of them should be limited. In the proposed model care was taken to minimize free-riders. The proposed measures to limit free riding of stakeholders are fines (continuous if no remedies occur), criminal charges and the termination of a business entity.

16. ORPHAN AND EXISTING PRODUCTS

“Orphan products” are products of which the producers are non-existent due to bankruptcy or some other reason while “Existing (pre-existing) products” (sometimes referred as “historic” items) are products on the market at the time the EPR policy is to be introduced [47]. Orphan and existing products are a reality in South Africa and the proposed management model includes orphaned and existing products that need to be recycled.

16.1 Financing options for addressing orphan and existing products

The proposed ADF fee which should be levied at the sale of new items will be used to fund the recycling efforts of end of life (EOL) equipment, regardless if the WEEE is orphan or existing/pre-existing products. New product sales should thus fund all current WEEE.

16.2 Non-recyclability of products

If a product is essential, non-recyclable, and the only product available in South Africa, the ADF fee must be set at a level that will ensure the product is safely discarded at a hazardous site. If there are alternative recyclable products on the market the non-recyclable product must be given a time period of two years to be changed to a recyclable product. If there is more than one alternative product the ADF fee should be the same for all similar products but the difference between the normal ADF fee and the cost to dispose of the non-recyclable item must be funded by the producer.

17. COMPETITION ISSUES

The proposed EPR model ensures fair competition in the import market, the product market, the recyclable materials market, the product collection (transport) market, and the recycler market,

18. WEEE DESIGN AND TREATMENT SYSTEMS IN SOUTH AFRICA

To eliminate problematic practices associated with the environmental protection in South Africa the researcher suggests: All refurbishers and recyclers must be ISO 14001 compliant, all recyclers must be in position of a Precious Metals Refining License, a waste transportation permit must be obtained which will allow a recycler/refurbisher to transport WEEE, a second hand goods license to enable the recycler/refurbisher to be in position of second hand goods, alternatively the above three license will be replaced by a SAWEEEA recycler license with a well-defined and specified recycling focus which enable recycling of precious metals, transportation of WEEE and of being in position of second hand goods.

19. FUTURE WORK

At publication of the paper the focus is on a ***proposed*** WEEE management model for South Africa. The proposed model was developed from litereture reviews, observations, and informal discussions with stakholders in the e-waste industry. Research is still in progress and thus no data can be provided to support the proposed model. Data will be collected during the second half of 2016 to test and validate the proposed model.

20. CONCLUSION

The environmental impact induced by WEEE and the value of the materials contained in WEEE need to be addressed in South Africa. Recycling efforts are mainly conducted for the financial benefit of recyclers while environmental problems are not addressed. To address the problems and opportunities it is vital to introduce legislation and a WEEE management model. Public awareness regarding environmental protection needs urgent attention to ensure the safe disposal of WEEE.

21. ACKNOWLEDGEMENTS

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BUSINESS INTELLIGENCE PERFORMANCE MEASURES IN LOCAL GOVERNMENT

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ABSTRACT

An estimated 2800 violent service delivery protests occurred from March 2004 to March 2008 in South Africa. The period between 2009 and 2013 had no less than 10 000 public gatherings. The use of violence during protests increased from under 50% of protests in 2007 to more than 80% of protests in 2014. Service delivery protests have become a way for the public to show their discontent with local government and unfulfilled promises by politicians.

Business intelligence and analysis can aid local government to make better use of available resources that are needed to support an ever growing public demand. This paper attempts to show that performance measures, as part of business intelligence and analysis, can be used to help local government address the grievances of service delivery protesters.

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1. INTRODUCTION

The period between 2009 and 2013 had no less than 10 000 public gatherings. Poor service delivery was cited as the cause in 45% of these public gatherings, while the use of violence during protests increased from under 50% of protests in 2007 to more than 80% of protests in 2014. Metropolitan municipalities bore the brunt of protests between 2012 and 2014 with 55% of protests occurring within the borders of metropolitan municipalities. [1]

A survey done in Gauteng in 2009 showed that 57% of respondents were satisfied with national government, 50% with provincial government and only 40% were satisfied with their municipalities. Respondents stated that they were not satisfied with local government in 27% of the cases, while 13% stated that they were very dissatisfied. [2]

South Africa seems to have the required legislative framework for good governance, as will be illustrated in this paper. The apparent failure of strategy execution and a lack of skills has been cited as the biggest hurdle to the proper functioning of local government. The importance of community participation and communication between government and citizens on expenditure should, however, not be overlooked. [3]

This paper attempts to illustrate how performance measures can be used to help local government to overcome some of the barriers caused by poor strategy execution and communication, a source of frustration for service delivery protesters. The following aspects will be addressed in the paper:

- The South African local government landscape;
- Management control systems, with a specific focus on the role and function of performance measures; and
- The use of performance measures within local government in North America.

The next section focuses on the South African local government landscape.

2. THE SOUTH AFRICAN LOCAL GOVERNMENT LANDSCAPE

Local government in South Africa is faced with numerous challenges. One of these challenges is the waves of service delivery protests across South Africa. Service delivery protests mostly stem from the lack of access to basic services, including access to sanitation, water, refuse removal, electricity and basic housing. [4]

The local government landscape in South Africa will be explained in more detail in this section. The focus will fall on the levels of local government in section 2.1 and the nature and extent of service delivery in South Africa will be examined in section 2.2. The local government legislative and planning framework is presented in section 2.3.

2.1 The levels of local government in South Africa

The Republic of South Africa has a parliamentary system that operates at both national and provincial level with all bodies of government adhering to the supreme rule of law, the Constitution.

At provincial level, the burden of service delivery lies with three different kinds of municipalities:

- Category A or metropolitan municipalities. There are six metropolitan municipalities in South Africa with more than 500 000 voters in each. Metropolitan municipalities are completely distinct from local or district municipalities;
- Category B or local municipalities. There are 231 local municipalities in South Africa. Local municipalities are often directly associated to towns and cities that are not part of metropolitan municipalities; and
- Category C or district municipalities. District municipalities oversee local municipalities, between three and six local municipalities are grouped together under a district municipality. There are 47 district municipalities in South Africa that coordinate and assist development and service delivery between local municipalities. Citizens who live in low population areas, like wildlife and game parks, fall under district municipalities.

All local services and development are undertaken by metropolitan municipalities, while local and district municipalities share the burden.

Municipalities are responsible for some of the following functions:

- Electricity delivery;
- Sewage and sanitation;
- Refuse removal;
- Municipal health services;
- Municipal roads;
- Street trading;
- Parks and recreational areas;
- Local tourism;
- Water for household use;
- Storm water systems;
- Fire fighting services;
- Decisions around land use;
- Municipal public transport;
- Abattoirs and fresh food markets; and
- Libraries and other facilities. [5]

Local government, or municipalities, are responsible for the provision of services to the community through accountable and sustainable methods. Municipalities must also promote social and economic development and encourage the community to be involved with the issues that affect them. The aim of encouraging local community involvement is to ensure that services and issues can be prioritised by the community as the beneficiaries. [6] [7]

The levels of local government are clearly set out by the national government of South Africa through parliament. Service delivery has been a ground level issue for most of South Africa's young democracy.

2.2 The nature and extent of service delivery in South Africa

Service delivery protests mostly stem from the lack of access to basic services, including access to sanitation, water, refuse removal, electricity and basic housing. The Financial Crisis that occurred from 2007 to 2009, have exacerbated the problem as South Africa lost the most formal sector jobs of any major country in the world after Spain. Over one million formal jobs were lost. [8]

Besides being sparked by inadequate service delivery and a high unemployment rate, service delivery protests share a set of characteristics:

- Service delivery protests take place in informal settlements or low-income areas that form part of metropolitan municipalities or large cities;
- Service delivery protests bear little to no evidence of formal planning or association with institutions;
- Protesters feel marginalised; and
- Protesters feel that they are not being heard by political figures. [2]

The lack of community involvement and communication by officials and local authorities adds fuel to the fire of these protests. The perception that protestors have can be altered by better communication channels between local government and citizens. [8] [6]

Regulations have been introduced to aid local government in service delivery. In the next section reference will be made to the South African local government legislation and legal framework. Specific reference will be made to the Local Government: Municipal Systems Act, 2000 (Act No. 32 of 2000) and the National Development Plan 2030.

2.3 Regulations and guidance on performance management and measures in local government

Local government in South Africa operates within a legislative framework. Specific reference will be made to:

- The constitution of the republic of South Africa;
- The National Development Plan 2030; and
- The Local Government: Municipal Systems Act.

The constitution of South Africa states that the public must participate in policy decision making processes and that public administration should make information of an accurate nature available to the public in a timely and accessible nature.

Chapter 13 of the National Development Plan 2030 suggests ways to improve service delivery and that a new funding model for municipalities is needed. [8] [6]
The National Development Plan 2030 identifies key areas that need to be focussed on to improve local government and service delivery.

- Accountability and oversight should be strengthened – Citizens need access to information to hold public servants and politicians accountable;
- Interdepartmental coordination needs to happen – Communication between officials to make decision making easier; and
- Relations and oversight between national, provincial and local government is needed – An enabling framework and oversight is needed so that resource use can be planned over provinces and municipalities. [9]

The Local Government: The Municipal Systems Act dictates that municipalities must adopt a performance management system and, at the same time, ensure community involvement with setting performance measures. The Local Government: Municipal Systems Act describes a performance management system in municipalities as a framework that represents how the cycle and processes of performance planning, monitoring, measurement, review, reporting and improvement will be conducted, organised and managed, including determining the roles of the different stakeholders.

The performance measures must include input, output and outcome measures. The performance measures must be measurable, objective, relevant and precise and also be reviewed annually. [10]

The act prescribes certain performance measures. These are:

- The percentage of households with access to basic level of water, sanitation, electricity and solid waste removal;
- The percentage of households earning less than R1100 per month with access to free basic services;
- The percentage of a municipality's capital budget actually spent on capital projects identified for a particular financial year;
- The number of jobs created through municipality's local, economic development initiatives including capital projects;
- The number of people from employment equity target groups employed in the three highest levels of management;
- The percentage of a municipality's budget spent on implementing its workplace skills plan; and
- The financial viability of a municipality as expressed by the following ratios:
    - Debt coverage = $\frac{\text{Total operating revenue received - Operating grants}}{\text{Debt service repayments}}$
    - Outstanding service debtors to revenue = $\frac{\text{Total outstanding service debtors}}{\text{Annual revenue received for services}}$
    - Cost coverage = $\frac{\text{Available cash + Investments}}{\text{Monthly fixed operating expenses}}$

The Auditor-general's report on the Public Performance Management Act for the financial year 2014-2015 covered 167 national and provincial departments and 301 public entities. The report showed a slight improvement in unqualified financial audits but these were still at a dismal rate of 28% of audits. The Auditor-general states in the report that reviewing and monitoring laws and legislation by leadership is needed. [11]

South Africa seems to have the necessary legislative framework for good governance, as shown in this section. The biggest hurdles to the proper functioning of local government has been cited as:

- Failure to execute strategies;
- A lack of skills;
- A lack of community participation; and
- A lack of communication between government and citizens. [3]

Strategy execution is often enhanced through the implementation of management control systems and more specifically through effective measurement and reporting on carefully selected performance measures. Over time a number of techniques and artefacts have been developed to assist managers in this process. In the next section a brief discussion on some of the most cited techniques and artefacts that are included in the management control systems discourse will be presented. The concepts management control systems and performance management are often used interchangeably in the literature. In this paper the concepts will also be used interchangeably.

3. MANAGEMENT CONTROL SYSTEMS

The definition of management control has evolved since its first recorded use by Robert Anthony (1965), where he stated that management control is a process to ensure that resources in an organisation are obtained and used efficiently and effectively towards the accomplishment of goals. Lowe (1971) expanded the definition to include accountability and feedback from stakeholders, in a system of information gathering, in an enterprise that is adapting to changes in its environment. The information is then used to track the achievement of goals and make corrections where necessary. [12] [13] [14]

The management of modern organisations requires an interdisciplinary and systems thinking approach to handle the complex interactions between departments and between strategy and execution. A number of studies around management control systems have resulted in the development of various techniques that attempt to ensure the most efficient use of resources. Performance measures are used to report on the efficiency of an organisation. Some of the most cited techniques include:

- Activity Based Costing;
- Balanced Scorecard;
- Benchmarking;
- Budgeting;
- Just-In-Time;
- Total Quality Management;
- Economic Value Added;
- Six Sigma; and
- Decision support systems. [13] [14] [15] [16] [17]

A detailed analysis of each of these techniques is beyond the scope of this paper but each of these techniques are briefly introduced in the next section. The section concludes with an introduction to decision support systems, its application and potential value.

3.1 Management Control System: Techniques and artefacts

Activity Based Costing – Activity Based Costing reveals the flow of an organisation's resources. The consumption of resources to deliver a service or create a product, as well as the generated income from these activities is revealed. [18]

Activity Based Costing consists of two phases:
- The resources consumed to create products or to deliver services are identified; and
- The resources are directly allocated to specific products or services. [13]

Managers can use Activity Based Costing to focus on areas that will have the biggest impact on expenditure and income generation. [18]

The Balanced Scorecard – The Balanced Scorecard is a management control system that makes use of financial and non-financial measures to address the shortcomings of accounting systems that rely on historic information alone. The measures used are part of four groups:
- Learning and growth;
- Business processes;
- Customer focus; and
- Fiscal focus.

The exact measures used with a Balanced Scorecard approach may differ between organisations and between business units, divisions or departments within an organisation. [13] [14]

Benchmarking – Benchmarking seeks to learn from the experiences of existing and successful organisations by establishing the standards and examining the processes used. Benchmarking attempts to correlate desired outcomes with certain inputs and reduce ambiguity. [16]

Budgeting - Budgeting is a form of planning and setting goals, but can also be used to evaluate performance in review. Resource allocation and control is the main aim of budgeting. [15]

Just-In-Time - The aim of Just-In-Time as a management control system is to improve the quality of manufacturing by improving production processes. Improving production processes are mainly achieved through the:
- Reduction of production costs;
- Elimination of waste; and
- Recognition of worker's abilities.

In essence, the right amount of goods are produced at the right time. [19]

Total Quality Management - Total Quality Management emphasises:

- Continuous improvement;
- Reducing rework;
- Constant measurement of results; and
- Long term thinking.

Total Quality Management attempts to improve the bottom line of an organisation holistically, therefore, the list above only captures the essence of Total Quality Management. [20] [16]

Economic Value Added - The creation of shareholder value in a private organisation can be measured using Economic Value Added. Economic Value Added is calculated by deducting the cost of debt and equity from operating profit. Economic Value Added is sometimes used alongside return on investment and earnings per share. [13] [15]

Six Sigma - Six Sigma uses the captured data from business processes to continually reduce defects in the delivery of goods or services. Six Sigma attempts to have less than 3.4 defects per million opportunities, therefore, a success rate of more than 99.99%. Opportunities are the number of chances that a unit, in the case of manufacturing, would have a defect. [13]

Decision support systems - Decision support systems is a term used to describe computer based systems, mostly databases and software, which aid in solving problems and making decisions. Organisations can separate the viewable data by department or management level to ensure the privacy of information, for example limiting human resource information to only be viewed by the human resources department. [13]

The technology trends that started the data era can be loosely attributed to the start of the internet in the 1970s and the ubiquitous nature of the World Wide Web that followed. [21]

Special skills and capabilities have been fostered to enable organisations to extract information from these vast amounts of data with numerous benefits, including:

- Timely access to information;
- Reduced cost;
- Increased productivity; and
- Improved employee and customer satisfaction. [13]

In the next section business intelligence and analysis is introduced. Business intelligence and analysis uses performance measures to understand and keep track of trends in an organisation, enabling easier and better decision making. The communication of ideas and abstract concepts between stakeholders, such as different levels of local government, are aided by business intelligence and analysis.

3.2 Business intelligence and analysis

Business intelligence and analysis forms part of a set of philosophies and tools that aid business leaders in decision making. Business intelligence and analysis refers to:

- The gathering and use of information to map out an organisation's position relative to its competitors and customers in a given market and economic climate – An organisation's internal and external environment is mapped and put in context; and
- A system or process that an organisation uses to gather and analyse information before using the insights obtained to make decisions. [22]

Business intelligence and analysis as a decision support system has evolved over the years, starting as early as the 1970s. The two primary steps in business intelligence and analysis are:

- Collecting data; and
- Extracting the information from the data. [23]

These steps and their interaction are shown in the illustration below:

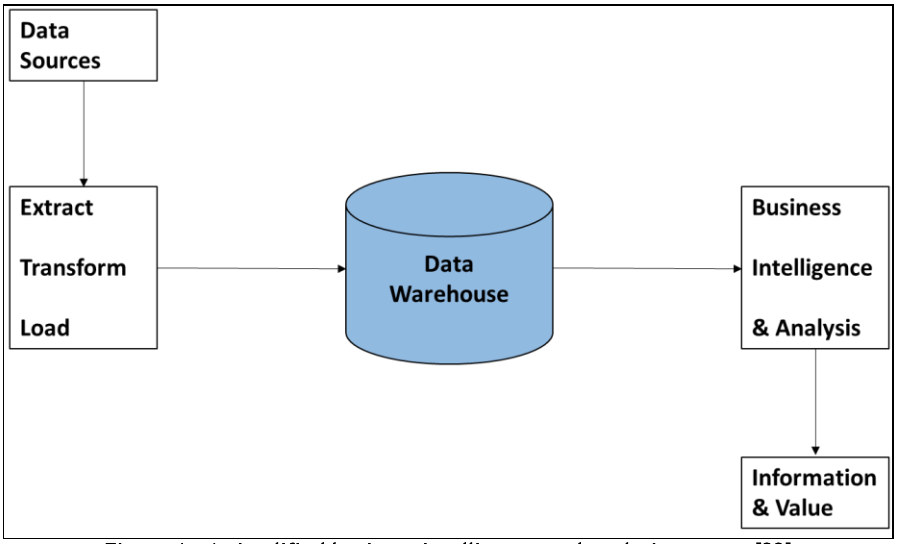

Figure 1 - A simplified business intelligence and analysis process [23]

A survey of 1 447 decision makers found that the deployment of business intelligence and analysis solutions increased by 39% since 2012. The survey also found that organisations with a longer history of using business intelligence and analysis reported a six fold increase in meeting the following objectives:

- Enhance communication and collaboration;
- Accelerate innovation of products and services; and
- Improve customer experience. [24]

In 2011, 97% of companies with revenue of more than $100 000 000 per year made use of business intelligence and analysis. [25]

Management control systems are underpinned by performance measures and are used to determine what needs to be measured and reported on. The next chapter focusses on performance measurement and management. Focussing on performance measurement and management lays the foundation to show the value of using performance measures in local government.

3.3 Performance measurement and management

Business performance measurement and management is a combination of management and analytic processes that allows managers of an organisation to achieve pre-determined goals. [26]

Business performance measurement and management involves three main activities:

- The selection of goals;
- The consolidation of measurement information relevant to the organisation's achievement of these goals; and
- The interventions made by managers in light of this information.

Business performance measurement and management evaluates the business in a holistic way that goes beyond each division or department. The strategic and operational objectives of an organisation can be aligned. [27]

A good performance measure is difficult to determine and depends on the needs of the organisation or institution. There are similar characteristics between the different measures that organisations consider good performance measures. [28]

Good performance measures keep track of, and enable business functions that are key to the effective and efficient delivery of goods and services that are of a consistent and good quality. The data used by performance measures need to be accurate and unambiguous in order to be trustworthy and be a single version of the truth, avoiding conflict and debate that inhibits implementation. Manipulation of performance measures should be difficult, but performance measures should still be easily accessible and comprehensible. Performance measures that are easily comprehensible aids in better implementation of corrective measures when they are needed and does not create conflicting conclusions. The effectiveness of performance measures can only be of concern when the users are also responsible for decisions taken or the outcome that is being measured. Creating information from the underlying data by reducing the volume, yet still being timely enough is key. [28]

A manager may use different performance measures to keep track of unfolding events or ensure that objectives will be obtained within the allotted time given by higher management. Delegated tasks and the respective performance of employees can be tracked and measured, but what to track and measure is the key to effective performance measurement.

Performance measures can be used to monitor or alter the behaviour of systems, especially when people are a key part of the system. A caveat of performance measuring is that people will alter their usual behaviour to modify the outcome of performance measures, sometimes by circumventing safety or best practice procedures, in order to show an improvement before a management review. [29]

Manufacturers may measure certain indicators on a daily or hourly basis, sometimes even as close as possible to real-time. Measuring the performance of machines and systems on such a regular basis allows companies to keep a consistent standard without sacrificing safety or decreasing profits, allowing intervention before a major event can unfold.
[30]

The identification of applicable performance measures starts by investigating the measurable outcomes of a system or process. The outcomes are then measured against the inputs from previous parts of the process or system. A generic process for identifying performance measures is shown in the illustration below. [31]

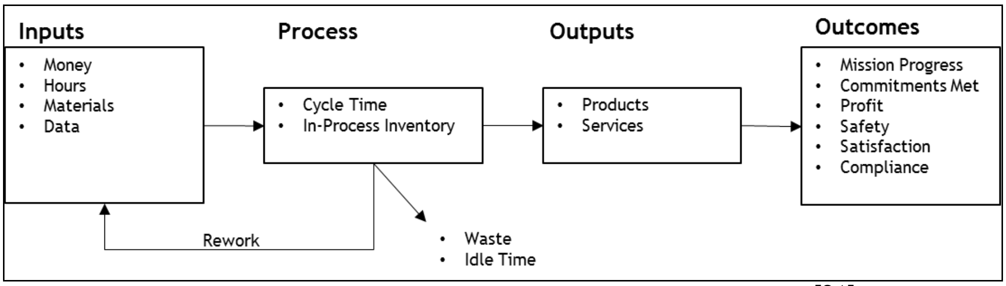

Figure 2- A generic process for identifying performance measures [31]

The assessment of performance in the public sector is different to the assessment of performance in private organisations. The underlying difference between public sector performance measurement and private sector performance measurement is that:

- Private firms focus on profit and performance measurement and are dependent on a variety of technical procedures; and
- Public sector entities focus on a narrower set of particular social and political objectives. [28]

The legal framework and legislation discussed in section 2 provides a solid base for management control systems and can be used to eliminate at least some of the hurdles to the proper functioning of local government. The existence of a legal framework and legislation is however not enough and implementation is necessary. Evidence that performance measurement, management or reporting adequately takes place in local government in South Africa could not be identified during the research for this article.

There are different ways to identify and implement performance measures in an organisation. The discussion in section 3 shows that a properly defined decision support system provides an excellent context for identifying and implementing performance measures.

The next section discusses the results from the implementation of performance measures in North American local government entities. The discussion can be seen as a benchmark for the implementation of performance measures in local government.

4. RESULTS FROM IMPLEMENTING PERFORMANCE MEASURES IN LOCAL GOVERNMENT

The implementation and use of performance measures in local government in the United States of America are evolving from quantitative measures to more results oriented qualitative measures that also aid in decision making.

A survey of local government in the United States of America, involving 47 counties and 168 cities, showed positive results for the use of performance measures. The findings showed that using performance measures had enhanced programme management in 71% of respondent's cases and 68% agreed – while 15% strongly agreed – that the use of performance measures had resulted in an increase in efficiency. Communication between branches of local government also improved after implementing performance measures.

The most positive results yielded from the use of performance measures were:

- Improved communication with budget officers;
- Improved communication with ward councillors;
- Improved communication with citizens;
- Improved communication between departments;
- An increase in awareness and focus on results from local government;
- An increase in awareness of factors that affect results;
- An increase in service quality;
- An increase in the effectiveness of department programs; and
- Better adaptability of programs to achieve the desired results.

The research confirms that implementing performance measures in local government improved communication within and across branches of government and between local government and citizens. Discussion about the results of government activities are facilitated by performance measures and the decision making process is aided by relevant information from performance measures. [32]

Performance measures at branches of local government were mainly used as budget development tools, but some respondents have successfully used performance measures as tools to communicate satisfaction levels from citizens and as knowledge sharing to citizens. [28]

Effective communication between spheres of government and between local government and citizens may remove the perception of marginalisation. [2]

Different departments at different levels of government have different needs and uses for performance measures. Parliament may focus on policy implementation and effectiveness, while national government's treasury department is more interested in financial performance and wastage and citizens at local government level are concerned with service delivery and effective tax expenditure. [28]

The Balanced Scorecard has been cited as an invaluable framework for identifying and implementing performance measures in local government. In a survey of 184 local government entities in North America the following broad types of performance measures were created and implemented with positive results:

- Financial performance;
- Operating efficiency;
- Customer satisfaction; and
- Employee performance; [33]

The use of one or more management control systems to identify performance measures is a step in the right direction for local government in South Africa to comply with the existing legislation.

No data collection standards were present in South African municipalities in 2009 and local government information was being assembled by National Treasury. This fact makes it difficult to determine the precise performance measures that should be used, but points to the fact that data capturing processes and systems are not in place or inadequate to make the data available in a trustworthy and timely fashion to allow analysis to take place. [34]

The results from implementing performance measures are clearly positive, but a well-defined system for data collection, measurement and reporting is also necessary. Decision support systems provide an excellent context for identifying, implementing and tracking performance measures.

5. CONCLUSION

The main aim of business and government might differ but that does not mean that local government entities, like municipalities, cannot make use of tried and trusted methods to ensure that resources are used efficiently and effectively. Equating revenue in the private sector to profit and revenue in the public sector to tax, makes input performance measures comparable between the two. The same thinking can be applied to products and services provided in both sectors. [35]

Employees in local government who are included in the development and determination of performance measures are more likely to make use of and find value in performance measurement. The budget effects of performance measurement are influenced by the presence and comprehensive use of performance measures in budget processing and performance. However, the simple presence of performance measures in documentation does not mean they will be used effectively in decision making, correct performance measures at appropriate stages of the budgeting process removes the chances of information overload. [32] [33]

The results from implementing performance measures in North American local government entities are positive and enables strategy execution and better communication between stakeholders. Performance measures can, and should, be implemented into local government in South Africa. The biggest hurdle to introducing performance measures into South African local government entities seems to be the lack of data capturing standards and processes. Future research needs to determine to what extent performance measures are adequately implemented in South African local governments and how a properly defined decision support system can aid implementation.

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IMPLEMENTATION OF FMECA APPROACH FOR RELIABILITY IMPROVEMENT ON DRUM PRODUCTION LINE

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ABSTRACT

Manufacture of industrial packaging products requires multiple processes and machines. It is imperative to ensure that these machines are reliable and available when required to perform tasks. The case-in-point, a drum manufacturer, has experienced numerous equipment breakdowns or failures on the steel drum production line. These failures affect the reliability of the drum production line. The purpose of the study was to improve machine reliability and reduce downtime for the drum production line. Reliability analysis was conducted based on the data that was collected on the MP2 system from the records for previous three months. The analysis gave evidence that major counter-measures were pertinent to improve line reliability. A cross-functional team was instituted to conduct FMECA as risk assessment to determine failure modes and failure effects of critical equipment, and incorporate the criticality analysis. The reliability of the welder and seamer equipment improved after the implementation of FMECA and one can conclude that FMECA can be the vital tool for companies that thrive for optimal performance.

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1. INTRODUCTION

The manufacturing industry is machine-driven and its productivity and efficiency are key factors which influence the competitiveness of different companies in this sector. There are metrics associated with the logistics and maintenance support infrastructure, which are inherent within the overall effectiveness measures of a plant system and the degree to which the system is able to accomplish its mission. Organisational success and competitiveness is highly dependent on logistics and maintenance support infrastructure as a major element of the system and its availability when needed. Plant productivity depends on equipment maintenance which influence the plant availability and reliability. Machine reliability and availability is crucial for the sustenance of business and satisfying the customers by ensuring on time delivery of products conforming to the quality specifications. Hence a maintenance system should be instituted to reduce the frequency of equipment failure by comprehending the failure mode and effects so as to improve equipment reliability and availability. Failure Mode, Effects, and Criticality Analysis (FMECA) is the identification of potential process failures, the expected modes of failure and causes, failure effects and mechanisms, estimated rate of recurrence, level of criticality, and the procedure needed for compensation such as undertaking preventive maintenance [1]. This paper deals with the improvement of reliability of a drum production line using FMECA approach. The current and future risks are identified, assessed and examined and pertinent preventive maintenance actions are implemented with the view to strengthen the maintenance support infrastructure and reduce breakdown frequency of equipment.

2. BACKGROUND

Globalisation or the integration of economies, markets, industries, cultures and policy-making around the world, has raised the level of competition in meeting customer requirements for both local and global manufacturing companies. Failure to meet customer requirements can be suicidal for business sustainability, and thus it is imperative to improve equipment reliability and availability to enhance agility in responding to customer needs [2]. Machine breakdowns have a direct impact on reliability and availability of the plant or machines to perform its required tasks. Most companies envisage having higher reliability on their machines or plant, however they do not anticipate risks in advance in order to take necessary preventive actions or conduct preventive maintenance.

The case study company, a drum manufacturer specialises on metal packaging and supply their product to chemical and petroleum manufacturing companies in South Africa. The drum manufacturer also does corrective maintenance on most equipment and machines.
The challenge faced by the company is that it has old equipment for drum assembly line and most of these machines are not on the preventive maintenance plan. The company is also facing challenges in terms of supply support for the indispensable spare parts and the associated inventories required for the performance of unscheduled and scheduled maintenance, and hence it is difficult to get the needed spares when these machines fail. Frequent machine breakdowns have huge cost implications, since they result in downtime which may result in failure to meet customer requirements, as well as unsatisfied customers which may open the gap for competitors. Given this background, this paper focuses on improving the reliability of the drum assembly line by using FMECA approach.

Figure 1 shows the flow diagram for the drum production line. The steel drum production is a multi-step process involving the uncoiling of the steel, leveling, and shearing of the material, after which the material is edged and stacked. This is followed by body formation of the steel drum by rolling the steel sheet into a round body drum, electric resistance welding, and then flanging to create lips on the shell. The flanged body is then turned into a w-shaped body at the wedger and the rings from corrugating add rigidity and reinforces the drum shell. Material for the top and bottom lids is sent to punch press for formation of bottom and top covers. These lids are taken to the seamer to make the barrel seals. At the seamer, as the shell rotates in a spinning clamp, the rollers kill the edges of the shell and top lids. This creates an interlocking seam which is then flattened by the subsequent rollers. The same process occurs for the assembly of the bottom lid. The final assembly is then tested for possible leaks, painted, coated, and cured, after which the plug is fitted to produce a customer-ready drum.

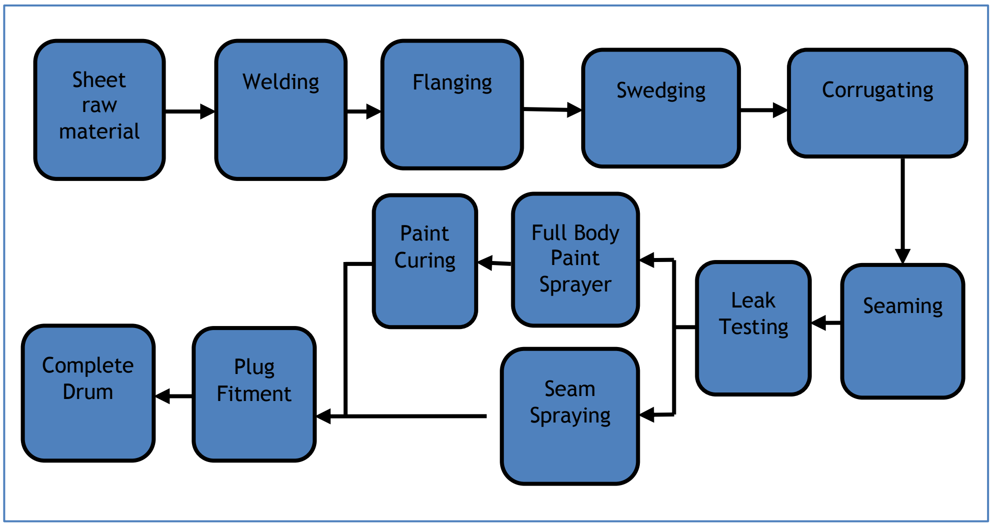

Figure 1: Schematic for the steel drum production line

3. OVERVIEW OF FMECA

FMECA is a methodology developed as an extension to Failure Mode and Effects Analysis (FMEA). FMEA details the distinct failures of a system through the identification of failure modes, as well as identifying the causes and effects of the respective potential failure modes on system service, after which appropriate detection procedures and corrective actions are defined. FMEA can be extended by Criticality Analysis procedure (CA) for the modes of failure to come out as Failure Mode Effects and Criticality Analysis (FMECA) [3].

FMECA is a detailed systematic procedure for analysing systems with the view to identify potential failures, their causes and effects on system performance, safety of the personnel, as well as effects on the environment by means of criticality analysis [4]. It is ideal for FMECA to be conducted in the development stage, even though conducting FMECA on an existing system or machine can also yield substantial benefits [5]. FMECA may also be used to prevent defects and improve product safety, quality and availability of machines. However, the main purpose of FMECA is to determine the product design, manufacturing process or equipment failure mode, discover the influence of failure on the equipment or system and to provide qualitative and quantifiable assessment, and then take corrective actions and preventive actions [6]. The results acquired from conducting a FMECA may be implemented to improve reliability, availability and maintainability of the equipment.

FMECA is a highly informative technical approach which is characterised by failure mode, that is the manner of failure, and causes connected at each failure mode. However, one failure mode can be connected to more than one cause. The failure mode can be examined in terms of performance measurement for each element of the equipment or system. The result of each and every failure mode is signified as effect and should be analysed and recorded in FMECA [7].
FMECA is a broadly-applied method which can be executed in diverse steps of the product life cycle such as design and development, manufacturing, distribution, services and other activities to improve quality, availability and reliability. FMECA is widely utilised in many industries and has been used in the automotive industry to identify potential failures in advance and take preventive actions [6]. FMECA is applied to determine risks of failure in the process or equipment to ensure that the company or organisation meet customer requirements such as quality products and ensure that equipment is always available to perform its function [8].

Companies use FMECA for many different reasons, but the main idea is to apply FMECA to analyse risks of failure mode and for improvement purposes. Applying FMECA provides an opportunity to investigate and identify critical elements of the equipment or system [6]. If FMECA analysis is successfully conducted, it would yield a data table that comprise highly enriched knowledge. The quality of FMECA depends on the validity and the timely nature of the processed data [9]. On overall, FMECA is an effectual tool for continual and effecting the proposed changes would yield better reliability and safety results [10]. However, in this paper, FMECA is essentially used to improve machine reliability and reduce downtime for the steel drum production line.

4. METHODOLOGY

The methodology used to improve reliability at the drum manufacturer commenced by instituting a cross-functional team and defining the system requirements. A functional analysis of the maintenance actions that were required to restore a system to operational use were identified. The failure modes or manner in which

drum production line equipment could potentially fail to meet its requirements or fail to function were identified. The causes of failure or potential reasons behind a failure mode were then determined. Determination of the effects of failure or potential non-conformance was then undertaken after which failure means detection were identified. This was accomplished by establishing all the current controls, design features and verification procedures that would result in the detection of potential failure modes.
A qualitative assessment of the seriousness of the effect of the potential design failure mode was executed to determine the severity of a failure mode. The degree of severity was measured on a scale of 1 – 10, with very high effects being 9 to 10 and minor effects being 1. The frequency of occurrence or probability of failure of each individual failure mode was then determined using a scale of 1- 10. Remote failure (failure is unlikely) was allocated a 1-2 while very high (failure is almost inevitable) was indicated as 8 -10.
The probability that design features, aids or verification procedures will detect potential failure modes in time to prevent a system-level failure are also crucial in implementing FMECA. Thus, it was also crucial to determine the probability that the failure will be detected and this was scaled from 1-10, with absolute certainty of detection being ranked 1-2 while absolute certainty of non-detection was ranked 9-10. The risk priority number (RPN) which is a product of the severity, occurrence, and detection rankings was then computed to facilitate the analysis of failure mode criticality. It was used as a means of prioritising potential failures and for the identification of critical areas so as to reduce the overall degree of severity, occurrence, and detection rankings.

5. SCENARIO BEFORE FMECA IMPLEMENTATION

The reliability analysis was conducted on key machines on drum assembly line to identify the reliability of each machine. The data was collected on MP2 maintenance software with the objective to analyse the reliability and focus was on the breakdowns to determine Mean Time Before Failure (MTBF) for each machine as it is a main parameter of reliability. The performance of each machine or equipment was sampled for a period of three months.

5.1 Mean Time Before Failure

Table 1 shows the MTBF results for the key machines for the drum production line. According to the results, the leak tester experienced the longest MTBF of 480 hours followed by the flanger and swedger which have 320 hours. On the other hand, the welder machine has the least MTBF (8 hours) compared to all other machine. That means the welder machine broke more frequent than other machine, and then followed by seamer with the MTBF of 80 hours.

Table 1: MTBF per equipment

Equipment	Welder	Flanger	Swedger	Corrugator	Seamer	Leak tester
MTBF (hours)	8	320	320	160	80	480

5.2 Reliability analysis

Reliability can be defined as the probability that a system or product will perform in a satisfactory manner for a given period of time, or in the accomplishment of a mission, when used under specific operating conditions. The reliability function R(t) may be expressed as

$$R(t) = 1 - F(t) \qquad (1)$$

where F(t) is the probability that the system will fail by time t. F(t) is basically the failure distribution function or the unreliability function. If the random variable t has a density function f(t), (i.e. probability that the variable takes the value f(t)) then the expression for reliability is

$$R(t) = 1 - F(t) = \int_t^\infty f(t)dt \qquad (2)$$

Assuming that the time to failure is described by an exponential density function, then

$$f(t) = \frac{1}{\theta} e^{-t/\theta} \qquad (3)$$

where θ is the mean life, t is the time period of interest, and e is the natural logarithm base (2.7183). The reliability at time t is

$$R(t) = \int_t^\infty \frac{1}{\theta} e^{-t/\theta} dt = e^{-t/\theta} \qquad (4)$$

Mean life (θ) is the arithmetic average of the lifetimes of all items considered. An exponential probability function can be used to represent random failures and is widely used to model reliability phenomena. The assumption is that the failure rate of a system is independent of its age and other characteristics of its operating history, and given that scenario, the mean time to failure can be used to describe reliability with permissible accuracy once the exponential distribution parameter, the failure rate, is directly associated with mean time to failure [10]. The mean life (θ) for the exponential function is equivalent to Mean Time Between Failure (MTBF). Thus,

$$R(t) = e^{-t/M} = e^{-\lambda t} \quad (5)$$

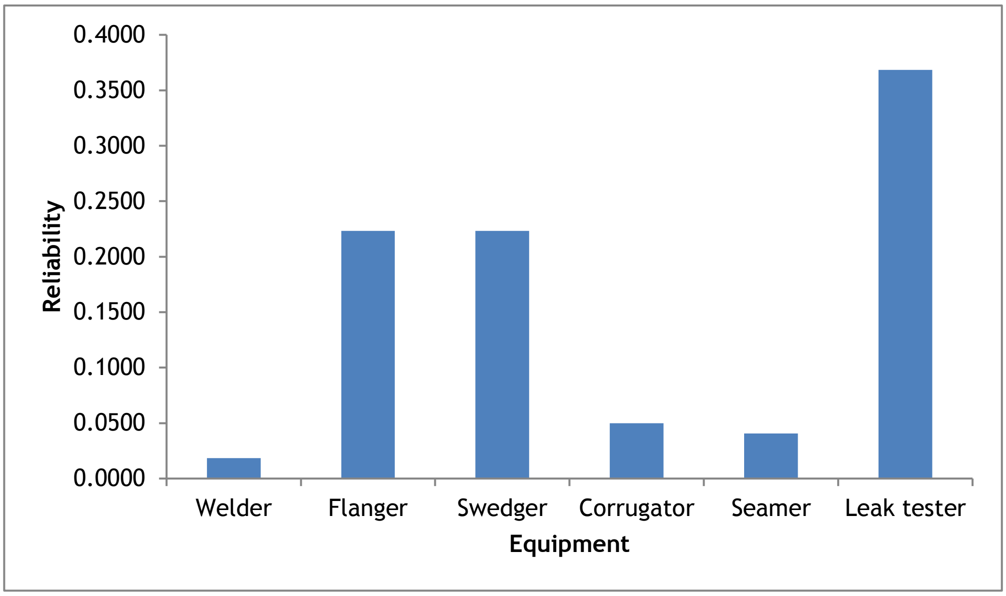

Figure 2: Reliability per equipment

Figure 2 shows the reliability of the key equipment of the drum production line, based on reliability analysis. The plant generally operates for about 8 hours a day for 20 days a month, which cascades to 480 hours for the three month period. Figure 2 indicates that the welder and seamer have less reliability compared to other equipment from the sampling period of three months. The possible reasons that these two machines could have less reliability compared to other machines is the numerous number of breakdowns they experienced from that sampling period of three months is poor preventive maintenance system or failure to adhere to planned maintenance by the maintenance department.

6. IMPLEMENTATION OF FMECA

A cross-functional team comprising members from the maintenance department, machine operators and their supervisors as well as member from the stores department was developed. The failure modes or manner in which the welder and seamer could potentially fail to meet requirements or fail to function were identified. The causes of failure were then determined. A qualitative assessment of the seriousness of the effect of the potential design failure mode was executed to determine the severity of a failure mode using a severity rating scale shown in Table 2. The frequency of occurrence of each individual failure mode was then determined using the occurrence rating scale shown in Table 3, after which the probability that design features, aids or verification procedures will detect potential failure modes in time to prevent a system-level failure was also ascertained using the detection rating scale shown in Table 4.

Table 2: Severity rating scale

Rating	Description	Definition
10	Dangerously high	Failure could mean physical injury to the user or an employee
9	Extremely high	Failure would result in violation of national regulations
8	Very high	Failure makes the equipment inoperable or unserviceable
7	High	Failure would result in significant customer dissatisfaction
6	Moderate	Failure would cause partial breakdown
5	Low	Failure's impact on equipment/process performance would be sufficient to generate complaints

4	Very low	Failure would result in minor performance loss
3	Minor	Failure is a small nuisance but does not result in performance loss
2	Very minor	Failure may have such minor consequences thus is unlikely to be apparent
1	None	Failure would not be noticed or affect the equipment/process

Table 3: Occurrence rating scale

Rating	Description	Potential Failure Rate
10	Exceedingly high	Failures occurring more than once/day
9	Very high	Failures occurring every three to four days
8	High	Failures occurring once/week
7	Relatively high	Failures occurring once/month
6	Moderate	Failures occurring once every three months
5	Relatively low	Failures occurring once every six months
4	Low	Failures occurring once a year
3	Very low	Failures occurring once every one to three years
2	Relatively remote	Failures occurring once every three to five years
1	Remote	Failures occurring once in more than five years

Table 4: Detection rating scale

Rating	Description	Definition
10	Complete Uncertainly	Equipment is either not inspected or the effects of failure are not detectable
9	Very Uncertain	Highly unlikely to detect failure
8	Uncertain	Very unlikely to detect failure
7	Very low	Equipment undergoes 100% manual inspection
6	Low	Equipment undergoes 100% manual inspection using go/no-go or other mistake proofing gauges
5	Moderate	Fair chance of detecting failure
4	Relatively high	Good chance of detecting failure: 95%
3	High	High chance of detecting failure: 99%
2	Very high	Equipment is 100% automatically inspected
1	Almost certain	There is 100% automatic inspection with excellent maintenance of the inspection equipment

The probability that the failure will be detected was then determined, after which the risk priority number (RPN) was then computed using the formula shown in Equation 6.

$$RPN = S \times O \times D \quad (6)$$

In this case, *S* represents the severity index which relates to the assessment of the magnitude of the failure mode's effect on machine or component operation. *O* designates the occurrence index which relates to the probability that a failure mode occur within a defined period, and this generally depends on prior knowledge of the reliability of the equipment or component under study. *D* is the detection index and this is a function of the ability to identify, diagnose and eliminate or preventing the commencement of a breakdown prior to the manifestation of its effects on the system or personnel [4].

Table 5 shows the RPN rating for potential failure modes for the welder. It indicates that there is a higher risk on the lap gauge, skew roller and weld wheels potential modes since each has an RPN of 560.

Table 5: Determination for RPN for Welder

Equipment component	Potential Failure Mode	Potential Failure Cause	Potential Failure Effect	Current Process Controls	Severity	Occurrence	Detection	RPN
Lap gauge	Loose lap gauge	Vibration	Misalignment of overlap	None	8	7	10	560
Skew rollers	Seized bearing	No lubrication	Misalignment of overlap	None	7	8	10	560
Weld wheel	Weld wheel poorly performing	Wear and tear	Excessive leakers	None	8	7	10	560
Insulator	Cracked or broken insulator	Loose insulation, vibration	Electrical faults	None	9	4	10	360
Control panel	Incorrect temperature readings	Electronic failure	Inconsistent temperature	Visual from screen	9	10	2	180
Cooling system	Leaking water pipes	Old pipe and excessive pressure	Welder head heat up	None	8	3	10	240
Transformer	Broken windings	Machine overheating	Equipment stops working	None	10	2	10	200

The recommended actions were then identified for the welder components and that include instituting a Planned Maintenance (PM) once every two weeks and that responsibility was given to the maintenance planner as shown in Table 6.

Table 6: Recommended actions and results for welder

Equipment component	Potential Failure Mode	Recommended Action	Action Taken (Yes/No)	Action results			
				Severity	Occurrence	Detection	RPN
Lap gauge	Loose lap gauge	Conduct PM once every two weeks	Yes	8	4	7	224
Skew rollers	Seized bearing	Conduct PM once every two weeks	Yes	7	5	7	245
Weld wheel	Weld wheel poorly performing	Conduct PM once every two weeks	Yes	8	6	8	384
Insulator	Cracked or broken insulator	Conduct PM once every two weeks	Yes	9	2	7	126
Control panel	Incorrect temperature readings	None					
Cooling system	Leaking water pipes	Conduct PM once every two weeks	Yes	8	2	8	128
Transformer	Broken windings	Conduct PM once every two weeks	Yes	10	2	7	140

Figure 3 visually depicts that there is the higher risk on the pressure accumulator potential failure mode as it has RPN of 360 and the corrective or prevention measure on the pressure accumulator needs to be priorities as it shows that there is higher criticality or risk on that potential failure mode. The recommended action that was then implemented was putting in a monthly preventive maintenance schedule for seaming chuck and rollers and that responsibility was given to the maintenance planner. The other recommended action that was implemented was putting in a monthly preventive maintenance schedule for seaming chuck and rollers and that responsibility was given to the maintenance planner as well.

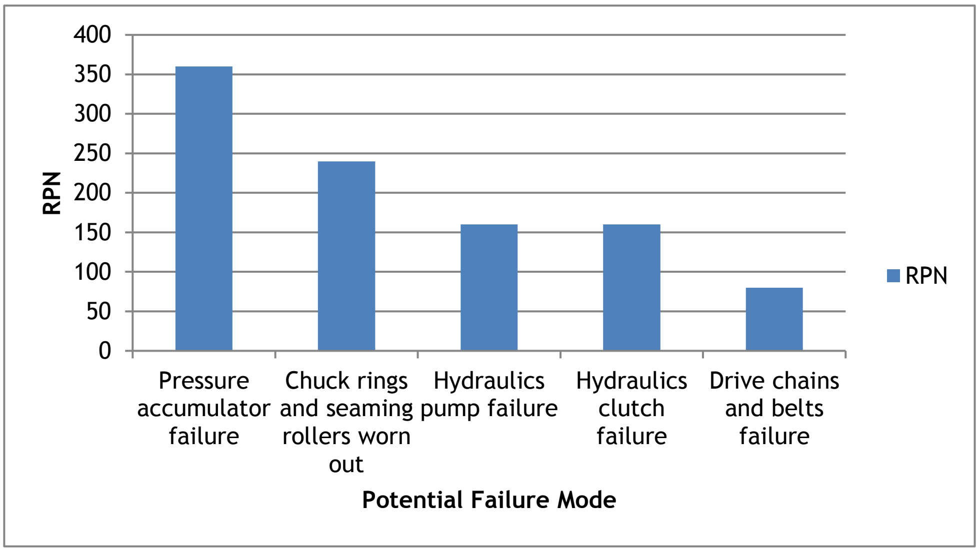

Figure 3: Seamer RPN rating

7. FINDINGS AFTER FMECA IMPLEMENTATION

The FMECA results for the key equipment were reviewed after corrective or prevention measures were taken for the high risk areas of improvement.

Table 7: RPN List from welder FMECA after the improvements were implemented

No.	Potential Failure Mode	RPN
1	Weld wheels worn out	384
2	Seized bearing	245
3	Loose lap gauge	224
4	Loose insulation	180
5	Leaking water pipes	140
6	Broken windings	128
7	Inconsistence temperature	126

Table 7 shows the RPN rating for potential failure modes of the welder after the proposed improvements have been implemented. The findings indicates that the RPN for lap gauge, skew roller and weld wheel potential failure modes have declined from 560 to 224, 245 and 384 respectively after corrective or prevention measure was taken and the average risk for equipment failure has dropped. Therefore, one can conclude that there has been a notable improvement on the reliability of the welder.

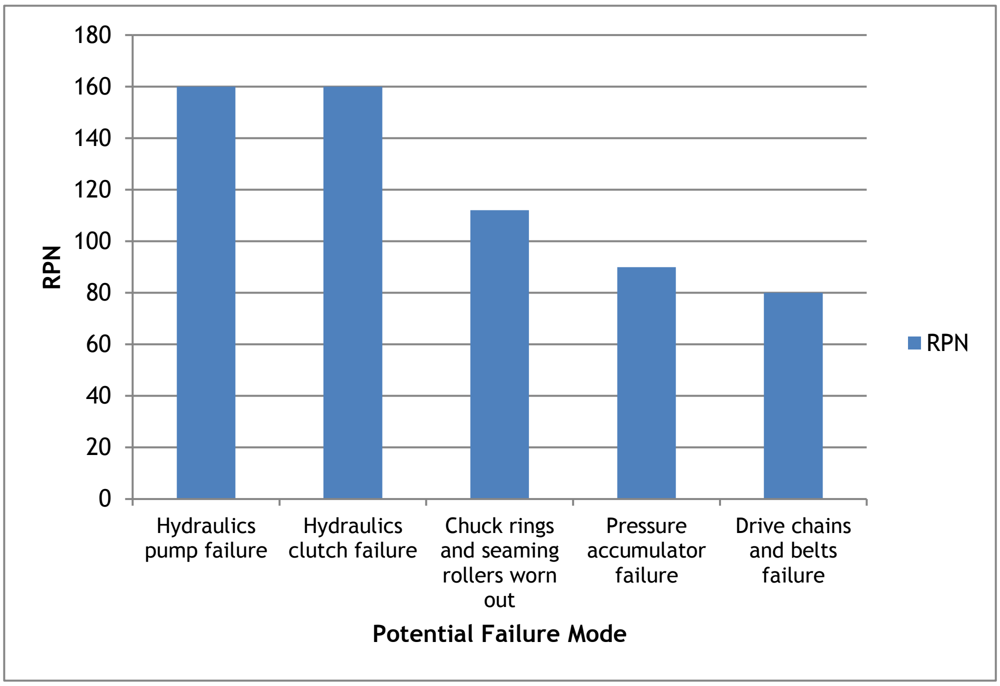

Figure 4: Seamer RPN rating (improved)

Figure 4 shows the RPN rating for potential failure modes of the seamer after the proposed improvements have been implemented. This finding rate all the RPN as based on it criticality on RPN calculations and that the RPN for pressure accumulator potential failure mode has declined from 360 to 90 after corrective or prevention measure was taken and the average risk for equipment failure has dropped. Therefore, there is an improvement on the welder and seamer as shown in Table 8.

Table 8: MTBF per equipment after improvements were implemented

Equipment	MTBF (hour)	Failure Rate	Reliability
Welder	120	0.0083	0.0183
Flanger	320	0.0031	0.2231
Swedger	320	0.0031	0.2231
Corrugator	160	0.0063	0.0498
Seamer	150	0.0067	0.0408
Leak tester	480	0.0021	0.3685

Table 8 shows the reliability per equipment after the FMECA has been applied. The findings indicates that the reliability of the welder and seamer have improved after FMECA approach and implementation of planned maintenance on the critical equipment. However, there is still more room for continuous improvement, and FMECA is a good starting point for implementation of Reliability Centered Maintenance (RCM) and company-wide Total Productive Maintenance (TPM).

5 CONCLUSION

The essence of the paper was to explicit show that substantial improvement in the reliability of a drum production line can be achieved by using FMECA approach. Potential equipment failure modes, effects of the failure modes, as well as criticality of the effects were identified for the drum assembly line. The areas of improvement were identified and corrective and prevention measures were implemented resulting in the improvement of the reliability of welder and seamer. FMECA assisted the company to identify the potential failure modes and effects and identify the areas of improvement. After the risk analysis has conducted based on RPN the company managed to put in place corrective and prevention measures to prevent failures which improved the reliability of drum assembly line. The benefits derived from implementation of FMECA were reduction in the number of breakdowns as the MTBF of welder increased from 8 hours to 120 hours after the machine was put on preventive maintenance plan and MTBF of seamer has improved from 80 hours to 150 hours. Concurrently, the reliability of these machines improved, which improved the overall availability of the whole production line. It was also noted that most of the machines for the drum production line were not on the preventive maintenance plan and preventive maintenance should also be extended to these machines equipment or equipment components. It is recommended that the drum manufacturer commits itself to implementation of full scale RCM and TPM. On overall, FMECA can be the vital tool in the organisation and companies could adopt the same approach to optimise their performance.

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UNDERSTANDING THE REAL COST OF POOR QUALITY: CASE STUDY AT BOSCH SOUTH AFRICA (AUTOMOTIVE INDUSTRY)

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ABSTRACT

No company wants to lose money on what could have been prevented and there is no better place to highlight this than in the cost of poor quality. The automotive industry continues to see an increase in the cost of poor quality, costs it cannot justify nor sustain. This paper seeks to investigate the real costs of poor quality by using a case study at Bosch in South Africa, limiting it to one particular incident in November 2015 affecting numerous customers. It further seeks to highlight the importance of balancing productivity against quality in an industry that has a huge growth potential that is threatened by financial losses.

All spheres of management and all employees within organizations are affected by the cost of poor quality, but the worst inconvenienced are the customers who in turn choose to publish such inconveniences to the general public, thus reducing sales. A reduction in sales and loss of customers is perhaps the biggest nightmare the executives have to battle with as they attempt to bring escalating costs down to acceptable levels.

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1. INTRODUCTION

The 2015 Takata airbag recall that is said to have affected some 34 million vehicles is perhaps the largest the automotive industry has seen to date [1]. It can be argued that the crisis has cost the company (Takata) far more than what it would have budgetted for as quality expenses, as per norm in the industry. Similar recalls have been seen in the recent past, e.g. Toyota's accelerator pedal recall of 2014 (4.4 Mio), Ford's parking gear recall of 2014 (21 Mio), General Motors'ignition switch recall of 2014 (5,8 Mio). Although the real costs of these recalls are kept a close secret by suppliers and manufacturers, it is a known fact that they are exhubitant and all stakeholders in the automotive manufacturing industry should strive to minimise and eliminate such unjustifiable costs.

Board of Directors and Executive Managers in the industry would be concerned about the escalating costs of sales, especially those that could have been prevented, e.g. overtime costs due to internal inefficiencies, and internal/external quality costs – the focus of this paper being on quality costs. These costs are eroding profit margins and denying investors and interested parties growth potential and quicker returns-on-investments. Managers across all levels in both supplier and original equipment manufacturers would be interested in understanding the nature and extend of these costs that are both avoidable and preventable. It is expected that in the application of "management by objectives," all managers will in a near future begin to be given quality costs reduction targets due to current unsustainable levels.

Arguably, the worst hit in the supply chain are the Tier 1 and lower tiered suppliers, as they often do not have the financial capacity to handle a costly automotive recall. The cost of replacing or repairing one component in a recalled vehicle can often amount to a thousand times what the original supplied product cost as would be seen in the case study herein. Data available seem to suggest that the bulk of recalls in the past five years till end of 2015 have been supplier related. If this is going to be a trend going forward, original manufacturers need to be worried as reputation is at stake and it means potential loss of sales and profits. Pressure is therefore on the suppliers to understand costs of poor quality and minimise them to negligible levels.

This paper uses a case study at Bosch South Africa on an incident from November 2015 affecting two of main customers (names withheld for customer protection).

2. RESEARCH OBJECTIVES, DESIGN, AND METHODOLOGY

It is the primary objective of this paper to investigate the real costs of poor quality in the automotive industry by using a case study at Bosch plant in Brits. This primary objective is supported by the following secondary objectives:

- Research and document cost of poor quality in general
- Identify causes of poor quality in the automotive industry
- Research and document classification of quality costs
- Research and document accounting methods for poor quality (defect) costs
- Recommend methods of improving classification and financial accounting of poor quality (defect) costs.

A number of empirical study methods are used by various researchers (Sila, 2006; Ugboro, 2000) [9-10] to solve practical problems; in this this paper, an "action research" methodology is employed. Cooper & Schindler (2011) [13] define an action research as *"a study carried out in the course of an occupation to investigate an identified challenge and to improve methods and approaches of those involved."* The challenge identified by researcher in this paper is the incorrect quantification and understanding of the real cost of poor quality.

This paper, in agreement with Cooper & Schindler [13], seeks to improve understanding of the problem, and improve cost calculation and classification methods.

The research further takes the positivism research philosophy, i.e. a belief already exists that a phenomena exixts independently of a researcher and can be detcted through direct observation. Sekaran & Bougie [14] defines the approach as follows, *"The positivist or mainstream approach evidences the way to achieve the truth, believing that it is always possible to predict that world."*

Data was sourced from an automotive manufacturing concern in South Africa. The company is a Tier-1 supplier to the seven Original Equipment Manufacturers (OEM) in the country and has export contracts. Period of analysis is a 30 days period from 15 November to 15 December 2015; this period is significant because the chosen quality incident falls within it. Except for this particular incident falling within the period, it has also been a period in which a lot of customer complaints are received and it is, therefore, not surprising that a major quality problem from this plant occurred during the period.

3. LITERATURE REVIEW

3.1 Cost of poor quality

Besterfield [2] devoted a significant portion of his work to expand on available literature in defining the cost of poor quality as,

"… Those costs associated with the non-achievement of product or service quality as defined by the requirements established by the organization and its contracts with customers and society. Simply stated, it is the cost of poor products or services."

His view, supported by Foster [3] and Oakland [4], is that quality assurance or control should contribute to the bottom-line and that minimizing cost of poor quality will lead to an increase in organizational profits. In today's highly competitive and cost-driven business environment, management of any institution will have an interest in this simple method of improving productivity.

From a "Cost and Management Accounting" perspective, Niemand et al. state that the cost of poor quality are costs incurred due to the existence of poor quality [5].

3.2 Classification of quality failure costs

Available literature makes a distinction between two cost categories for quality, i.e. cost of conformance (COC) and cost of non-conformance (CON). Foster defines the COC as expenses incurred by an organization to assure quality, and CONC as expenses incurred due to poor quality [3]. Because organizations compete on costs and investors are interested in quicker returns, both cost categories need to be monitored to ensure a balance. This sentiment is backed up by Oakland when he states,

"The costs of quality are no different from any other costs. Like the costs of maintenance, design, sales, production/operations, and other activities, they can be budgeted, measured, and analysed" [4].

A popular cost model within the Quality Management Systems (QMS) field is known as the PAF model, an acronym for Prevention, Appraisal, and Failure. This model was developed by Joseph Juran (1951) and Arman Feigenbaum (1956) with an intention to categorize quality costs into three broad categories, which were further broken down into sub-categories according to the following tables [1-3].

Table 1: Prevention costs

Type	***Explanation***
Product/service requirements	Determination of requirements and the setting of corresponding specifications for incoming materials, processes, intermediates, finished products, and services.
Quality planning	Creation of quality, reliability, and operational, production, supervision, process control, inspection, and other special plans.
Quality assurance	Creation and maintenance of the quality system
Inspection equipment	Design, development, and/or purchase of equipment for use in inspection work.
Quality training	Development, preparation, and maintenance of training programs for operators, supervisors, staff, and mangers to both achieve and maintain capability.
Miscellaneous	Clerical, travel, supply, shipping, communications, and other general office management activities associated with quality.

Table 2: Appraisal costs

Type	*Explanation*
Verification	Checking of incoming material, process-set-up, first-offs, running processes, intermediates and final products, and testing against agreed specifications.
Quality audits	Costs incurred during checks to determine if the QMS is functioning satisfactorily.
Inspection equipment	Costs of calibrating and maintaining equipment used in all inspection activities
Vendor rating	Costs of assessing and approving of all suppliers, of both products and services.

Table 3: Failure costs

Type	*Explanation*
Internal failures	Costs incurred when the results of work fail to reach design quality standards and are detected ***before*** products are transferred to the customers.
External failures	Costs incurred when the results of work fail to reach design quality standards but are only detected ***after*** products have been transferred to the customers.

Of the three cost categories according to the PAF model, prevention costs are deemed to be the most difficult to quantify due to their subjective nature [3]. Clear guidelines on defining or classifying quality costs have been attempted, but this has not taken away subjective nature of some of the types defined in literature [6].

Oakland developed a poetic definition of the three cost categories [4],

- Prevention costs: costs of doing it right the first time.
- Appraisal costs: costs of checking if it is right.
- Failure costs: costs of getting it wrong.

Popular with the PAF model is the cost improvement model used to depict the relationship between quality cost and awareness levels within an organization [6]. This pictorial view is given in Figure 1.

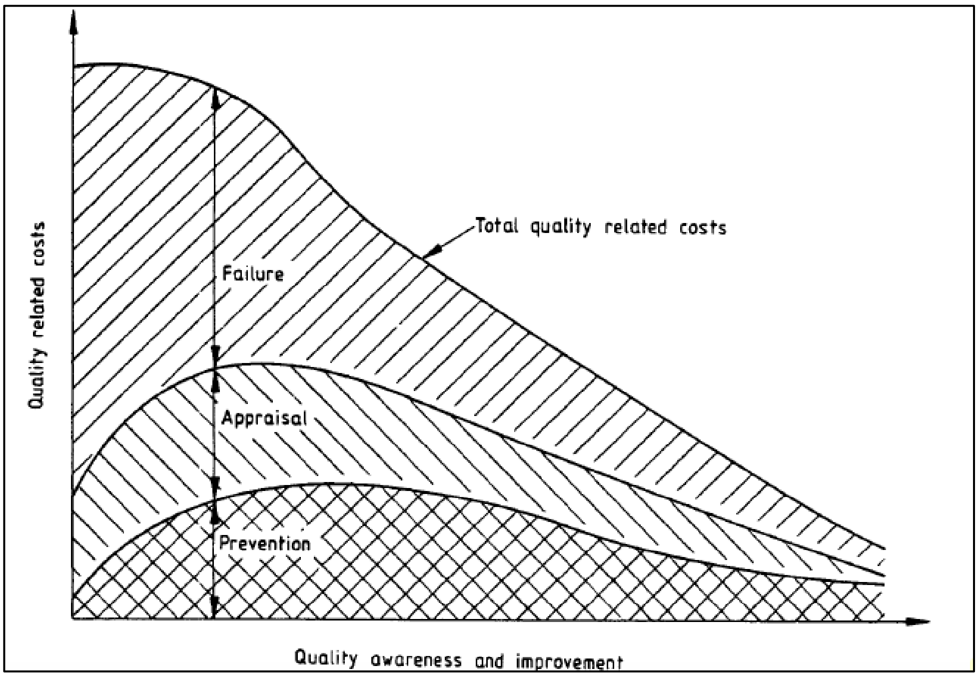


Figure 1: Increasing quality awareness & improvement activities (Source: BS6143: 1992)

Although the model is presented as a continuous improvement model, there can never a point in time where total quality costs are equal to zero. In order to keep failure costs at a minimum, some appraisal and prevention costs have to be incurred. In the automotive industry, requirements on ISO/TS16949 makes it impossible to keep total quality costs at zero, e.g. quality planning, audits, inspections, calibrations, and continual improvements are mandatory requirements for which resources have to be made available [7].

An important message to be deduced from a model in Figure 1 is that as quality awareness & improvement are increased, the total cost of quality decreases. The model suggests that to improve profit margins through quality as a strategy, quality awareness and improvement should be increased. Using the TQM philosophy, all levels of employees should be covered in the quality awareness and improvement initiatives [4].

Alternative to the PAF, a process cost model was developed and published as a standard by the British Standards Institution [8]. The standards calls for a move away from traditional means of reporting on quality defects (rejection and defective materials reports) to a presentation of quality reports in financial terms. This paper will argue for this assertion but go beyond and call for correct classification/calculation of quality related costs.

In expanding on the Taguchi quality loss function, Teli and Majali [15] outlines the following key benefits:

- *We cannot reduce costs without affecting quality*
- *We can improve quality without increasing costs, and*
- *We can reduce cost by reducing variations; when we do so, performance and quality will automatically improve.*

Taguchi makes a significant contribution towards quality literature by stating an implied relationship between quality and costs, and proposing simple means by which quality and costs can be improved within organizations.

4. THE PROBLEM

4.1 Background

In most assembly processes, various subcomponents are joined together by a variety of methods, e.g. welding, glue application, riveting, and screwing. The joining process is an important product characteristic that requires proper process controls. In the automotive industry, various methods are applied to document and control the process parameters that have a bearing on the joining product characteristic. A Failure Mode Effect Analysis (FMEA) is used as an analytical tool to assess the impact of failures and potential failures on the functioning of a product and quantify these in a risk form using a Risk Priority Number or equivalent rating criteria [12]. Figure 4.1 is an example of an applied FMEA method.

Process Step / Function	Requirement	Potential Failure Mode	Potential Effect(s) of Failure	Severity	Classification	Potential Cause(s) of Failure	Current Process Controls Prevention	Occurrence	Current Process Controls Detection	Detection	RPN	Recommended Action	Responsibility & Target Completion Date	Action Results: Actions Taken Completion Date	Severity	Occurrence	Detection	RPN
Op 70: Manual application of wax inside door panel	Cover inner door, lower surfaces with wax to specification thickness	Insufficient wax coverage over specified surface	Allows integrity breach of inner door panel Corroded interior lower door panels Deteriorated life of door leading to: •Unsatisfactory appearance due to rust through paint over time. • Impaired function of interior door hardware	7		Manually inserted spray head not inserted far enough	None	8	Variables check for film thickness Visual check for coverage.	5	280	Add positive depth stop to sprayer	Mfg Engineering by 0X 10 15	Stop added, sprayer checked online	7	2	5	70
												Automate spraying	Mfg Engineering by 0X 12 15	Rejected due to complexity of different doors on the same line				
						Spray head clogged - Viscosity too high - Temperature too low - Pressure too low	Test spray at start-up and after idle periods and preventative maintenance program to clean heads	5	Variables check for film thickness Visual check for coverage.	5	175	Use Design of experiments (DOE) on viscosity vs. temperature vs. pressure	Mfg Engineering by 0X 10 01	Temp and Press Limits were determined and limit controls have been installed- Control charts show process is in control Cpk=1.85	7	1	5	35
						Spray head deformed due to impact	Preventative maintenance programs to maintain heads	2	Variables check for film thickness Visual check for coverage.	5	70	None						

Figure 4.1: FMEA Example (Source: AIAG FMEA Manual, 4th Edition).

FMEA, after identifying what is critical and important, becomes an input for the Control Plan which "*provides a structured approach for the design, selection, and implementation of value-added control methods for the total system*' (AIAG, 2008) [13]. Figure 4.2 shows an example of a Control Plan of a set-up dominant process from the AIAG manual.

CONTROL PLAN

☐ Prototype ☐ Pre-Launch ☑ Production — Page 4 of 23

Control Plan Number: 001	Key Contact/Phone: J. Davis /313-555-5555	Date (Orig.): 1/26/2008	Date (Rev.): 2/2/2008
Part Number/Latest Change Level: 22521211/G 11-2-92	Core Team: Product Development Team (E01) - See List	Customer Engineering Approval/Date (If Req'd.)	
Part Name/Description: Plastic Injection Molded Grill	Organization/Plant Approval/Date	Customer Quality Approval/Date (If Req'd.)	
Organization/Plant: 4-B Grill Co. Plant #3 — Organization Code: 0123	Other Approval/Date (If Req'd.)	Other Approval/Date (If Req'd.)	

PART/ PROCESS NUMBER	PROCESS NAME/ OPERATION DESCRIPTION	MACHINE, DEVICE, JIG,TOOLS FOR MFG.	CHARACTERISTICS			SPECIAL CHAR. CLASS	METHODS					REACTION PLAN
			NO.	PRODUCT	PROCESS		PRODUCT/PROCESS SPECIFICATION/ TOLERANCE	EVALUATION/ MEASUREMENT TECHNIQUE	SAMPLE SIZE	SAMPLE FREQ.	CONTROL METHOD	
3	Plastic Injection Molding	Machine No. 1-5	18	Appearance		*	Free of blemishes	Visual Inspection	100%	Continuous	100% inspection	Notify Inspector
				No blemishes			flowlines	1 st piece buy-off			Check Sheet	Adjust/re-check
							sink marks	1 st piece buy-off			Check Sheet	Adjust/re-check
		Machine No. 1-5	19	Mounting hole loc.		*	Hole "X" location	Fixture #10	1st piece	buy-off per run	Check Sheet	Adjust/re-check
							25 ± 1mm		5 pcs	hr	x-R chart	Quarantine and adjust
		Machine No. 1-5	20	Dimension		*	Gap 3 ± .5mm	Fixture #10	1st piece	buy-off per run	Check Sheet	Adjust and re-check
		Fixture #10	21	Perimeter fit		*	Gap 3 ± .5mm	Check gap to fixture 4 locations	5 pcs	hr	x-R chart	Quarantine and adjust
		Machine No. 1-5	22		Set-up of mold machine		See attached set-up card	Review of set-up card and machine settings		Each set-up	1st piece buy-off	Adjust and re-check
											Inspector verifies settings	

Figure 4.2: Control Plan Example (Source: AIAG APQP/CP, 2nd Edition).

These two methods are herein referenced and explained because of their role in preventing failures within the automotive industry. When correctly applied as quality tools for identifying and limiting process failures, FMEA and Control Plan are considered to be at the forefront of a preventive approach in Quality Management Systems in accordance with ISO/TS16949 [7]

4.2 Torque Process – The Failure

This empirical research work focuses on the failure of a torque process on an alternator assembly during a 15 November – 15 December 2015. In an alternator assembly, herein referred to as an "alternator", between eight and ten torque processes are employed to join various components together according to defined specifications. Adherence to these specifications is an important process characteristic as it is desired that none of the components torqued together gets loose during operation.

For an optimal operation of an alternator, it needs to be appreciated that if functions within a vibrating environment and potential loosening of screws and nuts becomes a possibility to be dealt with by observing torque specifications.

Figure 4.3 depicts the products in question with an exploded view to create an impression of some of the sub-components that requires joining together during an assembly process.

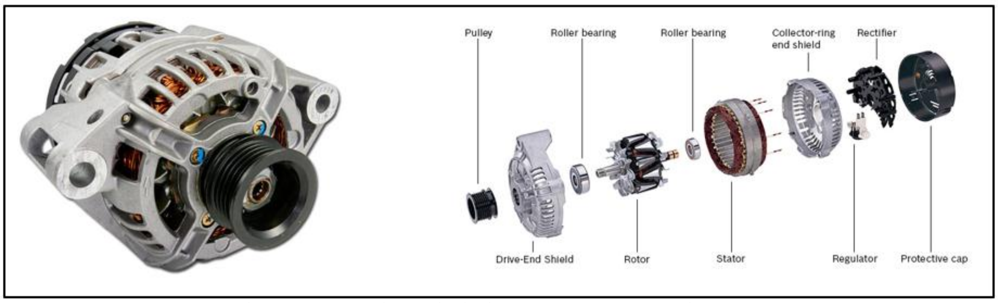


Figure 4.3: Alternator, with exploded view (Source: Bosch Automotive Parts)

In the assembly process, four throughbolts are used to join together the Drive-End and Collector-Ring End Shields. A simalteneous torque is applied to the four bolts by an automated torque driver (SE330 type) according to specifications. Figure 4.4 shows an overview of these four through-bolts.

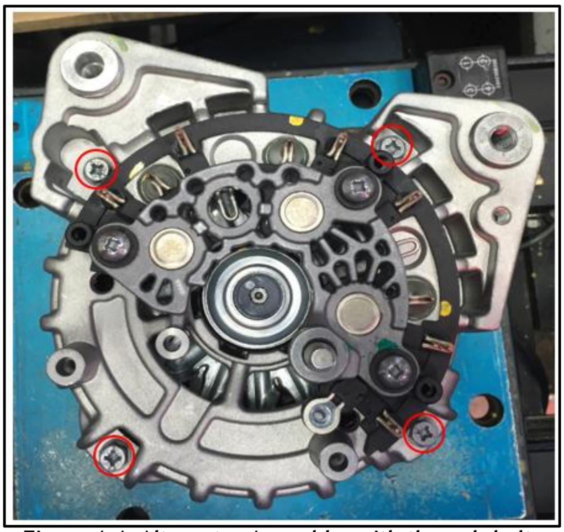


Figure 4.4: Alternator Assembly, with through-bolts

A required torque specification for each of the bolts is 4.00 to 4.6Nm according to design and manufacturing drawings. Durign the period under review, an average applied torque was 1.15Nm, almost a quarter of the specified torque.

4.3 What caused the failure?

Various tools are used in the automotive and other industries to find potential and real-causes of failures, most popular being the following: Ishikawa, 8-Dimensions (8D), 5 x Why Drill-Deep, IS/IS NOT.

An Ishikawa, commonly known as the fish-bone diagram is a good starting point in problem solving where a team can brainstorm around a problem. Potential causes of a problem (fish head) are identified and later tested within one or more of other techniques. For the loose through-bolts, identified potential causes are listed in figure 4.5.

One of the objectives of this paper is to highlight general causes of quality failures in the automotive industry and the example used herein reveals a number of these, e.g.

- Standard operating procedures not adhered to,
- Poor incoming quality (materials),
- Lack of management intervention,
- Ineffective quality checks,
- Poor maintenance,
- Incorrect use of equipment,
- Incorrect machine setting, and
- Ineffective training methods.

The list of possible contributors to poor quality is endless; the above examples are but the most common that come up in problem-solving efforts. Some quality defects are as a result of poor product/process design – they generally require a lot of in-process checks which increase the appraisal costs, otherwise the failure costs are in the increase.

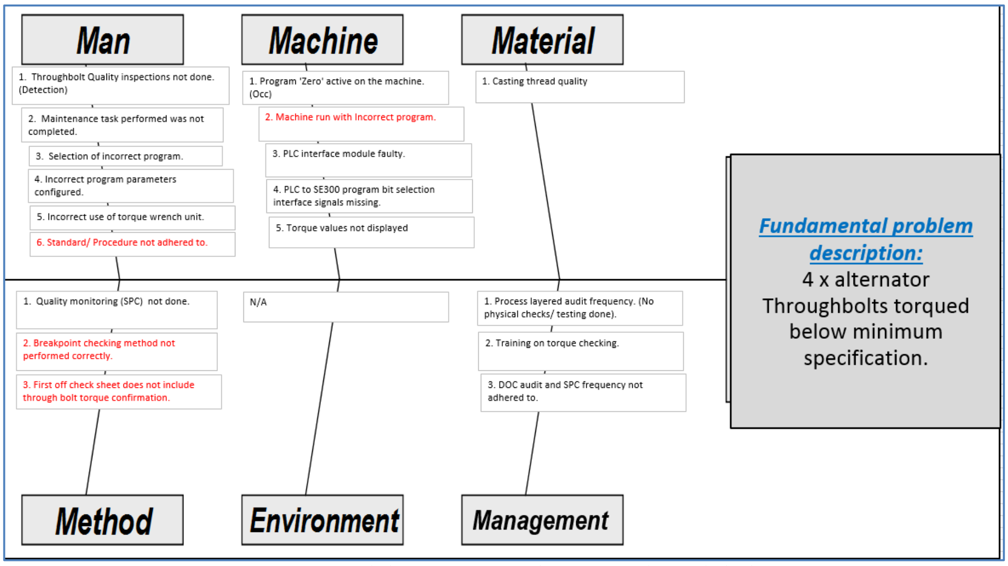


Figure 4.5: Ishikawa – Loose Alternator Through-bolts

Potential failures are categorised according to the 6M classification method, i.e. Man, Method, Mother Nature (Environment), Method, Material, Management. Items highlighted in red were chosen by a team to be further analysed and interrogated.

From a brainstorming action using an Ishikawa, a drill-deep analysis was carried out using a 5 x Why technique, where a questioning technique is repeated until an answer leads to a real root-cause. The application of this technique seeks to ensure that symptoms are separated from causes and thus lead to permanent eradication of failures by implementing corrective actions that address causes and not symptoms. Correct usage of this technique, therefore, has huge benefits to the industry and any other sector which wants to do a proper problem solving.

For the problem under analysis, figure 4.6 details a 5 x Why technique employed by a problem solving team. With this analysis, a team concluded that it was possible for the error to happen due to a lack of a system to prompt Maintenance Technician to ensure all interface plugs were replaced after maintenance activities were carried out on a torque driver. Same technique can be split into three sections, i.e.

1. Why did the failure occur?
2. Why was the failure not detected?
3. Why was the failure not prevented?

Figure 4.6 addresses the first of these 3 questions. On why was it not detected, analysis revealed that the torque verification process used by Product Auditors was ineffective. This is on the "management section" on Ishikawa.

Problem: Loose alternator through-bolts

Why 1: Why were 4 alternator through-bolts torqued below minimum specification?
Ans 1: Torque driver operated with incorrect program

Why 2: Why was the torque driver operated with an incorrect program?
Ans 2: Interface bits for torque program selection missing (defaulted to program zero)

Why 3: Why was the interface bits for program selection missing?
Ans 3: Interface plug was removed and not replaced after maintenance activities

Why 4: Why was an interface plug removed and not replaced after maintenance activities?
Ans 4: Maintenance Technician forgot to replace interface plug

Why 5: Why did the Maintenance Technician forget to replace interface plug?
Ans 5: No system in place to remind Technician to replace interface plugs after maintenance

Figure 4.6: 5 x Why Analysis – Loose Alternator Through-bolts

The impact of a failure in the company's maintenance and product audit functions caused a huge financial loss. This loss is a focus of this research paper. Products that were already delivered to products had to be contained, i.e. re-torqued manually to a defined specification. Some of the alternators were already assembled onto engines and these also required special actions as a risk of a completely loose alternator became evident.

Two customers were affected, names of which are not revealed to protect them. "Customer A" and "Customer B" shall be used as code names for the affected customers.

4.4 What was done?

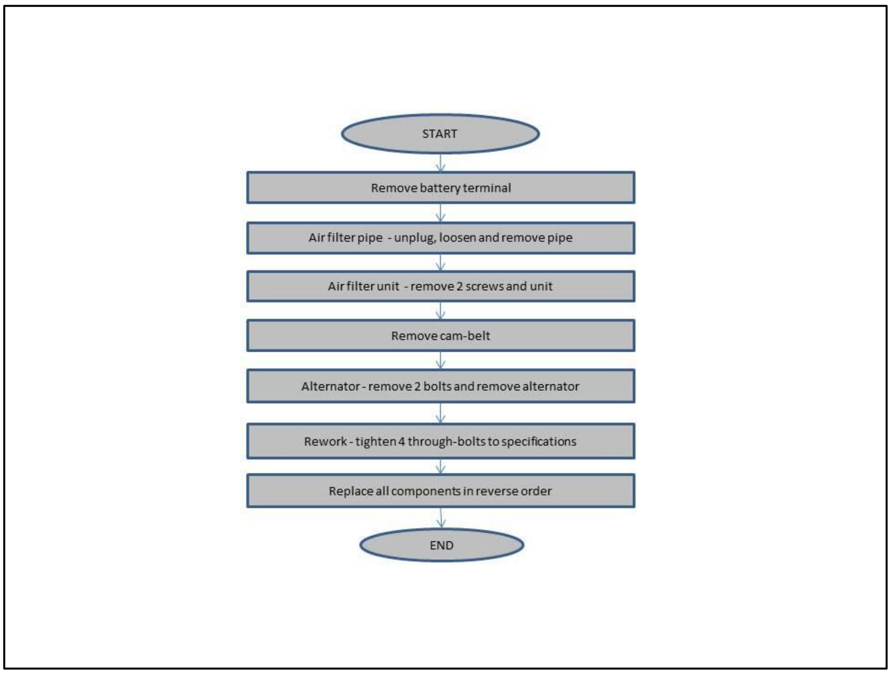
Customer A required an external sorting/rework team. The amount of parts that had to be reworked was 300 and no parts were fitted onto engines/vehicles.

Customer B was severely affected and required a team to be despatched to its manufacturing location for sorting and rework actions. This was carried out in a period of 14 days with a team of 13 persons with skills levels including Technicians, Engineers, and Managers. A total of 554 alternators had to be checked and reworked, i.e. re-torqued to required specification in the process represented by flowchart 1.

A flowchart is herein added to indicate the effort it took to rework all 554 alternators, a task requiring approximately 13 minutes per part, thus equalling 120 hours of active rework time. What the flowchart is not indicating are the following activities:

- Daily security checks for team members before and after rework activities,
- Driving and walking to various locations (manufacturing areas, warehouses, and ship yards) to carry out rework activities, and
- Activities to locate defective products through the logistics chain.

There was a total of 110 parts that could not be contained as they were already in a ship for export and a risk assessment was carried out and the risk was found to be minimal. It was argued that in the event any or all of the through-bolts came loose in the engine compartment, the bolts holding an alternator to an engine block would be sufficient to hold parts together and prevent disintegration.



Flowchart 1: Alternator rework procedure.

5. RESULTS AND DISCUSSION

For any organization to spend resources on fixing a quality problem that is both preventable and avoidable, should be a source of concern. Although the rework activity carried out in the case study employed in this paper prevented a recall activity and reduced risks to the customers, it left the manufacturer with a high external failure costs. An indication of costs that had to be accounted for is given below.

1. Travelling costs for 13 team members
2. Accommodation costs for 13 team members
3. Daily allowances for lunch incidental expenses
4. Labour costs for 13 members over 14 days

Although the internal directive of the company makes provision and requires all costs related to a rework activity to be accounted for, the available accounting tool excludes most of the costs identified above and focuses on the following:

1. Piece price, i.e. sales price per component if parts are returned, and
2. External (third) party labour costs.

In cases where failed parts are returned from customers and reworked in the plant, the labour and additional materials employed to carry out the activity are not accounted for. With this practice, it becomes impossible for real costs of quality to be understood and it results in a better projection of quality because of miscalculations. These miscalculations prevent management from intervening and curbing escalating quality costs. The weakness herein is a methodical failure since the available accounting policies make a distinction and correct categorization of different quality costs, but the available collected data used as an input for costing does not differentiate costs correctly.

From the popular model for depicting an optimum balance between prevention and failure costs (figure 4.7), it goes without a discussion that no organization will be able to achieve and maintain desired quality levels without investing in prevention costs. If the failure costs are increasing and the prevention costs remain the same, an organization will find itself in a difficult financial situation where the costs of manufacturing are increased and these cannot be recovered from the customers.

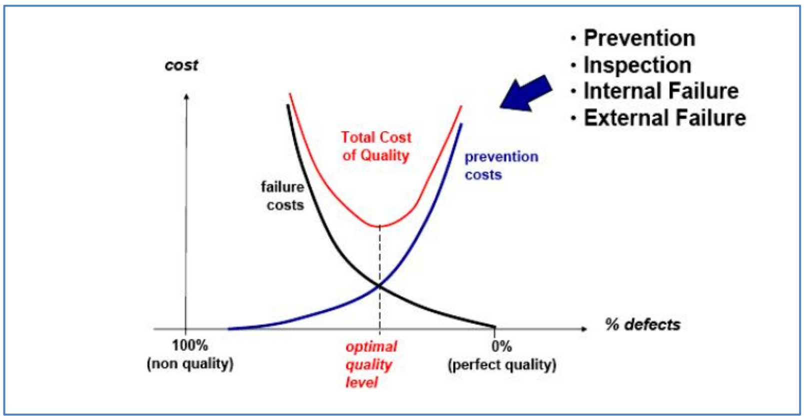


Figure 4.7: Optimum Quality Level - Cost of quality.

In management reports, the only distinction made is between internal and external failure costs, thus leaving out the other two costs classification of prevention and appraisal costs. In the case example for a given accounting period, a spike in the external failure costs as a result of the 14 days external rework using high skilled workers would have been observed. In the same case, there was an effort to inspect materials already produced (appraisal costs) but not delivered to the customers. In addition, there were process improvements initiatives (prevention costs) that had to be implemented in order to prevent the same defect occurring again; Machine Operators and other support staff had to be re-trained on the improved processes.

By making mention of a few examples of unaccounted quality costs in this case study, it is apparent that in any manufacturing plant, there will be many similar cases and a summation of these hidden costs has to be a source of concern for management.

In the example used, critical aspect such as waiting times due to increased inspection efforts whenever defective products are received from suppliers (internal and external), are not addressed.

Forster [3] correctly puts the challenge facing Quality and Accounting Professionals by stating,

> *"One of the impediments to the collection of quality cost data has been the lack of acceptable accounting standards for these costs. For example, the standard accounting*

definition for quality is "meeting specifications." This narrow definition limits organizations desiring to quantify and measure customer requirements as a means of improving service to the customer. A reason for this is that accounting rules require definitions that are not open-ended or open to alternative interpretations".

Quality managers have to take note of the limitations brought by the accounting principles and realise that until viable accounting models are designed, a skewed picture of real quality costs will continue to be projected, and such a picture does not support quality improvements due to the ice-berg effect where majority of costs are both hidden and unaccounted for.

6. CONCLUSION

The case presented in this paper is one of many incidents that occur in the manufacturing industries and in automotive industry in particular, research shows an increase in this occurrences [15]. The absence of a good accounting model to capture real costs of poor quality makes it difficult to quantify the extent to which quality contributes to business objectives. It, therefore, has to be understood that if organizations do not make an effort to quantify the true cost of poor quality, jobs and growth are at risk as return on investments are threatened by escalating costs.

Managers and specialists tasked with reduction of quality costs and continuous improvements have a duty of care in the methods used to collect costs related to costs of poor quality. Stakeholders have to be aware that when costs of poor quality is not correctly accounted for, cost management within a manufacturing entity becomes too difficult and budgeting and provision of resources cannot be effectively carried out.

Organizations have to be aware of escalating costs of internal and external failure costs and make some concerted efforts to reducing these by increasing on preventions and appraisal costs. The P-A-F paradigm prevents a simplified model of categorising quality costs and can be a good starting point in making sure that almost all costs related to making sure customers are satisfied, are classified and accounted for.

The British Standard model [6] for reduction of quality costs through quality awareness and improvement initiatives can only be effective when such quality costs are adequately classified and accounted for.

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EVALUATION OF WASTE-TO-ENERGY GRATE INCINERATION POWER PLANT DRIVERS AND BARRIERS FOR A SMALL SOUTH AFRICAN CITY: A SWOT ANALYSIS APPROACH

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ABSTRACT

The global share of energy from waste is approximately 0.4% of global energy consumption. The average amount of municipal solid waste generated in South Africa is equivalent to 11 GWh wasted energy. This paper focuses on the drivers and barriers to the establishment of a waste-to-energy (WtE) grate incineration power plant for a small South African city in the North-West Province. It employs strength, weakness, opportunity and threats (SWOT) analysis to analyse the drivers and barriers to implementation of such a plant. Strengths and opportunities were acknowledged as drivers to the establishment of such a plant and weaknesses and threats as barriers. A holistic investigation using a SWOT analysis showed significantly more drivers than barriers. The study proved that SWOT analysis can be used as both a preliminary technology selection tool and an investment decision-making tool.

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1. INTRODUCTION

South Africa is currently facing power shortages due to increase in demand, failure to invest in additional capacity and limited maintenance. Simultaneously, over the years, municipal solid waste (MSW) generation and management problems have escalated [1, 2] in response to constant population growth and expansion of urbanization.

A significant amount of energy is wasted in South African landfill, as over 90% of MSW is disposed of in landfill and dumped illegally without energy recovery [2]. Landfill poses a number of environmental problems, such as greenhouse gases (methane and carbon dioxide) emissions, leakages into groundwater and inefficient space utilization [3].

The global trend is that the focus in waste management strategies has shifted to harmonize with the goal of sustainable development through electrical power generation and minimization of the adverse effects of landfill [4, 5]. MSW can now be viewed as a useful resource and can be used as an alternative renewable energy source.

Waste-to-energy (WtE) thermal technologies have the potential to meet the goal of sustainable waste management [6]. Developed countries that have implemented WtE thermal technologies have boosted their recycling rates, minimized the adverse impacts of landfill and increased the renewable energy generation level [4, 7].

South African cities are faced with power shortages, high unemployment rates and MSW generation and management problems, with landfill and illegal dumping dominating waste management strategies. WtE thermal technologies can be used to harness energy wasted in the landfill of South African cities, at the same time creating employment.

Maisiri [8, 9], performed technological and performance evaluation of four WtE thermal technologies and financial analysis of WtE grate incineration power plant. This paper is a continuation of this work and its objective is to carry out a SWOT analysis for a WtE grate incineration power plant for a small South African city in the North-West Province.

The paper is organized as follows: firstly, an overview on WtE grate incineration power plant is presented in section 2. Small city WtE grate incineration power plant SWOT analysis (Section 3) is discussed next. Small city internal drivers and barriers to WtE grate incineration power plant is deliberated in section 4. This is followed by a discussion on external drivers and barrires to WtE grate incineration power plant in section 5. A discussion on SWOT analysis results (Section 6) and conclusion (Section 7) are presented last.

2. WASTE-TO-ENERGY GRATE INCINERATION OVERVIEW

WtE grate incineration technology, commonly know as mass burn, is a conventional technology used to thermally treat MSW and other waste streams in a suststainble manner. Waste is treated with the objective of recovering energy inform of heat and electricty [10, 11, 12].

Oualitative and quantitative analysis evaluations carried by Maisiri [8, 9] proved that WtE grate incineration is the dominant and commercialy accepted technology over other WtE thermal technologies. The investigation further indicates that grate incineration remains the preferred and most economical thermal technology in view of its reliability, capability to incinerate assorted waste, lower operational complexity and higher power efficiency [13].

WtE grate incineration has been in use for more than 130 years and more that 90% of European WtE plants use grate incineration, and there are more than 1000 operational WtE plant installations across the world [9,14]. Figure 1 shows WtE grate incienarion power plant process flow diagram. Selected existing WtE grate incineration power plants are presented in Table 1.

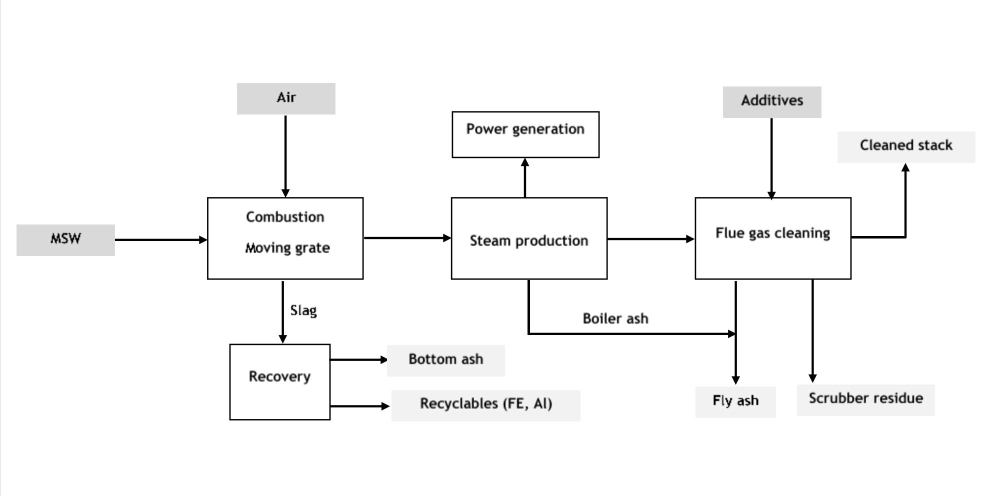

Figure 1: WtE grate incineration process flow diagram [14].

Table 1: Existing WtE grate incineration power plants [14].

Plant	Country	Discription	Capacity (Ton/year)
AEB, Amsterdam	The Netherlands	The largest plant in the Netherlands. Produces electricity with a total thermal efficiency of 30%.	1,370,000
Lakeside, London	UK	A recently commissioned merchant incinerator developed by a major UK waste management company. The plant processes residual MSW and other waste	410,000
Spittelau, Vienna, Austria	Austria	Relatively old conventional moving grate combustion plant. The first facility that used architectural treatment to gain public acceptance.	250,000
Issyles Moulineaux, Paris	France	The newest and largest incineration plant in France.	460,000
Reno Nord, Aalborg	Denmark	Modern incinerator in CHP mode and providing district heating to the local city.	160000 (line 4)

3. WASTE-TO-ENERGY GRATE INCINERATION SWOT ANALYSIS

SWOT analysis is a tool used for analysing internal and external environments in order to ensure a systematic approach and support in making decisions. Strengths and weaknesses are regarded as internal factors, while opportunities and threats are external factors [15].

In this study, SWOT analysis is applied by regarding WtE drivers and barriers for the small city case study as internal factors, while drivers and barriers outside the small city but within South Africa are regarded as external factors. Table 2 summarizes the strengths, weaknesses, opportunities and threats associated with establishing a WtE grate incineration power plant for a small city in the North-West Province.

Table 2: South small city WtE grate incineration power plant SWOT analysis [13].

Small city internal WtE investment drivers and barriers	
Strengths	**Weakness**
• Average MSW generation growth rate 3.04% per annum (Section 4.1.1) • MSW characterized by more than 80% of combustible material (Section 4.1.2).	• Dominance of wet months in a year in the small city (Section 4.2.1). • MSW yearly tonnages fluctuations (Section 4.2.2).

• Significant percentage of metals promotes material recovery (Section 4.1.2). • 98.3% dominance of landfill as MSW management strategy for the small city (Section 4.1.3). • Increased illegal dumping in the small city (Section 4.1.3).	• Absence of landfill diversion measures evidenced by no cost to dump waste at the landfill (Section 4.2.3). • Local culture of non-payment for service especially in the African and colored settlements (Section 5.2.4).
Small city external WtE investment drivers and barriers	
Opportunities • 90% dominance of landfill as MSW strategy at national level (Section 5.1.1). • National waste generation growth rate estimated 3.0% per annum (Section 5.1.2). • 34% of non-recyclable combustible waste in the national MSW characterization (Section 5.1.2). • Non-energy recovery methods used to treat health care risk waste (HCRW) (Section 5.1.2). • National power crisis, promotion of renewable energy (Section 5.1.3) • Intermittent nature of solar and wind energy (Section 5.1.3). • Accumulation of waste vehicle tyre (WT) stockpile nationwide (Section 5.1.4). • Anticipated implementation of carbon tax and offset incentives in the country (Section 5.1.5)	**Threats** • WtE thermal technologies are not allocated generating capacity in the REIPPP (Section 5.2.1). • Lack of enforcement of environmental legislation in the country hampers technological innovation in the waste sector (Sections 5.2.2). • High capital cost that requires access to investment subsidy from government institutions (Section 5.2.3). • Local culture of non-payment for service especially in the African and colored settlements (Section 2.4).5.

The small city internal and external drivers and barriers to investment in WtE grate incineration power plant are further explained in section 4 and 5.

4. SMALL CITY INTERNAL DRIVERS AND BARRIERS TO WASTE-TO-ENERY PLANT

An MSW management survey was performed for a small municipality in the North-West Province. Data were collected through interviews with representatives from the department of waste management. The collected data were analyzed and this section presents the drivers and barriers to implementation of WtE grate incineration plant identified from data analysis results.

4.1 Internal drivers to the implementation of WtE grate incineration

4.1.1 Municipal solid waste generation trends

MSW generation is on an upward trend due to the expansion of the small city and population growth. Figure 2 shows MSW generation trends for the small municipality. The average MSW generation growth rate was calculated at 3.04% per year [13].

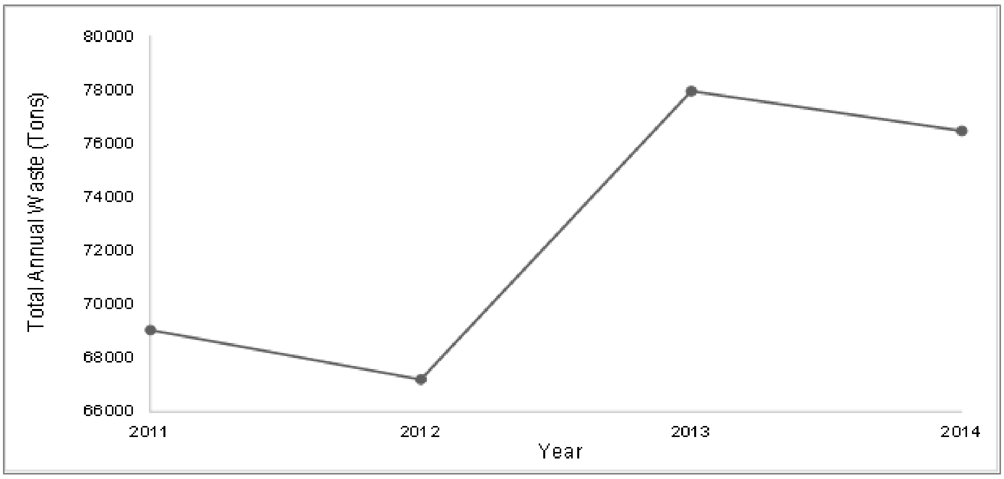

Figure 2: Small city MSW generation trends [9].

4.1.2 Municipal solid waste characterization

Table 3 shows MSW characterization for the small municipality investigated. MSW is characterized with more than 80% of combustible material of which plastic makes the highest percentage. The lower heating value (LHV) of MSW is estimated at 8.0 MJ/kg. There is significant percentage of metals which can promote metal recovery [13].

Table 3: Small municipality MSW characterization [9].

Waste Type	Percentage (%)
Builders rubble	2
Plastic	30
Paper	28
Organics, garden waste	8
Metals	6
Glass	13
Other (textile, disposable nappies, tyres, residue and miscellaneous)	13
TOTAL	**100**

4.1.3 Municipal solid waste management strategies

Landfill was identified as the dominant MSW management strategy for the small municipality investigated. On average 98.3% of the waste generated is landfilled while 1.7% is recycled. Figure 3 shows the contribution of landfill and recycling to the overall waste management strategy of the small city. Investigations proved that there is increase in illegal dumping in the small city [13].

4.2 Internal barriers to the implementation of WtE grate incineration

4.2.1 Municipal solid waste dampness

Data analysis results showed that the small city has five dry months in a year. Figure 4 shows the rainfall patterns recorded at the landfill. Damp MSW dominates because of wet months recorded [9].

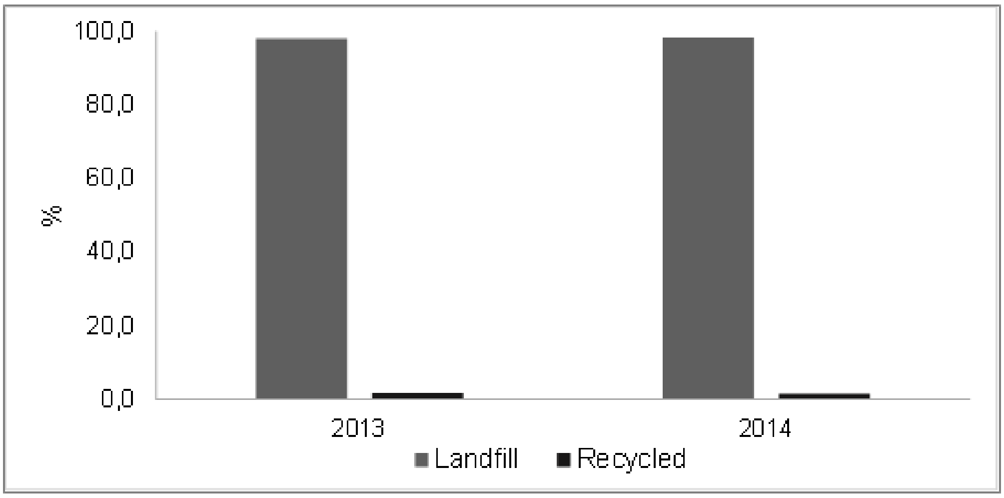

Figure 3: Contribution of landfill and recycling to the overall small city waste management strategy [9].

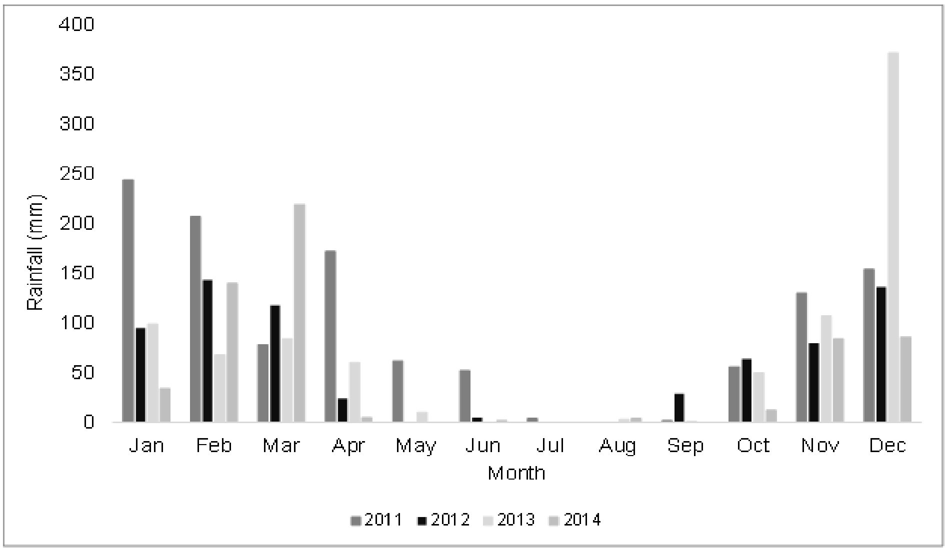

Figure 4: Monthly rainfall trends for the small city [9].

4.2.2 Municipal solid waste generation trends

Figure 2 shows variations in MSW generation trends from the year 2011 to 2014. The trends show significant fluctuations in the amount of MSW generated for the state period. This presents uncertainty in the availability of the waste stream to run the WtE grate incineration plant for the small city [13].

4.2.3 Landfill diversion measures

In developed countries landfill diversion is a major driver of WtE technologies [4]. Measures such as high fees charged on waste managed through landfill have been instituted. WtE grate incineration power plants' gate fees are relatively low compared to landfill gate fees. This leaves waste producers with no other option than using the WtE grate incineration plant as an alternative waste management strategy.

Contrary to this, investigations by Maisiri revealed that no landfill gate fee is levied by the small city in the North-West province and in South Africa at large. This makes landfill the cheapest waste management option and waste producers consequently choose this method. Local residents only pay an insignificant flat fee, embedded in their property bills, to local municipalities. Refuse collection fees vary with residential areas.

5. SMALL CITY EXTERNAL DRIVERS AND BARRIERS TO WASTE-TO-ENERGY PLANT

5.1 External drivers to implementation of waste-to-energy grate incineration

5.1.1 Municipal solid waste management trends

Investigations reveal that landfill dominates other waste management strategies in South Africa, regardless of the amendment of the waste hierarchy in 2011 [2, 16]. Landfill accounts for approximately 90.1% of waste generated in the country. It was noticed that MSW accumulation in uncontrolled dumpsites is rampant in South African cities [2].

Surveyed literature indicate that WtE thermal technologies make no contribution to the country's current MSW management strategies [17]. The current MSW management trends in South Africa offer an opportunity to implement WtE thermal technologies.

Significant waste divergence from landfill can be achieved in the country through WtE thermal technology initiatives. Figure 5 reflects the experience of countries that have implemented WtE thermal technologies. Noticeable decrease in landfill usage and boost in recycling levels can be seen [6].

WtE thermal technologies can boost recycling activities in the country considerably. Countries that have implemented WtE thermal technologies attest that WtE facilities appreciably improve material recovery. WtE facilities promotes recycling through metals recovered from air pollution control and bottom ash residue and in the feedstock preparation stage [6].

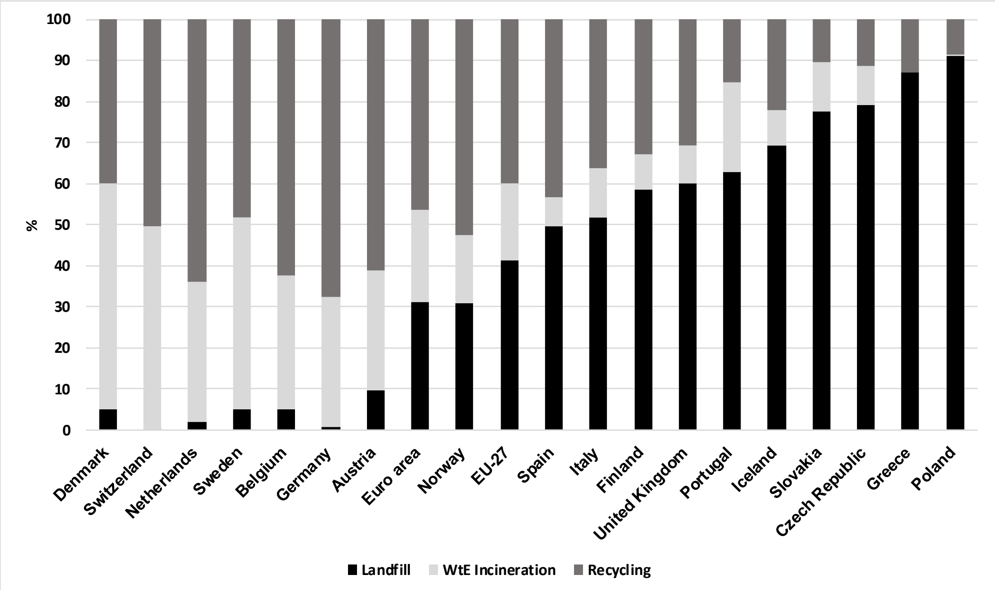

Figure 5: Percentage contribution of WtE incineration, recycling and landfill in managing MSW in EU [7].

5.1.2 Municipal solid waste generation trends.

MSW national generation was at 59 million tonnes in 2011. The national waste generation growth rate is estimated at 3.0% per annum [1]. The MSW composition is dominated by combustible non-recyclable waste with a percentage contribution of 34%. Table 4 shows South Africa's general waste composition by 2011.

In South Africa health care risk waste (HCRW) generation was estimated at 45 232 tonnes per annum in 2011. Gauteng province made the highest percentage contribution to HCRW [1, 18]. HCRW treatment facilities are not decentralized and there is no energy recovery during incineration [18, 19]. Significant illegal dumping of HCRW has been witnessed, with Gauteng recording most HCRW illegal dumping incidents [18].

Table 4: General waste composition [1].

Waste type	Percentage contribution (%)
Glass	4
Plastics	6
Paper	7
Tyres	1
Combustible non-recyclable MSW	34

Organic waste	13
Construction and demolition waste	21
Metals	14

5.1.3 South Africa's energy scenario

In 2014, South Africa was hit with blackouts in its major cities due to a shortfall in electrical energy generation capacity [20]. The shortfall in generation capacity was a result of increased demand, failure to invest in additional supply and limited power plant maintenance.

The renewable energy mix in South Africa comprise wind, solar energy, small-scale hydro generation, biomass and bagasse. MSW is also listed as a potential source of energy in the country. It is estimated that MSW equivalent to 11 000 GWh is wasted in South African landfill per annum [21].

The wasted energy in the landfill can be harnessed through direct incineration and by using methane gas. WtE thermal technologies best suit urban areas where a large amount of waste is produced and the costs of landfill sites are relatively high [22].

International Energy Agency statistics point out that residual MSW has the potential of replacing 2% of fossil fuel in South Africa [4], thus WtE technology can make a significant contribution to the country's renewable energy mix.

South Africa's renewable energy sector is dominated by wind and solar energy. Increasing the share of wind and solar power in the national grid might result in a long-term crisis. A large amount of intermittent renewables in the grid causes grid crush [23]. This is due to their spasmodic nature, which is unable to supply power at all times and when it is needed most.

Unlike wind and solar energy, a WtE grate incineration power plant has load flowing characteristics and has no intermittency problem. A WtE grate incineration power plant can be classified among peaking technologies and can operate 24 hours a day. The capacity factor of a WtE power plant is approximated at 90%. Implementation of WtE grate incineration technology can significantly boost renewable energy and increase national grid security in South Africa.

5.1.4 Waste vehicle tyre management

Muzenda [16] maintains that South Africa is currently faced with problems in waste vehicle tyre (WT) management. It is stated that there are over 60 million WT in South Africa. The illegal dumping and disposal of WT poses significant environmental problems. Landfill and stockpiling are the commonly used WT management strategy in South Africa [16].

The millions of WT lying in stockpiles, landfill and scattered in residential, industrial and rural areas are posing serious environmental and health problems. WT stockpiling causes significant problems such as breeding of insects and rodents, as well as risk of uncontrollable burning, which cause air pollution [16].

Including WT as a supplementary feedstock to a WtE grate incineration power plant has the potential of improving its financial model performance. This is possible through improving the feedstock LHV, thus boosting power generated.

5.1.5 Carbon tax

The Department of National Treasury states that carbon tax will be introduced to facilitate transition to a low-carbon economy. The government of South Africa is moving towards cutting green-house emissions by 34% and 42% in 2020 and 2025 respectively [24]. The move is significantly subject to the availability of sufficient financial, technological and capacity-building support by developed countries.

In order to include the cost of pollution on goods and services, carbon tax will be used as instrument that will ensure polluters, both producers and consumers, held accountable [24]. To this end, major consumers of electricity such as municipalities will incur large carbon tax. The use of alternative green energy such as WtE grate incineration can assist in offsetting such huge amount carbon tax.

WtE grate incineration reduce green-house gas emissions by approximately 13 000 tonnes carbon-dioxide equivalent for every 100 000 tonnes of MSW processed. For combined heat and power systems, green-house gas emissions are lowered by roughly 23 000 tonnes carbon-dioxide equivalent [4]. This means for a 200 000 tonnes capacity WtE grate incineration plant, carbon credits equivalent to 26 000 tonnes carbon-dioxide equivalent can be earned.

5.2 External barriers to implementation of waste-to-energy grate incineration

5.2.1 Renewable energy independent power producer procurement program allocations

Renewable energy independent power producer procurement program (REIPPP) is competitive tender procurement process, designed to promote renewable energy to match global trends and uphold the goal of sustainable development [25]. Table 5 shows summarized results of RIEPPP generation capacity allocation in bidding windows 1 to 4. WtE thermal technologies were not allocated generating capacity in the REIPPP. There has thus been no participation in WtE thermal technologies [26].

Table 5: RIEPPP total allocated and remaining generation capacity [27].

Technology	Total allocated and remaining generation capacity (MW) in bidding windows 1 to 4					
	1	2	3	4	Total allocated	Total remaining
Solar photovoltaic	632	417	435	415	1899	626
Onshore wind	634	563	787	676	2660	660
Concentrated solar power	150	50	200	0	400	0
Small hydro (< 40MW)	0	14	0	5	19	116
Landfill gas	0	0	18	0	18	7
Biomass	0	0	16	25	41	19
Biogas	0	0	0	0	0	60
WtE thermal technologies	0	0	0	0	0	0

5.2.2 Legislative framework

National environmental management in South Africa facilitated the development of regulations that support the Waste Act. These regulations are aimed at supporting innovation and divergence of waste streams from landfill [2]. However, lack of enforcement of environmental legislation has hampered technological innovation in the waste sector.

Investigations show that the authorization of waste management licenses has been hindering novelty and implementation of new technologies in the waste sector. The authorization process is expensive and unrealistically long. Reports of corruption in the system have been received [17].

Enforcement of environmental legislation will encourage different stakeholders to implement alternative technologies in the waste management sector. An effective, efficient and transparent authorization process will attract innovation in the country's waste management sector.

5.2.3 Waste-to-energy thermal technologies high capital investment

WtE thermal technologies involves high capital investment, operational and maintenance costs. In comparison with other renewable energy technologies, the capital cost of a WtE power plant makes it an unfavourable investment option. South Africa has no operating WtE thermal technologies at present. The capital-intensive nature of WtE thermal technologies calls for long-term security to investors.

The capital cost of WtE technologies in South Africa has not been well researched [19]. The capital investment figures used are taken from the experience of other countries that use WtE thermal technologies. Because of the availability and low cost of material, the estimated capital cost of WtE thermal technologies in South Africa might be significantly lower.

5.2.4 Local culture

The financial viability of a WtE grate incineration power plant in developed countries is noticeably influenced by the MSW gate fees. A negative price on waste has resulted in the success of many WtE grate incineration power plant projects. This means that waste producers must pay a fee to the plant operator for their waste to be processed [4].

The local culture of non-payment for service, mainly encountered in African and colored communities [28], promotes failure of the waste negative price model. This adversely affects the financial viability of a WtE power plant.

The local culture might necessitate a WtE plant financial model that will have a positive price on waste. This means that the WtE plant operator will have to pay waste generators for their waste to be processed. This decreases the anticipated revenue streams and may cause financial instability in a WtE grate incineration power plant. Nevertheless, that model will grantee residual waste stockpile for the plant.

6. SWOT ANALYSIS DISCUSION

SWOT analysis was applied in this study by considering small city case study drivers and barriers to the establisment of WtE grate incineration power plant in South Africa as the strenghts and weakness respectively. Drivers and barriers outside the small city but within South Africa were regarded as oppotunities and threats correspondingly.

According to Table 2, the identified strengths are more than the weakness while the opportunities acknowledged are significantly more than the threats. Thus the drivers to the implementation of a WtE grate incineration power plant are considerbaly more than the barrriers.

The drivers identified include an average of 90% dominance of landfill over other MSW management strategies, average MSW generation growth rate of 3% per annum, national power shortages, the intermittent nature of solar and wind energy and non-energy recovery methods used in treating health care risk waste (HCRW).

However, obstacles to execution, such as the legislative framework, lack of landfill diversion measures, high capital investment involved and local culture were acknowledged.

7. CONCLUSION

The purpose of this paper was to perform a SWOT analysis for a WtE grate incineration power plant for a small South African city. The analysis proved that the drivers to WtE grate incineration power plant implememenation are significantly more than the barriers identified. Thus SWOT analysis results proved that investment in a WtE grate incineration power plant for a small South African city is feasible. The investigations in this study proved that SWOT analysis can be used as both a preliminary technology selection tool and an investment decision-making tool.

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RESPONSIVE STRATEGIES AND SUPPLY CHAIN DECISION-MAKING FOR THE SOUTH AFRICAN WINE INDUSTRY

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ABSTRACT

Efficient supply chains have been the order of the day for most wine cellars in South Africa. However, not all wineries can benefit from the same strategy. For some, a responsive supply chain strategy may be considered in order to provide better returns on investment. This paper aims to have a look at how supply chain strategy choice has an impact on the strategic and tactical business decisions of a winery. Furthermore, it investigates which trade-offs need to be made between performance metrics within 'Inventory' and 'Sourcing' as supply chain drivers and how this impacts decisions and strategy.

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1 INTRODUCTION AND BACKGROUND

1.1 Wine industry background

The South African wine industry is one of the oldest industries in South Africa, dating back to 1655. More than 350 years later, South Africa is the world's 7th largest wine producer [14] and gaining more acclaim for quality wines. The wine industry is a large contributor to the country's GDP (through wine sales and tourism) and employs close to 300 000 workers – unskilled and highly qualified. [18]

To be competitive in the modern business world is not about having the most sought after or cheapest product, but rather the most effective supply chain. These days it is supply chains competing with each other rather than companies. [12] This can be easily grasped when looking at the contemporary consumer. They want their products on-time, at the best price, with flexibility and without forfeiting quality. Supply chain management is therefore at the heart of the modern organization.

For wineries to be profitable and competitive, improving their supply chains could be beneficial. [17] The focus of this paper is to establish how wineries can deploy the correct supply chain strategies for their various supply chains. It investigates how these supply chain strategy choices influence strategic and tactical decisions. The research studies the performance metrics a winery should take into account and which trade-offs need to be made between them as a result of supply chain strategy choice.

Supply chain strategies and supply chain decision-making are not concepts widely found in wine industry literature. [21] The wine supply chain is one of the most complex chains considering the nature of the product, the vast amount of role players and their interaction. [6] Recently some wineries from other 'new world' wine countries (Australia and Argentina amongst others) realized what the supply chain field can offer the industry. They are expectant to see the benefits of implementing various supply chain management tools and frameworks. [13] [6] In the South African wine industry, however, little research has been done on supply chains. According to Van Eeden et al, most wineries do not fully recognize the existence of supply chains within their company and have little accurate data available to inform decision-making. [20]

Since 2003 PwC has been collecting financial data in the wine industry. Their aim is to do forecasting in the wine industry, investigate the outlook industry players have for the industry and identify opportunities and threats in the industry. Only recently has PwC collaborated with the University of Stellenbosch and CSIR to focus on supply chains within the wine industry. [17] The research has identified the lack of understanding and expertise causing a major drawback for the wine industry, as wine producers are already under financial pressure. [20]

1.2 Problem statement and objective

South African wine cellars are not as profitable as they could be. Neither are they competitive enough globally. Van Eeden et al [21] indicated inventory management and supplier partnerships as some of the key challenges and issues in the wine industry. As South Africa's wine quality is gaining worldwide acclaim, one would expect the wine bottles to fly off the shelves. This, however, is not the case. The lack of customer segmentation, proper value propositions, partnerships and supply chain strategy in the wine industry could be possible hurdles in wine producers becoming more profitable and competitive.

The focus of this paper will be to:
1) Investigate the wine industry, its supply chain strategies and supply chain decision-making through literature.
2) Compile case studies of supply chain decision-making and strategies within wineries.
3) Determine a preliminary decision-making structure to take to wine producers. This decision-making structure will include strategic and tactical decisions to be made when applying a responsive supply chain strategy.
4) Discuss key performance metrics, measured in 'Inventory' and 'Sourcing' as drivers of the supply chain.

2 RESEARCH METHODOLOGY

This paper investigates supply chain strategies and key performance metrics by means of a literature study and case studies from the industry. Interviews and questionnaires gave the researchers clarity on the current state of supply chains in the wine industry. From there the researchers aimed to develop a decision-making framework for the wine supply chain, focussing on the supply chain strategy decisions, for the areas of inventory and sourcing.

Previous research was studied to understand what has already been done in this field. Not many previous studies on supply chains were found specifically in the wine industry. From literature, the researcher was able to identify the extent of the problem and possible ways of implementing different supply chain strategies.

Resources that were consulted include a search through online databases for journal articles, books and conference papers. These searches included key words such as “supply chain strategy”, “supply chain management”, “wine supply chain”, “wine industry South Africa”, “performance metrics and measurements” and “decision-making in supply chains” amongst others. Further informal knowledge and understanding of the matter was also gained by reading internal project documentation, magazine articles, online articles and conference proceedings. It is clear that the wine industry has not done much business or supply chain research, as the literature mainly consists of scientific studies to improve wine or grape quality. The South African wine industry is under financial pressure and some advice on streamlining supply chains would be beneficial. [17]

Gunasekaran [7] found a lack of case studies in the performance measurement field across all industries in 2004. Although there are more studies available now, the wine industry has not caught up with performance measurement yet.

The researchers investigated the supply chain decision-making and responsiveness through compiling case studies of three wine producers. Every wine farm had a unique supply chain challenge, from which they had to make strategic and tactical decisions. Data for the case studies were gathered through face to face interviews, telephone conversations, e-mails and questionnaires. Focus was placed on how the cellars developed a responsive supply chain strategy, if the wineries were successful in their implementation thereof and how this could be improved. From this process, the researchers deducted which metrics could help wineries perform better in terms of ‘Inventory’ and ‘Sourcing’ as supply chain drivers. The wine producers will stay anonymous throughout the study to protect their identity.

3 LITERATURE REVIEW

3.1 Wine supply chain studies

Limited studies have been done on supply chain optimization in the wine industry. Some research has been done on elements of supply chains, but not on supply chains as a whole, leaving room for improvement. *Figure 1* illustrates the elements in the wine supply chain. Such a supply chain should be drawn for every individual wine, because not all wines (products) can be modelled on the same supply chain and follow the same supply chain strategy. This makes the wine supply chain complex. [5] [1]

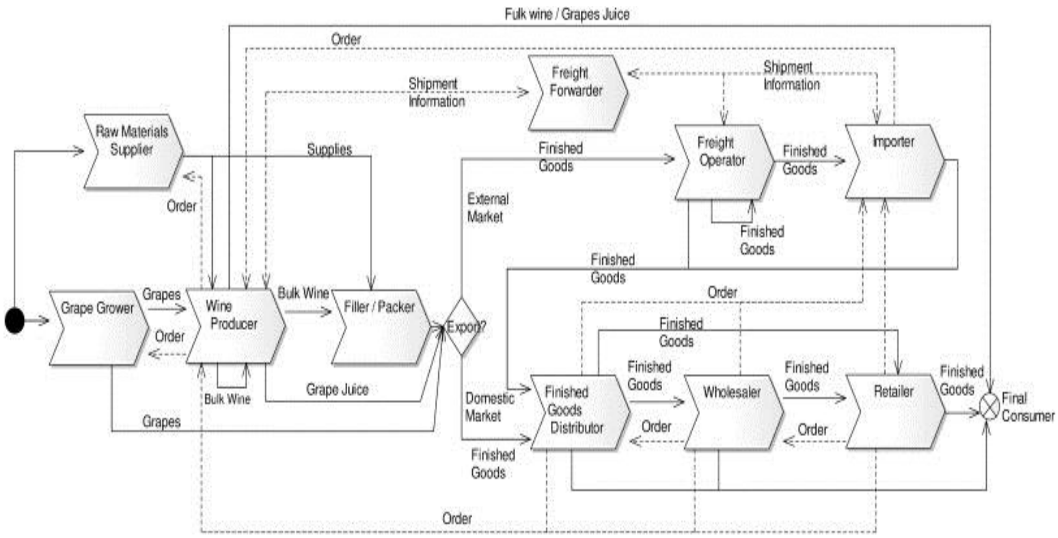

Figure 1: Wine supply chain [6]

South Africa produced 11 million hectolitres, 4.1% of the global wine production in 2015. [14] Wine production is increasing yearly and so are the export and import markets worldwide. The European market is now opening up to accept an additional 60 million litres of packaged wine tax free. [18] This means that South African wine producers would want to tap into that packaged export market more aggressively. Wineries need to focus on their supply chains and supply chain strategy in order to fulfil customer needs worldwide. [6] For South Africa to be more competitive than the other New World wine producers (Australia, New Zealand and the USA), the focus needs to shift to optimizing the supply chain and aligning the different supply chains to the winery's business strategy.

For the local market, distribution should be an area of focus. [11] Since grape growing and production is site specific, distribution for the local market should be streamlined. *Figure 2* shows the grape production areas in the coastal Cape area. [19]

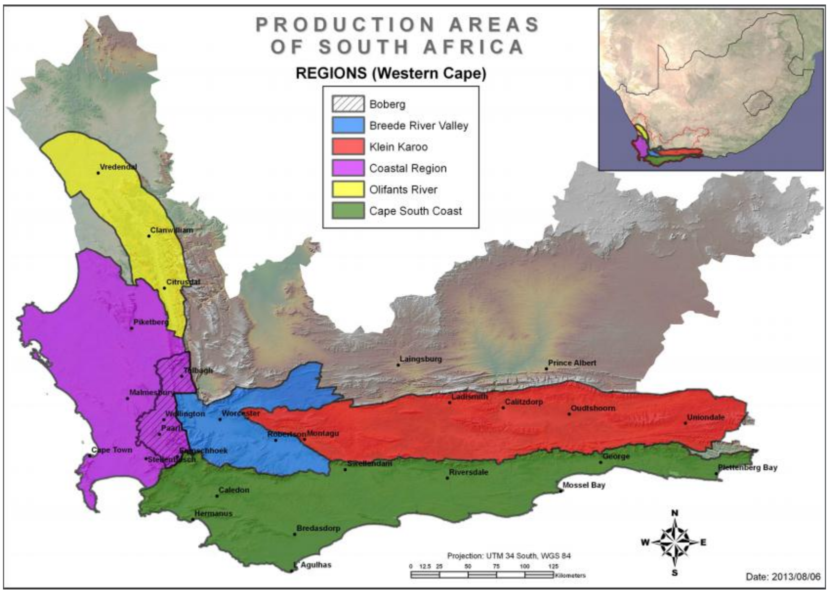

Figure 2: South African Wine Regions [19]

This makes responsiveness difficult to the northern part of the country. Responsive focussed wine cellars should invest in having distribution centres in other parts of the country. Alternatively, wine cellars can outsource their distribution to national wine distributors. It is, however, important that they choose a distributor with a similar footprint that has the same strategy, either being cost efficient or responsive.

According to PwC surveys, there are insufficient "industry best practices" or "performance indicators" against which cellars can measure themselves. They came to the conclusion that wineries willing to invest in a proper supply chain framework and strategy, will be leading the way in "new and innovative ways of doing business". [17] The development of such a framework to enhance decision-making could improve their return on investment, but requires a solid understanding of their supply chain strategy.

3.2 Business/ Competitive strategy

The company's business strategy identifies the customer needs and seeks to satisfy those needs through products or services, better than the competition. [3] If a customer segment buys wine and requires it to be delivered immediately, the winery's supply chain strategy should be set up for responsiveness in order to win the customer order. The winery will be able to charge a higher price on the product, because it is immediately available on customer demand. The ideal is to be as responsive as possible at a reasonable cost to this specific segment. [1] High inventory levels, company-owned facilities and effective information systems are some of the strategic decisions made by management in order to win these types of customers above the competition.

Business is governed by three tiers of decision-making: Strategic, tactical and operational. Each tier has an important function in management. This strategy should be aligned with their business strategy. Their business strategy can be described by "how the organization intends to create and sustain value for its shareholders." [9]

Strategic supply chain decisions are made by senior management, keeping all business areas in mind, advisably with leaders of each area involved. On the strategic level, company policies, competitive strategies, company financial plans and adherence to corporate goals are regulated by management. [7] Big decisions regarding the key logistical drivers are also considered strategic decisions, for example, whether or not to have the company's own facilities and equipment.

On a tactical level, decisions need to be made about keeping to the company's set strategic goal, adopting industry best practices and allocating resources in the most optimal way. [7] Tactical decisions often overlap with strategic decisions.

Operational decisions are short-term focussed and include decisions made every day on the job. These include adherence to and rescheduling of a production plan and the assurance that everything according to tactical level decisions gets implemented. [7] Operational decisions fall beyond the scope of this article.

3.3 Supply Chain Strategy

In Fisher's [4] very popular article "What is the Right Supply Chain for Your Product?" he lists the drivers of different strategies, shown in Table 1. There are major differences between the efficient and responsive strategies. The efficient strategy is usually implemented for functional products with low demand variation and profit margins. A responsive strategy is implemented for innovative products with high demand variation and profit margins. [4] [3]

Table 1: Supply Chain Categorization. (Adapted from Fisher [4])

	Physically Efficient	**Market - Responsive**
Primary Purpose	Lowest cost	Ability to meet unexpected demand High profit margins
Manufacturing focus	Cost efficient High utilization Full capacity	Quality of product Quality service Excess capacity, utilization buffer
Inventory Strategy	Make to order Minimize inventory to cut storage cost	Make to stock Invest in storage to be able to supply demand
Lead-time focus	Shortest lead time for lowest cost	Short lead time extremely important High investment
Approach to choosing suppliers (Sourcing)	Lowest cost at reasonable quality	Reliable suppliers, shorten lead-time,
Product-design strategy	Generic design to minimize cost Little to no differentiation	Customized wines Special requests can be fulfilled

Table 1 addresses some of the 'Inventory' and 'Sourcing' aspects in the supply chain, which is a main focus of this paper. For the wine industry, inventory refers to raw materials, work-in-process wine and the bottled finished goods. Sourcing would refer to agreements with suppliers of materials to make and package wine, i.e. grapes and/or wine and dry goods. The wine making process cannot be rushed, thus the market variation needs to be buffered with finished goods or bottled ready wine and a fast labelling facility. In order for a winery to be efficient in terms of 'Inventory', it needs to minimize inventory by implementing a make-to-order strategy, lowering storage cost. The opposite is true for a responsive strategy where more stock is kept in inventory (make-to-stock strategy), which makes the winery able to supply unpredictable demand. In terms of 'Sourcing', the efficient winery will opt for the lowest cost option every time, even if it has some minor quality implications. The responsive winery should have reliable suppliers, which delivers the right quality, at the right time at the shortest lead time.

The electronics industry has some of the same attributes as the wine industry and will be used as another example to demonstrate how 'Inventory' and 'Sourcing' can be used as supply chain drivers. Electronics also has a short life cycle, with the technology changing ever so quickly ("new" wine products are made yearly due to climate differences). Premium Brands are innovative products, with uncertain demand. Thus, according to Fisher [4], niche wineries and electronics can be dictated by a responsive supply chain strategy. Helo [8] also mentions that competition in the electronics industry is time based – you have to be first and fast to win orders. Therefore, dry goods need to be kept on hand, with extra capacity for manufacturing. Too much finished goods stock can easily be redundant due to the fast changing technology in electronics. Similarly, older white wines can become redundant and have to be sold at a markdown price as soon as the newest harvest seasons become available. The suppliers also need to be reliable, with short lead times in order to be responsive to the market pull.

According to Chopra [3], the key to achieving strategic fit and strong financial performance across the supply chain is to structure the supply chain drivers appropriately, to provide the desired level of responsiveness at a reasonable cost. In **Error! Reference source not found.**, Chopra illustrates where strategic fit is to be found. Wine cellars need to segment their customer-product offering and then place each of their supply chains in the matrix in *Figure 3*. This will dictate which strategy they need to follow for each individual supply chain.

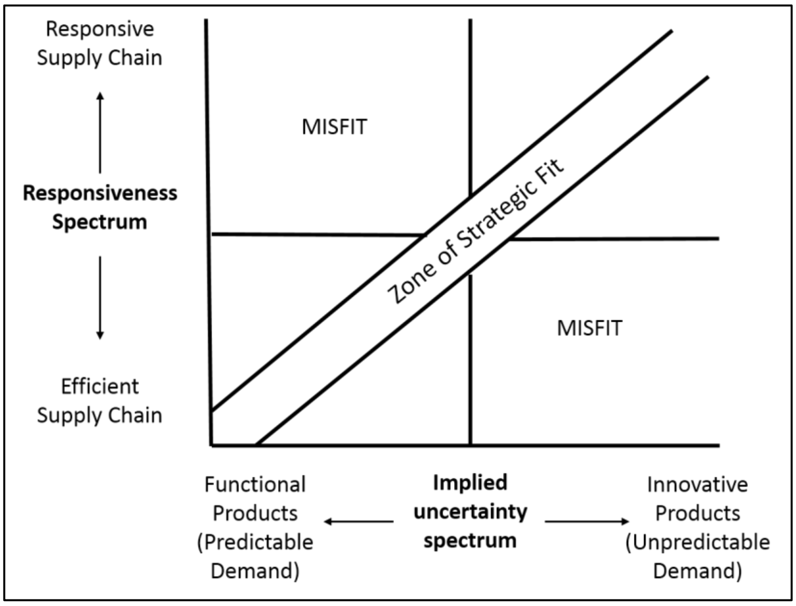

Figure 3: Achieving a fit in the supply chain [3]

According to Ambe "mismatched strategies are the root cause of problems that plague supply chains, and strategies based on a one-size-fits-all strategy often fail." [2] A common practice that wineries tend to neglect is segmentation. [21] Segmentation of customers and products into supply chains are crucial to the profitability of the winery, who need to understand the variety of customers they intend to serve. According to Osterwalder, every customer segment has different aspects they value. In order for the winery to win and keep customers, they need to approach these different segments to create value through applying the right supply chain strategy to every customer segment. [15] In this way all customer segments are satisfied by aligning the supply chain with the correct strategy. For example, when a customer wants the fastest delivery, irrespective of the cost – a responsive strategy will generate the most sales and potential profit.

3.3.1 Implementing an efficient supply chain strategy

Most wineries in South Africa implement an efficient supply chain strategy across all their supply chains. [21] Larger wine producers can make more profit selling high volumes. Some smaller wineries perceive this strategy to be successful and also tried it. With an efficient supply chain strategy, the focus is on economies of scale, cutting costs, sometimes compensating on quality. This strategy is suited for wineries that sell large volumes of wine, with a lower profit margin and a steady demand. The steady demand enables the company to reduce inventory and plan in advance for product replenishments with suppliers. Customers buy these products because of its low cost.

3.3.2 Implementing a responsive supply chain strategy

Perez suggests that where a fluctuating demand for products exist and market mediation costs are highly relevant, one of the three responsive strategies should be considered (agile, custom-configured and flexible). Perez reckons this will improve return on investment. The business provides capacity in response to changes in demand. [16] These supply chains are focused on the customer willing to spend a bit more when wanting a product immediately or with specification alterations. The manufacturer is geared to meet customer demand and might be able to increase profit margins in response to meeting customer specifications.

Wineries with innovative products and customers willing to pay a premium price should follow a responsive strategy. An **agile** strategy will be followed when customers value short lead times and when a company's business strategy is orientated towards high service levels and delivering on fluctuating demand. [16] Wineries on this strategy would compete in terms of product availability. The winery should have enough finished product inventory on hand. Or if they prefer to keep sufficient dry goods in inventory, they should ensure high reliability and extra capacity on their bottling/labelling line. Agility is needed in an unpredictable environment. [1]

A **custom-configured** strategy is uncommon in the wine industry. This could be because the opportunity does not exist to do this often. It probably would be more popular if a user-friendly system existed to "design" your own wine. On this strategy, a winery keeps no finished products in inventory, because of custom design at a premium price. However, to be responsive in the market, dry goods are kept in stock along with reliability from dry goods suppliers for expensive or bulky items, and excess capacity is required in production. This strategy is geared towards blending (and bottling) wine according to customers' specifications. [16]

A **flexible** strategy would play a bigger role in the distribution of wines, since the ability to meet fluctuating demand in terms of delivery is extremely important. This means that the winery needs to keep sufficient finished product inventory on hand in order to supply the demand. In the wine industry, inventory can be considered as components or unlabelled bottles with sufficient capacity to quickly assemble and ship. They should also have reliability in terms of distribution services: If a third party distributor is used, it should be extremely reliable. If the winery uses its own distribution trucks, etc., it should always have extra capacity leading to lower asset utilisation.

3.4 Supply Chain Decisions

The aim of business is to improve Return on Investment (ROI). Growing the supply chain surplus is the ultimate goal of a supply chain and in effect, the companies involved as a whole. In order to achieve a better business performance, it is of importance to track the key performance drivers and achieve a strategic fit between the supply chain strategy and competitive strategy.

As illustrated in **Error! Reference source not found.**, a winery needs to start by designing its 'competitive strategy': how it intends to win or maintain market share in that specific supply chain. Thereafter a supply chain strategy will be chosen to align with the competitive strategy and all further decisions must be based on these strategies.

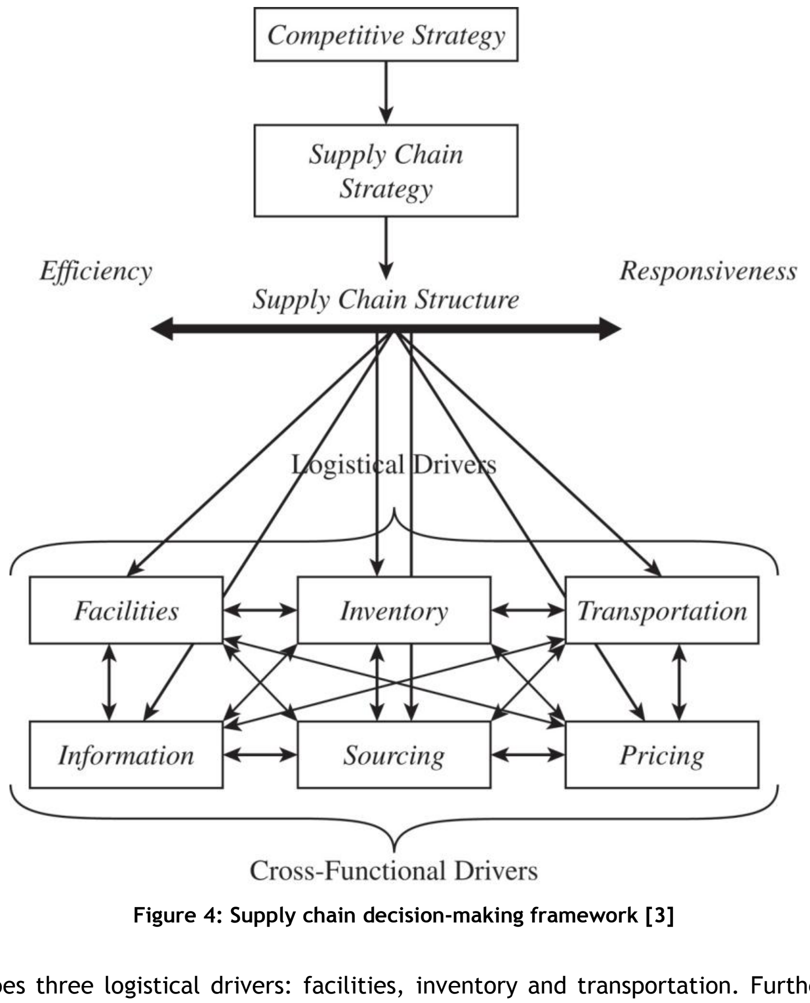

Figure 4: Supply chain decision-making framework [3]

Chopra [3] describes three logistical drivers: facilities, inventory and transportation. Furthermore, there are three cross-functional drivers that play a big role: information sourcing and pricing. All six of these key drivers encompass strategic decisions by management. The logistical drivers require decision-making about assets the company owns or outsources. The cross-functional drivers require decision-making about 'how' every logistical driver will be obtained, used, delivered, etc. All these decisions should be based on what the supply chain strategy entails. For example, if a winery intends to follow a responsive strategy, it should keep more inventory on-hand to meet unexpected demand. Alternatively, they could make use of reliable suppliers, with shorter lead times, but which would also be more expensive. Or they could invest in sufficient facilities to quickly bottle and/or deliver products.

Key to the winery's success is to deliver what they promise. It is no use to advertise for delivering products on short notice, but keeping low inventory and having unreliable facilities or suppliers. It takes time to build responsive trust, but quickly to break it.

3.5 Performance Metrics

Organizational performance metrics have received a lot of attention from industry. The use of metrics has not been studied and implemented so widely in the wine industry. [7] Currently there is no implemented performance measurement framework in the South African wine industry. [10] The development and implementation of such a framework is currently being investigated by several Master students at the University of Stellenbosch. Several students have completed their studies and some of these outputs are referenced in this paper. Supply chain performance can be enhanced through supply chain control, which can be executed in part by measurement. [7]

3.5.1 The trade-offs between different performance metrics

A business is not able to perform simultaneously at all competitive levels and should, therefore, have a strong notion of how they intend to gain their competitive advantage. Key to planning operations and supply chain strategies should include an operations focus and trade-offs. [9]

Every supply chain metric inhibits a trade-off that directly affects the strategy of the firm. These trade-offs are applicable in the wine industry. The researchers considered 'average inventory' and 'supply lead time' as performance metrics.

A winery cannot have both high and low 'average inventory' levels. Inventory will be considered as raw materials, dry goods and finished products. Keeping higher average inventory levels, allows the winery to be much more responsive to market demand, but at a higher cost. The efficient supply chain strategy will try to keep the average inventory levels of finished goods as low as possible in order to save on storage costs. Supply chain strategy and customer segments thus play a big role in determining how much average inventory will be kept on hand.

Having a shorter 'supply lead time' can assist a winery in not keeping too many finished products in inventory. Suppliers with shorter lead times and reliability would be more expensive, but being responsive on short notice will ensure satisfying customers changing demand patterns and assist in keeping those customers. These customers are usually also willing to pay a higher price to have delivery on time. This is also useful in the electronics industry as less inventory needs to be kept in stock (with a possibility of the stock becoming outdated). Being able to quickly assemble a product if suppliers are reliable and have short lead times, enables the producer to respond to demand without carrying unnecessary inventory. The same is true for the wine industry in the case where white wine becomes redundant once the new harvest season's product is available, thus keeping finished goods inventory low is an important strategy consideration.

4 CASE STUDIES

The researchers considered three different wineries, each with a range of products. Critical decision-making is required in order for the winery to achieve optimal supply chain and business performance. The researchers considered which decision-making measures should be taken into account and which trade-offs need to be made in order to achieve strategic fit for specific scenarios at each winery. Due to the space limitations of this paper, only a few relevant scenarios related to inventory and sourcing will be highlighted for each of the case studies.

4.1 Winery 1

This winery produces a special wine in small volumes with high quality expectations from the customers. One year the production of this wine was impossible due to low quality grapes. The dry goods were already ordered, including an imported, long lead time bottle. Dry goods are expensive and ordering should be postponed until final volumes are known in efficient strategies. The winery had two major problems in terms of this wine not being good enough for the 'special' quality wine:

1) What will be done with the excess 'low quality' wine?
2) What will be done with the bottles that were ordered?

The wine could easily be blended into another lower quality blend the winery produces and take up the storage space the 'special' wine would have used. Since this wine uses another bottle, locally made, more could be ordered and delivered easily. The imported bottle cannot be used for any other wines produced by this winery. Thus a choice needed to be made whether to store the bottles until the next harvest or to return it. Both options would incur a cost. In this case, the trade-off is being proactive with inventory in order to be able to react responsively versus postponing decision-making to be cost efficient.

As the wine industry is cash-flow sensitive, having cash tied up in inventory for a year can lead to problems. In order for this winery to remain responsive in such situations the following metrics can be considered:

1) Supplier reliability and lead time
2) Possibility of designing and producing the same bottle locally, in order to reduce lead time (the average cost of this also to be measured)
3) Cost of inventory versus supplier reliability
4) The amount of safety stock to be kept in inventory to supply demand

These measurements would provide feedback to management and inform better decision-making related to the areas of inventory and sourcing within a responsive supply chain strategy.

4.2 Winery 2

This winery is a small producer of premium and super premium wines. Over the years they have had a constant production volume and done their forecasting accurately in order to meet customer demand. They are able to be responsive in terms of bottling and labelling their premium wines. With excess capacity on the bottling and labelling line, they can quickly have wine ready to ship according to changing customer demands.

One year, however, a lower yield was harvested from the farm. This led to insufficient grapes for their super premium wines. These super premium labels were discontinued and the wine back blended into the premium wines. This was done at the risk of losing listings at restaurants and on retail shelves permanently. This would be the same effect if a respected cell phone company could not release a new device for a particular year, and thus lose customer loyalty.

In terms of strategic decision-making, this winery could consider sourcing high quality grapes from elsewhere in order to produce their super premium wines. Estate title considerations should be discussed and decided upon. It should be weighed against the responsiveness of the cellar, meeting customer expectations, and losing customer loyalty.

4.3 Winery 3

This winery produces a variety of wines, including single varietals and blends for the export market. In recent years, demand for the blends has been growing and the demand for single varietals is decreasing. In order for this winery to be responsive to customer demand, some strategic decisions need to be made.

Their main considerations should be if they will buy in more grapes to make blends, plant their own vineyards, use grapes from the single varietal production for blends and the additional facilities that are needed to produce these wines. These are all strategic decisions to be made at a senior management level.

If this winery intends to be successful in their responsiveness, they can consider the following 'Sourcing' metrics:

1) Consider purchasing price of grapes over time against the planting of own grapes
2) The quality of the grapes bought in
3) The reliability of quality and timeliness
4) The quantity of available quality buy-in

This winery needs to consider strategic partnerships with grape suppliers in order to ensure the quality and quantity of grapes they require for their various blends.

4.4 Decision-making

Throughout the case studies strategic and tactical decision-making were crucial to the success of these wineries. When problems arise, critical decisions should be made with supply chain strategy in mind. Table 2 provides an overview of the types of decisions to be made by the aforementioned wineries when they consider implementing a responsive supply chain strategy. Wineries with similar situations can follow suit. The focus of this article is only on 'Inventory' and 'Sourcing' as supply chain drivers, and thus the list is limited to these drivers and the related performance metrics.

Performance measurements can assist strategic and tactical decision-making to be more responsive in the supply chain. As mentioned previously in the case studies, there are different situations in which these metrics can be useful and a measure as to how responsive a winery can be. The trade-offs between efficiency and responsiveness should be considered when decisions are made so as not to implement conflicting strategies.

Table 2: Proposed performance measurements. (Adapted from Chopra [3])

Drivers of supply chain	Relevant performance metrics	Applicable to case study
Inventory:	Cash to cash cycle time	Winery 1, 2 & 3
Cycle inventory	Average inventory	Winery 1 & 2
Safety inventory	Inventory turns	Winery 1 & 2
Seasonal inventory	Safety stock	Winery 1, 2 & 3
Level of product availability	Order fill rate	Winery 2 & 3
	Fraction of time of stock out	Winery 2 & 3
Sourcing:	Average purchase price	Winery 1 & 3
In-house vs outsourced	Range of purchase price	Winery 1 & 3
Supplier selection	Average purchase quantity	Winery 3
Procurement	Supply quality	Winery 1, 2 & 3
	Supply lead time	Winery 1 & 3
	Fraction of on-time deliveries	Winery 1 & 3
	Supplier reliability	Winery 1 & 3

As responsive strategies are often implemented where quality products are produced and demanded by specific customer segments, the quality aspects are important considerations. The cost of quality, shorter lead times and reliability are high, but worth the investment to keep market share in responsive supply chains. Inventory cost is also higher in order to be more responsive, but easy calculations can be made to ensure responsiveness at the lowest possible cost.

5 CONCLUSION

The literature on the wine supply chain, the South African wine supply chain specifically, is very limited. It is necessary to consult other industries with overlapping concerns and similar production environments, as the electronics industry only mentioned in this paper. In further research, supply chains of industries such as the textile industry can be considered to compare with the wine industry. The wine industry is similar to the textile industry in the light that both constantly produce new products launched on the market as seasons and trends change. It sounds outrageous, but a winery effectively has new products every year with the changing harvest climates. The responsive winery can in a similar way be responsive to the market 'pull' due to accurate forecasting as the textile industry also needs to forecast trends and market demand. However, it is also crucial that the industry sets its own benchmarks and develop the necessary industry best practices to take the industry forward. The recent interest in the South African wine supply chain by industry role-players and academics is a positive sign and could benefit the industry in improving to the next level in terms of supply chain performance and competitiveness.

The development of frameworks to measure the performance of the wine supply chain within wineries, especially regarding decision-making, should make wine producers aware of the different options within their supply chains. Due to the nature of the product and the complexity of the supply chain, it most probably will take several years to implement frameworks and improve supply chains.

Since South African wines have been performing extremely well in terms of quality recently, the demand for South African wine is rising. In order to fulfil this demand, supply chain management and strategies will need to improve and grow in the South African wine industry over the next decade. Maybe a more responsive strategy can improve agility and the ability to meet the potential changing customer demands.

The authors propose that wineries segment their customer markets carefully and develop value propositions for each of these markets. In doing this, wineries should consider the option of developing responsive supply chain channels to serve some of these markets where appropriate. The metrics provided in this paper could assist wineries in making the correct strategic and tactical inventory management and sourcing decisions.

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DECISION SUPPORT HEURISTICS FOR COST ESTIMATION MODEL FOR INJECTION MOULDS

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ABSTRACT

Cost estimation of products in the tooling industry is a complex task requiring a lot of expert knowledge and sound judgement. Higher estimates may lead in losing orders or customer goodwill while lower estimation will affect business profitability. Hence accurate and timely cost estimation before tool, die and mould production is a key attribute for sustaining global competitiveness. Due to the skills shortages the South African tooling industry has experienced, a majority of Toolmaking firms take long times to quote a job. Furthermore results from benchmarking exercises of these firms have shown that a majority of quotes generated lack accuracy due to methods employed. In the paper, the key parameters to be considered when quoting the price of injection moulds are identified and ranked. The method of knowledge engineering was employed and heuristic data collected through interviews with five job quoting experts in the Western Cape Province tooling sector. Based on the information gathered, the Analytical Hierarchical Process (AHP) was used to rank the main parameters identified. The result of the survey can be used in the development of an expert system for quoting injection moulds in the South African Tooling industry.

Key words: Cost Estimation, Knowledge engineering, Injection moulds, Expert system

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1. INTRODUCTION

Tool-making firms adopt a crucial role in the manufacturing value chain, contributing significantly to quality, price and the delivery reliability of series production goods [1]. According to the International Specialized Tooling and Machining Association (ISTMA) statistics, up to 50% of any manufactured component's cost competitiveness is governed by tooling (Instimbi Annual Report, [2]).

The South African Tool, Die and Mould-making (TDM) industry plays a major role in the growth and existence of the local manufacturing sector. With rapid growth of globalization and fierce competition from tool-making firms in the East, timeous delivery of a quality tool, die or mould within the allowed budget in non-negotiable. Unfortunately, recent results from the benchmarking exercises conducted in the South African TDM sector have revealed that a majority of the firms suffer in the area of delivery lead times (Malherbe [3]) as shown in Figure 1. Though there are several reasons for this trend as explored by Dewa [4], the order processing function has been identified as one of the main bottlenecks in the Tool-making value chain for most companies observed.

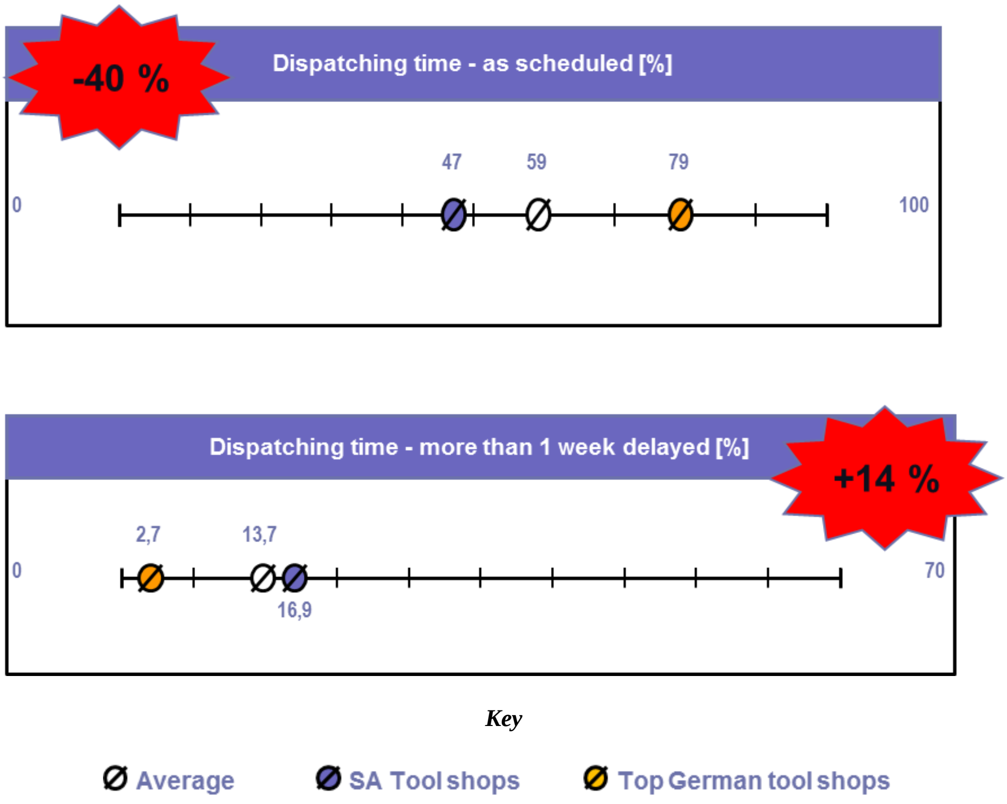

Figure 1: Due Date conformance trends [Rittstieg and Garms, [5])

At the present moment the job quoting process is time consuming since it requires great expertise and knowledge, which is currently in short supply within the TDM sector (Instimbi Annual Report, [2]). Most companies take long lead times (usually weeks) to quote a job and in some cases, the tool-making project doesn't end within budget as shown in Figure 2. A potential solution to the dilemna can be the development of knowledge-based (expert) systems for job quoting which encapsulate the main parameters required in pricing a job.

Part of expert system development involves interaction with field experts to derive key heuristic rules utilized in decision-making, a process known as knowledge engineering. The paper presents the key parameters used by expert cost estimators in the tooling industry during pricing jobs, with specific focus on the quoting of injection moulds. Five different tool-making firms were used in the study. Cost estimation experts in these firms participated in interviews and the parameters were derived. The paper is structured as follows: Firstly, the complexity of the quoting process is highlighted before different approaches to cost estimation of injection moulds are outlined. Secondly, the Analytical Hierarchical Process (AHP) is explored from the literature. Finally, we present the data collection methodology adopted, firm demographics before we finally show the results of the study.

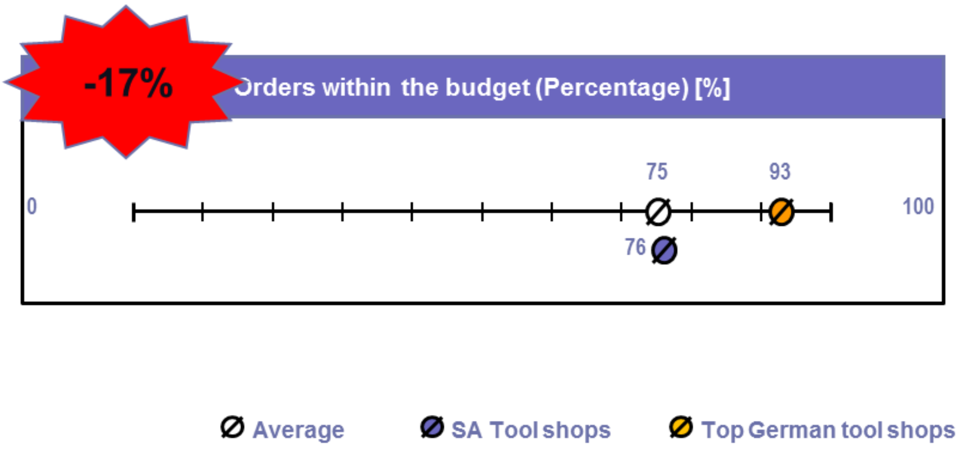

Figure 2: Orders completed within budget [Rittstieg and Garms, [5])

2. RELATED LITERATURE

2.1 Complexity of the Cost Estimation Process

The successful calculation of costs is an important requirement for the performance of injection molding companies. Higher estimates may lead in losing orders or customer goodwill while lower estimation will affect business profitability. However, determination of the overall costs of a tooling job is a complex process which requires great expertise and knowledge in tooling. According to Jones [6], the estimator needs to have sound judgement and knowledge in:

- Injection molding specifications and functions
- Reading and understanding of engineering drawings in both printed and Computer-Aided Design (CAD)
- Mould tool design
- Tool-making
- Mechanical engineering
- Basic physics
- Plastic material properties
- Behavior of polymer flow
- Injection moulding
- Basic electronics
- Robotics

A delay in quoting is bad practice. This is because research has shown that in the mould-making industry usually less than 10% of all offers turn into orders (Fonseca, M et al., [7]; Duverlie, and Castelain, [8] and Denkena et al., [9]). Hence accurate and timely injection mould quoting is key to survival in a cutthroat business environment. For timely quoting, the key elements to be considered in pricing the job should be known. The paper aims to identify the key parameters required in quoting an injection mould.

2.2 Cost Estimation systems

The overall goal of the cost estimation process is to ensure that all the costs related to a job are covered with a satisfactory profit realized. Furthermore, the final price of the product must be competitive on the market to avoid the risk of a lost order. To achieve this goal, injection moulding firms need to identify all the related costs incurred in manufacturing a mould, select an appropriate costing system and estimate the price based on the identified parameters and selected system. Manufacturing firms usually adopt the following costing systems; standard costing, absorption costing, marginal costing and costing based on machine hourly rates.

2.2.1 Standard Costing

Standard costing is a very common method used in the manufacturing industry. The method is based on established set standards for each manufacturing activity or process. These standards are derived from time study analysis and agreed upon within the organization. Usually, costs are classified broadly within the categories of direct, indirect and overhead expenses.

2.2.2 Absorption Costing

Absorption costing is an approach which ensures that all manufacturing costs are recovered by the products produced. The method is also referred to as full costing or complete absorption method. It involves identification and accurate assessment of all the costs a business incurs. Similarly, costs are broadly classified as either direct or indirect expenses. However, this method is best suited for determination of the selling price of products in a profitable way.

2.2.3 Marginal Costing

With both standard and absorption costing, the allocation of fixed and overhead costs can be complex to analyse. The costs behave in different ways as the production or sales volumes change. However, in marginal costing the behaviour of the associated costs is measured. In marginal costing, expenses are broadly categorised as either fixed or variable costs.

2.2.4 Costing based on machine hourly rates

Costing based on hourly machine rates is a system usually adopted where the majority of the production is done by industrial machinery. A machine rate per hour (MHR) is determined for each resource and used in determining the final cost of a job. Since the injection moulding process is heavily reliant on the use of Computer Numerically Controlled (CNC) machinery, this approach is usually the most appropriate for costing of injection mould jobs. Usually these systems are either applied using manual filing system or the estimator uses computerized packages to do the job [6].

2.3 Cost Estimation Approaches

According to Duverlie and Castelain [8], there are four different approaches estimators use when determining the price of a job. These are the intuitive, analogical, parametric and analytical methods. The intuitive method is employed when the estimator heavily relies on his or her experience to make decisions based on their knowledge. In most cases, gut feeling or rules of thumb are employed to make a decision using this approach. On the other hand, the analogical method uses similar jobs done based on historical records to approximate the cost of a new job. The parametric method seeks to evaluate the costs of a product based on specific parameters characterising the product. However, the product does not necessarily have to be fully described to follow this method. The analytical method allows for evaluation of the cost of a product from a decomposition of the work required into elementary tasks. This makes the analytical method to be mostly suitable for firms using a machine hourly rate costing system. The estimation process is complex in that so many different decisions are made at the same time. Hence, job estimation is a multi-criteria decision-making problem.

2.4 Analytical Hierarchy Process

The Analytic Hierarchy Process (AHP) is a multi-criteria decision-making methodology which was proposed by Saaty [10]. It uses a well-defined mathematical structure of consistent matrices and their Eigen vector to generate weights on the selection criteria [11]. To make decisions with AHP the following steps should be followed [12]:

1. The problem should be defined.
2. A decision hierarchy with the goal of the decision at the top followed by objectives from a broader perspectives, then intermediate level criteria is developed from the top level down to the alternatives.
3. A set of pair wise comparison matrices is developed with each element on an upper level used to compare the elements in the level immediately below it.
4. The priorities of the comparison the criteria in the upper level is used to weigh the criteria in the lower level immediately under it.

2.4.1 Problem definition

The facilitator interviews the decision-maker(s) to structure the problem and develop a hierarchical structure of the criteria which enables users to focus on specific criteria and sub-criteria when allocating the weights. Brugha [13] also proposed a complete guideline to structure a problem hierarchically and compiled hierarchies in different applications. To avoid large differences when decision making involves a large number of elements, the elements should be clustered [14].

2.4.2 Pair wise comparison

A pair wise comparison matrix is developed using a scale of numbers that indicates how many times more important or dominant one element is over another element, with respect to the criterion or property to which they are compared as shown in Table 1. The development of the matrix is discussed in section 4.5.

Table 1: Fundamental scale of absolute numbers [10]

Intensity of Importance	Definition	Explanation
1	Equal Importance	Two activities contribute equally to the objective
2	Weak or slight	
3	Moderate importance	Experience and judgement slightly favour one activity over another
4	Moderate plus	
5	Strong importance	Experience and judgement strongly favour one activity over another
6	Strong plus	
7	Very strong or demonstrated importance	An activity is favoured very strongly over another; its dominance demonstrated in practice
8	Very, very strong	
9	Extreme importance	The evidence favouring one activity over another is of the highest possible order of affirmation
Reciprocals of above	If activity I has one of the above non-zero numbers assigned to it when compared with activity j, then activity j has the reciprocal value when compared to i.	
1.1 – 1.9	If activities are very close	May be difficult to assign the best value but when compared with other contrasting activities the size of the small numbers would not be too noticeable, yet they can still indicate the relative importance of the activities.

2.4.3 Parameter ranking

The parameters investigated are then ranked by determining their priorities during the interview process. The priority rating of each parameter is obtained by finding the Eigen vector of the pairwise comparison matrix. This is achieved by raising the matrix to large powers and summing each row and dividing each by the total sum of all the rows [13]. Once the priorities have been determined, the principal Eigen value can be obtained from the summation of products between each element and the sum of the columns of the reciprocal matrix.

2.4.4 Checking for consistency

The final step in the process involves checking for consistency in judgement. This is done by measuring a Consistency Ratio (CR) as shown in equations 1 and 2.

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

Where λ_{max} is the Principal Eigen value of the pair wise comparison matrix and n is the dimension of the matrix. The Consistency Ratio (CR) is given by:

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

Where CI is the Consistency Index and RI is the Random Consistency Index given in Table 2. If the determined Consistency Ratio is smaller or equal to 10%, the inconsistency will be acceptable. However if the Consistency ratio is greater than 10%, they will be need to revise the subjective judgement.

Table 2: Random indices [15]

n	3	4	5	6	7	8	9	10
RI	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

2.5 Cost Estimation Parameters

The costing of a product in the manufacturing industry can be broadly classified into production, packaging and distribution-related costs. According to Jones [6], production related costs include contributing factors like machine-based operations, materials used, assembly or manual tasks and support processes. For accurate quoting, these broad categories need to be further explored and broken down. The paper seeks to fill this gap by exploring how toolmakers in the South African tooling industry reckon these factors during quoting while also exploring how these costs elements compare in terms of their contribution to the total cost of the product. Knowledge engineering can aid in deriving the information of how the parameters are reckoned while the AHP approach assists in the ranking of the identified parameters.

3. RESEARCH METHODOLOGY

The method of knowledge engineering was selected as the best approach to answering the research question. According to Lucas and van der Gaag [16], knowledge engineering involves interaction with field experts to derive key heuristic rules utilized in decision-making. As such, job quoting experts in five selected firms within the Western Cape Tooling industry were visited at different times and interviewed. All selected firms accepted to participate in the study and were visited at different times. The purpose of the interviews was to determine the key parameters required when quoting an injection moulding job. The companies selected were specifically specialists in manufacturing of injection moulds. Furthermore, the method of observational note taking was employed to determine the approaches and systems of quoting jobs the experts employed. Part of the interview involved the expert demonstrating how the price of a job was reached from the design drawing specifications to the preparation of the job invoice. An interview guide was prepared for the interaction process. The guide involved both open-ended and closed-ended questions which required the expert to give information on:

- Estimation approach employed
- Job costing system used
- Average time it took the expert to quote a new or old job
- Average due date and budget conformance
- Key parameters used in quoting

Each interview lasted for approximately 45 minutes with the interviewee taking the researcher through files and estimation platforms.

4. RESULTS

4.1 Firm demographics

The five firms observed are injection mould design specialists within the Western Cape Province Tool, Die and Mould-making (TDM) and Plastics manufacturing industry. The mean number of employees for the observed population of companies was 10.4 with a mean annual income of less than 10 million ZAR. Hence all the firms observed are classified as Small, Medium to Micro Enterprises (SMMEs) according to the classifications defined in South African National Credit Regulator by Mahembe [17]. The specific number of toolmakers in each of the visited firms is shown in Figure 3.

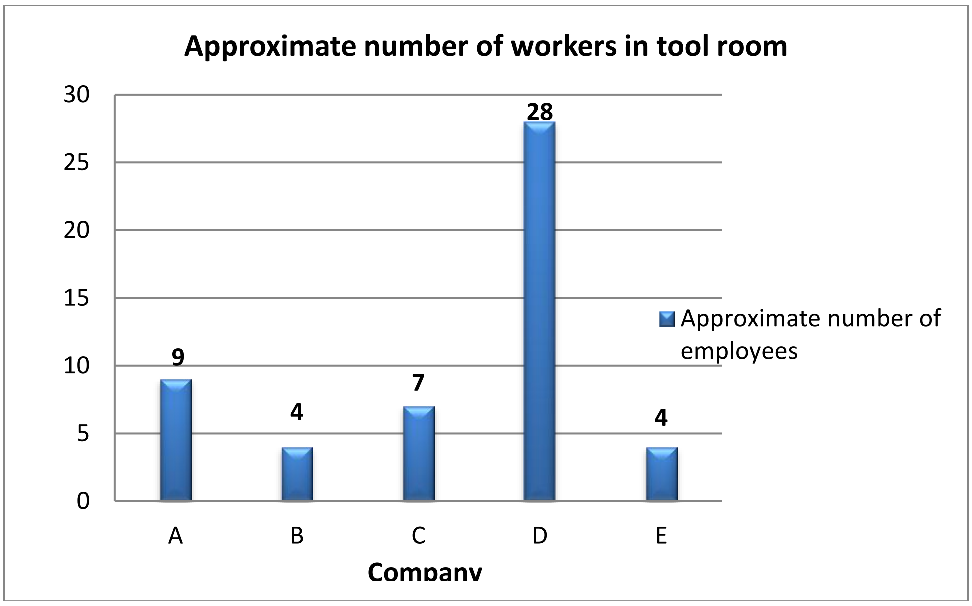

Figure 3: Number of employees in the tool room

Companies A, B, C and E are stand-alone Tooling firms while company D is a tool-room serving in-house operations of a larger organization.

4.2 Cost Estimation approaches and systems employed

Each of the visited firms was questioned on the job estimation processes and policies they adopted. Table 3 summarizes the job quoting approaches by the visited firms.

Table 3: Job quoting approaches

Expert from Company	A	B	C	D	E
Job quoting approach	Geometric-based; parametric	Intuitive; Analytical	Intuitive; Analytical	Geometric-based; Parametric	Geometric-based; Parametric
Software system	Excel	None	None	Excel	Excel
Manual or Computerized	Computerized	Manual (file system)	Manual (no system)	Computerized	Computerized with back-up filing system
Number of quoting experts	1	1	2	2	1
Experience of the expert (years)	19	28	23	40	33

Three out of the five firms visited utilized an excel-based system for quoting based on the parametric and geometric based approach with the remaining two using the intuitive method. It was interesting to note that the firms using the intuitive approach did not have any historical records of jobs done or record keeping system.

4.3 Cost Estimation lead times, due date and budget conformance

Since prompt quoting of jobs is paramount importance, the survey also sought to investigate the average time the experts interviewed spent quoting both old and new jobs. Furthermore, the respondents were given the opportunity to cite reasons for delays and failure to end the project within budget. Cost Estimators from companies A and E had the lowest lead times in quoting a job while Estimators from Company C admitted to struggle in sending a customer invoice early as shown in Table 4.

Table 4: Job quoting lead times

Company	A	B	C	D	E
Approximate number of days (New jobs)	2 days	3 - 5 days	7 - 14 days	3 - 5 days	2 days
Approximate number of Days (Old jobs)	Less than 24 hours	2 days	3 - 5 days	1 day	Less than 24 hours

All firms visited confirmed that the quote generated would never be accurate. In some cases, the firms experienced a profit or a loss. When queried on the major reasons for huge deviations between the quoted price and the actual cost of the job, the reasons shown in Table 5 were stated.

Table 5: Reasons for budget non-conformance

Expert from Company	A	B	C	D	E
Reason for failure to conform to budget	Excessive Labour hours	Inaccuracy in operation times estimation (labour hours)	Longer Operation times	• Wrong quote • Customer specification changes • Wrong quote • Planning inefficiencies • Labour costs	Overtime

The main reason stated for budget non-conformance and delays was a failure to control labour time so that it is within the plan. However, the respondent from company D was honest to highlight that at times non-conformance meant the quote was wrongly prepared in the first place.

4.4 Derivation and classification parameters

The greater part of the time spent during the visits was on identification of the key parameters used when quoting a job. Each expert was presented with an open-ended question to specify what the parameters were. To validate the responses given, each expert demonstrated with an example of a previously quoted job. The main cost elements identified were material, labour and machining costs as shown in Table 6. However, in most cases the experts broke down the cost elements to smallest elements possible. Experts from Company E had a more elaborate system which specified the parameters in the strictest detail possible. This eventually makes the cost estimation process of injection moulds a multi-criteria decision making process, hence justifying the need to use the AHP procedure to rank each of the cost elements according to their contribution to the total cost of an injection mould job.

Table 6: Derived costing parameters

Expert(s) from company	Cost Parameters derived
A	• Material • Cooling system • Machining • Labour • Tooling cutters • Outsourcing
B	• Material • Labour • Heat treatment • Design • Subcontracting • Outsourcing
C	• Material • Labour • Consumables • Heat treatment
D	• Material • Labour • Heat treatment • Machining
E	• Material and services ✓ Mould base ✓ Copper (electrodes) ✓ Cavity core steel ✓ Heat treating and plating ✓ Manifold hot-runner system ✓ Components ✓ Texture ✓ Tooling (cutters and inserts) ✓ Sample material ✓ Tooling delivery • Labour ✓ Data management ✓ Mould design ✓ Computer simulations ✓ Advanced engineering ✓ CNC machining ✓ General shop labour ✓ CMM parts

Based on the data collected and presented in Table 6, the costs incurred during injection mould manufacture can be broadly classified as:

- ✓ Material costs
- ✓ Labour and machining costs
- ✓ Services (outsourcing)

4.5 Ranking of Parameters – Analytic Hierarchy Process

4.5.1 Problem definition

In the costing of an injection mould, the key parameters to be considered are the material, labour, machining and service cost elements as depicted in Figure 4 below. These elements are further decomposed into the common constituent elements as shown in Figures 5, 6 and 7.

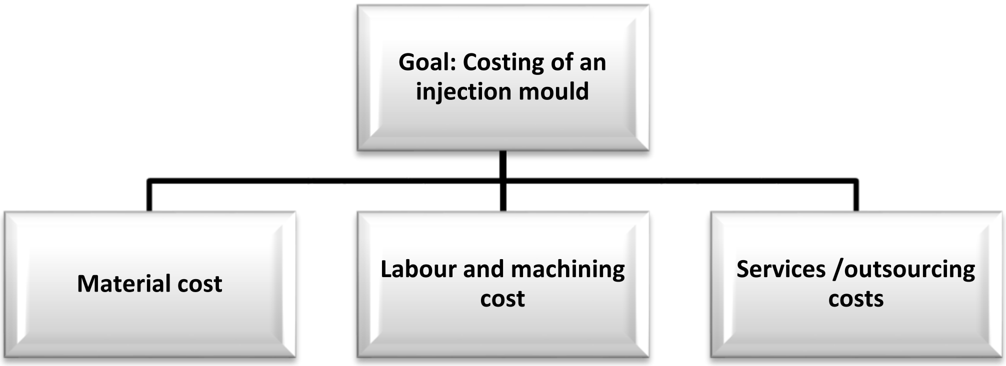

Figure 4: Injection mould cost top hierarchy

The material cost can be further broken down into the costs incurred in securing the mould base, copper electrodes, cavity steel core, hot runner system and the tooling components as illustrated in Figure 5.

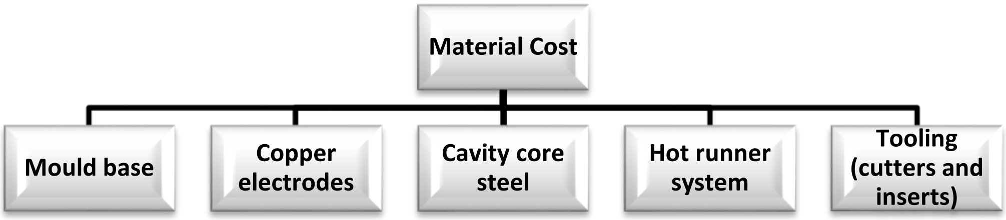

Figure 5: Material cost sub hierarchy

Simillarly, the labour and service cost components can be further broken down as illustrated in Figures 6 and 7 respectively.

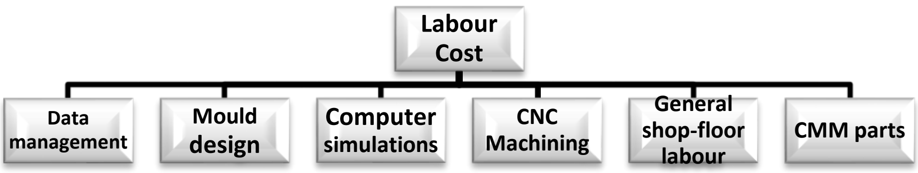

Figure 6: Labour cost sub hierarchy

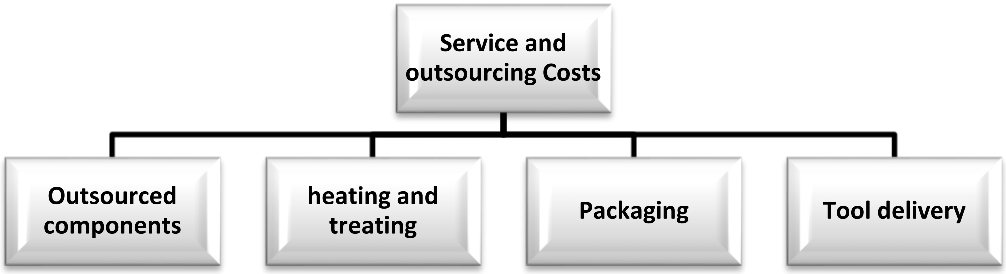

Figure 7: Service and outsourcing cost sub hierarchy

4.5.2 Parameter ranking

The methodology employed also included ranking of the parameters determined in terms of their contribution to the overall cost of a job. The purpose of the exercise was to identify the cost elements requiring careful estimation and stricter monitoring during the production phase since deviations carry huge consequences. To achieve this, three stages were followed which included:

1. Pair-wise comparisons

The cost estimator (decision maker) evaluates the relationships between the first level criteria i.e. the material, labour and service cost components. Questions were asked in the following format: *"How important are labour costs for a product to the material costs when it comes to contribution to the overall cost of the job?"* Based on the framework given in Table 1, on a scale of 1 – 9, a pairwise comparison value is assigned. Given that the L represents the labour costs, M the material costs and S the service costs, the pairwise comparisons derived are shown in Table 7.

Table 7: Pairwise comparisons

	L	M	S
L	1	6	9
M		1	4
S			1

All the experts interviewed identified labour costs as the most critical cost component requiring stricter reckoning, monitoring and control. One of the interviewees specifically stated that labour costs would always account for approximately 55 – 60% of the total mould cost. Hence, based on this analysis, labour-related costs were deemed to be having extreme importance compared to service related costs. Labour-related costs have a strong plus importance as compared to material-related costs while the cost of material is moderate plus with respect to service-related costs. The cost of the hot runner system and the mould base makes the material related costs relatively high in comparison to the service related costs.

2. Development of a pair-wise matrix

The pair-wise comparison matrix is completed by putting the inverse of the scales for the inverse relationships as shown in the Tables 8a and 8b respectively.

Table 8a: Pairwise comparison matrix

	L	M	S
L	1	6	9
M	1/6	1	4
S	1/9	¼	1

Table 8b: Column totals

	L	M	S
L	1	6	9
M	0.1667	1	4
S	0.1111	0.2500	1
Column totals	1.2778	7.2500	14

3. Priority determination and ranking

The pair-wise comparison matrix is normalized by dividing the values in each column by the column sum as shown in Table 9. To determine the priorities of each criterion, the normalized principal Eigen vector is obtained by averaging across the rows.

Table 9: Normalized table

	L	M	S	Priority	Rank
L	0.7826	0.8276	0.6429	0.7510	1
M	0.1305	0.1379	0.2857	0.1847	2
S	0.0870	0.0345	0.0714	0.0643	3

Row averages = $\begin{pmatrix} 0.7510 \\ 0.1847 \\ 0.0643 \end{pmatrix}$

Hence, based on the results, Labour costs are ranked first with material and service costs ranked second and third respectively.

4. Checking for consistency

The final step involves checking for the consistency of the solution by determining the Consistency Index as shown below:

Weighted sums = $\begin{pmatrix} (0.7510 \times 1) & + & (0.1847 \times 6) & + & (0.0643 \times 9) \\ (0.7510 \times 0.1667) & + & (0.1847 \times 1) & + & (0.0643 \times 4) \\ (0.7510 \times 0.111) & + & (0.1847 \times 0.25) & + & (0.0643 \times 1) \end{pmatrix} = \begin{pmatrix} 2.4379 \\ 0.5671 \\ 0.193911 \end{pmatrix}$

Consistency vector = $\begin{pmatrix} 2.4379/0.7510 \\ 0.5671/0.1847 \\ 0.193911/0.0643 \end{pmatrix} = \begin{pmatrix} 3.2462 \\ 3.0704 \\ 3.0157 \end{pmatrix}$

$\lambda_{max} = \frac{(3.2462+3.0704+3.0157)}{3} = 3.111$

Using equation (1), $CI = \frac{\lambda_{max} - n}{n-1} = \frac{(3.1111-3)}{(3-1)} = 0.055$

Hence using equation *(2)* the consistency ratio, $CR = \frac{CI}{RI} = \frac{0.055}{0.58} = 0.096 = 9.6\ \% < 10\%$

Since the CR < 10% the judgement can be accepted.

5. CONCLUSION

Cost Estimation is a crucial stage in the injection moulding industry. This process is handled by highly skilled in-house experts. The paper helped derive the main parameters Cost Estimators in the Western Cape Province Tooling industry use when quoting jobs. The AHP method ranked the parameters and labour-related costs were identified as the most significant cost element when it comes to contribution to total costs. Hence, proper monitoring and control of the production shop-floor during injection mould manufacture is key to due date and budget conformance. The results of this study can be used in the development of Costing expert Systems for toolmakers who specialize in Injection mould manufacture.

6. DECLARATION

This paper was done in partial fulfilment of a Ph.D. study in Industrial Engineering on the Development of a Holonic Control System for the Tool, Die and Mould-making Industry in South Africa conducted by Mncedisi Trinity Dewa.

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DEVELOPMENT OF A HEALTH REHABILITATION ACTIVITY MONITORING SYSTEM FOR TRANSTIBIAL AMPUTEES.

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ABSTRACT

This paper presents a novel approach for a remote activity and mobility rehabilitation monitoring system for transitibial amputees. The proposed system has the capability of monitoring ambulatory and mobility related activities such as standing, walking, sitting and walking on stairs. The design utilizes single channel inertial measurement signals to determine amputee performance. The methods involved in the system design include development of an embedded data acquisition system, data storage system, signal processing algorithm and the user interface. The final module of the system includes a data processing and presentation algorithm for clinical applications. Design parameters were based on normal human gait. The hardware and software for context-aware ubiquitous computing applications was developed. Subjects were tasked to perform random activities for three hours and the data was collected and analyzed. The system classified motions as walking, standing, laying, sitting and walking on stairs. The classification accuracy was 93.3%, due to challenges on classifying between walking upstairs and walking downstairs. The system error was 6.7%.

Keywords: Transtibial; amputation; mHealth; inertial, classification

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1 INTRODUCTION

Transtibial (below-knee) amputees fitted with prosthetic limbs often face difficulties due to the loading of the amputated site, boredom, lack of exercise and stress imposed by their new reality. Transtibial amputees often have the capability to regain normal movement more readily due to the availability of the intact knee which offers easy movement. However, due to the load bearing characteristics of the prosthetic limb, the amputees often find it difficult to accept the use of artificial limbs as compared to the use of clutches. Regardless of the type of surgical procedure used for amputation there is always severe pain experienced during rehabilitation thereby affecting the gait of the amputee. In some cases this has resulted in total rejection of the limb. During the immediate post-surgical procedure, prosthetists focus on minimizing swelling and preventing muscle flexion contractures. As recovery progress, focus is shifted on resuming normal activities and hence introduces the use of prosthetic limbs. The physician assists the amputee during the initial days of rehabilitation. This include training the amputee on the possible activities and movements that can be achieved using the fitted prosthetic limb. It is however difficult to determine the usability of the prosthetic limb by simple visual inspection as the amputee performs the predetermined activities under the guidance of the physician in the laboratory. Due to the desire to be discharged and the will to perform normal activities in society, the patient can easily set his mind to achieve the expected results. However, this will be different as compared to when the amputee performs daily mobility activities at home. Lack of exercises and reduced daily mobility at home may lead to increased weight gain thereby increasing the load bearing of the artificial limb and ultimate rejection of the artificial limb. This is even worse for an amputee whose cause of amputation was sugar diabetes as lack of mobility increases the effects of the disease. There are more than 300 000 amputees in South Africa and 60% of lower limb amputees in South Africa are as a result of sugar diabetes. In the United States of America there is an average of 133 735 new amputees per year [1]. Therefore one in every 200 Americans has received an amputation of which lower limb amputation accounts for 86% [2].

Biomechanics laboratories equipped with very expensive equipment such as optical motion tracking systems and imbedded force plates mainly focus on tracking human motion and performing dynamic analysis of physical behavior of individual body parts [3]. Such environments are not convenient for continuous patient monitoring. It is well known that the behavior of a patient in a laboratory is quite different compared to when the patient is at home [4]. Therefore there is a need to acquire data on how the amputee utilizes the prosthetic limb on a daily basis at home or at work. The data can then be used to improve prosthetic designs and motivate the amputees to live a good healthy lifestyle.

The objective of the proposed design is to determine the usability and acceptability of the prosthetic limb by an amputee by determining the type and extend of activities carried out by amputees during rehabilitation under minimum to no supervision. The proposed design is categorized as a remote mobile activity monitoring tool due to its capability of being integrated into Mobile Health Systems on information recording, conveyance and processing capabilities as a remote health care monitoring tool.

The paper unfolds as follows: section 2 presents an overview of mHealth System, section 3 presents different types of signals that could be harnessed from the limb, section 4 presents the design considerations, section 5 presents the development of data acquisition unit, section 6 presents the results of the design and section 7 concludes the research.

2 OVERVIEW OF m-HEALTH

The world currently revolve around Internet-Of-Things (IoT), however, the applicability of IoT based technologies such as e-Health in developing countries is still a challenge as the accessibility of the internet is still low. The increased usage of smart phones have however facilitated the rapid increase in the use of mHealth (Mobile Health) systems. These smartphones can also be used to acquire, receive and send data. The three fundamental issues on the applicability of mHealth technology are *acceptability, applicability* and mostly *adaptability* [5]. The technology is mainly evaluated on its appropriateness to the task at hand and the user rather than by its modernity or ease-in-use for developers. The objectives of mHealth technology for amputee rehabilitation include promoting healthy lifestyles, improving decision making capabilities of health professionals as well as patients, and enhance healthcare quality by improving access to medical and health information. mHealth systems also facilitates instantaneous communication in places where this was not previously possible. Centralised health care facilities, limited experts and poor infrastructure has been the driving factors for the implementation of mHealth systems in developing nations. The mHealth system has been around since the inception of telemedicine, however the application of mHealth had been limited due to the availability of smart phones and telecommunication infrastructure. The rapid increase in telecommunication operators and improved network coverage supported by decrease in smart phone cost has resulted in the sudden growth in mHealth systems. For almost a decade mHealth has been utilized within health care systems for treatment compliance, data collection and disease surveillance, health information systems and point-of-care support, health disease prevention and emergency medical response. There are several advantages of utilizing mHealth systems for amputee patient rehabilitation, these include [6]:

- Provide platform for connecting the amputees and the physicians in remote areas
- Provide a reliable platform for early diagnosis and treatment of amputation based diseases
- Provide real-time data acquisition for online and offline analysis
- Decrease time gap between data collection in the field and viewing of data.

3 METHODS AND MATERIALS

According to [7], technology integration is divided into two general frames: *processes* and *outcomes* that lead to development. The processes are then divided into data acquisition, processing and communication. The systematic procedure used to achieve the objective of using mHealth to monitor transitibial amputees was as follows:

- An electronic hardware system with the IMU sensors and the processor was developed
- An inertial measurement unit was mounted on the artificial prosthetic limb
- A data acquisition algorithm was developed and deployed
- On-board filtering was implemented as firmware for embedded sensors
- Sensor fusion technique was implemented for IMU sensor
- Data from the IMU sensors were stored in an SD Card as text files
- The acquired data was preprocessed using Matlab by applying the low pass and high pass filters
- The filtered signal was then used to determine a feature set
- Activity recognition was then determined using a classifier

A data set was collected from five normal subjects. Each subject was asked to perform the six activities (standing, sitting, laying, walking, walking upstairs and walking downstairs).Each activity was performed 10 times for a period of five minutes per activity. During the testing phase the activities were performed in a random order for a duration of three hours. The data was collected using an SD card located within the signal acquisition circuit. The training data was labeled according to the respective activity being carried out. After developing, training and testing the system, raw data was used to test for system classification accuracy.

4 DATA ACQUISITION SYSTEM

The reliability of a mHealth system is largely dependent on the quality of data acquired. The main goal of the data acquisition module is to record and store the raw data for further processing by the physicians. However, there are several factors that affect the quality of recorded data. These include sensor calibration, sensor positioning and general environmental condition. According to [8], knee rotation angle during walking can be determined using two gyroscopes one at the thigh and another one at the shank. However bulky designs suffer from frequency detection errors and make the user feel uncomfortable. The proposed system utilizes only one IMU unit which was mounted below the knee. Sensor fusion techniques have been the key aspect of robust data acquisition hence the combination of accelerometer, gyroscope and magnetometer signals in this proposed device provided a more reliable data acquisition system. The Python algorithm was used to acquire the desired signals and stored as a text file on a SD card.

4.1 Inertial measurement unit (IMU)

The use of a single IMU unit largely depend on the level of intelligence of the algorithm implemented for data acquisition. Most amputees would not be comfortable wearing a lot of sensors on their body during rehabilitation therefore a 3 axis accelerometer, 3 axis gyroscope and a 3 axis magnetometer were used along with a temperature sensor as a 9 degrees of freedom single IMU unit. The advantage of using the microelectromechanical systems (MEMS) is that the devices are small in package size, low power consumption, high accuracy, high repeatability and high shock tolerance. Their application specific performance programmability present an avenue for easy integration with existing technologies. In this regard a MP6050 model was used and the orientation of the axes of sensitivity and the polarity of rotation is shown in figure 1.

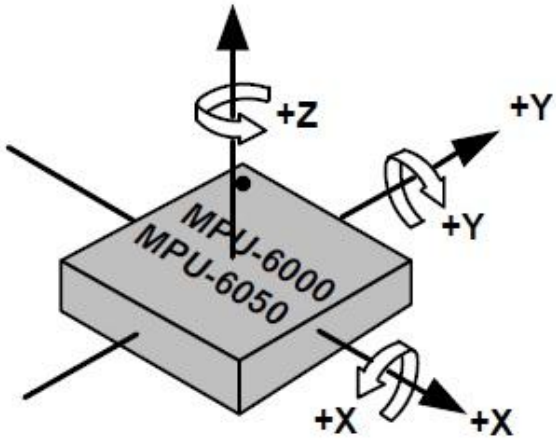

Figure 1: Orientation of Axes of Sensitivity and Polarity of Rotation

The objective is to acquire the accelerometer, gyroscope and magnetometer values so as to formulate a data set which can easily be used for activity recognition. To achieve such a data set there is a requirement for proper filtering and sensor fusion techniques. The design made use of arbitrarily defined zero-identity orientations which makes perfect physical alignment unnecessary and reduces the difficulty in extracting desired outputs. The sensor was equipped with an internal Digital Motion Processor (DMP) which allows 3D motion processing algorithms. The human body is not uniform and thus presents the possibility of imperfect sensor placement, therefore the quaternion orientation output and the quaternion operations were developed and deployed to account for the human body's irregularities thereby achieving accurate forward and downward vectors. The algorithm for detection of angles also incorporated the Kalman filtering technique.

A quaternion, q, is a fourth dimensional vector that can be interpreted as a third dimensional rotation:

$$\boldsymbol{q} = (\boldsymbol{i}x, \boldsymbol{j}y, \boldsymbol{k}z, w\ ) \quad (1)$$

$$\boldsymbol{q} = \left(\boldsymbol{u} sin\left(\frac{\theta}{2}\right), cos(\frac{\theta}{2})\right) \quad (2)$$

$$\boldsymbol{q} = (\boldsymbol{v}, w) \quad (3)$$

Where **u** is a vector defined as: $\mathbf{u} = (\mathbf{i}\,, \mathbf{j}\,, \mathbf{k})$ and **θ** is the measured angle.

To compensate for the misalignment and sensor placement problems, the gravity vectors of the sensor were considered since the gravity vector can align with one of the Cartesian coordinate axes of the device reference frame when in the calibration mode (starting position). Assuming that **g** is the expected gravity vector, $\boldsymbol{g_d}$ is the gravity vector from the device and $\boldsymbol{a}$ is the unit vector that denotes the axis of rotation from $\boldsymbol{g_d}$ to **g** and $\mathbf{q_0}$ is the rotational offset as a quaternion, then equation (3) is true.

$$\theta = arccos(\boldsymbol{g_d} \cdot \boldsymbol{g}) \quad (4)$$

$$\boldsymbol{a} = \boldsymbol{g_d} \times \boldsymbol{g} \quad (5)$$

$$\boldsymbol{q_0} = (\boldsymbol{a} sin\left(-\frac{\theta}{2}\right), cos\left(-\frac{\theta}{2}\right)) \quad (6)$$

The ultimate goal was to offset $\boldsymbol{g_d}$ so as to line up with **g**, this was achieved through the product of the filtering orientation and the rotational offset, $\mathbf{q_0}$ and the result was the tare orientation of the sensor. A *tare* orientation is the use of a certain orientation for the zero orientation instead of the orientation indicated by the reference vectors. Finally the forward vector of the sensor, $\boldsymbol{v_F}$, was determined as in equation (7) taking into consideration the filtered tare orientation of the device, $\mathbf{q_t}$.

$$\boldsymbol{v_F} = \boldsymbol{q_t q_0 v} \quad (7)$$

Where $\boldsymbol{v}$ is the unrotated forward vector in the sensor's space. However the determination of the down vector, $\mathbf{v_D}$ is almost similar to the forward vector hence the up-vector, $\mathbf{v_U}$ is the negative vector of the down vector as shown in equations (8) and (9).

$$\boldsymbol{v_D} = \boldsymbol{q_t q_0 v} \quad (8)$$

$$v_U = -v_D \tag{9}$$

4.2 Measurements

The determination of quantitative information for analysis was based on the standard normal gait analysis for humans. The quantities required by most physicians for the design to be clinically viable are *when, how long and how often* and *what* activity was being carried out as related to ambulatory and mobility activities. These can be translated to *walking, sitting, running, standing, walking upstairs and walking downstairs*. These activities can be determined by monitoring the accelerometer, gyroscope, and magnetometer readings to determine the roll, pitch and yaw of the limb. However, an inverted tilt measurement was also tested. Experiments were carried out using the Vicon Camera System to determine the joint angles of the lower limb during several activities with an emphasis on walking, sitting, running and standing. These values were used as design specifications. The acquired signals were then used to determine the design parameters and validation of the proposed design. The signals from the accelerometer, the gyroscope and the magnetometer were tested for variability during each individual activity. The data set contained the following information:

- Roll , Ø
- Pitch , θ
- Yaw , ψ
- Kalman Filtered Values (kalX, kalY, kalZ)
- Complimentary Filtered Values (compX, compY, compZ)
- Raw IMU data values (accX , accY, accZ) and (gyroX, gyroY ,gyroZ)

It should however be noted that only the signal features from the above mentioned parameters were used as input data to the classifier and not the raw signal. The roll and pitch were calculated using the accelerometer while yaw was calculated using the magnetometer. The accelerometer had a full scale of ±2g and a sensitivity of 16384 LSB/g. The gyroscope had a full scale of ±250 ^{0}/s and a sensitivity of 131 LSB/ (^{0}/s). The greatest set back with the use of IMUs is the sensor misalignment considerations, this is mainly defined as the angular difference between the sensor's axis of rotation and the system defined inertial reference frame (global frame). The roll, pitch and yaw rotation matrices can transform a vector such as gravitational field vector **g** under a rotation of the coordinate system about x, y and z resulting in R_x, R_y and R_z respectively.

$$R_x(\emptyset) = \begin{bmatrix} 1 & 0 & 0 \\ 0 & cos\emptyset & sin\emptyset \\ 0 & -sin\emptyset & cos\emptyset \end{bmatrix} \tag{10}$$

$$R_y(\theta) = \begin{bmatrix} cos\,\theta & 0 & -sin\theta \\ 0 & 1 & 0 \\ sin\theta & 0 & cos\theta \end{bmatrix} \tag{11}$$

$$R_z(\varphi) = \begin{bmatrix} cos\varphi & sin\varphi & 0 \\ -sin\varphi & cos\varphi & 0 \\ 0 & 0 & 1 \end{bmatrix} \tag{12}$$

However the yaw, $R_z(\varphi)$ is difficult to use as the accelerometer's z-axis is aligned to the earth's gravitational field. Therefore the roll and the pitch were more relevant.

4.3 Determination of the roll and the pitch

The roll and the pitch are also useful parameters which can be determined by using a single IMU sensor. In this regard raw accelerometer values were recorded and the roll and pitch was determined using equation (16) and (19) respectively. The Kalman filter and the complimentary filter were both applied to the signal under restricted pitch and unrestricted pitch conditions and the results are illustrated in figure 5. If G_p is the normalised accelerometer reading related to the roll (Ø) and pitch (θ) angles, then,

$$\frac{G_p}{\|G_p\|} = \begin{bmatrix} -sin\theta \\ cos\theta sin\emptyset \\ cos\theta cos\emptyset \end{bmatrix} \tag{13}$$

$$\frac{1}{\sqrt{kal_x^2+kal_y^2+kal_z^2}} \begin{pmatrix} kal_x \\ kal_y \\ kal_z \end{pmatrix} = \begin{bmatrix} -sin\theta \\ cos\theta sin\emptyset \\ cos\theta cos\emptyset \end{bmatrix} \tag{14}$$

$$tan\emptyset_{xyz} = \left(\frac{kal_y}{kal_z}\right) \tag{15}$$

$$roll\ ,\emptyset = actan\left(\frac{kal_y}{kal_z}\right) \quad (16)$$

$$tan\theta_{xyz} = \left(\frac{-kal_x}{kal_y sin\emptyset + kal_z cos\emptyset}\right) \quad (17)$$

$$tan\theta_{xyz} = \frac{-kal_x}{\sqrt{(kal_y^2 + kal_z^2)}} \quad (18)$$

$$pitch, \theta = -actan\left(\frac{-kal_x}{\sqrt{(kal_y^2 + kal_z^2)}}\right) \quad (19)$$

Where kal_x, kal_y and kal_z are outputs from the Kalman filter. However, the same roll and pitch can be determined using the *accX, accY, accZ* values which are the raw signals from the IMU before the application of either the Kalman filter or the complimentary filter.

4.4 Determination of tilt, ρ

The tilt angle, ρ of the lower limb from the original position when the subject is seated or standing in the absence of linear acceleration can be determined. The angle ρ, is between the gravitational vector measured by the accelerometer and the initial orientation with the gravitational field pointing downwards along the z-axis as shown in figure 2. In the algorithm this is used to determine the standing and seating position, hence distinguishing leg swing from a walking activity.

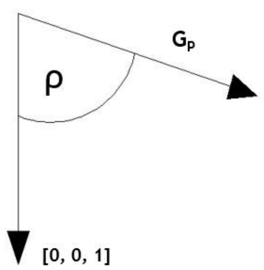

Figure 2: Tilt angle from vertical position.

Taking into consideration the accelerometer reading, **Gp** (acc_x, acc_y, acc_z) in the absence of linear acceleration, the tilt angle is determined as shown in equation (20).

$$G_p \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix} = acc_z \quad (20)$$

$$G_z = |G_p| cos\rho \quad (21)$$

$$cos\rho = \frac{acc_z}{\sqrt{(acc_x^2 + acc_y^2 + acc_z^2)}} \quad (22)$$

$$\rho = arcos\left(\frac{acc_z}{\sqrt{(acc_x^2 + acc_y^2 + acc_z^2)}}\right) \quad (23)$$

The algorithm was developed using Python to determine the roll, pitch and yaw angles. The minor changes of the mathematical expressions within the algorithm were handled by the libraries. Major challenges were on calibration and offset value detection.

5 ACTIVITY RECOGNITION

The activities were identified using both a threshold technique and pattern recognition system. According to [9], the clinical viability of the proposed system is largely dependent on the underlying recognition module's ability to detect a variety of activities that are performed routinely in many different manners by different individuals under different environmental condition. This however presents a bottleneck as the real world data is noisy and complex. The raw data acquired from the accelerometers, gyroscopes and magnetometer were stored as text files. Matlab was then used to filter the values so as to remove noise interference and consider only signals due to limb movement. Low pass filters and high pass filters were implemented in the algorithm. The pre-processing stage was done so as to reduce the processing time and minimize the computational complexity of the system. The signal acquisition algorithm had several outputs which included raw accelerometer and gyroscope readings before applying the Kalman and Complimentary filter, magnetometer readings, roll, pitch and yaw readings. The data set had 21 signals. This provided a large data set for activity recognition. However only a set of features were used to formulate a feature set which was then used as an input to the classifier as shown in figure 3.

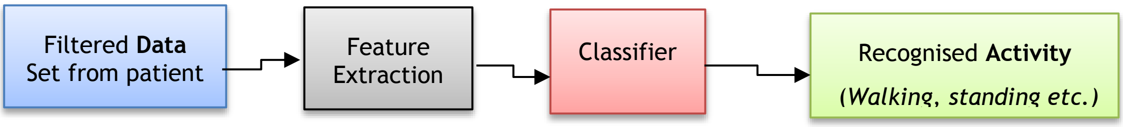

Figure 3: The Activity recognition Module

Although there are several signal features that can be used by signal classifiers [10], the most common ones are integrated EMG (IEMG), mean absolute value (MAV), modified mean average value (MMAV), variance of EMG (VAR), waveform length (WL) and Wilson amplitude (WAMP).

$$IEMG = \sum_{n=1}^{N} |h_n| \qquad (24)$$

$$MAV = \frac{1}{N}\sum_{n=1}^{N} |h_n|\, W(x) = \begin{cases} 1, & 0.25N \le n \le 0.75N \\ & 0, otherwise \end{cases} \qquad (25)$$

$$MMAV = \frac{1}{N}\sum_{n=1}^{N} |h_n|\, W_n \qquad (26)$$

$$VAR = \frac{1}{N-1}\sum_{n=1}^{N} h_n^2 \qquad (27)$$

$$WL = \sum_{n=1}^{N-1} |h_{n+1} - h_n| \qquad (28)$$

$$WAMP = \sum_{n=1}^{N-1} f(|h_{n+1} - h_n|)\, f(x) = \begin{cases} 1, & x \ge threshhold \\ & 0.5\,, otherwise \end{cases} \qquad (29)$$

$$Simple\ Square\ Integral, SSI = \sum_{n=1}^{N} |h|^2 \qquad (30)$$

$$Root\ Mean\ Square, rms = \sqrt{\frac{1}{N}\sum_{n=1}^{N} h^2} \qquad (31)$$

$$log\ detector\ , LOG = e^{\frac{1}{N}\sum_{n=1}^{N} log|h_n|} \qquad (32)$$

$$slope\ sign\ change\ , SSC = \sum_{n=1}^{N} f\,[(h_n - h_{n-1}) \times (h_n - h_{n+1})]\,,\ f(x) = \begin{cases} 1, & if\ h \ge\ threshold \\ 0, & otherwise \end{cases} \qquad (33)$$

These features formulated the input signal to the classifier. Each activity resulted in a unique feature vector. Therefore it was easy for the classifier to distinguish the activities.

6 SYSTEM ARCHITECTURE

The proposed system architecture consist of an IMU with an embedded Digital Motion Processor™ (DPM). The DPM provides an added advantage on an onboard processing unit before the signals are send to the main processing unit (MPU). This in turn reduces the computational time and complexity of the motion algorithms. The IMU and the microprocessor used I2C communication protocol thereby enabling a sensor fusion for all the four forms of signals from the accelerometer, gyroscope, magnetometer and the temperature sensor. The temperature sensor is inbuilt for monitoring the operational temperature of the device as shown in figure 4.

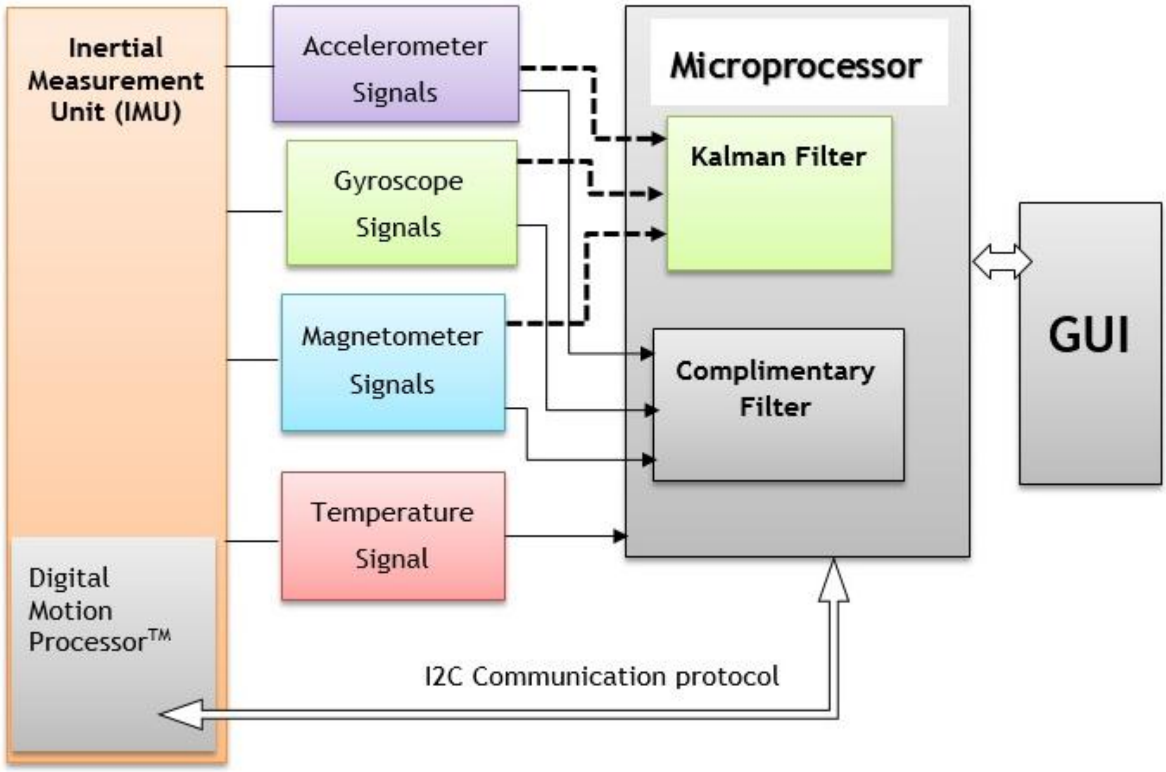

Figure 4: Proposed System Architecture

The main processing unit has a Bluetooth module which allows the uploading and downloading of files onto the personal computer where the GUI is resident. If internet is available on a mobile phone the files can be accessed using third party software. However, for those in remote areas where internet accessibility is limited or not present the SD card can be removed from the device and the information can be send via text file (data.txt).

7 RESULTS

The results presented in this section were recorded after calibration of the sensor so as to reduce the errors from offset and sensitivity mismatch. Tilt was determined by direct integral of the output of the gyroscope, however the error associated with the null bias stability affected the results as the signal period increased. This caused an apparent rotation even when the observed subject was stationary. Therefore this is not a recommendable method for a signal to be recorded over a period of hours or days. As a result the inclination angle was determined using accelerometer values under static conditions. The results were used to determine the movement of the lower limb when the amputee (subject) is seated or standing as illustrated in figure 5. Standing would produce a constant and almost steady acceleration at $10ms^{-2}$ in the x-axis (a_x), while the walking activity produces an oscillating signal around $10ms^{-2}$. Positions that can be monitored for such activity are the knee angle and the ankle angle during (dorsiflexion or plantarflexion) under static conditions.

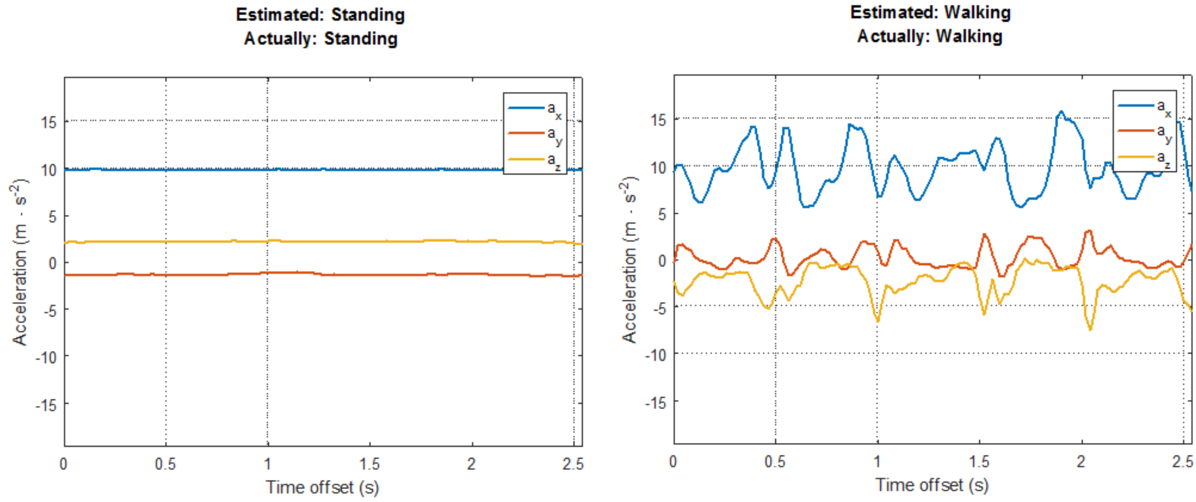

Figure 5: Standing vs Walking Accelerometer values (Where estimated resembles the labeled data points and actual is the real time performance of the classifier)

The gyroscope had notable drift under small periods, the features from the gyroscope was fused with accelerometer signals so as to reduce errors associated with the drift. The movement of the legs during walking or climbing stairs could both not provide convincing information for the adoption of raw gyroscope readings, as a result this reduces the classification accuracy. The accelerometer returned true values when the acceleration was progressive but suffered greatly from vibrations of the system. This has necessitated the implementation of the Kalman filter and complimentary filter as techniques to extract a useful signal. The two filters were both tested under the same conditions and the results are presented in figure 6.

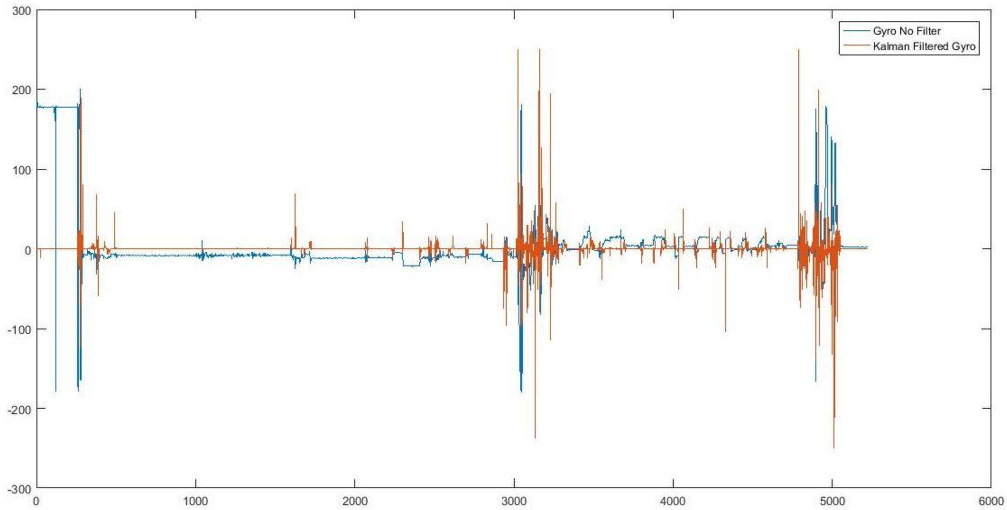

Figure 6: Comparison Kalman Filter and Complimentary Filter (Walking Activity)

The results show that the Kalman filter provides a smooth and useful signal with a steady state error of zero. The Kalman filter is an optimal estimator [11]. It infers parameters of interest from indirect, inaccurate and uncertain observations. The underlying principle is that if all noise is Gausian, the Kalman filter minimizes the mean square error of the estimated parameters. It is regarded as the best tool to achieve optimal estimates for linear systems through online real time processing [12]. The implementation was based on the fact that prior knowledge was not necessary as the filter relies on the last state and covariance matrix that defines the probability of the sate being correct. The strength of the Kalman filter is on adaptation and robust sensor fusion through the use of the prediction and the update equations [13]. The prediction equations predict current position of the artificial limb based on the previous position (state). The update equations check for IMU outputs reliability and how reliable the predicted state is as illustrated in figure 7.

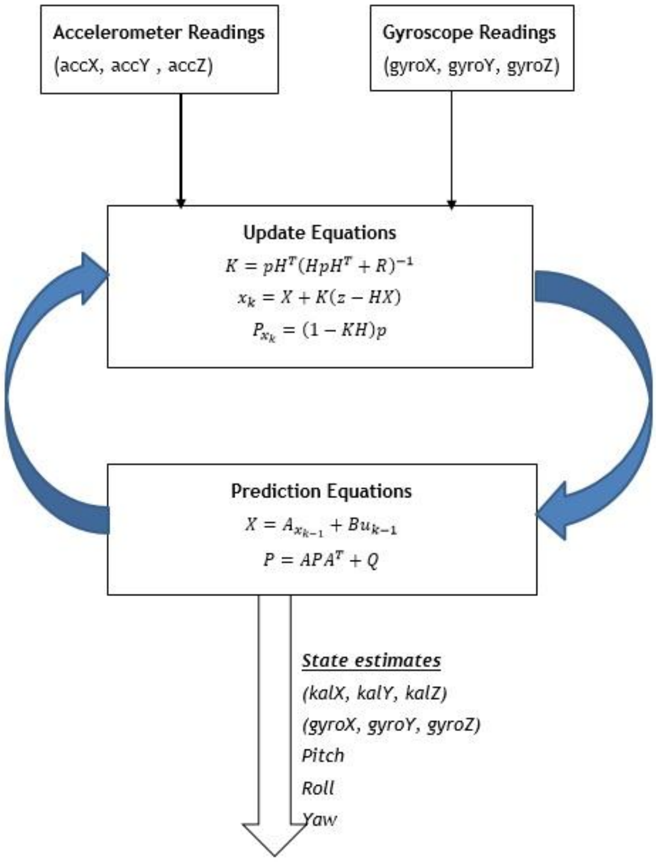

Figure 7: The Kalman Filter algorithm

Where x and X – represents the state (accX, accY, accZ) of the limb (signals to be filtered) , U is the action or the filtered signal (roll , yaw, pitch) (kalX, kalY, kalZ) , P and p – confidence coefficients and it shows how the filter is confident with the solution, it is initiated as a diagonal matrix of the variance, Q is the covariance of the process noise, H is the sensor model and initialized as diagonal identity matrix and adjusted during design, R – indicates the confidents of the sensors (accelerometer and gyroscope), it is the key for sensor fusion, z- these are the outputs or measurements returned from the sensors at each position and estimated by the filter when missing. I is the diagonal identity matrix. A and B are model matrices that represents how the system changes from one state to the other. After initial calibration, the algorithm begin with the current state, $\mathbf{x_{k-1}}$, the initial covariance matrix $\mathbf{P_{k-1}}$ and the current input u_{k-1} to get the predicted state X and predicted covariance matrix p. Then the achieved measurement was y_k and use the update equations to correct the initial predictions in order to get the new state matrix x_k and new covariance P_k. The process was then iterated in the algorithm.

The classification system employed the artificial neural network (ANN) with the determined feature set as input and activity as output. There was however a challenge on classifying walking upstairs and walking downstairs. Although the autocorrelation in figure 8 illustrates differences in amplitude, the signal frequency looked very similar. Principle component analysis was one of the feature extraction technique that was implemented so as to distinguish the walking downstairs and walking upstairs activity thereby reducing the classification error.

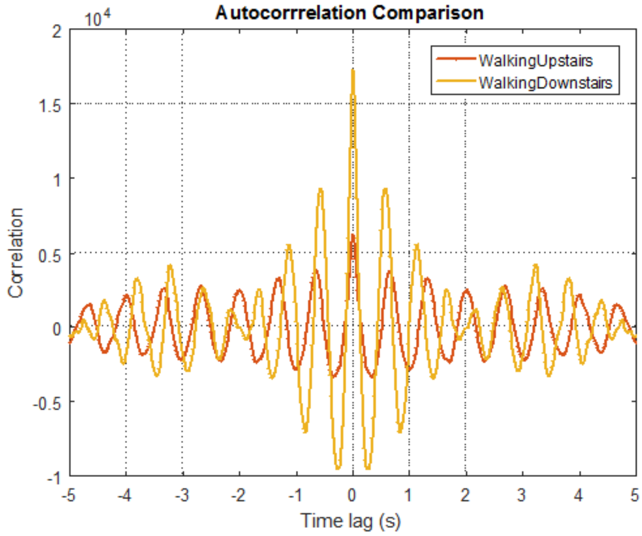

Figure 8: Autocorrelation Comparison of Walking Upstairs and Walking Downstairs

The autocorrelation was useful for frequency estimation especially for the low-pitch frequencies such as accelerometer values. The magnetometer signal was very difficult to utilize for activity recognition as it was affected largely by the presence of metallic objects. Even after the use of a plastic casing the readings were still affected, it was impossible to use shielded or screened casing. There was however clear distinction between walking on a flat surface and walking upstairs as illustrated on figure 9. The contribution of low frequencies on the walking upstairs as compared to walking on a flat surface was then detectable during feature extraction and used as a distinct feature.

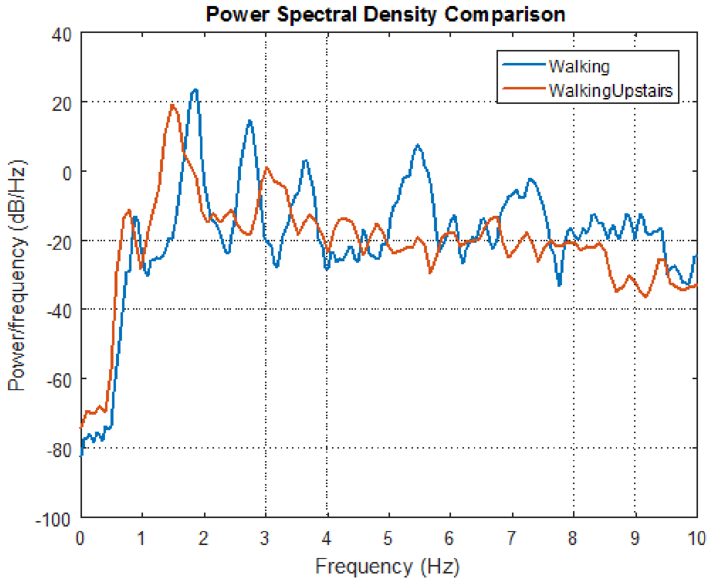

Figure 9: Power spectral density for walking and walking upstairs

The confusion matrix shown in figure 10 illustrates how the system was able to classify the activities. The system achieved 93.3% classification accuracy. The main contribution for the 6.7% error was largely due to classifying between sitting, standing and laying. There was also notable errors on the system on classifying between walking upstairs and walking downstairs. However to a larger extent the system was able to classify all mobility activities.

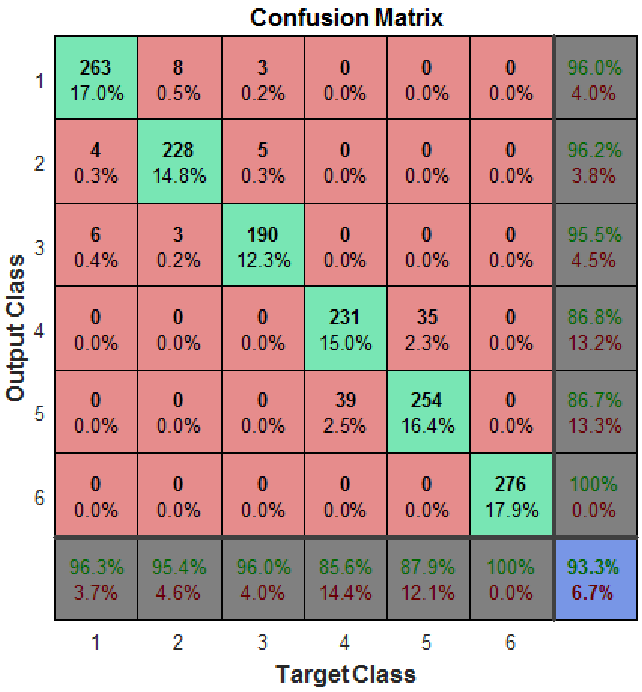

Figure 10: Confusion matrix

The confusion matrix shown in figure 10 illustrates that the system can reliably classify the activities. The designed electronic circuit and the proposed system architecture provided reliable information for the development of a Rehabilitation Monitoring System (RMS) for transitibial amputees who have received prosthetic limbs. The system was capable of recording daily activities responsible for mobility. The results can easily be used by clinicians to make informed decisions regarding the usage of the artificial limb. However, the developed system does not show the gait cycle parameters as it is only limited to activity recognition, length of activity and period of when the activity was performed. The activities can easily be visualized as illustrated in figure 11. However, the signal illustrated shows only one channel. The proper signal presentation will be implemented using Qt, which is a software development tool capable of running on several platforms including html, android and windows.

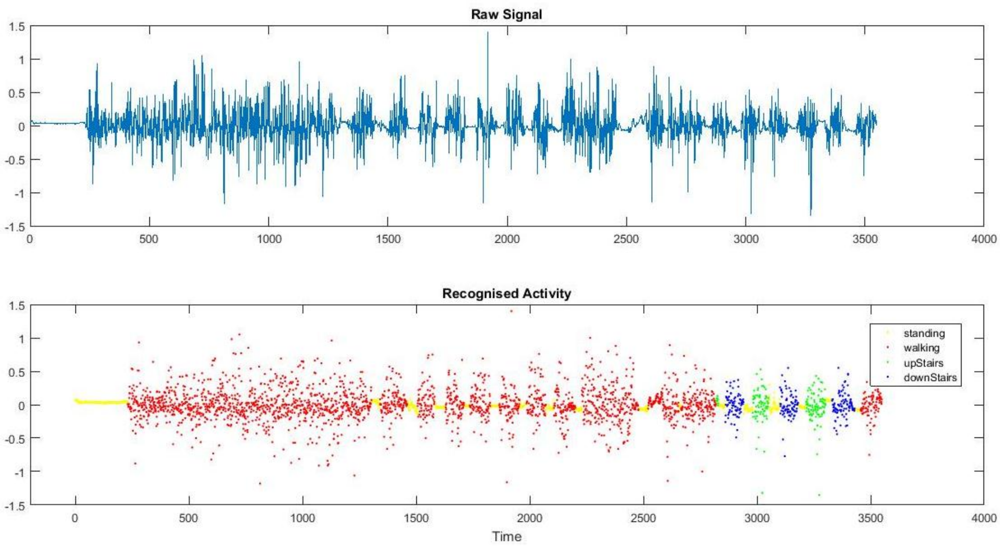

Figure 11: Classified signal

The results for hardware development and signal acquisition were not presented, the paper focused on results for activity recognition which determine the success of the hardware and signal acquisition system. The graphical user interface within Qt will include results such as type of activity, when the activity was done and duration of each activity.

8 CONCLUSION

The development of the mHealth System for rehabilitation monitoring of lower limb amputees was successful to a greater extent. However, there are other areas which we recommend still need attention such as data security as the system is supposed to provide high level security to personal information. The technology concept proved to be cheap and easy to integrate into already existing healthcare monitoring systems. One of the novelties of the system is its machine learning algorithm, sensor fusion and use of single nodal data acquisition system. The use of information from a single nodal point requires high level machine learning language as it is well known that information gained from multimodal sensors can offset the information lost when sensor readings are collected from a single location. However, in our case the need for a single sensor was to reduce the number of components mounted on the artificial limb, reduce system cost and introduce a new technique. The reliability of the decision made when a signal is lost is based on the capability of the Kalman filter to project a signal based on past signal inputs. Recommendations for further improvement include miniaturization of the architecture, full utilization of the embedded DMP, a standalone signal processing and presentation mobile application.

The proposed design will assist on the rapid implementation of mobile health systems in South Africa. The benefits which will be realised on the full roll-out of the system include drug performance monitoring, improved home based care system, reduced queues at public hospitals as Medical Doctors could now assess the patient via the mobile platform and the outbreak of common diseases in some remote areas can easily be detected during the initial stages. The proposed system is an add-on tool to an already existing functional platform. Much of the health care system is carried out by the Healthcare Systems Research Group at Stellenbosch, which focuses on telemedicine and its related technologies.

The on-going research will ultimately result in the development of hardware and software for context-aware ubiquitous computing applications.

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IMPACT OF MANUFACTURING STRATEGY ON OPERATIONAL PERFORMANCE: A CASE STUDY OF ZIMBABWEAN MANUFACTURING INDUSTRY

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ABSTRACT

The relationship between manufacturing strategy and operational performance was studied within the ambit of world class manufacturing. The study investigated the extent to which manufacturing strategies were being applied in the case of an alcohol manufacturer in Zimbabwe as well as in the Zimbabwean manufacturing industry as whole. The derivation of manufacturing strategies for successful manufacturers; and the linkage of these strategies to corporate strategies of the firms was assessed. The study evaluated the involvement of manufacturing managers in strategy development; and determined the manufacturing strategies being employed. Data from the alcohol manufacturer and a sample of forty members of the Confederation of Zimbabwean Industries' (CZI) manufacturing firms were used. Ninety percent of the manufacturers had a corporate strategy and there was a significant relationship between existence of corporate strategy, manufacturing strategy and operational performance. The alcohol manufacturer had no documented manufacturing strategy but considered two competitive priorities (cost and quality) in planning. The study also revealed that manufacturing firms used a combination of competitive priorities in coming up with manufacturing strategy, with corporate strategy being derived from manufacturing strategy. This study recommends that manufacturing priorities drive the strategic management process necessitating the presence and input of manufacturing technical managers in the strategy formulation process.

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1 INTRODUCTION

Globalisation has tightened competition in the Zimbabwean manufacturing sector with products from companies across the globe landing in Zimbabwe at almost half the price of the same product produced in Zimbabwe [1] & [2]]. The manufacturing sector is one of the four wealth generating sectors in Zimbabwe [2], contributing 30% to the country's GDP at its peak in the late 90s [3]. With this sector now contributing a meagre 2.3% to Zimbabwe's GDP as of 2012 [2]; the need to strategically position companies in this sector cannot be overemphasized. The bottom-line purpose of strategic planning in the manufacturing sector is to ensure long-term viability and growth, the cornerstones of which are quality to customers, returns to owners, and opportunities for employees. As noted by Platts and Gregory [4], manufacturing systems improvements have traditionally been the responsibility of technical personnel, cost reduction often being the primary aim with little awareness of, or attention being paid to other business factors including quality, flexibility and delivery period. Lacking in sound manufacturing strategies that are consistent with overall business strategies, such manufacturing systems have thus failed to contribute satisfactorily to the competitive position of their companies [4].

Manufacturing is an important component in corporate success, a view that has spurred the development of manufacturing strategies in companies seeking competitive advantage, yet there is a realisation that understanding of manufacturing strategies creating competitive capabilities and profits is weak [5]. According to Ehie [6], manufacturing strategy refers to the specific competencies in the areas of cost, quality, delivery and flexibility that are developed to achieve the competitive advantage in a firm. Traditionally, the manufacturing system has been limited to addressing technical issues of production [7]. However, as early as 1969, Skinner [8] noted that the manufacturing function can and should be employed as a competitive weapon with manufacturing strategy providing the long term guideline to plan, schedule and control value adding activities and decisions that over time, enable a business unit to achieve a desired set of specific capabilities [9]. The link between strategy and performance has been the focus in manufacturing strategy research with a positive relationship between manufacturing strategy and performance being reported [10]. The manufacturing success-business performance relationship is however indirect. To link manufacturing to overall business performance requires management to exploit manufacturing capabilities to operationalize manufacturing strategy [11].

1.1 Competitive priorities and Manufacturing capabilities

The early contributions of manufacturing strategy researchers have highlighted the strategic role of the operations and manufacturing function in establishing firm performance [7]; [8] & [9] Competitive priorities are the attributes of an organization that attract customers; the potential points of differentiation between an organization and its competitors. They define the set of manufacturing objectives and represent the link to market requirements [12]. Researchers consider these competitive priorities to be the link between market requirements and manufacturing [13]. The manufacturing function is expected to implement structural and infrastructural decisions that are consider low cost, quick delivery, flexible designs and superior quality [10]. While some authors suggest innovativeness and service as additional priorities [14] & [15], research and strategy theories consistently stress the four basic dimensions of cost, quality, delivery and flexibility [16].

Operationalization of manufacturing strategy occurs through a pattern of decisions, an observation acknowledging the influence of management on the development and performance of the system. Decisions within the manufacturing functions determine which resources to use and what routines or practices to employ and emphasise in order to achieve the manufacturing objectives. This set of practices, resources, and routines used, ultimately determine the operating characteristics of the manufacturing system, i.e. the manufacturing capabilities that together with competitive priorities influence the firm's manufacturing performance [17]. Thus, manufacturing capabilities can be viewed as the link between manufacturing strategy content and manufacturing performance. Manufacturing strategy has adopted the notion of capabilities from strategic management literature, particularly the resource-based view (RBV) of the firm proposed by Wernerfelt [18] and Barney [19]. The basis in RBV is that resources are not uniformly distributed across firms making the deployment of these resources a potential source of competitive advantage. The resources, to be of competitive advantage, must be assets, routines, or practices controlled by a firm that are valuable, rare, imperfectly imitable and unsubstitutable [19].

Corbett and Claridge [20] denote capabilities as the ability of a firm to apply resources to act or achieve a goal, and further states that capabilities form the primary basis for competition between firms. In manufacturing strategy literature, capabilities are conceptualised as a business unit's intended or realised competitive performance or operational strengths and are therefore assessed using measures of operational performance, which typically includes cost, quality, flexibility, and delivery measures [21]. Swink and Hegarty [22] suggest that this performance-based approach to capabilities is conceptually aggregated to clearly direct the proper use of manufacturing resources. Different from the performance-based approach to capability research that is dominating the manufacturing strategy literature is the routine based approach to explaining the heterogeneity of firms. Capabilities are identified as high-level routines or bundles of routines [23]. Compared to resources, routines and capabilities built on routines are embedded in the dynamic interaction of multiple knowledge sources and are more firm-specific and less transferable. For instance, a firm may have machines, input material, financial resources, and operators available to manufacture their products. However, to facilitate efficient manufacture and to achieve superior performance effective routines need to be developed to make all resources work in harmony and to enable dynamic information and knowledge exchange among individuals. Again, this clearly implies that manufacturing practices constitute a very important part in the development of manufacturing capabilities.

1.2 Manufacturing Strategy and Corporate Strategy: the link

Researchers have called for the alignment of the manufacturing strategy with the corporate strategy as well as involvement of the manufacturing aspect in formulating the corporate strategy to improve business performance [24]. The role of the manufacturing system in the company's competitive strategy has increasingly been realised from a strategic planning point of view [7;10]. Manufacturing strategy, in addressing goals and strategic decisions to face competition, seeks to align the firm's management approach to manufacturing with the corporate strategy that ultimately ensures business success [7]. The resource based theory suggests that a business unit's ability to achieve its profit maximization goal is a function of its ability to assemble and deploy appropriate resources that will provide it with sustainable competitive advantage in the market place [25]. Manufacturing strategy focuses at least in part on these resource decisions, being the means by which competitive strategy is implemented, and thus a major contributor to firm success.

1.3 Capacity utilisation

Operational performance can be inferred from the firm's capacity utilisation. As Ray [26] notes, business decision and policy formulation mostly depend on economic indicators however manufacturing capacity utilization becomes a key indicator of economic performance by giving a measure of resource-use efficiency. Having determined the competitiveness of the manufacturing economy and the supply-side factors that affect manufacturing, the design capacity of the economy can be ascertained. This is essentially the volume that can be produced by the economy in different product categories. The average capacity utilization for the Zimbabwean manufacturing sector in 2012 was 44.9% [27]. The design capacity represents the output that the economy can optimally produce at any given time, and this does not necessarily correspond to the capacity that is actually utilised. Various constrains will affect capacity utilisation, and from the metrics relating to cost and time, optimum capacity utilisation can be determined. Klein and Summers in Nyaoga et al. [28] define productive capacity as "the total level of output or production that could be produced in a given time period". *The Statistics South Africa Manufacturing: Utilization of Production Capacity Survey* defines capacity utilisation - measured as a percentage - as;

> "*utilisation which can feasibly be attained by [an] establishment with its current fixed assets and without significantly increasing unit costs as a result thereof*"

Note should thus be taken of the fact that capacity utilisation is economic in a given range, outside of which, the cost of production increases and reduces the ability of manufacturing to compete against other economies. The measurement of actual capacity utilisation should therefore be accompanied by the measurement of the range in which capacity utilisation is economic.

2 HYPOTHESES

The research sought to show how the manufacturing strategy links to the corporate strategy and ultimately, to operational performance. Three distinct hypotheses stemming from the main objective were proposed:

i. The relationship between manufacturing strategy and corporate strategy;
ii. The relationship between existence of a manufacturing strategy and; capacity utilisation; and
iii. Employees involved in developing the manufacturing strategy.

2.1.1 The link between Manufacturing strategy and corporate strategy

The type of manufacturing strategy that a firm emphasizes depends on its chosen competitive priority or priorities. Linking manufacturing strategy with business strategy uses market requirements to establish the performance criteria against which manufacturing can be measured. This necessitates an orientation based neither on products/markets nor on manufacturing exclusively, but a strategy that embraces the market / production interface, so that the degree of fit between the proposed market strategies for the corporate coincide with manufacturing's ability to support these strategies at the business and corporate levels. The strategic role of operations has been emphasized as being important in light of increasingly fierce global competition [10]. The research question was to establish whether there was a link between manufacturing strategies in Zimbabwean manufacturing firms and the corporate strategies of the firms. The research hypothesised that:

(H1) There is a positive relationship between the manufacturing strategy and corporate strategy in Zimbabwean Manufacturing firms.

2.1.2 Existence of manufacturing strategy and capacity utilisation

Superior manufacturing improves the odds of relative business success, thus manufacturing success generates opportunity for overall business success [5]. Amoako-Gympah and Acquaah [10] indicate a firm able to achieve both high design and conformance quality, cost reduction and concomitant improvements in efficiencies, high volume and mix flexibility and reliable on-time delivery can expect to achieve competitive product pricing, ensure customer satisfaction, fast response to market changes and overall, potentially increase sales growth and market share (factors in business success). The link between manufacturing strategy and firm performance has already been established with manufacturing strategy literature expounding on the veracity of manufacturing strategy-firm performance relationship [10]; [25] & [29]. This study extends the view, hypothesising that manufacturing strategy influences a measure of firm performance – the operational parameter of capacity utilisation. In determining how manufacturing strategies for successful manufacturing firms were derived, the level of capacity utilisation was used as an indicator of operational performance. The research thus tested the hypothesis that:

(H2) There is a positive relationship between existence of a manufacturing strategy and capacity utilisation.

2.1.3 Responsible employees for manufacturing strategy development

Research has already noted how participation of manufacturing managers in the strategy development process has the potential for eliminating incongruent strategic goals thus aligning manufacturing needs with those of the corporate in realising strategy [30]; [31] & [32]. High levels of manufacturing managers' participation in strategic decision-making has already been shown to relate positively to performances as measured by growth in sales, return on total assets, market share and sales [29]; [33] & [34] . When strategy formation is approached as a process involving both operational and top management, top management intent embodied in corporate strategy effectively combines with operations activity to create realized strategy. The involvement of manufacturing plant managers in organizational level strategy development was assessed. The research sought to determine if employees responsible for manufacturing plants were involved in strategy development at corporate level for firms with manufacturing divisions in Zimbabwe. Hypothetically;

(H3) There is a positive relationship between the involvement of manufacturing plant managers in corporate strategy development and operational performance.

3 METHODOLOGY

The research focused on manufacturing firms in Zimbabwe and the case of one alcohol manufacturer with specific emphasis on its manufacturing approaches and polices as well their linkage to corporate goals and strategies. The survey and case study research design were used in the study. Information was obtained from manufacturing executives of the selected manufacturing firms in Zimbabwe both for the survey and case study.

3.1 Population and sampling

The target population for this study was manufacturing firms in Zimbabwe, the sampling frame being the Confederation of Zimbabwean Industries' list of manufacturing firms in Zimbabwe. Respondents were manufacturing executives of the manufacturing firms as well as the Alcohol manufacturer's top management team. Stratified random sampling was applied with the population being divided into five strata based on industrial location using Zimbabwe's five business hub (the provinces: Mashonaland, Manicaland, Matebeleland, Masvingo and Midlands). A random sample was then drawn from each province.

3.1.1 Data collection

Survey research is often associated with deductive theorizing and is popular in business and management research [35], allowing the collection of large amounts of research information from a sizeable number of people in a way that is economical, giving information that is easily comparable and easy to standardize [36]. For the survey, a questionnaire to manufacturing managers of manufacturing firms in Zimbabwe was used for data collection. Questionnaires were administered personally in order to increase the response rate and to increase contact with the respondents. The questionnaires were pre-tested on two firms before the final administration. Corrections were made to the questionnaire based on suggestions and recommendations from the pretesting. Fifty (50) questionnaires were administered to representatives from the manufacturing firms, 40 (80%) of the sampled population responded. For the case study 10 structured interviews were conducted with top management at the alcohol manufacturing firm for data collection.

3.2 Measurement of variables

The existence of corporate strategy (V1) and existence of manufacturing strategy (V2) as well as management commitment to and emphasis on the strategic approach were determined based on responses to each of the questions in Table 1. The strategic emphasis and thus preferred manufacturing strategy (V3) was evaluated based on the average emphasis the firm placed on each of the four competitive priorities of cost, delivery, flexibility, and quality. Respondents indicated their understanding of the derivation of manufacturing strategy (V4) and its link to corporate strategy by stating their view in terms of the manufacturing strategy- corporate strategy relationship. Involvement of technical personnel in strategy formulation (V5) was determined as presence or absence of technical managers in strategy formulation meetings while one measure of firm performance, capacity utilisation (V6), was used to determine operational performance.

Table 1: Measurement of variables

Variable	Variable Description	Question	Response
V1	Existence of Corporate Strategy	Has your firm articulated a corporate strategy?	1- Yes 2- No 3- Don't know
		What is the frequency of review of the corporate strategy?	1- Bi-annually 2- Annually 3- Two years 4- Continuously 5- Not sure
V2	Existence of Manufacturing strategy	Has your firm articulated a manufacturing strategy?	1- Yes 2- No 3- Don't know
		What is the frequency of review of the manufacturing strategy?	1- Bi-annually 2- Annually 3- Two years 4- Continuously 5- Not sure
V3	Manufacturing strategy	Indicate the factor(s) that your firm emphasises in determining the manufacturing direction of the organisation	0. There is no manufacturing strategy 1. Quality, 2. Delivery, 3. Cost; 4. Flexibility 5. Combination of factors
V4	Derivation of Manufacturing strategy	Rate the relevance of the strategic approach to organisational growth.	1. Extremely relevant 2. Very relevant 3. Relevant 4. Not very relevant 5. Not relevant at all
		How does the manufacturing strategy of your organisation relate to the corporate strategy?	1. Manufacturing strategy is derived from corporate strategy; 2. Corporate strategy is derived from manufacturing strategy; 3. The two are not related; 4. Manufacturing strategy doesn't exist; 5. Don't Know
V5	Manufacturing Management involvement	To what extent are senior manufacturing personnel involved in strategy formulation meetings?	1. Never; 2. Rarely; 3. Always
V6	Capacity utilisation	What is the current capacity utilisation of your firm as a percentage?	1. 0-25% 2. 26-50% 3. 51-75% 4. 76-100%

The study controlled for firm size and age. All sampled organisations were medium to large manufacturing operations with a minimum of 50 employees and having been in operation for over 5 years. Manufacturing firms responding to the survey comprised of 65% private organisations, 25% government departments and 10% public companies. The effect of this ownership was not factored in for this study. Respondents in the survey research were manufacturing plant managers, i.e. technical managers responsible for managing the manufacturing firms or divisions in their firms (Table 2). Respondents for the case study were executive mangers responsible for crafting the firm's corporate strategy

Table 2: Profile of respondents (survey research)

Designation	Responses
Managing Director	2
Technical/operations Director	11
Plant Manager	10
Engineering Manager	8
Production Manager	7
Plant Engineer	2
Total	40

3.3 Hypotheses tests

The *Cramer's V* statistic was used to determine associations amongst variables. In estimating relationships among variables, Cramer's V is independent of sample size. *Cramer's V* ranges between 0 (no relationship) and 1 (perfect relationship).

$$Cramer's\ V = \sqrt{\frac{\chi 2}{N(L-1)}}\ ;\ \text{where L = min } (h,\ k) \qquad [1]$$

4 FINDINGS

All respondents in the survey research were manufacturing plant managers, i.e. technical managers responsible for managing the manufacturing firms or divisions of their firms. The highest number of respondents (27.5%) were technical/operations directors, then plant managers (25%), engineering managers (20%) and production managers (17.5%), plant engineers and managing directors making up five percent each.

Results indicated that 70% of the sampled firms are operating above 50% capacity utilisation with the greater number or organisations being in the 75-100% capacity utilisation band. 90% of the sampled organisations had corporate strategies in place while 72.5% had developed manufacturing strategies. Of those firms with corporate strategies, 75% had manufacturing strategies in place. The relationship between existence of corporate strategy and manufacturing strategy is significant (Cramer's V= 0.713; p = 0.000 for α = 0.05, n = 40) (Table 3), indicating that the existence of manufacturing strategy is related to the existence of corporate strategies in the organisation.

Table 3: Corporate strategy * Manufacturing strategy Cross-tabulation

		Manufacturing strategy exists			
		0	Yes	No	Total
Corporate strategy exists	Yes	0	27	9	36
	No	2	0	0	2
	Dont know	0	2	0	2
Total		2	29	9	40
Cramer's V		0.713			
Approx. Sig		0.000			

All firms (100%) that did not have corporate strategies either did not have manufacturing strategies or did not know about manufacturing strategies while 75% of those that had corporate strategies had manufacturing strategies as well. Of the 36 firms that had corporate strategies, 42.5% derived manufacturing strategies from the corporate strategy, 25% derived corporate strategy from manufacturing strategy while only 5% indicated that there is no relationship in their view between their firm's corporate and manufacturing strategies. 80% of the firms that derived corporate strategy from manufacturing strategy recorded 76-100% capacity utilisation, while only 47.1% of those deriving manufacturing strategy from corporate strategy were in the 76-100% utilisation band. (Table 4).

Table 4: Strategy derivation * Capacity Utilisation (%) Cross-tabulation

		Capacity Utilisation (%)					
		0-25%	26-50%	51-75%	76-100%	Total	%
Strategy derivation	Manufacturing from corporate strategy	0	3	6	8	17	42.5
	Corporate strategy from manufacturing strategy	0	0	2	8	10	25.0
	The two are not related	0	0	2	0	2	5.0
	Manufacturing strategy doesn't exist	4	3	0	0	7	17.5
	Don't Know	2	0	0	2	4	10.0
Total		6	6	10	18	40	100
Cramer's V			0.554				
Approx. Sig.			0.000				

The association between the existence of manufacturing strategy and capacity utilisation is significant (Cramer's V=0.595, p = 0.000 at α = 0.05) (Table 5). Successful manufacturing firms sampled (with capacity utilisation in the range 76-100%) reported that they have manufacturing strategies in place. 77.8% of firms that did not have manufacturing strategies were operating below 50% capacity utilisation while 89.7% of firms that have manufacturing strategies were operating above 50% capacity utilisation.

Table 5: Manufacturing strategy * Capacity Utilisation (%) Cross-tabulation

		Capacity Utilisation (%)				
		0-25%	26-50%	51-75%	76-100%	Total
Manufacturing strategy exists	Yes	0	3	10	16	29
	No	4	3	0	2	9
	Don't Know	2	0	0	0	2
Total		6	6	10	18	40
Cramer's V		0.595				
Approx. Sig.		0.000				

In determining the considerations when formulating manufacturing strategy, and thus determining the firm's emphasis on the competitive priorities, responses indicated that 79.3% of the firms that have manufacturing strategies consider a combination of factors including quality, delivery, cost, and flexibility in manufacturing strategy formulation with only 20.7% considering cost alone in the formulation of manufacturing strategy. Further, successful manufacturing firms (with 76-100% capacity utilisation) involve senior manufacturing managers in strategy formulation meetings (64% of the organisation in the maximum capacity utilisation category involve manufacturing managers in strategic planning meetings always). There is a significant (Cramer's V= 0.524, p=0.000, α =0.05) association between manufacturing management contribution in strategic planning meetings and by extension, operational performance (Table 6).

Table 6: Capacity Utilisation (%) * Senior Manufacturing management involvement Cross-tabulation

		Senior manufacturing management involvement				Total
		0	Never	Rarely	Always	
Capacity Utilisation (%)	0-25%	2	2	2	0	6
	26-50%	0	3	0	3	6
	51-75%	0	0	4	6	10
	76-100%	0	2	0	16	18
Total		2	7	6	25	40
Cramer's V		0.524				
Approx. Sig.		0.000				

4.1 Management approach for the Case

The management interview for the case focused on the existence of manufacturing strategy, its relationship to the corporate strategy as well as considerations in determining the manufacturing direction for the firm. The alcohol manufacturer, like other manufacturing firms in the country, has been affected by industry wide problems that include high production costs due to old machinery and skills flight. Yet the firm has enjoyed monopoly as the only Zimbabwean manufacturer of potable alcohol. Limited by its capacity (size), the firm has continued to lose potential customers to importers of potable alcohol who are able to land the import at the Alcohol manufacturer's cost of production posing a veritable threat if the organization pursues the same operating strategies into the future. From interviews with management at the alcohol manufacturer, evidence that managers realise the relationship between the existence of a deliberate manufacturing strategy and sustained operational performance exists. All the interviewees (100%) in the case study consented to the existence of a corporate strategy in the group, they all agreed that there is no documented manufacturing strategy at the alcohol manufacturer and highlighted the need for a structured process for establishing a manufacturing strategy as a necessary improvement to the firm's strategy process. The capacity utilisation for the case was in the 76-100% band thus classifying the firm as one of the few successful firms that do not possess a manufacturing strategy given 22.2% of firms in the survey that did not possess a manufacturing strategy were successful. In terms of competitive priorities in determining the manufacturing direction for the case, 60% highlighted that the approach employed was a quality based manufacturing approach, while 40% considered it to be a combination of cost and quality. The results showed that whilst the case did not have a documented manufacturing strategy, they were employing some of the competitive priorities used as basis for deriving manufacturing strategies.

5 RECOMMENDATIONS

The strategic approach to manufacturing is critical to operational performance. In particular, the existence of manufacturing strategies is essential for the success of manufacturing firms in Zimbabwe. Manufacturing firms are recommended to adopt corporate and manufacturing strategic planning approaches for the successful running of their operations. The research showed that manufacturing firms that had both corporate and manufacturing strategies recorded better performance. Further those firms that derived their corporate strategy from the manufacturing strategy recorded better operational performance. The data suggests thatsuccessful manufacturing firms derive their corporate strategies from their manufacturing strategy. Thus manufacturing firms are recommended to adopt the strategic approach in which manufacturing priorities drive the strategic management process. Further, successful manufacturing firms involve senior manufacturing management in the strategy formulation. It is recommended that manufacturing firms ensure the presence and input of manufacturing management in their strategy formulation process. From an analysis of operations at the case, the operation at full capacity (76-100% capacity utilisation) without a manufacturing strategy was possibly due to the prevailing situation in which the firm enjoyed a more or less monopolistic hold to its market, a situation that is not guaranteed to last with competition growing and the changing economy. Adoption of a deliberate and documented manufacturing strategy is recommended.

6 CONCLUSION

The research showed that almost every manufacturing firm had a corporate strategy and that there was a significant relationship between existence of corporate strategy, manufacturing strategy and operational performance. The research also showed that successful manufacturing firms had established corporate and manufacturing strategies and that the existence of a manufacturing strategy is positively associated with operational performance. Manufacturing firms used a combination of competitive priorities (cost, delivery, flexibility, quality) in coming up with manufacturing strategy and those firms that derived their corporate strategy from the manufacturing strategy showed more success that those that derived their manufacturing strategy from the corporate strategy. The research verified that successful manufacturing firms involved senior manufacturing managers in strategy formulation meetings. There was a significant relationship between the presence of manufacturing management contribution in strategic planning and operational performance.

The research has shown that the strategic approach to running a manufacturing concern ensures success. Manufacturing priorities drive successful manufacturing firms through the corporate and manufacturing strategy. While the research shows that there is significant application of the strategic approach to running successful manufacturing industries in Zimbabwe, there is need to study the overall strategic management process of these firms from planning to implementation. Given Zimbabwe's unique economic, political and social environment the test would be to determine the applicability of conventional strategic management methods and processes. The success emanating from the implementation of strategic approaches to manufacturing, particularly as firms seek to achieve world class standards, the choice of strategy and its implementation will be all the more critical.

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A SYSTEMATIC COMPARISON OF DONOR FUNDED SUPPLY CHAIN AND COMMERCIAL SUPPLY CHAIN CHARACTERISTICS

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ABSTRACT

Commercial supply chains and donor funded supply chains are driven by distinctive mechanisms and purposes, and the factors that make the operational environment of donor funded supply chains unpredictable, complex and dynamic, differ from those that cause this complexity in a commercial supply chain environment. Although literature contains several theories and frameworks to assist in the design, measurement and management of commercial supply chains, there is a significant research gap related to the formal study of donor funded supply chains. In this research, several examples of donor funded supply chains are investigated in order to systematically compare and highlight the key differences between donor funded supply chains and commercial supply chains.

1. INTRODUCTION

Since the introduction of supply chain management in the 1980s, commercial supply chains have been studied extensively, leading to the development of several theories and frameworks to assist in their design, measurement and management. There has, however, been less formal study of donor funded supply chains. Donor funded supply chains play an important role in relieving human suffering and addressing prioritised global health challenges and, as such, often function under circumstances that might make traditional commercial supply chains unviable. The factors that make the operational environment of donor funded supply chains unpredictable, complex and dynamic, may differ or be more severe from those that cause this complexity in a commercial supply chain environment [1]. As such, though commercial supply chains and donor funded supply chains share many similarities, there are distinct differences between the two that should be considered when developing management practices and principles for donor funded supply chains [2]. This article investigates several examples of donor funded supply chains, including medical-, relief-, agricultural- and nutritional supply chains, with reference to relevant characteristics, to systematically compare and highlight differences between donor funded supply chains and commercial supply chains. The characteristics in Table 1 represent the range of business functions and services included in a supply chain as defined by three popular[1] commercial supply chain focussed models:

1. the Mentzer Model [3];
2. the Global Supply Chain Forum (GSCF) Model [4]; and
3. the Collaborative Planning, Forecasting and Replenishment (CPFR) Model [5].

The characteristics in Table 1 are divided into two sections, those that are included in the comparison of donor funded and commercial supply chains in this article, and those that are not. All characteristics that are defined by at least two of the three models presented, are included in the discussion. Furthermore, three characteristics that proved exceptionally different for donor funded supply chains and commercial supply chains (namely trust, agility, and structure and components) are also included in the discussion.

Table 1: Perspectives on the range of characteristics included in a supply chain

Characteristics	*Mentzer Model [3]*	*GSCF Model [4]*	*CPFR Model [5]*
Characteristics discussed in this article:			
Structure & Components	x	-	-
Stakeholders	x	-	x
Trust	x	-	-
Goals & Objectives	x	-	x
Finances	x	x	-
Customer Service & Marketing	x	x	x
Research & Development	x	x	-
Demand & Forecasting	x	x	x
Procurement	x	x	x
Manufacturing	x	x	x
Logistics	x	x	x
Agility	-	-	-
Characteristics not discussed in this article:			
Customer Relationship Management	-	x	-
Supplier Relationship Management	x	-	-
Returns Management		x	-
Product Development & Commercialization	-	x	-

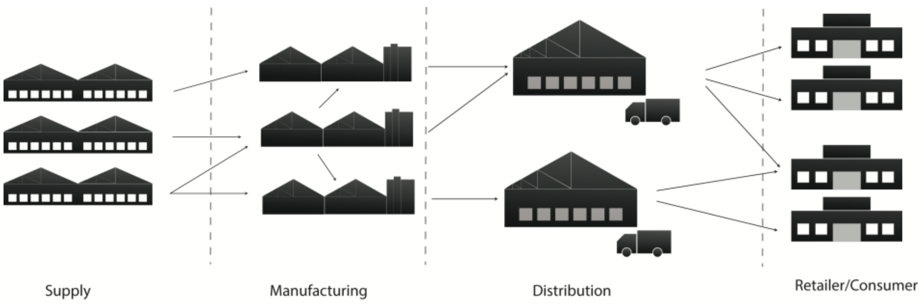
[1] These models have been referenced frequently in supply chain management literature (including in: Naslund and Williamson [6], Amemba [7], Davis-Sramek et al. [8], Campuzano and Mula [9], and Tracey et al. [10]).

2. ANALYSIS OF DISTINGUISING CHARACTERISTICS

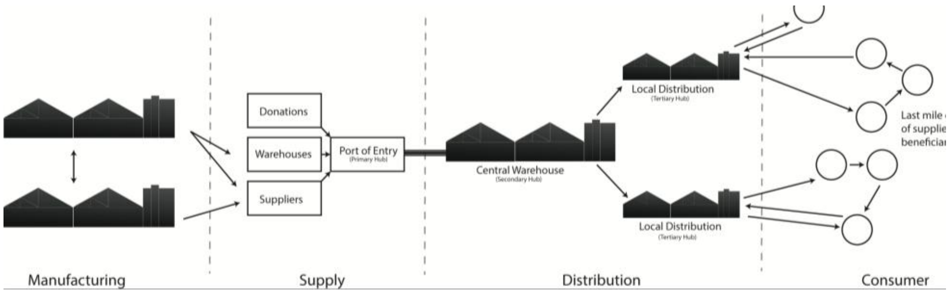
In this section, the characteristics of donor funded supply chains and commercial supply chains are described and contrasted. The discussion is structured in accordance with the distinguishing characteristics identified in Table 1. The focus is on highlighting structural differences between the supply chains.

2.1 Supply chain structure and components

A typical commercial supply chain encompasses the activities and processes related to the flow, transformation and transportation of goods [11], as illustrated in Figure 1.a. In donor funded supply chains, the supplies often flow through various shipments as illustrated in Figure 1.b. The supplies mainly comprise pre-positioned stock in warehouses, in-kind donations and supplies obtained from suppliers after manufacturing [12]. The supplies are transported, in most cases from several locations worldwide, typically to a primary warehouse, from where they are moved to a large secondary warehouse where they are stored, sorted and distributed to local distribution centres. These distribution centres deliver the supplies to the populations in need [13]. The structure and components of a donor funded supply chain will differ for each setting. For example, in relief chains the manufacturing activities and processes are not necessarily included in the supply chain, while in medical and nutritional supply chains a significant amount of time, effort and research typically goes into manufacturing activities [13, 14].



(a)



(b)

Figure 1: (a) A typical commercial supply chain. (b) A typical donor funded supply chain.

Furthermore, a supply chain comprises of an upstream (global) segment and a downstream (domestic) segment. The upstream segment includes activities such as manufacturing, procurement, financing, forecasting and warehousing; while the downstream segment includes the in-country storage and distribution to retailers and consumers. A key difference between donor funded supply chains and commercial supply chains, is that although these two segments are primarily managed as two coupled segments in a commercial supply chain, they are ordinarily decoupled from one another in a donor funded supply chain [14]. The global segment(s) is typically managed by international foundations and remains fairly uninvolved once the supplies reach the country. From there on the domestic segment is typically separately managed by the government or other local organisations to administer part of the local distribution and the last mile distribution of suppliers to beneficiaries, as seen in Figure 1.b. This is often due to the unsupervised nature of donor funded supply chains, since there is no individual organisation or primary stakeholders that governs the entire supply chain or has authority to instigate coordination between actors and activities [15].

2.2 Stakeholders

In commercial supply chains, the primary stakeholders (shareholders) are often seen as the owners of the supply chain [16] and their interests guide the firm's policy [17]. The primary stakeholders in donor funded supply chains are the host government and NGOs [16]. All actors, except national aid agencies, require approval from the host government, and sometimes the neighbouring government, in order to operate within the country [18]. NGOs can include numerous actors such as international aid agencies as well as small organisations that are formed within the local communities [18]. Though commercial organisations also have multiple stakeholders such as its customers, employees, retailers and suppliers, each with different needs, meeting the needs of all these stakeholders rarely conflicts with the shareholders' and organisation's long-term goals and objectives [19]. In contrast, the principal goals, missions, interests, capacity and constraints of stakeholders in donor funded settings are often different and conflicting [20, 21]. Furthermore, the stakeholders involved in the donor funded setting, can be categorised as (i) actors that exist in the area and are linked to it, or (ii) international actors. These two groups normally take different perspectives and approaches to donor funded settings and will often perform operations differently, adding to the complex nature of donor funded supply chains [22].

2.3 Trust

Trust between the actors and stakeholders of the different supply chain activities and stages is crucial for positive long-term performance. The majority of the commercial sector spends a significant amount of time and resources to build a lasting relationship with their partners [23]. In several donor funded situations however, different actors form a network with a shared purpose of relieving the suffering of people, but there is often not sufficient time or resources for the opportunity to build trust before the network must begin to operate together [21].

Additionally, trust not only plays an important role between actors and stakeholders, but also between the organisation and the consumers [24]. For example, in Nigeria several mid-size Nigerian firms aim to produce nutrient-rich foods for undernourished populations. These products compete with foreign-produced products sold by donor-organisations. Consumers are doubtful about the quality of the locally produced products and trust is therefore low between the actors in the chain. This low-trust environment depresses innovation and creates prejudices against certain products (in this case those that are locally manufactured) [25].

2.4 Goals and objectives

Every supply chain has a goal towards which it operates. The fundamental goal of any supply chain is to "deliver the right supplies in the right quantities to the right locations at the right time" [13]. The main goals and objectives for commercial and donor funded supply chains, however, are quite different. The overriding goal for a commercial supply chain is financial profit [26]. These supply chains strive to make profits and provide financial returns to their shareholders [27]. In contrast, for donor funded supply chains, profits are not the goal; instead, typical goals include to produce value for money, be efficient and effective, ensure fair competition between suppliers, ensure accountability, and ensure procedures are executed ethically [13]. Furthermore, each organisation involved in the supply chain strives to achieve its own purpose and mission [19, 28].

Similar to commercial supply chains, donor funded supply chains are also concerned about their financial well being, since financial stability is an important aspect of their mission and sustainability. However, in contrast to commercial supply chains where the strategic objectives are based on the financial returns paid out to the shareholders and the value created through delivering high quality goods and services to the consumers [13], finances are viewed as constraints rather than objectives in donor funded supply chains [29]. For donor funded supply chains, the goal is to reduce human suffering, save lives and improving quality of life, within the financial constraints. The strategic objectives are therefore to ensure financial sustainability and to ensure effective flow and operations [19]. Both supply chain types consider customer service and cost in their goals and objectives, but they bring different dimensions to the concepts. For commercial settings the aspects are considered primarily from the perspective of maximising profits, while in donor funded situations, these are considered primarily from the perspective of maximising the wellbeing (or in some cases, minimising the mortality) of the population [30].

2.5 Finances

The life blood of an organisation is its finances since this ensures the organisation remains functioning. A notable difference in the finances of donor funded and commercial supply chains is the source of income. In commercial supply chains, the defining source of income is the income earned from the sale of goods and services. In donor funded supply chains, however, the recipients of the goods and services often pay nothing or very little and there is consequently no income, or at least no profit, from this source. Rather, the income to fund the operations of donor funded supply chains are sourced from individuals and organisations that expect no personal benefits in return (though these sources may of course expect benefits for the intended recipient population), where in commercial supply chains, revenue sources are customers that purchase goods and services for their own benefit [19, 31]. All of the transactions that occur between the different partners throughout the stages of the supply chain are referred to as the financial supply chain. Attention is often placed on the integration of the physical and financial supply chain, since failure to identify and improve any weaknesses within the integration can threaten both chains' liveliness [32]. In donor funded supply chains, the source of revenue can include government funding [A6] and charitable donations from individuals and organisations [13]. Ordinarily, donors provide the majority of the funds for the activities. Donations consist of free goods and/or services or financial contributions to support the operations [18]. Consequently, a functioning financial supply chain is essential in ensuring that financial contributions can be utilised [33]. Typical challenges experienced in donor funded financial supply chains include: lack of formal provisions with local financial institutions and suppliers that can cause difficulties with transfer processes [34]; and irregular funding cycles (especially for smaller agencies) due to contributions being donated for particular operations rather than for the agency's activities in general [35]. Regular and effective financial flows are essential for the accurate functioning of any supply chain.

A last feature that frequently creates challenges in a donor funded supply chain's finances, is when the chain has two separate financial supply chains. One that is internationally financed by one or more global funds and one that is domestically financed within a given country [14, 36]. This corresponds with the decoupled upstream and downstream segments of some donor funded supply chains. A donor funded supply chain with different financial supply chains (international and domestic) faces a unique situation when it comes to price and demand elasticity. Demand in the internationally donor financed supply chain is ordinarily inelastic to small changes in price, when compared to the domestically financed portion. Therefore, when examining the overall market in this type of donor funded supply chain, the demand curve will be flat and unresponsive to large volume changes or small price changes. However, at a certain stage in the domestically financed supply chain, the volume will drastically increase when the price descends below a certain threshold [14].

2.6 Marketing and customer service

For commercial supply chains, the customers are any individual or organisation that buys and receives the product or service [13]. In donor funded supply chains the customers are often seen as the end-consumers that receive the intended aid. However, since donors play such an important and influential role in donor funded supply chains, a majority of NGOs instead view the donors as the customers. With this perspective, the NGOs deliver a service to donors; the service being providing aid to those in need [37]. Commercial supply chains view the final customer as the source of income for the entire supply chain, where in donor funded supply chains the final customer (the people who receive aid) rarely takes part in a transaction [38, 39]. In donor-funded supply chains, the customer often does not have a choice of product, while in most commercial supply chains the customer can analyse the market and choose which product, out of several options, to buy [39]. Therefore, where commercial supply chains market their product to the customer, donor funded supply chains must target the donors and convince them to provide some contribution [38].

In donor funded supply chains, an important issue concerning the distribution of the supplies directly to the consumers, is equity and fairness. When comparing the geographical spread of consumers with the availability of supplies over time and space, one population or group could easily be favoured over another [40]. In commercial supply chains, large amounts of time and money are typically allocated towards market segmentation with dedicated departments typically assigned to segment the consumers and market the product or service according to the segments [41]. This is not the case in donor funded supply chains, where the main goal, in terms of market segmentation, is to ensure the fair distribution of supplies [14]. In donor funded supply chains, there is often less choice with regards to which locations to distribute products to, with the overarching objective being to provide supplies and services to populations in need, regardless of their location.

2.7 Research and development

Research and development plays an important part in the improvement and growth of an organisation and its supply chain. It involves investigative activities that either lead to the development of new products or processes, or the enhancement of current products and processes. In donor funded supply chains, challenges can arise when donors provide funds only for specific activities. As an example, donors typically provide funding specifically for operational activities; therefore, strategic improvements activities, such as research and development, often have to be put on hold until funding that can be utilised for these activities becomes available [13]. In commercial supply chains, on the other hand, financial resources are typically allocated to both strategic and operational activities [42]. In many commercial settings, an organisation will spend large amounts of time and money on research and development, with some having a separate department focussing only on developing new or improving current products and processes [43]. Most donor funded supply chains, on the other hand, have to rely on global initiatives such as the World Health Organisation, UNITAID, The United Nations Children's Emergency Fund, etc. to develop new products and help with the improvement of processes [14, 44, 45].

2.8 Demand and forecasting

A principle difference between donor funded supply chains and commercial supply chains is the stability and / or predictability of the demand. Due to the nature of the types of challenges that donor funded supply chains typically seek to address, demand tends to be less stable and / or predictable than for commercial supply chains [46]. Typical differences in terms of demand elasticity, demand patterns and forecasting abilities are discussed.

In donor funded settings, there are often different types of demand items with different elasticity. For example, in disaster relief supply chains, some items are in demand only once (such as tents), others are recurring (such as water), some demand items can expire (such as food) while others may be carried over (clothing). Or in medical supply chains, where a patient follows a treatment regime specific to the patient's condition, out of a number of possible treatment regimes. Each regime is unique in that it can comprise of different quantities of different drug formulations to be prescribed for different lengths of time [14]. Due to the various types of demand, each often with different transportation requirements, there is a heightened risk of the demand overwhelming the distribution network's capacity [40].

Another difference is the demand pattern [13, 47]. For many commercial supply chains, demand occurs from recognised locations and orders are often placed in fixed quantities, in consistent time intervals from fixed suppliers [48], under these conditions, demand is steady and can be anticipated [47]. However, these conditions rarely occur in donor funded settings where demand is often unpredictable and occurs in irregular amounts and time intervals. Various factors contribute to this unpredictability including the impact of the situation, demographics, social and economic conditions of the area, as well as the type of supplies [38]. In some cases, the locations are unknown until the demand occurs [47]. For example, relief supply chains only know the demand location after a disaster has struck or in medical supply chains a disease or virus, such as TB or Ebola, can unexpectedly spread in a country creating a sudden large demand in that country.

An environment that would allow easy and effective forecasting involves predictable demand; unlike the demand characteristics in donor funded settings as described above. Donor funded supply chains often exist in a complex and irresolute environment, where time is imperative to save lives. The long distance between different stakeholders in the supply chain and the distance between them and the area of the incidents intensifies the uncertainty. In many instances, the correct information is not available or never makes it to the stakeholder(s) that need it [1]. When the correct information is unavailable, assumptions about the types and quantities are made [49]. Examples such as the global TB epidemic and the Haiti earthquake in 2010, illustrate the presence of uncertainty in donor funded situations [1].

2.9 Procurement

Procurement involves all the activities related to the acquisition of goods, services or works from the raw materials stage through to the end product [50]. In donor funded situations, procurement can often represent the biggest percentage of the expenses, depending on the situation [26] For example in medical supply chains, the procurement of diagnostics and drugs is very expensive, while in relief supply chains, logistics and distribution is often more expensive than the procurement of supplies. Donors provide the majority of the funding required for procuring goods and services [51]. The procurement process in a donor funded supply chain is typically exceptionally different from commercial supply chains due to the different environments in which they operate. For example, in relief chains, there is often pressure to immediately deliver goods or services, due to the desperate needs of the population, without knowing the exact quantities [26], while in some medical supply chains an order is placed several months before receiving any supplies. For the majority of donor funded supply chains, purchasing decisions are made through a competitive bidding process and short-term contracts or agreements are set up, whereas in commercial supply chains a lasting relationship is often built with their partners to set up long-term agreements and contracts [23]. Procurement coordination, which is often applied in commercial supply chains, is difficult to implement in donor funded supply chains due to the uncertainties in demand, characteristics of donor funding, limited information and the specific procurement processes of donor funded supply chains [20].

2.10 Manufacturing

Processes included in the manufacturing aspect of the supply chain are the manufacturing of the product, formulating and packaging, inspection, and shipping and transport. Under conditions of stable and / or predictable demand (as often occurs in commercial supply chains), the majority of manufacturing processes can be forecast-driven. In contrast, the unstable and / or unpredictable demand typically experienced in donor-funded supply chains represents a risk to manufacturers and causes some manufacturers to employ an order-driven process where the procurement and manufacturing process only begin once an order is received [14]. The manufacturers must therefore take on suboptimal inventory structures and manufacturing processes, which lead to higher prices and longer lead times [44, 45]. The limited actual demand and lack of accurate forecasting weakens the manufacturers' confidence to produce large volumes of supplies. Therefore, they manufacture the supplies in smaller batch sizes that are not cost effective. This occasionally necessitates manufacturers to ask a higher price for the finished product. Because of the longer lead times, countries are pressured to place orders months or even years in advance. In many cases, the inaccurate forecasting either leads to shortages, when needs are forecasted too low, or destruction of expired goods, when needs are forecasted too high [14].

In several cases, manufacturers have few incentives to invest and innovate for new products, demand is difficult to pool in order to negotiate price reductions, and forecasting to plan production and avoid product shortages is difficult [14, 52]. Additionally, the difficult nature of the products in specialised donor funded supply chains, such as medical or nutrition chains, leads to a low market attractiveness for manufacturers. For these reasons, there are often only one or small number of manufacturers per product, while in the commercial sectors there is rarely a manufacturer who has a monopoly in the market. This restricted market structure and lack of competition among manufacturers creates additional challenges for managing other supply chain aspects such as price and availability [14].

2.11 Logistics

An important function required to support the activities of the supply chain, is logistics [39]. Logistics, in general, incorporate a variety of activities throughout the different phases of the supply chain, such as transportation, warehousing and customs clearance [53]. In commercial supply chains, logistics can be defined as the process of managing the product-, information-, and financial flows from the source to the final customers [22], while in donor funded supply chains it is defined as the process of managing these flows from the donors to the affected populations [54]. Logistics is one of the fundamental elements, if not the most important, in any supply chain [18], since it is crucial for effective and efficient delivery, is a typical expensive part of the supply chain and it provides feedback about all aspects of execution, such as supplier effectiveness, cost and timeliness of transportation etc. [53].

Transportation in donor funded settings are typically very different than in commercial settings [51] with the biggest logistical challenge in donor funded supply chains being the complexity of the conditions in which they operate [30]. For example, poor existing transportation infrastructure and geographical characteristics including mountains, islands, etc. may discourage some commercial sectors to target areas, but donor funded supply chains have to deliver supplies to populations in need regardless of these conditions. Another challenge is obtaining the appropriate information about the conditions of the infrastructure, since sufficient communication and information technologies may be unavailable in particular Low- and Middle Income Countries [20]. The majority of donor funded supply chains do not own and operate their own vehicle fleets, but instead rely on local or international logistic agencies. Although several commercial supply chains are also reliant on external logistics companies, the majority do invest in their own vehicle fleets. In some donor funded settings, especially in medical supply chains, the distribution is narrowed to only state run distribution systems that makes incentive structures difficult to create and implement. Nonetheless, even when distribution is done through private networks, the regulations and small market size can inhibit sufficient competition. In commercial supply chains, several distribution channels are often used in order to achieve expanded reach [52].

The resources required for distributing goods and services of a commercial supply chain, is often generic and widely available. Therefore, the majority of the consumer product companies in a commercial supply chain use horizontal collaboration, in order to create a distribution pool that will increase the delivery rate of shipments without an increase in cost [52]. The unpredictable demand patterns in donor funded supply chains would make scheduling and, consequently, collaboration exceedingly difficult [20]. In certain donor funded settings, such as nutrition and medical supply chains, the resources required for distribution are specific and require investment. However, by providing affordable goods and services, the revenue rates are relatively low, which results in poor investment. The delivery rates in donor funded supply chains are therefore lower, due to the inability to create distribution pools [52].

2.12 Agility

Agility, in a supply chain context, can be defined as the chain's ability to effectively perform in an unpredictable and changing environment [55]. In certain supply chain settings, the needs of the populations will change. Their need will either grow or decline, leading to changing priorities within the supply chain. Additionally, in donor funded settings, the dynamic nature of priorities and local conditions often require different responses, resources and capabilities than in a traditional commercial supply chain [1]. For example, when initially developing the supply chain there might not have been the necessary roads, ports, warehouses etc. and the supply chain would have been designed with these conditions in mind. However, if roads or ports are constructed over time, the supply chain should be redesigned to incorporate the changes in the conditions. There are several situations in which the responsibilities, workforce, routes and carriers and various other components of the supply chain had to be changed, adapted or redesigned to meet the changing conditions [38]. Commercial supply chains also change due to certain conditions, but rarely as rapidly (and sometimes frequently) as donor funded supply chains [1].

A supply chain with an agile strategy is continuously ready to change [56] and can promptly respond to changes in demand and the market [57]. The supply chain strategy, however, must be aligned with the business strategy and goals and tailored to meet customer requirements. Therefore, the unique characteristics of commercial and donor funded supply chains will affect their supply chain strategy and processes [13]. While both commercial and donor funded supply chains encourage agility throughout the chain, their reasons for doing so are often different. For commercial supply chains, agility is a key strategy that allows them to compete in the global market by improving delivery rates, operational performance and cost performance, among other things [58, 59]. Since the environment of donor funded supply chains is typically characterised by uncertainty and several actors [60], they practice agility in managing different relationships between donors and actors [61], evaluating impacts of distributed supplies and monitoring various ongoing activities [51]. The upstream activities and processes in donor funded supply chains are often acknowledged for its agility [38].

3. SUMMARISED COMPARISON OF KEY CHARACTERISTICS

In summary, the biggest differences between the two supply chains can be ascribed to the four following causes associated with donor funded supply chains:

- The nature of the demand, especially its instability and unpredictability.

- The overarching goals of reducing human suffering, saving lives and improving quality of life which leads to different actions and decisions than in profit-oriented commercial supply chains.
- The end-consumer is not a source of revenue and sometimes does not even take part in a transaction, instead the main source of income comes from donors.
- The often challenging terrain, regulations and infrastructure associated with some of the populations in need.

For the sake of clarity, the most salient differences between typical donor-funded supply chains and commercial supply chains, discussed in Section 2, are summarised in Table 2.

Table 2: Summary of characteristics for commercial and donor funded supply chains

Characteristics		*Commercial SC*	*DFSC (general)*
Structure & Components		Upstream (global) segment and downstream (domestic) segment primarily managed as two coupled segments by primary stakeholders	Upstream (global) segment and downstream (domestic) segment are ordinarily decoupled from one another
Stakeholders	*Primary Stakeholders*	Shareholders (that guide the organisation's policies, goals and decisions)	Host Government and some NGOs
	Other Stakeholders	Several stakeholders with different needs – rarely conflicts with shareholders interests	Stakeholders have different, often conflicting, goals, missions, interests, capacity and constraints with different perspectives and approaches
Trust		Spend time and resources to build lasting relationships with their partners	There is often not enough time or resources to enable the building of trust
Goals & Objectives	*Main Goal*	To make profits and provide financial returns to shareholders	To produce value for money, be efficient and effective, ensure fair competition between suppliers, ensure accountability, and ensure procedures are done ethically
	Objectives	'Owners' of the supply chain share the organisations policies, goals and decisions	Each organisation involved in the supply chain strives to achieve its own purpose and mission
Finances	*As an objective*	Strategic objectives are based on the financial returns paid out to the shareholders and the value created through delivering high quality goods and services to the consumers	Finances are seen as a constraint rather than an objective
	Revenue	Income earned from the sale of goods and services	Government funding and donations from individuals and organisations
	Financial Supply Chain	Manages payment transactions and orders collectively	Often has a separate chain for international flows and domestic flows
Customer Service & Marketing	*Customer characteristics*	Any individual or organisation that buys and receives the product or service	Often seen as the end-consumers that receive the intended aid, but some view the donors as the customers
	Choice of product	End-consumer can analyse the market and choose which product, out of several options, to buy	End-consumers often do not have a choice of product
	Target	Market their product to the customer	Targets donors and convince them to provide some contribution
	Market segmentation	Large amounts of time and money is allocated towards market segmentation – in most cases dedicated departments are assigned to segment the consumers and market the product/service according to the segments.	Doesn't spend time and money to market product differently to market segments – since the consumers are in need of the product, the goal is to provide supplies and services to populations in need.

Research & Development (R&D)		Financial resources are typically allocated to both strategic and operational activities with large amounts of time and money allocated for R&D	Typically, funding is provided specifically for operational activities and not R&D. Instead, they have to rely on global initiatives for their R&D.
Demand & Forecasting	*Stability*	Relatively stable and predictable demand	Irregular amounts at irregular intervals
	Demand Pattern	Occurs from recognised locations in fixed quantities at consistent time intervals	Often unpredictable and occurs in irregular amounts and time intervals
Procurement		Often build a lasting relationship with their partners and set up long-term agreements and contracts	Often use a competitive bidding process and short-term contracts or agreements are set up
Manufacturing	*Processes*	Processes can be forecast-driven due to the relatively stable demand patterns	Processes are mostly order-driven due to the unpredictable demand
	Volume	Typically uses economic batch sizes and order quantities. One manufacturer often has several customers and can produce larger volumes.	Supplies are manufactured in smaller batch sizes that are not cost effective, since the limited actual demand and lack of accurate forecasting weakens the manufacturers' confidence to produce large volumes of supplies.
	Market & competition	Manufacturers rarely have a monopoly in the market	The difficult nature of products and lack of incentives leads to a restricted market structure and lack of competition.
Logistics	*Definition*	Process of managing flows from source to the final customers	Process of managing flows from the donors to the affected populations
	Collaboration	Often implements horizontal collaboration, to create a distribution pool	Unpredictable demand patterns makes collaboration difficult
Agility		A key strategy that allows them to compete in the global market by improving delivery rates	Used in managing different relationships between donors and actors, evaluating impacts of distributed supplies and monitoring various ongoing activities

4. CONCLUSION

Several examples of donor funded supply chains were compared with commercial supply chains, with reference to several relevant characteristics. The characteristics that were discussed were primarily selected based on their identification in at least two well-known models, with three characteristics that do not meet these criteria also being discussed due to their salience. Although alternative characteristics are certainly discussed in other models and literature, those encountered and studied throughout the course of this research can confidently be categorised under the characteristics presented in Table 1.

This article mainly served as an exploratory high-level study, aimed at defining the field of donor funded supply chains in terms of how the main drivers and characteristics differs from commercial supply chains. Further value can be brought to the field by investigating how these differences should be taken into account when developing management practices and principles for donor funded supply chains.

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AN EVALUATION OF WASTE AND COSTS AT A TEXTILE FACILITY: A CASE STUDY

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ABSTRACT

The textile industry continues to face challenges in view of realignment to the context of globalization and competition. The industry has a myriad of issues with which it has to contend with, which are tortuously entwined and symbiotic. It is a vehicle of economic development and growth and a major contributor to the GDP. In addition, the textile industry is a major provider of employment and a vital component in the supply chain of the clothing industry. The aim of the textile industry in South Africa (SA) is to harness its potential in terms of human capital, natural resources and technological impetus in order to become a preferred international supplier. The textile and clothing industry accounted for 14 % of manufacturing employment and a major contributor of tax revenue. The textile industry offers a range of services in terms of its diverse production facilities – from natural fibres to synthetic fibres to non-wovens. This includes spinning, weaving, tufting, knitting, dyeing and finishing. The methodology that was most appropriate for the evaluation was a case study because it provides the ability to infiltrate aspects of waste and costs in the organisation. The study enabled the collection of important information and data that can be used to improve the current experiences.

Key words: textile industry, economic development, production facilities, continuous improvement

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1. INTRODUCTION

The textile industry continues to play a major role in terms of employment, however formal employment decreased by approximately 40% in the last decade [15]. Some of the reasons for this are the increasing wage rates of the sector with an adverse decline in productivity. In addition, the application of inefficient work methods, overpriced raw materials that are normally imported from around the world and dependant on the rand/dollar exchange, aged equipment that require repair on an ongoing basis that ultimately result in the industries uncompetitiveness [2]. The global arena bolsters the impact on the industry through cheap imports. Labour laws are perceived to favour the employee, adding the burden of an already struggling industry[3]. It was decided that an evaluation be done in order to address internal inefficiencies as well as exploring cross-industry innovation to determine if the waste can be recycled into products for a different market[6]. In view of the clothing and textile industry protection from imports, the industry is now placed in a predicament, where the cost factor in terms of production facilities are priority. The industry is continuously focused on cost-cutting measures to improve productivity [10;11;13].

2. LITERATURE REVIEW

The textile industry requires competitive strategies in order to maintain its position in the global economy. These strategies provide significant impact on the financial viability in terms of the organisations manufacturing capabilities[1;4]. It may be used as a competitive weapon against national and international markets vying for the same products.

The textile industry in particular may implement particular dimensions of competitive strategies in the context of the textile industry. Ward et al [14]postulates five magnitudes which he believes are imperative for for global competitiveness. These are product flexibility, volume flexibility, price, quality, dependability in order of importance in the textile industry.

Glock and Kunz [7] mentioned that the “winning of orders” is vital in the textile fraternity. Their focus is similar to Peng, however they focus on price, product design and variety. On the other hand Hill postulates performance of the product as a qualifier criterion in the textile industry. The adds to the organisations pursuit for service excellence in manufacturing.

Krajewski and Ritzman and Malhotra [9] mention “a more detailed list by differentiating four different aspects namely, cost; quality; time; and flexibility. Their list then included low-cost operations, high-performance design, consistent quality, fast delivery time, on-time delivery, development speed, customisation, and volume flexibility.”

Stevenson [12] on the other hand recommends three areas of competitive advantage which he believes would lead the organisation to global competitiveness:

- cost leadership – lean pricing to attract the market ;
- differentiation – an exceptional product that is in demand;
- focus – an exclusive marketplace based on cost leadership and differentiation strategy.

In order to achieve the above mentioned strategies Ramdass indicates that it is imperative that the textile industry defines its worker performance in terms of the prevailing working conditions. In this argument, the ergonomics of the workstation and job design as well as the physique of the operator are critical components especially in the textile industry [18].

2. METHODOLOGY

A case study methodology creates an enabling environment in terms of understanding complex phenomena in terms of three stages. The first and most important one is its alignment to the research question. In this case the research question is “what is happening in the textile industry in terms of improvement strategies?” This would provide an exploration of the current status on the industry through a descriptive analysis. The second reason for the choice of the case study method is that it is a real world phenomenon where data is collected in the natural setting. Thirdly the methodology is appropriate in that it evaluates the current situation for the purpose of improvement.

3. RESULTS AND DISCUSSION

The paper focuses on four critical areas in the thread manufacturing process. The reasons for this are multi-fold and include human resources in terms of training, efficiency, quality and productivity. The four areas that are investigated include spinning, twisting, dyeing and final winding departments that are the core components of thread manufacturing process.

3.1 Spinning

Introduction to the spinning process

The spinning process has been expanded due to the fact that it is a critical process in textile manufacturing, especially in the manufacture of thread for the clothing industry. After the sliver has passed through the different speedframe processes in the preparation department, the end product, which is called roving has to be transformed into yarn. This is achieved by means of ring spinning frames, giving the roving its draft and twist. The roving passes through the drafting area, the guide eye and the traveler onto the bobbin. The roving speed of the bobbin is very high, taking the traveler and roving with it. Every revolution of the bobbin puts one turn in the length of roving between the traveler and the front drafting rollers. Due to the friction of the traveler against the traveler ring and the traveler lags a little behind the speed of the spindle causing the yarn to be wound onto the bobbin. For a given count the amount of twist in the yarn can be varied; this is:

- By increasing or decreasing the speed of the drafting rollers – the more material is given the less the amount of twist.
- By using lighter or heavier travelers – the further it stays behind in comparison with spindle speed, the quicker the up winding, the less twist is inserted.

The amount of twist inserted into the yarn depends on its end use as twist affects the strength of the yarn. Warp yarns must have more twist than yarns of the same linear density used for weft knitting. The direction of the spinning twist is normally “z.”

The first issue that was observed was the high levels of waste in the spinning area [5]. On analyzing the doff weights , it was found that that there was an average of a 35% variation between doff weights of the same count as well as that the weight was below the expected weight.

The waste and inefficiency was the result of the following:

- Lack of operator patrol
- Spindles broken
- Faulty spinning
- Tight ring tubes
- Spindles not started after doff (changes on a regular basis)

Table 1: Ring Spinning Machine Analysis (waste)

MACHINE	NO.OF SPINDLES	NO NOT WORK	LOSS IN GRAMS	LOSS PER MONTH
Machine 1	420 spindles	15 (100 GRAMS)	1500 (120)	180000
Machine 2	420 spindles	25	2500	300000
Machine 3	420 spindles	20	2000	240000
Machine 4	420 spindles	16	1600	192000
Machine 5	420 spindles	45	4500	540000
Machine 6	420 spindles	35	3500	420000
Machine 7	420 spindles	37	3700	444000
Machine 8	420 spindles	41	4100	492000
Machine 9	420 spindles	34	3400	408000
Machine 10	420 spindles	43	4300	516000
Machine 11	420 spindles	33	3300	396000
Machine 12	420 spindles	26	2600	312000
Machine 13	420 spindles	37	3700	444000
Machine 14	420 spindles	25	2500	300000
Machine 15	420 spindles	27	2700	324000
Machine 16	420 spindles	10	1000	120000
				5628000 (5628)

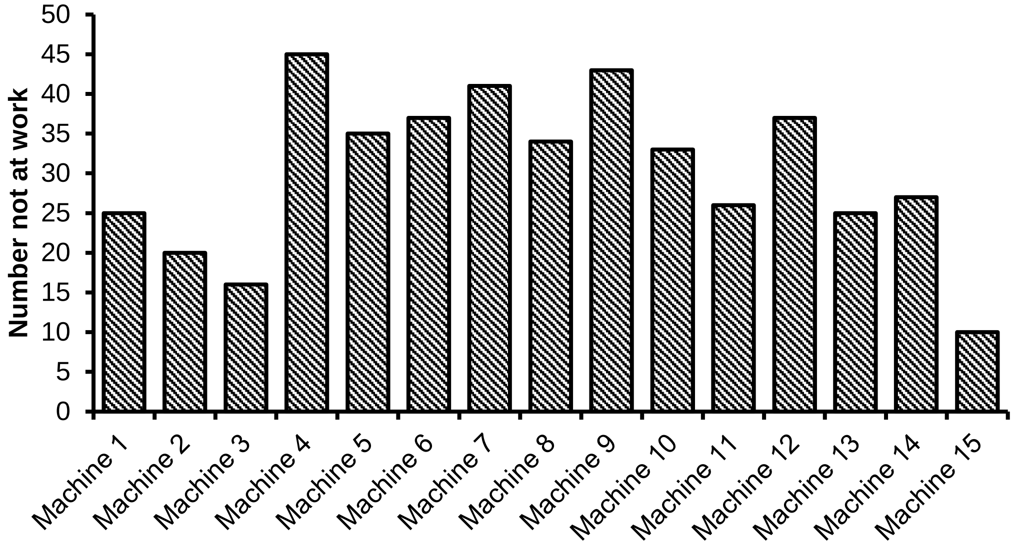

Figure 1: Spindles not working per machine

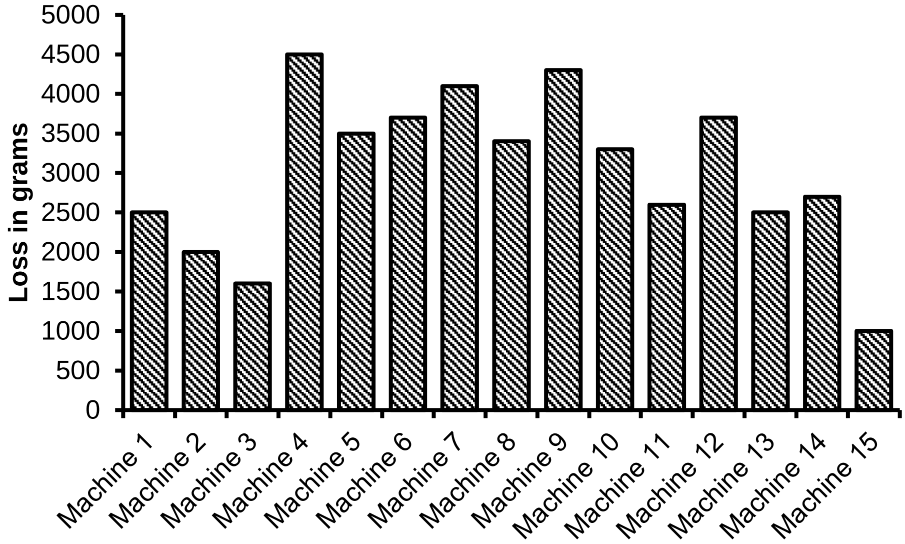

Figure 2: Loss of production in grams

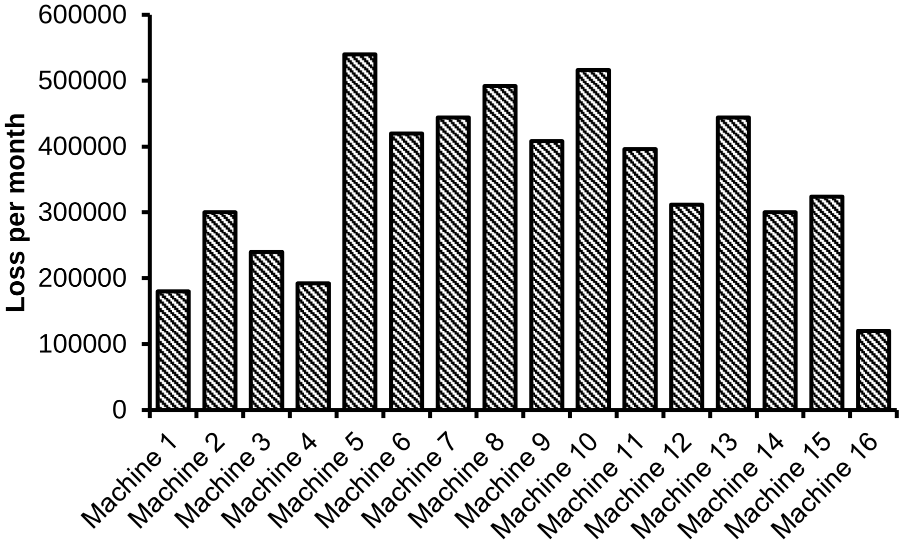

Figure 3: Loss of production per month

Human Resources

- In terms of the ergonomics of the spinning operation the following was identified:
- The loading of machines required tall men (due to the weights that required lifting when loading the machines)
- The unloading of the machine required shorter men due to bending required when offloading spindles.
- Transport and weighing required bin with wheels as well as durable material for the construction of the bin.

Recommendation to HR

- Employment of men as per criteria for the different operations
- Development of a bin for the doffing of machines
- Pattern of patrol of machines

Quality

The development of a quality plan that samples the output of each machines at regular intervals.

Machine maintenance

It was recommended that there be the repair and replacement of all worn parts as they occur and the total refurbishment at shutdown which is in December.

This evaluation was applied to all sections that were studied.

3.2 Grey Mill – Hamel stage 2 twisting

The twisting process generally involves threads being put together and twisted to form the respective specifications required by the customer. Twisting is generally satisfactory but machine wear in terms of the peeling of protective plating on both top and bottom rollers was a cause for concern.

Problems that were observed in this area are the following:

- Inefficient Operator patrol – it was observed in the sample that too many spindles were not in operation.
- Cheese shape - output cheese shape must be parallel – variable tension would result in uneven shape
- Mandrells are problematic and cradles must be in line and in good working order.
- Differing dimensions of stainless steel springs in use required correction.

3.3 Gilbos winding

Problems that were observed in this area are the following:

- Inefficient operator patrol – It was observed in the sample that too many spindles were not in operation.
- Thread running through deep cuts in the tensions resulting in damaged thread.
- Oil deposits on outputs from leaking damper
- Knock-offs were not working properly, causing larger packages that pick up dirt.

3.4 Hamel down-twisting

Problems that were observed in this area are the following:

- Ceramic guides broken and damaging thread
- Thread was running against metal
- Thread not positioned behind guide rod
- Rusty rollers contaminate thread
- Incorrect distance between twisting bobbin and metal guide
- Variation of travelers used on one machine
- Dirty machinery

3.5 Dyehouse

To maintain high standards of quality and to meet the specified requirements, it is important that the 'fast dyed' threads have the highest colour fastness attainable. Colour laboratory recipes are formulated with this aim in mind and selection of dyestuffs restricted to those which are capable of producing the required levels of colour fastness. However certain fastness characteristics of dyed material are dependent on both the recipe formulation and the dyeing process, and routine fastness testing of bulk dyelots was necessary. In this regard the dyehouse is automated but relies for the correct proportions in terms of dyestuffs going into the dye vessel. Should there be colour problems the batch is redyed into black to prevent waste. At this stage, all machinery is maintained accordingly. However, if a lot is dyed and the colour is not correct, the entire lot is scrapped.

3.6 Final winding - Scharer Lubrication

An important stage in the final winding process is the lubrication process which is imperative for the clothing industry. During the sewing process, the needle becomes hot due to friction, therefore the thread requires lubrication to prevent thread breaks on a regular basis.

This is a messy process, therefore machine cleaning is required on a regular basis. The following was observed in the process:

- Regular thread breaks that lead to waste due to inefficient patrolling of operators
- Different types of empty centres were used in the lubrication process, one much thicker than the other and causing problems in terms of tension. This needs to be adjusted by the mechanic, alternatively use the same thickness of centres
- Machine checks on a daily basis due to the process itself
- Complete installation of new clearers
- Damaged centres causing excess breaks

Leeson winding

Problems that were observed in this area are the following:

- Missing ceramic eyelets above the creel peg
- Damaged tension disc springs
- Reposition bail roller arm where necessary
- Leaking wax troughs
- Ergonomics of label insertion onto vicone

3.7 SPT Cop winding

Problems that were observed in this area are the following:

- Make up and inspection need re-evaluation
- Machines are in good working order

SPT cone winding

Problems that were observed in this area are the following:

- Input creel peg needs attention
- Work-layout requires investigation in terms of ergonomics
- Material handling to next stage
- Lubrication – needs to be maintained
- New clearers installed
- Output centres are damaged

Hacoba vicone winding

Problems that were observed in this area are the following:

- New work methods required
- Programme settings for the machine on day shift only
- Thread breaks were frequent – caused by thread sloughing off machine
- Optimum speeds require re-evaluation
- Cutting knife be moved forward to enable easier doffing
- Tensions on the thread need evaluation as diameter of cones vary.
- Quality of empty vicones are problematic and need investigation

Hacoba cone winding

- Plunger housing to be checked and replaced as necessary
- Wing assemblies, that is the traverse guides need evaluation and replacement

4. ANALYSIS

A disturbing issue that was observed was that a person was specifically hired to cut up waste. With reference to the Table 2 below the approximated waste per annum for the organisation was 7000 kilograms. This was done for over 10 years. The monetary value that was wasted in the form of waste was insurmountable. The graph shows that most of the waste was generated in the spinning department.
In the endeavour to reduce waste the following action was taken from an industrial engineering perspective:

- Define the problem – generation of waste in each process of manufacturing
- Identify the causes of waste – input/process/output
- Identify the principal contributor of waste
- Develop a strategy to address and curtail waste creation

The following table provides the waste per department

Table 2: Breakdown of waste and costs per department

	SPINNING	TWISTING	DYEING	FINISHING
JANUARY	57 (16.50)	125 (18.00)	300 (25.00)	85(33.00)
FEBRUARY	128	400	235	56
MARCH	255	350	255	86
APRIL	85	352	145	120
MAY	120	285	186	95
JUNE	95	125	85	51
JULY	112	156	128	123
AUGUST	100	115	201	76

SEPTEMBER	68	125	98	102
OCTOBER	125	300	129	84
NOVEMBER	80	250	158	100
DECEMBER	138	96	100	63
	1363 (22489)	2523 (45414)	2020 (50500)	1042 (34386)

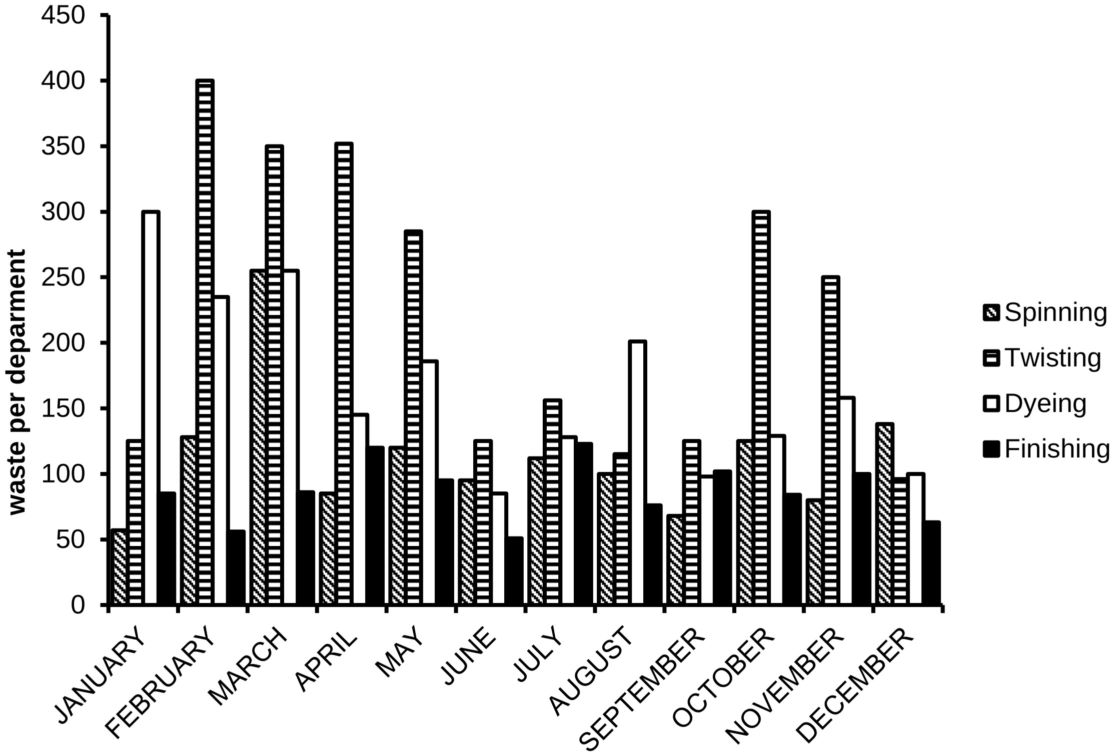

Figure 4: Waste per department per month

In terms of cost the dying department was a major contributor. In terms of quantity the twisting department was the major contributor of waste. Management decision on the matter was that that the project will start in the spinning department because the input from spinning is important for the other processes.

Table 3. Breakdown of causes of waste

SPINNING	TWISTING	DYEING	FINISHING
Filament damaged/cut	Incorrect twist	Incorrect colour	Operator error
No cotton	Wrong ply	Machine malfunction	Machine error
Defective material	Defective machine	Operator error	Quality standards not met
Defective rollers	Quality standards not met	Quality standards not met	
Worn rollers	Variance in spindle turns	Defective input material	
Defective input material	Operator error		
Quality standards not met			

A programme was developed to address the above problems. Regular discussion on the 5s principles was implemented and drastic measures were taken to reduce waste throughout the organisation. The maintenance team was asked to investigate and correct all machine related problems. Human resources performed training and retraining on all operator-related problems and the work-study department provided standard operating procedures for all operations. The quality department performed quality tests on all input/output of materials on a regular basis. Weekly productivity and operator efficiency reports, together with the waste report were presented to executive management since inception. This was carefully scrutinised and each departmental manager was asked to report on the progress that was made using the 5s principles.

5. CONCLUSION

Commitment from all stakeholders is imperative in order to gain the rewards of this programme. Moreover, the rewards may be seen over a period of time and difficult to quantify. However, this case demonstrates the saving gained on the reduction of waste in the textile industry.

Discipline means instilling the ability to do things the way they are supposed to be done. This involves training and inculcating good habits and having everyone practise them, thus encouraging the continuity of good habits. As the final S in the 5-S, it propagates the 5-S practice by ensuring that the former 4-Ss are carried out conscientiously. Making the 5-S a daily routine helps to maintain orderliness at the workplace. Setting up the 5-S is useless if it is not followed through, as things will return to its previous state if they are not well maintained. Taking a further step, discipline also includes reviewing current practices and revising them to keep them relevant. It also means striving for kaizen, which is the Japanese equivalent for continuous improvement.

There is a definite relationship between worker performance and working conditions. They found that the problems with most workstations centred on two design-related problems – the physical components of the workstation and the nature of the job or job design. In the case of this study, it was important to hire personnel that are able to reach the top of ring spinning machines. Today's workforce is multiracial, male and female, and includes disabled and ageing workers. Body shapes, sizes, capabilities and limitations vary greatly, yet many workstations do not take these factors into consideration, as they are set up in a rigid structure. To compound these problems, workplace physical structures may be designed for a minority of workers.

A “good” workstation, (one that promotes machine-worker interface) therefore, should be developed with the anthropometric measurements of the majority of workers as a standard and should allow flexibility. In addition to these physical layout problems, the pace of work and the type of work has changed. Employees are expected to produce more output quickly, and, because of the faster access to information, employees are being asked to make more and more decisions around their tasks. These factors are potential stress builders [3;14], however the encouragement of staff to take ownership of their process creates an environment of collegiality that encompasses building relationships.

Lastly, it is recommended that machine maintenance and the measurement of productivity be implemented as this would be able to monitor all aspects in the manufacturing process.

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EMPLOYEE RETENTION STRATEGIES: FACTORS FOR GENERATION Y BURSAR GRADUATES

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ABSTRACT

The nature of work is changing, and so are the elements which are necessary to manage these different transformations.

The focus of this study was to determine which factors were important to Generation Y engineering bursar graduates from a particular organisation; in particular those within their first 5 years of work. A theoretical framework from the literature was developed, and the Case Study research method was applied.

The results showed that *Job satisfaction* had the greatest influence as a retention factor. It was found that there was a difference between factors which influenced an employee to stay or leave.

1. INTRODUCTION

The nature of work is changing, and so are the elements which are necessary to manage the different transformations - such as workforce demographics, awareness of social and environmental corporate responsibility which are taking place. Some of the contributing factors to these changes are globalisation, technology, where and how people work, as well as workforce expectations [1] [2] [3] [4]. As a result of these transformations taking place in the workplace, the risk of a disengaged workforce is high; and hence the implication for employee retention strategies. The external factors (such as economic crises, the dynamics in the labour market, and even political instability), have a profound and direct impact on the internal changes which take place within individuals. Workplaces are changing from being areas of generally economic and social activity to being places where individuals are seeking meaning, value, support and purpose to their lives [5].

In light of the transformation which is taking place in the workplace arena, it is evident that financial incentives and/or financial security are not sufficient as sole "retention drivers"- there are other factors which need to be considered to drive and support organisational sustainability through these changes [6].

1.1 Problem Statement

The organisation which forms the focus of this study runs a bursary scheme program. This program aims at developing young talent, and providing an opportunity for that talent to be part of the organisation. After the completion of studies, the expectation is that the bursary holder "work back" the period over which they were sponsored.

The early loss of bursaried graduates has implications for the organisation in the long run. It has been shown that 'tenured employees drive far greater value than those who are "cycling through" the business' [6]. The investigation of the critical factors affecting this early loss of bursary graduates has the potential to benefit the development and application of certain strategies to address the retention, as well as the growth, of incoming talent to the business.

The purpose of this study, thus, was to determine what factors are essential in the development of retention strategies (those which respond to the workplace transformation(s) taking place); with specific regard to engineers within their first 5 years of work.

1.2 Research Question(s)/Hypotheses

The focus of the study was on employees from a particular organisation, and the research question was framed as:
What factors are important to the young engineer (within 5 years working experience) in the work context, which could contribute to the development of effective retention strategies for this segment of the workforce?

1.3 Research Objectives

The objectives of the research were to:

- Develop a conceptual framework from the literature incorporating relevant factors that may affect the retention of young engineers in the organisational workforce.
- Use the conceptual framework to develop survey questions, and to frame the responses from the interviews, so as to elicit key factors
- Establish which factors are essential in the development of employee retention strategies for young engineers who have joined the organisation through the organisation's bursary scheme (within 5 years working experience)
- Recommend how the current employee retention strategies need to accommodate the above factors
- Comment on how the findings relate to the role of spirituality in the workplace, and the consequent implications for employee retention strategies

1.4 Limitations and Constraints

The study and its findings were limited by the following:-

- It was not possible to include employees who had left the company in the study, as their contact details were not available.
- The information (separation data) related to the employees who had left the company was limited to the history capacity of the data system being used to capture these details (i.e. it was not possible to access the historic data from before the system was implemented).
- The study was also limited to the number and the type of respondents that completed the survey (responses to the survey were optional to the recipients of the survey).

A Literature Review was conducted which covered the following areas:-

- The changing workplace
- Spirituality at work
- Knowledge workers
- Employee Retention Strategies
- Generation Y at work

2. DEVELOPMENT OF A THEORETICAL FRAMEWORK

A study by [7] developed a *Content Model for Employee Retention* from a review of the major theories over the last fifty years, which helped explain why employees stay with an organisation or leave. The reviewed literature from this study was used to generate a theoretically-derived set of factors.

The literature on (i) Generation Y, (ii) Knowledge workers, and (iii) Spirituality at work was surveyed to determine relevant factors that may affect the retention of young engineers. It was evident from the comparison of the area-specific factors that there is some overlap of factors in some of the areas. An Affinity Diagram approach was followed to group the various factors into broad themes. These consequent themes are presented in Table 1.

Table 1: Retention Factors used in the Survey

(Definitions of the factors from the *Content Model for Employee Retentions* study have been used as defined in the study [7]. The factors emanating from the Affinity Diagram were defined as suggested by the perused literature).

Retention Factor	Definition
Advancement opportunities	The amount of potential for movement to higher levels within the organization
Constituent attachments	The degree of attachment to individuals associated with the organization such as supervisor, co-workers, or customers
Extrinsic rewards	The amount of pay, benefits, or equivalents distributed in return for service
Flexible work arrangements	The nature of the work schedule or hours
Investments	Perceptions about the length of service to the organization
Job satisfaction	The degree to which individuals like their jobs
Lack of alternatives	Beliefs about the unavailability of jobs outside of the organization
Location	The proximity of the workplace relative to one's home
Non-work influences	The existence of responsibilities and commitments outside of the organization
Organizational commitment	The degree to which individual's identify with and are involved in the organization
Organizational justice	Perceptions about the fairness of reward allocations, policies and procedures, and interpersonal treatment
Organizational prestige	The degree to which the organization is perceived to be reputable and well-regarded
Growth	The prospect of growth in various facets (e.g. employee, human, personal); self-actualisation

Energising environment	An energising culture, in which aspects such as creativity, excitement, fun, inspiration, transformation are active
Learning organisation	An environment where continuous learning is encouraged; programs available such as mentorship, skills development, training, etc.
God in the organisation	An environment which is "soulful", which contains "spiritual" values, has an element of sacredness
Values	An organisation which is grounded in values such as morality, respect, authenticity, open communication, transparency; where a greater vision is communicated and shared
Nature of work	Work in which the job design is aligned with the employee's personal life interests, is challenging, knowledge-based work, appropriate job design
Flexibility	An environment which allows for autonomy, independence, ease of movement, work-play balance
Career path	An organisation which offers a clear career growth and development plan; a career path aligned with personal life interests; targeted development programs
CSR/ Civic activities	A caring company, which is active in community development/ has a reputable CSR program
Intrinsic reward systems	Being rewarded in a manner which results in personal satisfaction (e.g. recognition; sense of meaning, choice, competence, progress)
Meaning	Finding purpose, relevance, inner-connectedness, etc. in the work that is being done
Technology	An organisation which is technologically-savvy, has leading technology, innovative
Leadership/ Management	The type of organisation leadership/ management style e.g. a cool and laidback management style, servant leadership, etc.
Workplace relationships	An environment in which the workplace is a community; promotes teamwork, comradeship, networking, cohesion

3. RESEARCH METHODS

A Case Study of the Type 2 design [8] was used.

The following data collection methods were used (as indicated in Table 2):

Table 2: Sources of Evidence

Source of Evidence	Type of Evidence
Documentation The purpose of this evidence was to determine what employee retention strategies were employed by the organisation.	• Previous Graduate Development Programme (GDP) Policy • Current GDP Policy • Company's Talent Management (TM) Department documentation • Company's website
Archival records The purpose of this evidence was to determine the reasons for separation by previous employees	• Separation data (of bursar graduates who had separated from the company)
Survey The purpose of this evidence was to determine which retention factors would cause an employee to stay and/or leave the organisation	• Survey results (Likert scale was used)

Interviews The purpose of this evidence was to supplement the information from the perused documentation. Interviews were held with the custodians of the various elements of the organisation's employee retention strategies so as to better understand the context of the documentation.	Semi-structured interviews with: • Acting Manager: Bursary Services Office • Senior Manager: Talent Management (People and Organisational Effectiveness) • Senior Manager: Graduate Development Programme Office • Head of Wellness and Benefits

Validity and Reliability

To ensure research validity, the following were applied:

Construct validity:

- Multiple sources of evidence were used
    - Documentation
    - Archival records (Separation data)
    - Survey
    - Interviews
- A Case Study Database was created to provide a chain of evidence

External validity

- The results were related back to the Literature that was reviewed (in order to generalise the results to the broader theories)

Reliability:

- A Case Study Protocol was used
- A Case Study Database was created

4. RESULTS

The aim of this research was to determine which factors would be required in the development of retention strategies for young engineers (those between 0 – 5 years of work); in particular, graduates who had joined the organisation through the bursary scheme.

A conceptual framework of these factors was drawn up, incorporating retention factors which were mentioned in the Employee retention strategies, Knowledge workers, Generation Y and Spirituality at work literature. The framework was used to develop survey questions which were posed to the employees at the organisation, who had joined the company through the bursary scheme. All respondents were considered to be part of Generation Y (Gen Y) in this study as the year brackets are not strictly bound (the last generation with strict time-frames is the Baby Boomer 1946 – 1964 [9]).

The factors were tested for personal congruence (PC) ("what would make you stay with the company?") and personal incongruence (PI) ("what would make you leave the company?"). The collected data was compared according to:-

- Tenure (engineers who had been with the company for less than five years, and those who had been employed for more than 5 years)
- Gender

Analysis of data

The responses from the Likert scale data was organised to reflect the modes and respective percentages.

The respondents had the option to add comments in addition to indicating their level of congruence with the given factor. The nature of the received comments differed: some of the comments were related to the included factors, others were more general comments on the design and development of employee retention strategies, some were commentary on the organisation's methods, while some had a more personal commentary (i.e. what factors were important for the particular individual).

Inferential statistics (Mann-Whitney U test) were applied to determine whether there was a difference between the populations which formed the focus of this study (employees who had been with the company for i) more, and ii) less than 5 years), as well as between the genders.

A significance level of 0.05 was applied; with the null hypothesis being that there was no significant difference between the responses. Both uni-directional and non-directional tests were performed (as indicated in Table 5 and Table 6).
The U-value was determined using an Online Calculator [10]; and the following formula was used to calculate the z-value.

$$N_1 = sample\ size\ in\ population\ 1$$

$$N_2 = sample\ size\ in\ population\ 2$$

$$z = \frac{U-(N_1 N_{2/2})}{\sqrt{\frac{N_1 N_2 (N_1+N_2+1)}{12}}} \quad [11]$$

The following null hypotheses were rejected under the Personal Congruence factors (Rejection of the null hypothesis implies that a significant difference existed between the two groups on the respective factors):-

- For the Tenure-based tests, the null hypothesis was rejected for the *CSR/ Civic activities* factor (non-directional test);
- For the Gender-based tests, the null hypothesis was rejected for the *Flexible working arrangements* and *Organisational Justice* factors (non-directional test)

No null hypotheses were rejected for the Personal Incongruence factors.

It is evident from Table 3 that a blend of different retention factors is required by young engineers; and that these factors do not significantly differ from those of longer-tenured engineers.

Table 3: Comparison of Tenures against Overall Results (Greater Influence)

Personal Congruence	**Overall**	**< 5**	**> 5**
Job satisfaction	92%	95%	86%
Energising environment	92%	94%	89%
Career path	90%	90%	89%
Learning organisation	90%	95%	81%
Nature of work	89%	89%	89%
Advancement opportunities	87%	89%	83%
Flexibility	87%	85%	89%
Intrinsic reward systems	86%	85%	86%
Growth	85%	89%	78%
Extrinsic rewards	84%	79%	92%
Workplace relationships	83%	85%	78%
Flexible work arrangements	83%	84%	81%
Organizational justice	81%	82%	78%
Technology	78%	81%	72%
Meaning	77%	74%	81%
Leadership/ Management	77%	82%	67%
Values	74%	74%	75%
Location	69%	69%	69%
Organizational prestige	58%	63%	50%
Organizational commitment	56%	56%	56%
Non-work influences	50%	50%	50%
CSR/ Civic activities	47%	53%	36%
God in the organisation	45%	44%	47%
Investments	44%	47%	39%
Constituent attachments	39%	40%	36%
Lack of alternatives	37%	37%	36%

Personal incongruence	**Overall**	**< 5**	**> 5**
Job satisfaction	60%	56%	67%
Advancement opportunities	59%	61%	56%
Extrinsic rewards	58%	55%	64%
Organizational justice	55%	52%	61%
Non-work influences	54%	53%	56%
Career path	51%	45%	61%
Growth	50%	48%	53%
Nature of work	50%	47%	56%
Leadership/ Management	48%	47%	50%
Intrinsic reward systems	47%	44%	53%
Location	47%	50%	42%
Flexibility	41%	35%	50%
Values	39%	42%	33%
Learning organisation	39%	39%	39%
Meaning	39%	37%	42%
Workplace relationships	36%	34%	39%
Energising environment	31%	31%	31%
Flexible work arrangements	31%	27%	36%
Organizational commitment	31%	32%	28%
Lack of alternatives	31%	32%	28%
Technology	29%	29%	28%
Organizational prestige	26%	26%	25%
Constituent attachments	23%	24%	22%
God in the organisation	22%	23%	22%
Investments	18%	23%	11%
CSR/ Civic activities	14%	13%	17%

Table 4: Comparison between Gender Results

	Greater influence				Greater influence	
Personal Congruence	**Female**	**Male**		***Personal Incongruence***	**Female**	**Male**
Job satisfaction	100%	88%		Advancement opportunities	62%	58%
Energising environment	97%	89%		Job satisfaction	62%	59%
Organizational justice	97%	72%		Extrinsic rewards	56%	59%
Intrinsic reward systems	97%	80%		Organizational justice	56%	55%
Flexible work arrangements	94%	77%		Non-work influences	53%	55%
Nature of work	94%	86%		Growth	50%	50%
Advancement opportunities	91%	84%		Nature of work	50%	50%
Learning organisation	91%	89%		Leadership/ Management	47%	48%
Growth	91%	81%		Career path	47%	53%
Career path	88%	91%		Location	47%	47%
Extrinsic rewards	88%	81%		Intrinsic reward systems	44%	48%
Flexibility	88%	86%		Flexibility	41%	41%
Workplace relationships	85%	81%		Meaning	38%	39%
Leadership/ Management	85%	72%		Organizational commitment	35%	28%
Meaning	82%	73%		Flexible work arrangements	35%	28%
Values	79%	72%		Constituent attachments	32%	19%
Location	79%	64%		Values	32%	42%
Technology	76%	78%		Workplace relationships	32%	38%
Organizational prestige	68%	53%		Learning organisation	29%	44%
Non-work influences	59%	45%		Energising environment	26%	33%
CSR/ Civic activities	56%	42%		God in the organisation	26%	20%
Investments	50%	41%		Technology	24%	31%
Organizational commitment	50%	59%		Organizational prestige	24%	27%
God in the organisation	47%	44%		Lack of alternatives	24%	34%
Lack of alternatives	35%	38%		CSR/ Civic activities	12%	16%
Constituent attachments	29%	44%		Investments	6%	25%

Table 5: Inferential Statistics Results: Personal Congruence

	Gender				Tenure (T)				
	N1 =34	N2 = 64	z Den		N1 = 62	N2 = 36	z Den		
	Female	Male	133.9851		T < 5	T >5	135.6982		
	Gender, Non-directional				Tenure			Non-directional (+-1.96)	Uni-directional (+-1.65)
Personal Congruence	**U**	**z Num**	**z***	**Null Hypothesis**	**U**	**z Num**	**z***	**Null Hypothesis**	**Null Hypothesis**
Non-work influences	893	-195	-1.4554	Retain	1109.5	-6.5	-0.0479	Retain	Retain
Constituent attachments	975	-113	-0.8434	Retain	1055.5	-60.5	-0.4458	Retain	Retain
Energising environment	834	-254	-1.8957	Retain	935	-181	-1.3338	Retain	Retain
Flexible work arrangements	804	-284	-2.1196	Reject	995.5	-120.5	-0.8880	Retain	Retain
Advancement opportunities	933.5	-154.5	-1.1531	Retain	1032.5	-83.5	-0.6153	Retain	Retain
Extrinsic rewards	1016	-72	-0.5374	Retain	935.5	-180.5	-1.3302	Retain	Retain
Organizational justice	758.5	-329.5	-2.4592	Reject	993.5	-122.5	-0.9027	Retain	Retain
Values	977.5	-110.5	-0.8247	Retain	1034.5	-81.5	-0.6006	Retain	Retain
CSR/ Civic activities	927.5	-160.5	-1.1979	Retain	833.5	-282.5	-2.0818	Reject	Retain
Investments	952.5	-135.5	-1.0113	Retain	1011.5	-104.5	-0.7701	Retain	Retain
Leadership/ Management	873	-215	-1.6047	Retain	1030	-86	-0.6338	Retain	Retain
Career path	909	-179	-1.3360	Retain	971	-145	-1.0685	Retain	Retain
Technology	1073	-15	-0.1120	Retain	1012	-104	-0.7664	Retain	Retain
Job satisfaction	831	-257	-1.9181	Retain	963.5	-152.5	-1.1238	Retain	Retain
Learning organisation	911.5	-176.5	-1.3173	Retain	932.5	-183.5	-1.3523	Retain	Retain
Organizational prestige	934	-154	-1.1494	Retain	964.5	-151.5	-1.1164	Retain	Retain
God in the organisation	913	-175	-1.3061	Retain	1090.5	-25.5	-0.1879	Retain	Retain
Growth	1009.5	-78.5	-0.5859	Retain	880.5	-235.5	-1.7355	Retain	Retain
Meaning	863.5	-224.5	-1.6756	Retain	1004	-112	-0.8254	Retain	Retain
Intrinsic reward systems	842	-246	-1.8360	Retain	1000	-116	-0.8548	Retain	Retain
Organizational commitment	1012.5	-75.5	-0.5635	Retain	1085	-31	-0.2284	Retain	Retain
Workplace relationships	1057	-31	-0.2314	Retain	1051.5	-64.5	-0.4753	Retain	Retain
Lack of alternatives	1058	-30	-0.2239	Retain	1056.5	-59.5	-0.4385	Retain	Retain
Location	833	-255	-1.9032	Retain	1075	-41	-0.3021	Retain	Retain
Flexibility	925	-163	-1.2166	Retain	916	-200	-1.4739	Retain	Retain
Nature of work	900.5	-187.5	-1.3994	Retain	994.5	-121.5	-0.8954	Retain	Retain

Table 6: Inferential Statistics Results: Personal Incongruence

	Gender, Non-directional				Tenure			Non-directional (+-1.96)	Uni-directional (+-1.65)
Personal incongruence	**U**	**Num**	**z***	**Null Hypothesis**	**U**	**Num**	**z***	**Null Hypothesis**	**Null Hypothesis**
Non-work influences	1038	-50	-0.3732	Retain	1002.5	-113.5	-0.8364	Retain	Retain
Constituent attachments	1069	-19	-0.1418	Retain	1087.5	-28.5	-0.2100	Retain	Retain
Energising environment	964.5	-123.5	-0.9217	Retain	1054.5	-61.5	-0.4532	Retain	Retain
Flexible work arrangements	1055	-33	-0.2463	Retain	999.5	-116.5	-0.8585	Retain	Retain
Advancement opportunities	959.5	-128.5	-0.9591	Retain	1017	-99	-0.7296	Retain	Retain
Extrinsic rewards	1026	-62	-0.4627	Retain	1023	-93	-0.6853	Retain	Retain
Organizational justice	1014	-74	-0.5523	Retain	941	-175	-1.2896	Retain	Retain
Values	894.5	-193.5	-1.4442	Retain	1087	-29	-0.2137	Retain	Retain
CSR/ Civic activities	1064	-24	-0.1791	Retain	1055	-61	-0.4495	Retain	Retain
Investments	916	-172	-1.2837	Retain	958	-158	-1.1643	Retain	Retain
Leadership/ Management	1073	-15	-0.1120	Retain	1005	-111	-0.8180	Retain	Retain
Career path	947	-141	-1.0524	Retain	976	-140	-1.0317	Retain	Retain
Technology	1051	-37	-0.2762	Retain	1095	-21	-0.1548	Retain	Retain
Job satisfaction	1047	-41	-0.3060	Retain	907.5	-208.5	-1.5365	Retain	Retain
Learning organisation	980	-108	-0.8061	Retain	1104	-12	-0.0884	Retain	Retain
Organizational prestige	991.5	-96.5	-0.7202	Retain	1104	-12	-0.0884	Retain	Retain
God in the organisation	895	-193	-1.4405	Retain	1025	-91	-0.6706	Retain	Retain
Growth	1078.5	-9.5	-0.0709	Retain	1077.5	-38.5	-0.2837	Retain	Retain
Meaning	1078	-10	-0.0746	Retain	1075	-41	-0.3021	Retain	Retain
Intrinsic reward systems	1052	-36	-0.2687	Retain	1008	-108	-0.7959	Retain	Retain
Organizational commitment	971	-117	-0.8732	Retain	1102	-14	-0.1032	Retain	Retain
Workplace relationships	1040.5	-47.5	-0.3545	Retain	1082	-34	-0.2506	Retain	Retain
Lack of alternatives	1074	-14	-0.1045	Retain	1077	-39	-0.2874	Retain	Retain
Location	1028	-60	-0.4478	Retain	1062	-54	-0.3979	Retain	Retain
Flexibility	1013	-75	-0.5598	Retain	862	-254	-1.8718	Retain	Retain
Nature of work	1054	-34	-0.2538	Retain	1005.5	-110.5	-0.8143	Retain	Retain

Table 7 shows the relation of each of the sources to the conceptual framework. The Survey results which had a greater influence of more than 50% were highlighted; and the influence on PC or PI was indicated in the Survey column. The factors from the Separation Data were marked with a PI in the *Sep Data* column as these factors contributed to employees leaving the organisation.

The relation of the sources (other than the Survey and Separation Data results) to each of the conceptual framework factors was tallied to indicate which factors were prominent in the perused information from the organisation (which related to the employee organisation's retention effort)

The counts of the factors which had both PC and PI scores above 50% are highlighted in the *Tally* column.

Table 7: Relation of Study Findings to the Conceptual Framework

	Survey	*Archival*	*Doc*	*Interviews*				*Tally*
Conceptual Framework	**Results (>50%)**	**Sep Data**	**TM, GDP**	**Bursary**	**TM**	**GDP**	**W&B**	**Count**
Job satisfaction	PC, PI	PI						0
Energising environment	PC			*				1
Career path	PC, PI	PI	*		*	*		3
Learning organisation	PC	PI	*		*	*		3
Nature of work	PC		*					1
Advancement opportunities	PC, PI		*					1
Flexibility	PC					*	*	2
Intrinsic reward systems	PC	PI					*	1
Growth	PC, PI	PI	*				*	2
Extrinsic rewards	PC, PI	PI	*	*		*	*	4
Workplace relationships	PC					*		1
Flexible work arrangements	PC						*	1
Organizational justice	PC, PI							0
Technology	PC						*	1
Meaning	PC						*	1
Leadership/ Management	PC	PI					*	1
Values	PC					*		1
Location	PC	PI						0
Organizational prestige	PC		*		*			2
Organizational commitment	PC	PI					*	1
Non-work influences	PC, PI	PI				*	*	2
CSR/ Civic activities						*		1
God in the organisation								0
Investments						*		1
Constituent attachments								0
Lack of alternatives								0

5. DISCUSSION

The study considered both the factors which would result in the bursar graduate staying with the organisation (PC factors), and those which would contribute to departure from the organisation (PI factors). These factors for bursar graduate engineers within 5 years working experience were found to be:-

PC factors

- Job satisfaction
- Learning organisation,
- Energising environment
- Career path
- Advancement opportunities

PI factors

- Advancement opportunities
- Job satisfaction
- Extrinsic rewards
- Non-work influence
- Organisational justice

Table 8: Top 5 ranking PC and PI factors

	Overall		Tenure < 5 years		Tenure > 5 years	
Personal Congruence	*Job satisfaction*	*92%*	*Job satisfaction*	*95%*	*Extrinsic rewards*	*92%*
	Energising environment	*92%*	*Learning organisation*	*95%*	*Flexibility*	*89%*
	Career path	*90%*	*Energising environment*	*94%*	*Energising environmen*	*89%*
	Learning organisation	*90%*	*Career path*	*90%*	*Career path*	*89%*
	Nature of work	*89%*	*Advancement opportunities*	*89%*	*Nature of work*	*89%*
Personal Incongruence	**Overall**		**Tenure < 5 years**		**Tenure > 5 years**	
	Job satisfaction	*60%*	*Advancement opportunities*	*61%*	*Job satisfaction*	*67%*
	Advancement opportuniti	*59%*	*Job satisfaction*	*56%*	*Extrinsic rewards*	*64%*
	Extrinsic rewards	*58%*	*Extrinsic rewards*	*55%*	*Organizational justice*	*61%*
	Organizational justice	*55%*	*Non-work influences*	*53%*	*Career path*	*61%*
	Non-work influences	*54%*	*Organizational justice*	*52%*	*Non-work influences*	*56%*

The below points will be discussed from the study's results:

- What do bursar graduates want from the organisation
- The organisation's approach to employee retention strategies
- Spirituality at work

What do Gen Y bursar graduates want from the organisation

It is evident from

This **blend of different retention factors suggests that employees value both career pursuits (e.g. *Career path*, *Advancement opportunities*, *Learning Organisation*); as well as those which support personal satisfaction at work, as well as personal pursuits (e.g. *Job satisfaction*, *Energising environment*, *Non-work influences*).**

Of the factors suggested by literature, those with the most influence appeared to be more highly reflective of knowledge workers retention factors, with factors such as *Career path* and *Advancement opportunities* appearing as great influencers for both PC and PI

that a blend of different retention factors is required by young engineers; and that these factors do not significantly differ from those of longer-tenured engineers

This blend of different retention factors suggests that employees value both career pursuits (e.g. *Career path*, *Advancement opportunities*, *Learning Organisation*); as well as those which support personal satisfaction at work, as well as personal pursuits (e.g. *Job satisfaction, Energising environment, Non-work influences*).

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The respondents identified with some of the factors from the Gen Y literature as well; such as *Growth, Job satisfaction, and Meaning*. These factors also matched the motivational variables of "training and development", and "challenging and interesting work" [12, p. 413] (factors which were found to significantly influence employees in both public and private sector organisations [12]).

The factors which ranked high for PC were not the same as those which ranked high for PI (
). This illustrates that there is a difference in the reasons that would encourage an employee to stay and those which would cause an employee to leave the organisation. Again, the difference in the percentages of the top ranking PC and PI factors suggests that the factors used in the conceptual framework influenced the respondents' PC (what would make the employee stay with the organisation), more than they did the PI (what would make the employee leave the organisation) with the factors.

Job satisfaction was an important factor to take into consideration for both groups (overall PC greater influence of 92%, and overall PI greater influence of 60%; Table 3,
). This implies that more efforts are required to ensure a good organisation-individual fit. The use of psychometric tests could assist in this approach; however the realities of a shrinking labour market and urgent organisational needs could perhaps taint this as a more idealistic approach than a practical one.

If Employee Retention is defined as: "a process in which the employees are encouraged to remain with the organisation for the maximum period of time" [13, p. 80], the "maximum period of time" is a unit which needs to be reviewed. With the low influence that *Lack of Alternatives* had on the respondents' PC or PI, and that *"the current trend is that young employees typically transfer jobs after about 5 years..."* (PC General comments, Tenure < 5 years), the feasibility of an idea such as employee retention for bursar graduates is one that could possibly require greater consideration. Other elements would need to be considered, such as: How long is the "maximum period of time? What should it be? How is the answer to that determined? What makes that answer feasible from both an organisational and the individual's perspective (possibly the rate of return on investment)? These are questions that could be explored in future work.

The organisation's approach to employee retention strategies

Literature suggests that organisational approaches to employee retention are to have less of a "blanket" approach [7, p. 5]; such that the approaches to be adopted are more responsive to the needs of its workforce. The company has made an attempt at this by segmenting its talent pool, and by developing different processes to deal with each segment. However the type of segmentation could also be along demographics such as age and gender, as the results showed some differences in the factor ranking of the groups (Table 3,

Table 4).

The company has developed targeted development programmes for high-potential and high-performing employees (which can assist the organisation with dealing with the two-fold retention strategy challenges of not only how to minimise the possibility of losing good employees, but also how to identify the employees an organisation needs and wants to keep [14]). The development of such targeted programmes for other segmentation groups can also assist the organisation with the development of retention strategies which are relevant to the specific employee groups [7].

Targeted initiatives will have implications on the "Attract, Source and Develop" strategies, as these may need to be specific to the different groupings as well (e.g. Plant Support team members that feel under-developed after a certain period of time, as indicated by the PC comments under the *Advancement opportunities* and *General sections*).

A difference was found between the Talent Landscape elements and what is suggested by the EB/ EVP literature (e.g. there is less of a focus on the *collegial work environment* and *respect elements in the talent landscape)*. There was also less of a focus on the 'softer', or more people-centric, elements in the building blocks of the Strategic Talent Planning Framework .There is thus potential to develop in these ' softer', or more personal aspects of EB and EVP (e.g. work relationships, how employees are treated, etc.). This could potentially also relate to *Organisational justice* (i.e. having policies and guiding principles to address these 'softer' elements); and thus contribute towards addressing the PI influence of this factor.

The survey results suggest that the company should focus on a balance of career-specific and personal development. This is in order to increase the retention of its younger employees, who could potentially contribute to the growth of the organisation through the accumulation of institutional memory. This requires that the management of talent take on a more future-looking approach to the design of people processes in order to be able to predict trends that may occur (which would be due to the changes which may take place in the current young generation, as well as to anticipate the needs of future young graduates).

There did not appear to be an indication of how graduates are supported post-completion of the GDP. Because of the reduced guidance and focused assessment of the graduate employee post the programme, this could be risky for the continued personal and professional development and retention of the individual. It is thus important that the "bridge" between the early career and professional categories of the EB/ EVP Attraction and Retention portfolio support the graduate's transition from the GDP.

There is a need to adequately capture the reasons for departure. This can be done through ensuring that exit interviews are conducted with each exit from the company (although the integrity of such data may not always be reflective of the actual reasons. The outcomes from those interviews can be used as inputs to refining development programmes and retention strategies. The reasons can be addressed through the design of appropriate interventions which can prevent these reasons from recurring in the future.

Employers need to consider how the success of their retention strategies will be measured. The Employer Brand aspect of the company's Attraction and Retention portfolio also cites "Employer of Choice" as an outcome. Literature also suggests that a successful retention strategy can be indicated by the degree to which an organisation is an employer of choice [15]. This could mean that the measurement of an effective retention strategy could be related to the degree or success of talent attraction efforts. Other potential measurements could be the amount of "intellectual capital" that a company has, and the return on the educational investment put into the bursary scheme.

Spirituality in the workplace

One of the objectives of this study was to determine how the above findings relate to the subject of spirituality at work. This was done through the inclusion of such spirituality at work related factors into the survey. The results showed that these factors do indeed play a role in employee retention, with some of these factors scoring overall above 70% for the PC factors: *Energising environment* (92%), *Growth* (85%), *Meaning* (77%), and *Values* (74%) – all which support Job satisfaction at work. This was reflected in expectations of *"servant leadership"* (*Leadership/ Management* PC comment) and in sentiments that *"finding one's place creates a field where performance is easier and fun*" (*Meaning* PC comment, Tenure < 5 years). *Respect* (one of the principles used to define spirituality [16] was also cited as a top driver for both attraction and commitment from the CEB study [17]. Organisational culture has a role to play in how employees experience spirituality at the workplace (*"Fear and blame is the culture currently being driven in my company. This stifles creativity, excitement, fun and inspiration"* – *Energising environment* PC comment, Tenure > 5 years). Creativity was also one of the seven principles which the Institute for Management Excellence used to define spirituality [16] as cited by [18].

Although *Extrinsic rewards* featured in the top 5 PI factors across the different categories, the Survey comments suggest that the sense of making a difference, of *Meaning*, is also required (e.g. *"Money is not the main driver anymore for most engineers. Career development and a sense of making a difference is more important" (Extrinsic rewards PC comment, Tenure > 5 year)*).

Despite the above, it was found that ideas of 'God' at the workplace had a low influence in PC and PI (as indicated by the low ranking of *"God" in the organisation* factor in both instances). Some respondents primarily identified this factor with Religion (*"Please no gods"* (*'God in the organisation* PC Comment, Tenure > 5 years); and *"Religion has absolutely no place in a workplace, unless it is a religious organisation. I find the inclusion of religion in workplaces at best annoying, and at worst obnoxious and insulting"* (*'God in the organisation* PC Comment, Tenure < 5 years). This is despite the definition that the factor was about *"An environment which is "soulful", which contains "spiritual" values, has an element of sacredness*").

The CSR/ Civic activities factor also displayed low ranking overall and within the different groups.

The high-ranking of the *Job satisfaction* (both PC and PI) and *Energising environment* (PC) factors, and the theme of the importance of a work-life balance suggest that the idea of spirituality at work is a considerable aspect to explore within the area of employee retention strategies. (Albeit more of an 'elusive' and perhaps abstract idea to work with – unlike e.g. *Career path/ Advancement opportunities, Intrinsic rewards, Flexible work arrangements*). The application of such a factor definitely requires a more aware and astute understanding of workforce needs and expectations.

6. CONCLUSION

The design of employee retention strategies as a whole is a complex process; when taking into account the intricacies of human nature and the different life paths that people follow (be it out of personal choice or personal circumstance).

The results did not show any significant difference between the differently tenured groups. This could primarily be because of both populations being Knowledge Workers and generally belonging to the same generation (Gen Y). What was evident though is that individuals at different stages in their personal and professional lives would have different needs; and that a balance between these segments is of great importance.

This has implications for how employees are supported throughout their working career. Although a young graduate may have some support during the GDP phase, this can affect the continued growth and development of the individual after s/he exits from the GDP. This necessitates that the TM and HR strategy for the greater workforce be adequately structured to ensure the continued retention of the internal talent pool, and that leadership/ management is sufficiently equipped to enable the employee retention effort.

This need is compounded by a highly dynamic and competitive labour market landscape which is vying for the same talent. This requires that organisations reflect (and invest) more deeply into how their objectives and operations can be realised through human capital resources. There is a need for current employee retention strategies to be more employee-centric; i.e. that they need to respond to the needs of the individuals of the workforce. This can be achieved through the development of "highly targeted initiatives" which can be approached through more demographic segmentation of the workforce (e.g. aspects like age and gender). This will allow for the inclusion of the 'softer' elements of employee retention. In that way a more holistic framework to employee retention strategies at the organisation can be developed.

A difference was also found between the factors which came out of the interviews, but which were not indicated in the perused documentation. It is important that the employee retention documentation (as well as GDP documents) comprehensively reflect these (possibly) implicit elements; as well as the initiatives that the organisation has been place to support the retention of its employees.

The measurement of the effectiveness and success of an employee retention strategy (one that is more holistic and more reflective of employee-needs) needs to be considered. This entails developing ways to measure the outcomes of the EVP and EB strategies; and includes the investigation the measurement of investment on intellectual capital and efforts to attract the talent in the first instance.

Future work would include the measurement of the success of employed retention strategies; as well as alternative methods of retaining institutional memory. More research can be conducted on contrasting the needs of the Gen Y with those from earlier Generations, so as to more adequately account for these differences in the employee retention effort. The feasibility of the expected retention period (i.e. how long should employees be retained for; considering the changing nature of work, and the nature of knowledge workers) should be explored as well.

This research would also need to be expanded to other companies (multiple-case, embedded i.e. Type 4 Case study design).

The implications of the study's overall findings to the organisation's current employee retention strategies were discussed; and the consequent recommendations are summarised below.

Recommendations from the Research
In summary, it is recommended that:

- The refinement of employee retention strategies needs to take into consideration the mix of factors (between career and personal pursuits) which are required by employees.
- Organisation should be responsive and allow for some flexibility to be able to accommodate employees' personal situations.

- Extrinsic rewards do play a factor in employee retention; and the organisation should continue to maintain the benefits which are offered to employees.
- (Linked with the *Extrinsic rewards* factor) The organisation should ensure that "perceptions about the fairness of reward allocations, policies and procedures, and interpersonal treatment [7, p. 6] (i.e. Organisational justice) are managed and adequately addressed.
- Job satisfaction was a key factor for both PC and PI. This requires that the job-fit and organisational-fit of the individual be determined; to ensure that an individual is well-placed in a position that can add value to both the employee and the organisation.
- The employee retention strategies which are reliant, or based on the extended tenure relationship and loyalty that an individual may have with and towards an organisation should be reviewed.
- The organisation can consider segmentation of the talent pool along other factors such as demographics (e.g. age, gender, culture, etc.) or professional disciplines (staff in a particular working environment e.g. Plant Support engineers) to identify retention factors which may be specific to the particular segment. This will enable the development of targeted employee retention programmes which are relevant to the particular employee groups' needs.
- The preceding recommendation will also enable for the development of more individual-centric and holistic approaches to employee retention.
- The Employee Retention strategies should clearly be differentiated from the Employee Attraction strategies. Although the two may be concomitant in Workforce Planning; it is important to understand which of the strategies fulfil which purpose.
- Leadership/ Management should be trained and equipped to enable a working environment which supports employee retention.
- The organisation should also offer mentorship programmes which support the graduate post-completion of the GDP. These mentorship programmes could also be of benefit to new and existing employees generally (so as to support the continuous development of the individual).
- The employee retention documentation needs to be fully reflective of all the initiatives and developments (social, recreational, etc.) that the organisation offers its employees. The development of comprehensive documentation on such retention strategies can help address any gaps, as well as ensure effective communication of such initiatives to the workforce.
- The information emanating from the exit interviews needs to be captured in detail, and utilised in the further development of employee retention strategies to address these gaps.
- The idea of spirituality at work is a considerable aspect to explore within the area of employee retention strategies. Albeit an almost abstract idea to work with, literature suggests some guiding principles, as well as methods with which this can be measured.
- The actual (quantifiable) measurement of an effective retention strategy needs to be considered.
- The developers of employee retention strategies should maintain a future-facing approach in the design of people processes. This is so that trends and possible changes in the talent landscape can be predicted and prepared for.
- It may be worthwhile to consider alternative methods of retaining institutional memory; as the knowledge worker attributes of Gen Y and the engineering profession could result in early loss of employees who move elsewhere for employment.
- Organisations should determine what a 'realistic' expectation of the period of employee tenure is; and have a method of measuring the feasibility of such a period.

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DESIGNING A MOBILE LABORATORY SOLUTION FOR RAPID TUBERCULOSIS TESTING BY MEANS OF THE CEPHEID® GENEXPERT® DEVICE

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ABSTRACT

Tuberculosis (TB) poses a major health risk in South Africa. The problem is particularly pronounced amongst employees in the mining industry, where South Africa has the highest TB incidence rate in the world. Diagnostic laboratory testing is a crucial component of managing TB and multi-drug resistant (MDR) TB. Mobile laboratories that are housed in vehicles are one option for reaching communities to expand diagnostic coverage. The World Health Organisation endorsed, GeneXpert® platform can be used for the diagnosis of TB and MDR-TB and is sufficiently robust to be used as a point-of-care device. The study reviews the GeneXpert®-based TB diagnosis process, to accurately determine the operations that are to be supported by the mobile laboratory. Consequently, this technology has enabled the development of a mobile laboratory for TB testing. This article describes the development of a concept design for such a mobile laboratory solution. The concept design considers various functional, safety and storage aspects as well as ergonomic principles to ensure an effective testing procedure along with the health and safety of the laboratory technician. A costing estimate for the design is also provided. Owing to the high incidence of TB amongst employees in the mining industry, the design has been developed with deployment in peri-mining communities in mind.

Keywords: Design, diagnostics, ergonomics, GeneXpert®, mobile laboratory, tuberculosis

1. INTRODUCTION

Tuberculosis (TB) along with the Human Immunodeficiency Virus (HIV) make up the two largest health challenges to South Africa. The World Health Organisation (WHO) rates South Africa as having the second largest estimated TB incidence rate (834 per 100,000 population) and the sixth largest incidence by absolute number (an estimated 450,000) in the world [1]. Furthermore, South Africa is categorised as a high MDR-TB burden country [1]. South Africa's mining industry has the highest infection rate worldwide amongst mine workers, with an incidence rate of 948 per 100,000 miners, compared to global- and Sub-Saharan incidence rates of 128 and 350 per 100,000 respectively [2]. Furthermore, it is estimated that 89% of the approximately 500,000 mineworkers in Southern Africa have latent TB infection [3].

In an attempt to combat tuberculosis amongst miners and their families, fifteen Southern African countries, including South Africa, Lesotho and Botswana, signed the 'declaration on tuberculosis in the mining sector' at a meeting of the Southern African Development Community (SADC) in August 2012. The declaration is to guarantee commitment by the member states to improve the lives of miners affected by tuberculosis [4]. Briefly summarised, the various governments pledge their commitment to address tuberculosis in the mining industry in accordance with SADC [5] protocols to eventually eliminate tuberculosis in the region. In addition the declaration also identified priority areas that require immediate attention.

This article describes the development of a concept design for a cost-effective mobile laboratory for testing sputum samples for the presence of tuberculosis. Central to this design, is the GeneXpert® MTB/RIF test endorsed by the WHO as a rapid and effective tuberculosis testing method. The GeneXpert® is a point-of-care device that can diagnose tuberculosis and drug resistant tuberculosis with an especially high sensitivity and accuracy, even in patients that are HIV-positive [6]. The compact and relatively robust (in comparison to traditional diagnostic laboratory instrumentation) nature of the GeneXpert® platform opens the opportunity for the development of more manoeuvrable and cost effective manners of reaching peri-mining communities, such as through the use of mobile laboratories. This in turn enables more effective monitoring and treatment of tuberculosis as well as the gathering of more comprehensive population health monitoring data.

The design, although proposed for testing in peri-mining communities, is relevant and replicable for diagnosis in other settings in the country or abroad. Furthermore, the majority of elements in the design consideration would be directly applicable to the development of mobile laboratories for other compact testing devices, aimed either at TB or other diseases. Finally, the approach that is followed in generating the design could be useful in designing other mobile laboratory solutions.

The article describes the methodology that was followed to develop the concept design. Background is given on why TB is particularly pronounced amongst mining communities in South Africa as well as on the processes of diagnosing TB in South Africa with the GeneXpert® device. The design considerations and recommendations are presented whereafter the concept design is described and illustrated. A costing estimate for the concept design is also presented.

2. METHODOLOGY

In order to comprehend the problem and acquire the necessary knowledge to develop a solution, two National Health Laboratory Service (NHLS) laboratories were visited (one in Cape Town and one in Port Elizabeth). Activity-flow diagrams were drawn up for the national algorithm (national prescribed TB-testing process); the testing process with the GeneXpert® as well as the proposed testing method in the mobile laboratory. From the knowledge gained during field visits and the literature review, a set of operational and engineering specifications were compiled which were used for guiding the concept design process. Three concept designs were developed and evaluated, and, after careful consideration, the final concept was selected and refined using Google SketchUp software. The final design is illustrated and discussed, after which the cost estimation for the mobile laboratory is presented.

3. BACKGROUND

This section briefly describes tuberculosis and the Southern African mining industry; similar mobile laboratories; the GeneXpert® device; and testing TB methodologies in South Africa.

3.1. Tuberculosis in Southern Africa's Mining Industry

The rate of TB-infections has increased extraordinarily from the beginning of the 21st century. A study performed in 2011 estimated that the mining industry is responsible for an additional 760 000 TB cases every year in African mining communities [4]. These are, amongst other factors, the consequence of exposure to silica dust; crowed living conditions and, most prominently, the high HIV prevalence [4, 7].

According to the '*Stop TB'* organisation, the average infected miner spreads TB to an estimated fifteen people in their community [4]. This is a major problem owing to a ripple effect that is carried from the peripheral mining communities through to other countries such as Mozambique, Swaziland and Lesotho to which many migrant workers return, in some cases after having been exposed to silicosis, HIV and TB [8]. It is estimated that two million ex-miners live in Lesotho, South Africa, Mozambique and Swaziland [2]. The risk of contracting TB in a high disease burden area, is up to ten times higher for miners than for the general population; and miners that have contracted TB are 3.6 times more likely to die from it [3].

The mining industry in South Africa plays a significant role in the economy, contributing 18% (8.6% directly and 10% indirectly) to the Gross Domestic Product (GDP) in 2013 [9]. In spite of the recent instability in the mining sector caused by wide-spread labour unrest and fluctuations in global commodity prices, the sector experienced a growth of 3.5% between 2010 and 2015, still contributing 8% (directly) to the GDP in 2015 [10]. Approximately 500 000 mineworkers are employed in Southern Africa and an estimated 9.6 million workdays are lost due to tuberculosis infections [2]. TB-related reduced productivity in miners thus has an impact on the economy of Southern African countries, where mining can contribute up to 25% of the GDP [3].

South Africa has signed the 'declaration on tuberculosis in the mining sector'. The declaration states that the main challenges miners, previous miners and the peri-mining communities experience are the lack of access to basic social and health services, effective cross-border systems, and no treatment regimen, legal protection or compensation for respiratory problems developed due to working circumstances [11].

3.2. Similar Mobile Laboratories

There is limited literature available on similar mobile laboratory solutions and none could be found that use the GeneXpert® device or are solely for testing for TB. However, a few examples of mobile laboratories targeting other diseases are briefly discussed. Partec developed a CyLab™ for HIV monitory, TB- or malaria testing. A four-wheel Mercedes Transporter was used and the laboratory is detachable from the vehicle [12]. Another design for testing and monitoring meningitis in West Africa, equipped a Renault Kangoo with a laboratory relying on solar power for the first rollout phase[13]. The second roll-out phase used a Toyota Hilux, with a detachable laboratory that does not rely on solar power. These are examples of small laboratories, similar to that being developed in this study. Larger mobile laboratories mounted on trucks are used frequently for various services.

3.3. The GeneXpert® Device

The Xpert® MTB/RIF test functions on a molecular level and incorporates modern deoxyribonucleic acid (DNA) technology to detect tuberculosis by testing a sputum sample [14]. The procedure is fully automated, easy and safe to use, does not require a conventional laboratory and is highly accurate in identifying both tuberculosis and Rifampicin-resistance in one test [15]. The test produces one of four outcomes, namely: (i) positive and Rifampicin susceptible; (ii) positive and Rifampicin resistant; (iii) negative; or (iv) an unsuccessful test. A particular advantage of the test in the South African context is the diagnostic accuracy in patients that are HIV positive [16].

Point-of-care (POC) testing occurs when a patient is tested near or on the same site where the results will be reported and the treatment is given. The four-module device is portable, robust and requires minimal training with regard to operating and maintaining the device – making it suitable for POC testing [17]. Limitations associated with implementing the GeneXpert® in point-of-care testing are the environmental conditions such as the temperature, and requirements with regard to uninterrupted power supply, regular maintenance and annual calibration.

The WHO compiled a document which outlines the requirements and actions that should be considered by countries before and during the roll-out and implementation phases. There are two checklists in this document, the first pertaining to the key prerequisites countries should meet before the roll-out phase and the second list containing key actions to be undertaken for implementing the test efficiently [18].

3.4. Testing Tuberculosis in South Africa

The implementation of the GeneXpert® assay does not eliminate the need for conventional TB culture, microscopy and drug susceptibility tests. The 'national algorithm' prescribes the steps that must be followed in NHLS laboratories for diagnosing TB. This section describes TB-testing processes which form part of the national algorithm.

3.4.1. National Algorithm

The algorithm starts with the initial GeneXpert® test. The results of the GeneXpert test along with the patient's HIV-status determine the next steps in the algorithm to be followed. The mobile laboratory, being equipped with a GeneXpert®, will play a role in this initial diagnostic step. Two sputum samples are taken from the patient: one is used for the GeneXpert® test and the other is stored in the fridge. An unsuccessful test requires a retest. If there is still enough of the prepared sample left to retest, and the reagents have been added less than three hours prior, the sample can be retested, otherwise a new sample should be prepared and tested.

In the case of a positive GeneXpert® result and HIV-positive patient, the second sample is sent for TB culture and microscopy testing. Patients that are HIV-negative are initiated on to TB treatment following a positive GeneXpert® result.

3.4.2. GeneXpert® Procedure

The GeneXpert® procedure was observed at the NHLS laboratory in Port Elizabeth. Although some institutions indicate that the samples require incubation, it is not necessary and at this laboratory, the samples are shaken and put aside for a few minutes. The GeneXpert® test is genotypic, implying that the samples can be prepared at room temperature. In contrast, smear microscopy testing, being phenotypic, requires incubation of the sample at 37 degrees Celsius.

Samples are sorted upon arrival and receive a unique barcode. The barcode, along with the patient information is logged into the NHLS computer system. Sample reagents that come in plastic bottles containing about 8 millimetres of fluid, are added to the sputum sample in a 2:1 ratio. A bottle of sample reagent is used per sample, even though there might be an adequate amount of liquid left for a following sample. Next, using a pipette, 2ml of the solution is extracted and added to an empty GeneXpert® cartridge, which has a corresponding barcode. In the fixed site laboratory environment, these steps take place within a class-2 bio-safety cabinet.

The batch is then moved to the GeneXpert®, where each cartridge is scanned into a GeneXpert® computer. The cartridge is inserted into the slot allocated by the computer system. After the results are printed, the laboratory technician checks for any unsuccessful tests. If a sample was unsuccessful, there is still enough prepared sample left to redo the test and the sample was prepared less in three hours ago, it may be added to a new cartridge and retested. The successful results, being either negative or positive, are added to the patient's file after which the national algorithm is followed to determine the next steps.

3.4.3. Mobile Laboratory Process

The mobile laboratory is designed to be used as diagnostic support for clinical partners that screen patients and take samples, typically in a tent. The mobile thus supports the GeneXpert® testing procedure similar to that followed at fixed-site laboratories and is displayed in Appendix A. Only one sample taken from a patient is sent for testing by the GeneXpert® and accordingly the laboratory design only allocated storage space, including refrigeration space, for one sample.

The only controversial aspect of the mobile laboratory design is the protection of laboratory personnel during the sample preparation procedure at fixed laboratory sites, GeneXpert® samples are typically prepared for testing in a biosafety cabinet. However, installing a biosafety cabinet in a mobile laboratory creates challenging requirements in terms of air vents and sensitivity to peripheral air flows. The standard operating procedure manual for the GeneXpert® MTB/RIF test indicates that, in instances where a bio-safety cabinet is not available, the sample should be heat inactivated in a hot air oven (20 minutes at 85ºC or 30 minutes at 80ºC). The inclusion of a hot air oven in the mobile laboratory proved infeasible, due to the large size of the required oven, the large required power supply and the increased processing time for samples. According to SMEs, adequate ventilation and the wearing of the necessary protective clothing, will be considered sufficient protection during sample preparation in mobile laboratories in South Africa. Therefore, the mobile laboratory design has been developed without a biosafety cabinet or a hot air oven. Options for providing additional protection to mobile laboratory personnel during sample preparation is discussed in more detail in Section 7.

The laboratory is designed to accommodate two four module GeneXpert® machines, allowing for roughly eight tests to be run each taking approximately two and a half hours. Taking setup and packing-up times into consideration, approximately sixteen samples can be tested each day. The mobile laboratory is designed to accommodate one laboratory technician.

4. DESIGN CONSIDERATIONS AND REQUIREMENT SPECIFICATIONS

This section describes the ergonomic and operational requirements that were taken into consideration during the design development. The South African Military standards 127 volume 1 (RSA MIL STD 127: Vol. 1) was predominantly used for the ergonomic calculations. Where possible, dimensions are chosen so that the 95th percentile male will fit in and the 5th percentile woman will be able to reach.

4.1. The Vehicle

The required contents of the mobile laboratory were determined based on a detailed analysis of the mobile laboratory process, with consideration given to the design capacity (16 samples to be tested per day). The approximate required size of the mobile laboratory was calculated based on the the required contents. The Volkswagen Crafter was consequently chosen as the vehicle to accommodate the design. The vehicle has a long wheelbase (4.3m) and a person is able stand upright comfortably throughout the rear of the vehicle. An upgraded suspension and at least 80kW output are specified. A retractable awning is also to be added to the side door of the vehicle.

The floor is specified to be covered with 9mm thick protective cladding which is crack and scratch resistant, lightweight, anti-slip even when wet, and oil and chemical resistant. The walls are also specified to be covered in a lightweight composite cladding and the windows specified to have anti-theft protection.

4.2. Workspaces and Storage

The layout and dimensions of the workbenches, desk and seating as well as the equipment and components to be included in the laboratory are discussed in this section.

4.2.1. Layout and dimensions of the workbenches and aisle

A number of ergonomic principles were taken into consideration during the design of the workbench layout and height. Work must be kept as close to the body as possible to avoid outstretched arms and a twisted posture which place stress on the lower back [19]. Frequent work should be within 25cm of the body, with occasional work between 25cm and 50cm [20]. The height of work surfaces should be comfortable in order to avoid (i) shoulder fatigue, caused by surfaces that are too high; or (ii) strain on the back, caused by surfaces that are too low. In general this is achieved when the arms are hanging down naturally and the elbows are bent 90 degrees. For fine work, the work surface can be raised by up to 20cm above elbow height [19].

The elbow sitting height was used to determine the height of the desk workbench, incorporating the adjustment capability of the chair. It is not possible to ensure perfect height for all possible body types owing to people generally not falling in the same percentile for all the possible measurements (e.g. a 90th percentile height, but a 60th percentile elbow height). A desk height of 720mm is specified, where a shorter person can use a foot rest if required.

For the workbenches where the technician will be standing, the height is specified at 900mm which includes an added 100mm owing to the work requiring some precision. A minimum aisle space of 1.2m is recommended by the Occupational Health and Safety Act (OSHA). Owing to space being limited in the laboratory and only one technician working in the area implying no back-to-back work, a minimum aisle space of 850mm is specified for the mobile laboratory. The dimensions for all the devices and components were evaluated and accordingly, the workbench on which the GeneXpert® devices will stand, is specified to have a depth of at least 420mm (allowing for the accompanying UPS, barcode-scanner and laptop). The sink and fridge requires a workbench depth of at least 400mm and 490mm respectively. The workbenches are specified to hold the weight of all the equipment and to be of a composite stainproof and waterproof material.

4.2.2. Seating

Factors taken into consideration during the design of seating include: (i) the trade-off between under-bench space available for storage and space assigned to seated work; (ii) the estimated time to be spent on an activity; (iii) the risk of unsecured contents moving around during transit or being stolen from the vehicle. A chair bolted to the floor has limited adjustability and takes up floor space. A swivel chair for computer-based work is specified, whilst the sample preparation work is to be done in a standing posture. The chair is fastened to the side of the desk and the floor to secure it during transport, yet the distance from the desk and the chair height remain adjustable.

4.2.3. Components and Equipment

The laboratory is specified to have storage space for at least one month's supply of consumables such as GeneXpert® kits, gloves and N95 masks, calculated in accordance with a daily workload of at most 16 tests, adding safety stock for gloves, masks and bio-hazard bins. The sizes requirements were estimated by either measuring components at NHLS laboratories and suppliers or from online specifications.

Two four-module GeneXpert® systems are included in the design, each requiring a UPS, scanner and laptop. An independent laptop and printer are also required for desk work. The UPS is specified to supply at least 450 VA for 20 minutes.

A small fridge of 90 litres is specified to store at least two 16-sample holders. The laboratory requires water and accordingly a small sink with two 25 litre water canisters is specified. The canisters are located inside the cabinet, the supply-canister is equipped with a submersible pump to supply water and the drainage-canister allows for overflow to the outside of the vehicle. The sink and canisters were chosen to ensure the canisters fit in the cupboard, underneath the sink.

Specific bio-hazard bins with bags are used for any biomaterial waste. Space is allocated for one bin and storage space for three extra bins. The bins are from hard cardboard and use minimal storage space when folded up. Another bin with heavy duty plastic bags is also specified for general waste. This minimizes the amount of bio-hazard waste that is generated as this waste entails an expensive waste-removal procedure. Laboratory coat hangers and extra storage space is allocated in the laboratory along with a SABS approved fire extinguisher. Additional, but not essential items that are included are two folding-up chairs, a filing system, glove and hand-sanitiser fixtures, and a white board.

4.3. Lighting

The correct design of lighting is particularly important in laboratories, given the work hours, intensity and importance of tasks. Lighting intensity in laboratories can be up to twice that of general office environments [21]. The aim is to design the lighting to be high performing and energy efficient. Where possible the use of natural light should be encouraged as this reduces power consumption and is one of the most visually effective light sources.

Visibility, which is the clarity at which an object is seen, is dependent on illumination, contrast and visual angle. The colour rendering index (CRI) of a light source is a measure of its ability to duplicate various objects' colours in comparison with a natural (ideal) light source. The higher the CRI the better the visible light spectrum is reproduced, possibly reducing the illumination levels that would have be required in the same circumstances without a higher CRI. Natural light has a CRI of 100. A light's colour temperature is measured in degrees Kelvin (K). Lower colour temperatures (±3000 K) tend toward being more golden while colour temperatures of approximately 6000 K have a blueish tint [22].

The ceiling and walls should have a minimum of 80% and 65% reflectance respectively in order to ensure effective lighting [19]. The ceiling of the mobile laboratory has the most potential to contribute to light-distribution and accordingly the ceiling is specified to be matte-white which conforms to a recommended reflectance level of 0.8. A matte finish limits the reflectance of images from bright sources [21].

In laboratories the direct lighting aspect should be between 20% and 40% [19]. Lights are to be located directly above the edge of the workbench and parallel to the work surface. Alternatively the lights can be installed between two workbenches [21].

Fluorescent (T5 and T8), incandescent, light emitting diodes (LED) and low watt ceramic metal halide lamps were evaluated for inclusion in the laboratory. The South African National Standards 10114-1:2005 does not have guidelines specifically for mobile laboratories, but a minimum of 300 lux for laboratories can be derived [23]. A value between 75 and 90 can be approximated for the CRI resulting in an intermediate to cold colour appearance. Four 220V 5050 LED light strips were specified for the laboratory, located above the counter edges. The light strips take up little space, are energy efficient and provide the required CRI, luminance and temperature levels as mentioned previously. The two sets of lights are to be independently controlled and equipped with dimmers to save energy and ensure adjustability. The floor is specified to be dark grey which has low reflecting properties along with matte-white counter tops.

4.4. Temperature Regulation

A roof-mounted air conditioner is included to prevent ambient temperature exceeding 28°C (a requirement for the GeneXpert® cartridges). The temperature sensors are specified to be installed near the GeneXpert® devices. The most common indexes used to measure heat exposure are wet-bulb globe temperature (WGBT) and the metabolic load. These are also used to analyse the comfort level as well as how long an acclimatised and un-acclimatised worker can function under given conditions . The work in the mobile laboratory is not strenuous and far from the lactic threshold. Metabolic heat calculations for males and females respectively indicate that they would be able to work comfortable even if the temperature is at the maximum of 28ºC (permitted by the GeneXpert).

4.5. Electricity Requirements

The laboratory is specified to function from grid power as well as a generator. Lessons learnt from previous mobile laboratory solutions, such as the Kangoo laboratory previously mentioned, indicate that solar power solutions for mobile laboratories are unreliable and do not provide adequate power.

The generator must carry the maximum load which is calculated by using the equipment's maximum power (watt) or current drawn (ampere). The generator is specified to have an electric start and a wheel-set which should be custom made if not included, owing to all the generators providing power of above 5300 Watts weighing more than 80 kilograms. The item which has the the largest impact on the load that is to be carried by the generator is the air conditioner. The top four electricity consuming devices are displayed in Table 1. Insulation can be installed in to the mobile laboratory walls, but this is unlikely to make a meaningful contribution to temperature control.

Table 1: Top four electricity consuming devices

Appliance	Information (maximum)			# required	Safety factor	VA	Watt
	input A	input V	watt usage				
Air-conditioner	12	230	3500	1		2760	3500
UPS	2	230	240	2	1.8	1656	864
GeneXpert	0.95	200	240	2		380	480
Laptop	4.62	19.5	90	3		270.27	270

The vehicle is to have power points for at least all the electrical devices along with a deep cycle standby battery system and power socket for grid power.

4.6. Securing Equipment during Transit

Any equipment that may shift during transit is to be secured by means of loading trays, bolted to either the vehicle or workbenches and secured during transit with a nylon strap with a female-male connector clip. The trays should be made specifically to the equipment's size to ensure movement is minimised.

The loading ramps for the generator are to be secured with a storage bin bolted to the door, as well as straps for both the ramps (illustrated in Subsection 5.4). The generator is to be secured with a three meter ratchet strap, which is to be attached to fixtures submersed in the floor. The scanners are to be bolted to the workbench and all cupboard doors and drawers are to have self-locking mechanisms.

4.7. Noise and Vibration

The standard noise threshold limit, prescribed by OSHA for an eight hour period, is 85 A-weighted decibels (dB(A)). There is a correlation between the time of exposure and the noise level e.g. the daily limit is reached after only a hour's exposure to 89dB(A). Noise levels are reduced by decreasing sound transmission between the source and the receiver. Ear plugs, such as standard disposable earplugs (having a noise reduction rating (NRR) of 31) provide adequate protection for noise levels below 95dB(A) [19].

The GeneXpert® emits less than 69dB at a low frequency and will not produce irritating or harmful sounds. The specified generator is likely to emit approximately 99 dB(A) at 7m distance, which would therefore be harmful to a person. At a distance of 30m, the noise level from a generator would be approximately 86dB(A). The outdoor setting and the laboratory walls are likely to further lower the noise levels inside the mobile laboratory. A lead allowing for the placement of the generator at least 30m from the laboratory is included in the design providing sufficient noise-protection. Vibration from devices are unlikely to present a risk to health in the mobile laboratory.

5. CONCEPT DESIGN

As mentioned, the Volkswagen Crafter 50 2.0 Tdi is used in this design. Dimensions not available on the vehicle brochure were measured directly from the model. The wheel arc housings take up a significant amount of space, restricting design possibilities slightly owing to the space between housing being 978mm. A general view of the floor-area of the vehicle and laboratory can be seen in Figure 1.

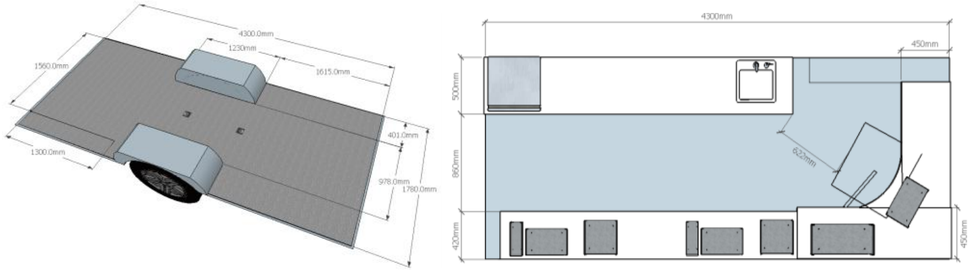

Figure 1: Floor layout of the loading area and top view of the design

After evaluating various design alternatives, a layout with two countertops, one on either sides of the vehicles length, was selected. This leaves an aisle width of 860mm. The aisle width is deemed sufficient as there are no overhead storage compartments and no back-to-back work is to occur as the mobile laboratory. A general view of the mobile laboratory is displayed in Figure 2. To the front of the vehicle, in the corner opposite to the sliding door, a rounded corner desk is installed. The desk height is 720mm and the minimum counter depth 450mm, increasing to the corner of the vehicle. The height of the standing-workbenches is 900mm and all workbenches have a foot clearance of 100mm depth and 100mm height. The worktops have an overhang of 45mm for possible spills and general standing comfort.

Figure 2: General view of the mobile laboratory

5.1. Sample Preparation Workbench

The left side workbench, viewed from the back doors, has a depth of 500mm. This bench is purposed for sorting and preparing the samples and displayed in Figure 3. The fridge is allocated closest to the back doors. The opening beneath the countertop allows for a comfortable standing position as well as placement of the biohazard and general-waste bins. The general-waste bin consists of bracket fastened to the side of a cabinet, with a frame to secure a plastic bag with. The bin design takes up minimum space and allows for quick refill and disposal. The biohazard bin is secured with a strap, also partially fastened to the side of the cupboard. There is a three drawer cabinet installed above the wheelhouse enclosure, which can be used for storing the contents of an opened GeneXpert® kit (pipettes, sample reagents etc.) A paper towel dispenser is fastened to the wall, along with a glove box holder, a white board and to the right side, a 30mm towel rack and coat hanger. A two door cabinet with the sink and water canisters, both secured with straps, can also be seen. The clean and waste water tanks are clearly marked. There is also storage space for two extra folded up bio-waste bins.

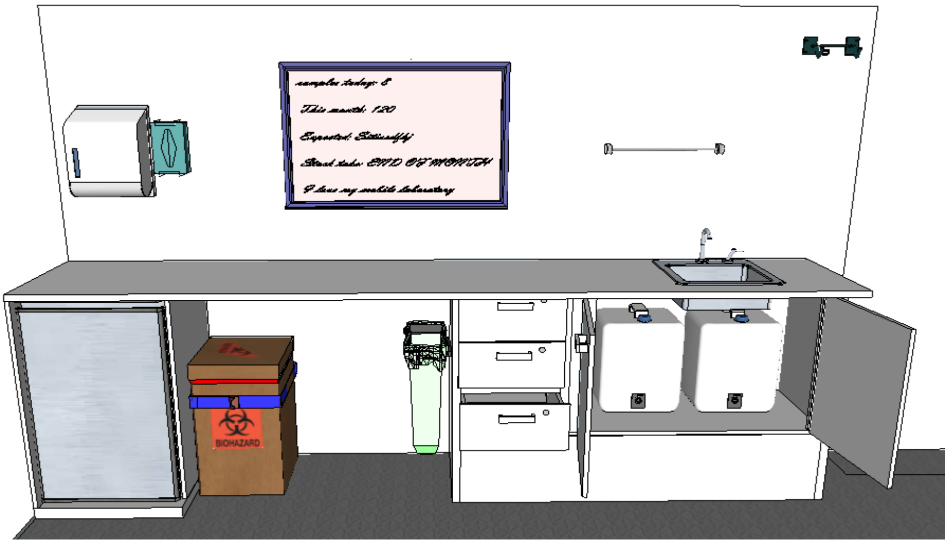

Figure 3: Left workbench

5.2. GeneXpert® Workbench

The workbench on the right side is 420mm deep, with all the devices placed on the counter top as illustrated in Figure 4. The space in the middle is to place the prepared sample cartridges before transferring these into the respective GeneXpert® devices. The loading trays and straps are also displayed in the figure. In the one drawer there is enough space for the three boxes of gloves and one to two boxes of masks. The longer two door cabinet to the left, above the wheelhouse, is designed for storing seven to eight boxes of GeneXpert® kits. To the right of the cabinet is a SABS approved 2.5 kilogram fire extinguisher, fixed with a bracket to the side. There is a two door cabinet, split horizontally in the half, with storage space for a first aid kit and the thirty meter extension lead for the generator. Underneath, with a flip-down door, storage space is allocated to two camping chairs to be used outside by the mobile laboratory technician and driver during breaks times. The wheelhouse is not covered completely, to allow for more standing space, because the foot clearance here is already slightly less than 100mm.

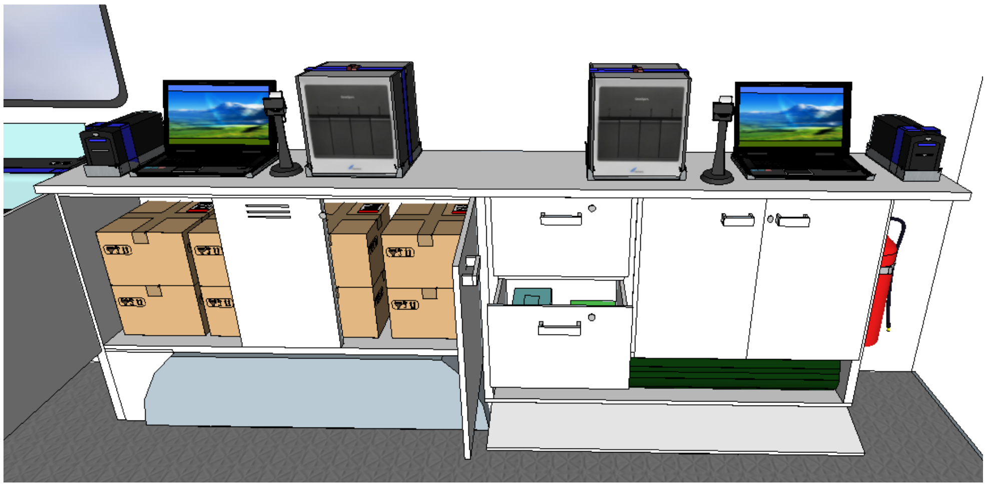

Figure 4: Right workbench

5.3. Corner Desk

The corner desk worktop, displayed in Figure 5, offers space for the printer with its loading tray as well as the laptop. The desk has a two drawer filing cabinet as well as a smaller stationary drawer. The swivel-chair is also displayed in the figure.

Figure 5: Corner desk with swivel chair

5.4. Transit and Generator storage

The transit view is displayed in Figure 6. The generator is loaded off and onto the laboratory by ramps which extend to two meters, but when stored are only about 860mm long. The steel storage bin is located on the lower part of the door to minimise the chance for lower-back injury. Each ramp weighs 6kg and is fastened individually with a strap.

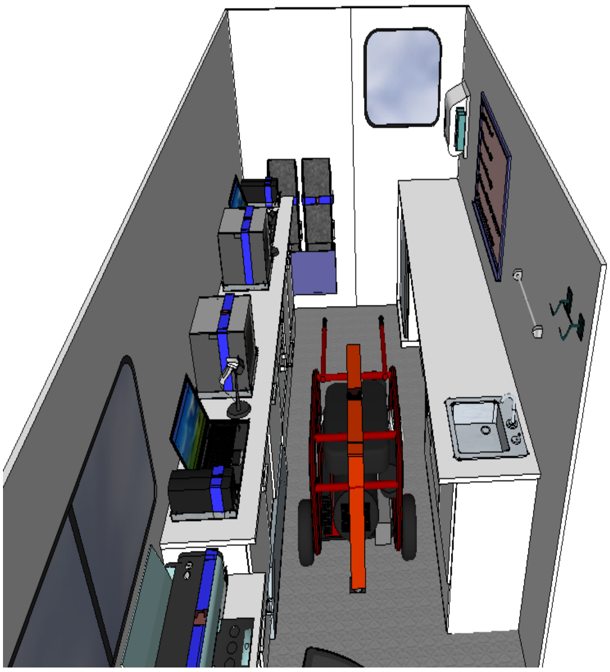

Figure 6: Transit view (air-conditioner and lighting not shown)

6. COST ESTIMATION

The total cost for the mobile laboratory infrastructure was estimated at R659,420 (R202,917 without the vehicle cost) in 2014. A breakdown of the various cost components is given in Figure 7. Adjusting for inflation, the estimated 2016 costs are R731,883 and R225,214 respectively. The cost estimate includes the mobile laboratory infrastructure and excludes equipment that would typically be provided by the laboratory organisation using the mobile laboratory, such as the GeneXpert® devices, printers, laptops and consumables (such as test kits, gloves and masks).

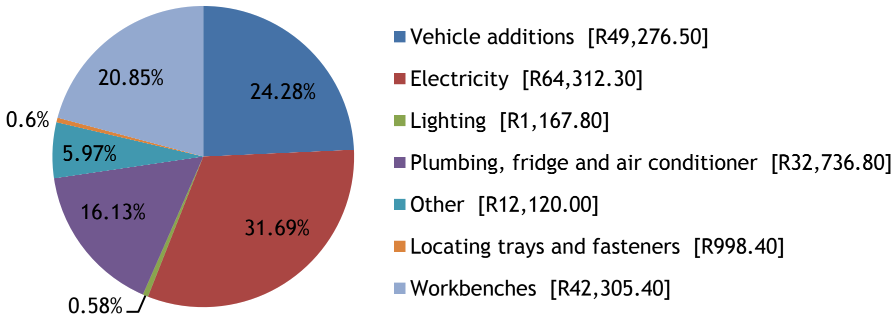

Figure 7: Cost contribution summary - excluding base price of the vehicle (2014 figures)

7. ADDITIONAL SAFETY CONSIDERATIONS

There is potential space for the bio-safety cabinet in the vehicle, but the required additional power, air vents and the unreserved sensitivity to any external air flow influencing the effectiveness of the cabinet, pose challenges to the installation. To ensure the safety of the laboratory technician, additional concepts that will improve ventilation as well protection against airborne infections should be investigated further. Possible solutions to be evaluated include a custom made lateral airflow system which regulates incoming fresh air as well dispersing air to the outside of the vehicle. HEPA-filters can be installed in the sample preparation area and custom made protective masks and clothing should be evaluated. A custom made oven to heat only a few samples at 80ºC can also be considered. It is imperative that a mask covers and encloses the technician's mouth and nose - specific attention should be paid to the fit around the nose bridge. An alternative solution may be a bio-safety helmet or mask which encloses the technician's head and shoulders, with an optional oxygen or air-filter system attached.

8. CONCLUSION

This article described the process of developing a concept design for a mobile laboratory to be used for diagnosing tuberculosis using the GeneXpert MTB / RIF test. The design was conceptualised with use in peri-mining communities in mind, though it could also be successfully implemented elsewhere. The concept design as well as a cost estimate were also presented.

The most important future design adjustment considerations relate to the protection of the laboratory technician during the sample preparation process, as well as to efficient air conditioning and the generation of power for the mobile laboratory. Alternative solutions for providing improved protection to laboratory technicians would include the installation of a customised lateral air flow system or oven. The generator poses a few challenges to the design, especially with regard to cost, noise and weight. The air conditioner contributes a significant portion of the required power load to be generated. If a more energy efficient air conditioner were to become available, this could significantly improve this aspect of the design. The use of renewable energy sources could contribute to extending the flexibility of the proposed mobile laboratory. An example of a mobile laboratory design where solar power solutions failed was cited and this motivated the decision to specify a generator in the concept design. However, renewable technology is developing rapidly and it would be worthwhile re-visiting this aspect of the design as new solutions become available.

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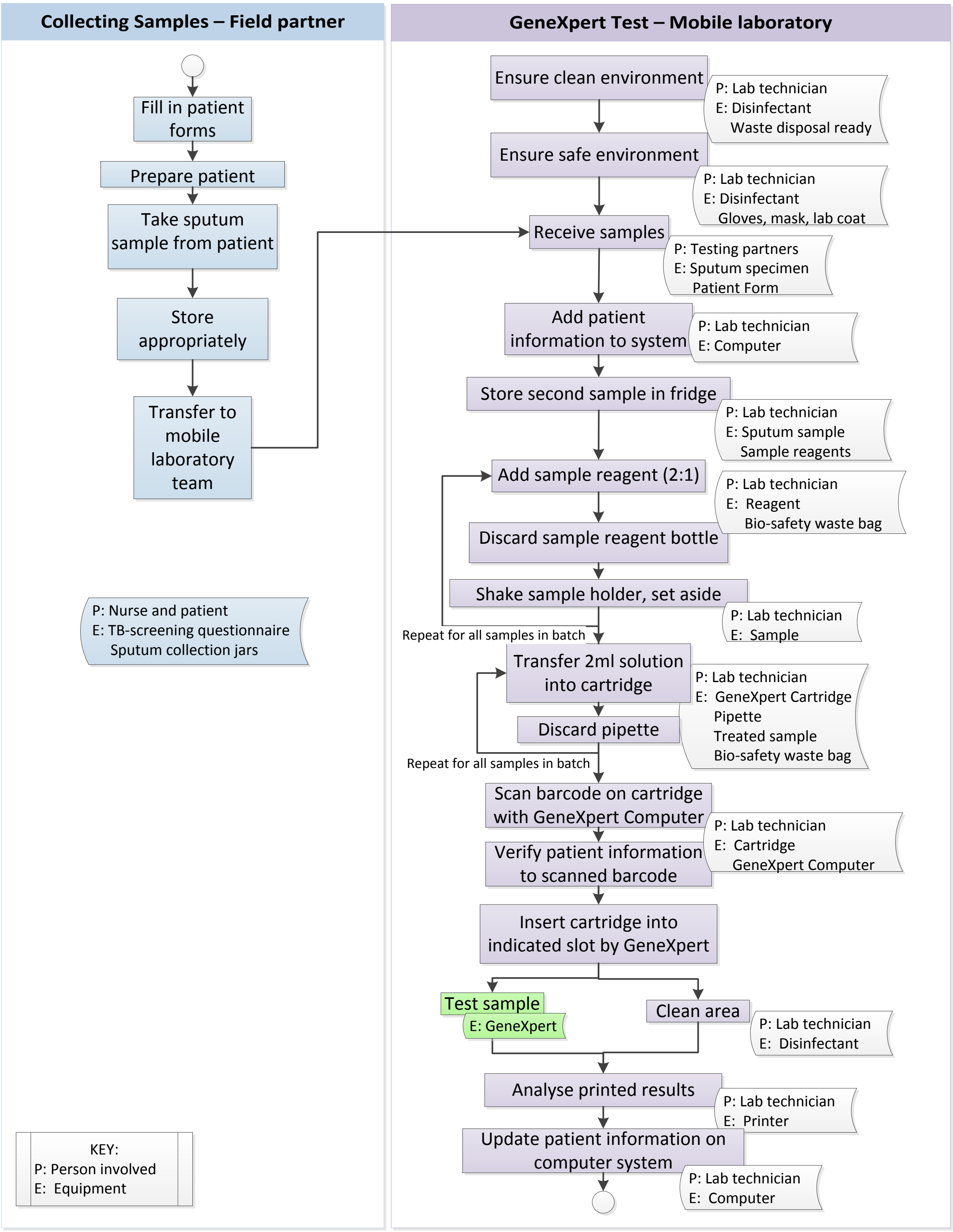
APPENDIX A

This appendix contains a diagram which displays the envisaged testing process for the mobile laboratory.



REDUCING THE COMMUNICATION COSTS OF A REMOTE MONITORING AND MAINTENANCE SYSTEM FOR AN ENERGY SERVICES COMPANY (ESCo)

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ABSTRACT

Demand-Side Management (DSM) initiatives can result in substantial electricity cost reductions. Energy Service Companies (ESCos) typically perform remote monitoring and maintenance to ensure sustained performance of these DSM initiatives. Mobile network service providers offer the flexibility required to allow an ESCo to monitor DSM initiative that are widely distributed across South Africa. Mismanagement of the communication infrastructure and the potential for excessive data usage threatens the financial feasibility of remote DSM maintenance. Software was developed to promote improved management of this communication infrastructure, and to monitor the accessibility, data usage and other communication vitals automatically and remotely. Optimal management of the communication infrastructure ensures the lowest possible base cost, while prediction based on data usage information allows for predictive maintenance in order to avoid or reduce excessive data costs. This paper presents the process of reducing the communication cost of an ESCo that actively monitors and maintains more than forty DSM initiatives. Improved asset management and automated monitoring resulted in a 73% reduction in the monthly communication costs.

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1. INTRODUCTION

When implementing Demand-Side Management (DSM) projects on a mine and industrial plants, Energy Service Companies (ESCos) typically develop specialised control systems that implement DSM strategies. Van Heerden *et al.* [1] and Van Jaarsveld *et al.* [2] describe the development and implementation of such systems. Du Plessis *et al.* [3] showed that remote monitoring and maintenance is vital for sustaining DSM performance and the resulting cost benefit. Furthermore, the overall maintenance process can be optimised by introducing automated diagnostics that span across the industrial system targeted for DSM intervention; the system that implements the DSM strategy; and the performance assessment and reporting system.

This cascade of monitoring, diagnostics and remote maintenance systems creates a complex scheme that is highly reliant on communication infrastructure that facilitates remote maintenance. Interrupted communication impairs the ability of maintenance personnel to assess DSM performance and perform reactive maintenance based on automated diagnostics. This threatens the sustainability of DSM initiatives and could result in lost financial savings. Therefore, to make DSM maintenance financially feasible, the cost of maintenance must be kept well below the potential financial savings produced through sustained DSM performance.

2. BACKGROUND

Blumberg [4] analysed the customer calls of more than twenty service organisations and found that most service requests do not require on-site assistance. According to Blumberg [4], 80% to 90% of software-related difficulties and 10% to 40% of hardware-related difficulties can be corrected with remote assistance. Since the publication of this work in 1982, the opportunities for remote monitoring initiatives have increased, as discussed by Weppenaar *et al.* [5], due to the rapid growth of the information and communication technology field. As mentioned by Yang *et al.* [6], these systems provide large organisations with the ability to collect, store and analyse information from distributed sites.

Du Plessis *et al.* [3] and Du Plessis *et al.* [7] presented the concept for an automated diagnostic system designed to assist an ESCo to maintain the performance of DSM initiatives remotely, and provided the results obtained after implementing this system. Du Plessis *et al.* [8] elaborated on the use of this new system by presenting case studies detailing diagnostics of the DSM strategy of mine water reticulation systems; and cooling auxiliaries on different mines. These works highlighted the contribution of continuous remote maintenance towards sustained DSM performance. Furthermore, the obtained results showed the value of automated diagnostics of the DSM implementation in general; and the DSM strategy in particular. The diagram in Figure 1 shows the complexity of the DSM implementation, the diagnostics system and the communication system that allows for automated diagnostics and remote maintenance.

Hardware components are connected through different networks. The equipment and instrumentation are connected to the Programmable Logic Controller (PLC) and Supervisory Control and Data Acquisition (SCADA) system through an industrial network. The DSM server connects to the PLC and SCADA system via an Ethernet network, and uses an Open Platform Communication (OPC) connection to read values from field instrumentation, and to control industrial equipment according to a specific DSM strategy.

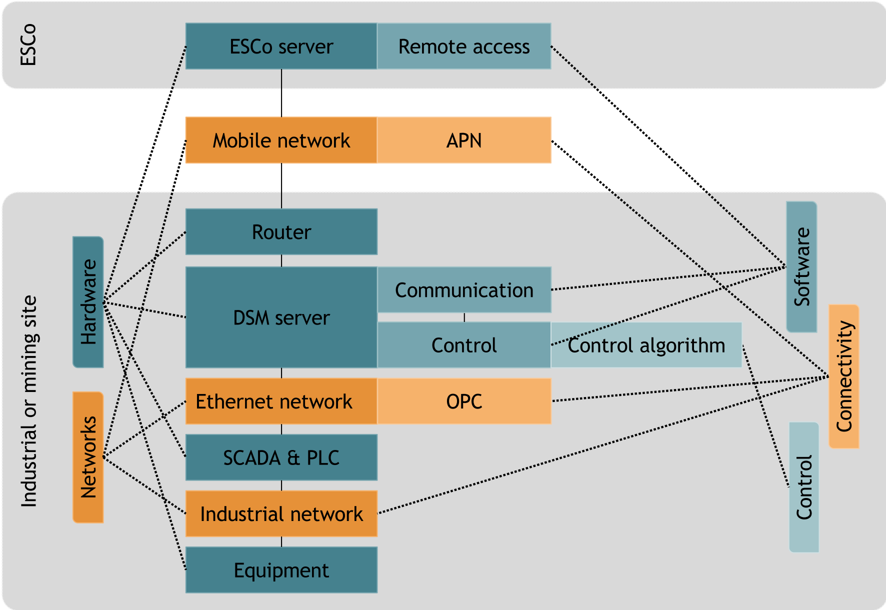

Figure 1: Remote diagnostics and maintenance system (constructed from [3], [7], [8])

A mobile router connects the DSM server to the ESCo server via mobile networks. Mobile networks provide the flexibility required to monitor DSM initiatives that are widely distributed across South Africa [9]. The execution of the DSM strategy is not reliant on this mobile network, yet, the mobile network allows for prompt notification of irregular operation. Furthermore, this mobile network connectivity also allows maintenance personnel to access the DSM server remotely in order to perform corrective maintenance.

Interruptions in mobile network connectivity threaten the sustainability of DSM initiatives. Some geographic areas experience weak or no signal for a specific mobile network service provider, which makes it impractical to use one service provider exclusively. A private Access Point Name (APN) provides a cost effective method for linking Subscriber Identification Module (SIM) cards from different service providers to the same secure network [10]. This private network only facilitates connectivity between SIM cards that are provisioned with access to this APN. Figure 2 shows a private APN facilitating connectivity between SIM cards from different service providers.

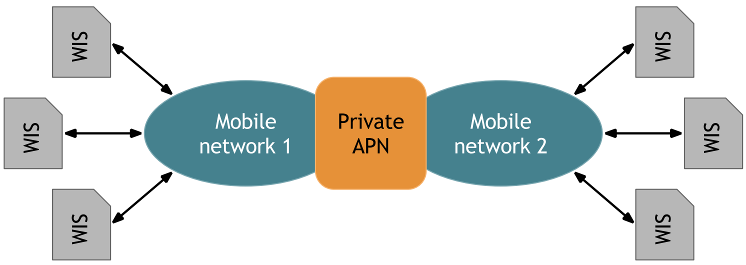

Figure 2: Data flow through an APN

SIM cards are linked to active mobile lines that are procured from mobile service providers on a contract basis, with fixed monthly data allocation. This ensures continuous connectivity and reduces the overhead created by replenishing prepaid lines on a monthly basis. In turn, the APN service provider charges a fixed monthly fee for each mobile line that is provisioned on their APN.

3. MANAGING COMMUNICATION COST

Data contracts are a major contributor to an ESCo's monthly communication bill, illustrating the roll of optimal managing of mobile lines in reducing communication costs. Mismanagement of mobile lines can result in the over-procurement of data contracts. However, optimal management of mobile lines, linked to SIM cards that are distributed across the country has proven to be challenging. Table 1 lists four circumstances that can be avoided or quickly identified through comprehensive management. The table also shows what risk factors are involved for each of these circumstances. The first risk factor indicates the potential for excessive data usage and cost. The second risk factor indicates that the SIM card has become unavailable for use and therefore could result in procurement of unnecessary contracts.

Table 1: Risks associated with mismanagement

Circumstance	*Risk factor*		*Description*
	Data usage	*Lost SIM*	
Unnecessary redundancy		X	Routers support failover to a secondary SIM card for areas with weak signal reception. Improved reception on one of the SIM cards voids failover. Secondary SIM card becomes dormant.
Accidental redundancy		X	Secondary router installed although the site already has a router that is not on the asset register.
Offline router		X	Router is broken, removed or disconnected.
Theft or abuse	X	X	Site personnel use a SIM card for personal use.
Malfunction	X		Failed data transmission is mistakenly perceived as successful, resulting in continuous retransmission of the same data.
Malware	X		Certain malware probe the computer network to infect other machines. Probing involves continuous transmission of small data packets that amount to large data transmission on a monthly basis.

Monitoring the cost of communication in general and the cost of individual lines in particular is the starting point to identify excessive data usage. The first option is to use information from the monthly bills to identify overspending based on a predefined budget. A monthly bill can however only be used to identify situations where excessive usage has already occurred. The bill will reflect the data cost of the previous month, or depending on the billing cycle and billing date, the cost of the month before the previous month. To illustrate this, Figure 3 shows the costs generated by a single mobile line over a five-month period in 2013. This figure also shows the cost reflected on the bill for each of these months. The first month shows the normal monthly cost of R 149. During the second month, this cost escalated to R 2 355, and excessive costs continued for the next three months.

If the billing date is set for the last day of every month, it does not allow sufficient time to consolidate the data usage for that specific month. Therefore, the bill received on the tenth day of Month 5 reflected the data cost generated in Month 3. At that stage, Month 4 already produced a similar data usage, which continued for the first ten days of Month 5. This resulted in a total overspend of R 58 185 during this five-month period. Therefore, using monthly bills to monitor communication cost does not significantly reduce the risk of excessive costs.

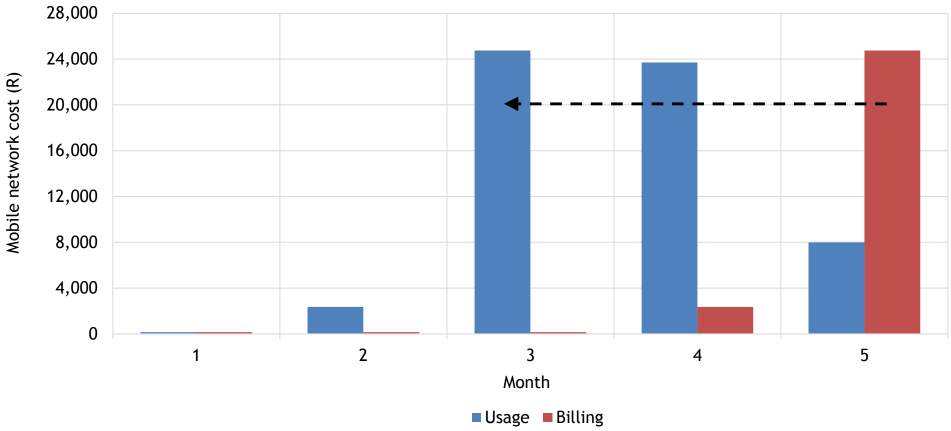

Figure 3: Delay between usage and billing dates

To improve the resolution of data checking, complete data usage reports were requested from the service providers on a weekly basis. These requests were occasionally serviced promptly, but other requests were delayed for up to a week. After escalating these requests week in and week out, it became apparent that this is not a sustainable method to monitor data usage figures. Most service providers grant access to account and billing information using an online portal. These portals allow for manual generation of data usage reports, which ensured that the reports could be generated consistently on a weekly or even daily basis. Importing this data on a daily basis remains a manual process that is prone to human negligence.

4. AUTOMATED MONITORING

Heyns *et al.* [11] emphasised the importance of performing a root cause analysis using appropriate information, before making decisions. Software was developed to request information from routers on a daily or even hourly basis, in order to promote access to the correct information, which allows for prompt reaction to identified risks.

4.1 Asset management

The developed software allows the user to import a detailed subscriber list holding information on the mobile lines registered at each service provider. In addition to this information, the software can import a list that links the private APN Internet Protocol (IP) addresses to the specific mobile line. Table 2 lists the information that is retained in the database of the developed software, and the reason why this information is required.

Table 2: Mobile line and APN information

Information	*Need*
SIM number	Unique serial number of the SIM card used for asset manage
Subscriber number	Unique number used to administrate the contract
Contract type	Indicates the size of the recurring monthly data allowance
Contract expiry date	Date after which a contract can be reviewed
Subscriber status	Indicates weather a subscriber is active or locked
APN IP address	Address used to access the site remotely

The software allows the user to allocate a mobile line or multiple mobile lines to a site or personnel. In extension to this, the mobile line that is allocated to a site might be allocated to different DSM initiatives implemented at that specific site. The software therefore enables administrative personnel to keep an electronic record of SIM card allocations, including the responsible person for each DSM initiative. Furthermore, the software allows maintenance personnel to gain remote access to the onsite DSM server, using the information in Table 2.

4.2 Monthly budgeting

The developed software also allows maintenance personnel to import monthly invoices in order to analyse the actual cost against the budget for individual mobile lines. The aim is not to exceed the fixed monthly contract cost, and therefore this cost is used as the budget for each individual mobile line. Any mobile line that exceeds the budget is highlighting for corrective action. Furthermore, the developed software provides an overview of budget and actual costs for the last year, assisting maintenance personnel to identify mobile lines that exceed the budget on a regular basis.

4.3 Communication checks

The developed software periodically checks the level of communication to all the SIM cards installed in on-site routers. The level of communication is calculated based on the number of successful ping requests sent to each router. This information is then used to calculate an average daily communication level for each router, which is combined to form a monthly profile. Personnel use this profile as an indication of the stability of the connection to each installed router. Additional information about the communication channel is obtained by sending Hypertext Transfer Protocol (HTTP) requests to the router. The information that can be requested from the router includes the signal level, the current active SIM (primary or secondary) and router serial number.

Furthermore, the software initiates Unstructured Supplementary Service Data (USSD) commands on the router in order to query the data balance of the mobile line linked to the installed SIM card. This data usage is then represented as a data usage profile from the start of the current billing cycle, giving maintenance personnel an indication of the data usage tendencies of each site. The software can provide a snapshot of the latest data usage figures for all mobile lines. A prediction of the total data usage at the end of the current billing period allows the ESCo to benefit from preventative maintenance, as discussed by Vermaak *et al.* [12].

5. IMPLEMENTATION

At the beginning of 2014, the total number of SIM cards used for remote maintenance peaked at 187, with a combined monthly cost of approximately R 50 000. No spare SIM cards were available, therefore requiring a new 24-month data contract every time a new SIM was required. In mid-2014, an investigation was initiated to verify the allocation of all SIM cards.

5.1 Investigation

The list of existing SIM cards and the last known allocation of each SIM card was imported into the developed software database. Figure 4 shows an outline of the investigation process. The first objective was to request a list of SIM cards that have been dormant for more than three consecutive months. This list was imported into the software and all the dormant SIM cards were marked for replacement. As a second objective, 44 personnel SIM cards were verified. The third objective was to verify SIM cards assigned to sites. Remote connections were used to verify 47 of these SIM cards, while 28 SIM cards required site visits for verifications and reinstatement of remote access. Installation records for portable data logger, that require voice contracts for dialup based data transmission, verified the locations of a further 22 SIM cards.

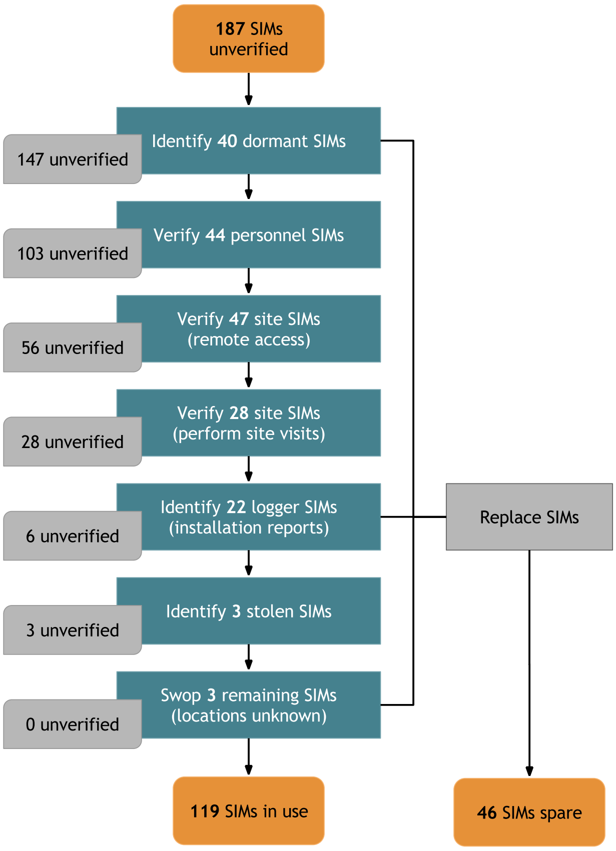

Figure 4: Investigation process

The itemised bills of the six remaining SIM cards were used to identify suspicious activity. Three of these SIM cards showed billing for SMS messages and voice calls to various unknown numbers. Voice calls to the three corresponding mobile lines verified that unauthorised individuals were using the SIM cards. The remaining three SIM cards could not be located and did not show significant data usage; therefore the SIM cards were replaced.

5.2 Automated data collection

This investigation resulted in an updated database of all the SIM cards owned by the ESCo, and a substantial increase in the number of spare SIM cards. The software was configured to start collecting information from all routers that are allocated to sites. Figure 5 shows the overview page of the developed software with a list of DSM initiatives and the responsible personnel. The APN IP address is used to request data from the router and the SIM card remotely. This data is categorised as indicated by the five blocks in Figure 5.

The software shows when communication to a site is lost for prolonged periods and will therefore assist to rectify problems promptly. In addition, the data usage profiles of sites are constructed and allows for reassessment of the contract type and additional bundling. This information is also vital before implementing risk-limiting strategies, in order to prevent necessary interruptions in communication.

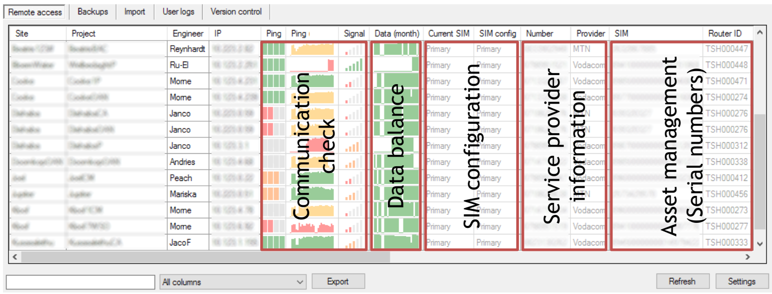

Figure 5: Communication overview on developed software

5.3 Reducing the risk of overspending

The next step was to ensure that the risk of excessive usage is reduced to a minimum. A cost limit is required in order to prevent excessive data costs as discussed in section 3. Mobile network service providers might offer the option to prevent data usage in excess of the allocated monthly data allowance. One of the ESCo's service providers did not provide this same option, however, it offered a cost limit instead. The mobile line is locked once the cost exceeds the budget by more than the elected cost limit amount. A mobile line lock prevents further charges and is only removed at the start of the next billing cycle. Figure 6 shows the maximum cost of six mobile lines with active cost limit of R 100. Line 6 exceeded the limit by up to R 1 500. The service provider stated that the exact cost incurred before the mobile line is locked cannot be guaranteed.

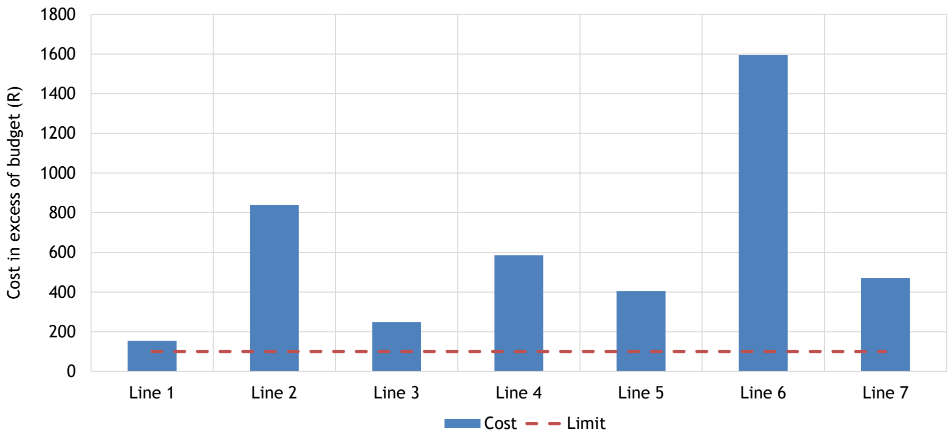

Figure 6: Monthly costs exceeding the cost limit

Although this unguaranteed limiting is not ideal, it was found that only exceptional cases would result in the budget being exceeded by more than R 1 000. Therefore, the risk of excessive costs that compare to the costs presented in section 3 is eliminated. Budget violations are further reduced by actively monitoring the data usage with the developed software. As discussed in Section 4, the automated monitoring system generates a data usage profile and predicts future data usage. This mechanism allows maintenance personnel to identify potential budget violations and take immediate corrective action to prevent or minimise the extent of overspending.

5.4 Reducing the base cost

Following the investigation process, 46 SIM cards became available for reallocation. There is however no need to keep such a large amount of SIM cards as spares. Therefore, a substantial portion of the spare SIM cards was marked for termination upon contract expiry. Base costs can be reduced further by contract upgrades, contract downgrades, and bundle adjustments. The automated monitoring software discussed in Section 4 allows for a data usage profile to be constructed. This profile clearly illustrates the behaviour of the mobile line, which can be analysed in order to determine whether a contract adjustment is required. If the overspending is found to be more expensive than a contract upgrade or a recurring data top-up, the contract is upgraded to minimise overspending. When a mobile line utilises significantly less data than the monthly allocation, a contract downgrade is considered after the contract expires.

6. RESULTS AND DISCUSSION

The implementation process started with a three-month investigation in June 2014. In October 2014, a pilot version of the developed software was implemented and updated with all the verified data. The software started to perform automated data collection. In subsequent months, the functionality of the software was expanded continuously.

6.1 APN cost reduction

Mobile lines could be cancelled immediately after the initial investigation because these contracts were still in place. Early contract termination results in a settlement cost comparable to the outstanding monthly costs until the contract end date. Figure 7 shows the monthly APN cost and the corresponding number of active mobile lines. Although the first mobile line cancellations only took place in May 2015, unnecessary APN subscriptions could be cancelled with a notice period of one month.

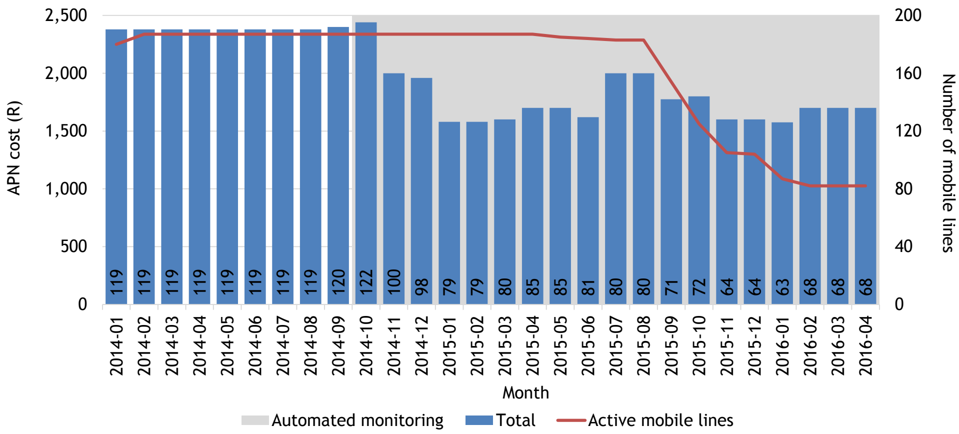

Figure 7: APN subscription cost and number of lines

In November 2014, the first 22 mobile lines were deregistered from the APN as shown in Figure 7. As mobile lines were marked for cancellation, APN registrations were further reduced to a total of 79 in February 2015. The number of APN subscriptions fluctuated over the following months as communication requirements change. An APN tariff increase caused the total cost of the subscriptions to increase in July 2015 even though the number of subscriptions was reduced. Despite this tariff increase, the total monthly APN cost was be reduced from R 2 440 in November 2014 to R 1 700 in April 2016.

6.2 Mobile line base cost reduction

The APN cancellations provided an immediate reduction in cost, but the proposed mobile line cancellations had a much larger potential cost reduction. Figure 8 shows the total monthly mobile line cost starting in January 2014, compared to the budget of each month. The monthly cost is calculated based on the total cost of voice contracts and the total cost of data contracts for the specific month. The bars in the figure also show the number of mobile lines allocated to each of these costs. It is clear that in January 2014, 67% of the costs were generated by 33% of the mobile lines. Many of these voice contracts could be replaced by data contracts, because dialup connections were not used any more.

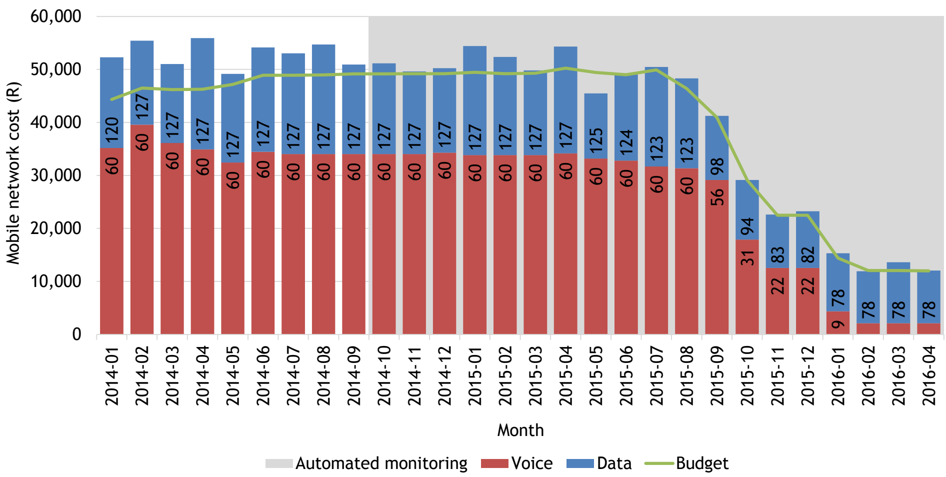

Figure 8: Mobile network cost breakdown

All SIM cards of mobile lines that were marked for cancellation were made unavailable for allocation to sites. Active management reduced the base cost of communication from R 44 324 in January 2014 to R 11 996 in April

2016. This reduction was achieved using the developed software to show the real demand for mobile lines compared to the current asset allocation. This resulted in a decrease in mobile lines from 180 to 82. In addition, expensive voice enabled contracts could be grouped together and replaced with existing data contracts in order to reduce unnecessary costs. The 60 voice enabled contracts were reduced to 4, which expired in June 2016.

6.3 Mobile line overspend reduction

In addition to reducing the base cost, the developed system allowed for better data usage tracking on a daily basis, hence reducing the incidence and severity of overspending. In Figure 8, only three major incidences of overspending occurred. In January 2015, a voice-enabled contract with no data allowance was installed on site in error. The mobile line immediately started to use data at a cost of R 2 per megabyte. The cost escalated and the SIM card was not being actively monitored because it was not allocated to a site. In February 2015, one of the personnel SIM cards was stolen and it was only reported stolen the next day. The thieves generated a bill of R 1 693.19 before the limit lock blocked the SIM card. In May 2015 overspending was identified on a mobile line that was prohibited from exceeding the monthly data allowance. Furthermore, the developed software showed a substantial data balance at the end of the billing period. This contradictory information was as result of a billing error that was rectified on the next bill.

7. CONCLUSION

Effective management of communication infrastructure can minimise the cost of monitoring DSM implementations distributed across the country. Communication costs can contribute considerably to the ongoing DSM maintenance cost and can have a negative impact on the overall financial savings achieved by a DSM initiative. This paper shows how the communication cost of an ESCo can inflate maintenance costs. The cost of communication should therefore be reduced to a minimum in order to ensure cost effective DSM maintenance.

When using a mobile network for communication, mismanagement results in an increased base cost, while sporadic data usage spikes results in costs that exceeds the budget. Software was developed to improve this management process and to increase the resolution at which communication-related information could be retrieved; from a monthly period to an hourly period. By focussing on preventative maintenance procedures, the risk of overspending was significantly reduced.

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AN EVALUATION OF PROJECT TEAM WORK: TEAM LEADERS' PERSPECTIVES

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ABSTRACT

Teamwork is an acceptable and structured process used by academics to assess progress in academic modules. Team leaders are usually elected to coordinate team activities required for the successful completion of projects. In the process of teamwork, team members and team leaders alike gain valuable skills that will prepare them for life and the world of work. In addition, management and teamwork are also an engineering programme requirement of the engineering accreditation body. This study reports on team leader interviews conducted on completion of a major project executed in an engineering module in an engineering programme. The research was conducted to investigate the effectiveness of team projects in terms of team member commitment, project execution and the associated skills practised. The research can contribute to the structuring of project teams, measures of fair assessment and improving the quality of team project experience.

1. INTRODUCTION

Cooperative learning, as an effective teaching method, has been defined as instruction that involves students working in teams to accomplish a goal while under conditions that include (Felder and Brent, 2004) [1]:

- elements of positive interdependence,
- individual accountability,
- face-to face interaction,
- appropriate use of collaborative skills
- team processing

Cooperative learning has been used by an Engineering department at a South African university to incorporate the teaching of engineering principles with team learning, communication development, leadership, initiative, and creativity (Lourens et al., 2015) [2], (Lourens et al., 2016) [3].

With the introduction of an engineering laboratory at the university, it was decided to introduce innovative teaching practices in a cooperative learning framework [2]. Accordingly, a project was developed for a specific engineering module where students utilised the modern facilities and equipment whilst introducing non-traditional methods of teaching and learning as based on the research of Froyd et al, 2012 [4], Kuri, 2014 [5], and Lenschow, 1998 [6]. The project brief required students to design and build a product that could be tested for speed and distance whilst meeting other specified criteria. Students were also encouraged to experiment with the size and length of all the parts on the product and to be as innovative as possible.

As the teamwork project for the specific module evolved over the years, several areas of interest and research were identified. Particular attention was paid to the design of the project [2] and the influence of compiling teams with varying learning styles [3]. This research reports on the feedback obtained from team leaders over the course of two years.

Therefore, the main aim of the research is to investigate how team leaders experience and manage teamwork. The investigation particularly referred to the Engineering Council South Africa's (ECSA) Exit Level Outcome 8 (Engineering Council South Africa, 2012) [7] which specifies individual and teamwork requirements for engineering programmes. This investigation could thus enhance the project brief or instructions issued to students. Furthermore, it is anticipated that this research can contribute to how team projects are designed, developed, managed, and assessed to improve the quality of the team experience for individual team members.

2. THEORETICAL FRAMEWORK

Five shifts have been identified in engineering education. and inlcudes [4]:

- an analytical emphasis in engineering science,
- outcomes based education,
- renewed emphasis on design,
- applying education, learning and social behavioural sciences research,
- the influence of information, communication and computational technologies on engineering education. [4].

The project associated with this research focused on design, learning and social science and the influence of information, communication, and computer technologies in engineering education. The project brief was discussed with teams prior to the commencement of the project. The explanation of the project requirements guided the students and highlighted the difficulties that could be encountered. The importance of teamwork, the required leadership, planning and time management was explained. This gave the students a better understanding of the required project outcomes and at the same time influenced the selection of the team members and team leaders by individual students.

Leadership and teamwork were thus emphasised right from the start of the project. Students were briefed on the importance and benefits of teamwork and its associated responsibilities, not only for the elected team leaders but also for individual team members.

2.1 Importance of teamwork

The emergence of team assignments, although not a new concept, represents a major trend in education [2], [4], [6]. This trend, according to Ford and Morice (2003) [8] could be the result of increased student numbers, which have forced academics to turn to team assignments to lessen the academic workload in certain modules. It could also be because employers value teamwork skills highly and seek development in university graduates in this area [8]. Furthermore, teamwork is also considered one of the Exit Levels Outcomes for an engineering qualification and therefore important to incorporate in the engineering curriculum.

The ECSA range statement for Exit Level Outcome 8 (individual and teamwork) is described by ECSA as follows [7]:

i. The ability to manage a project should be demonstrated.
ii. Tasks are discipline specific and within the technical competence of the graduate.

Management principles include:

i. Planning: set objectives, select strategies, implement strategies, and review achievement.
ii. Organising: set operational model, identify and assign tasks, identify inputs, delegate responsibility, and authority.
iii. Leading: give directions, set an example, communicate, motivate.
iv. Controlling: monitor performance, check against standards, identify variations, and take remedial action

Given the importance of meeting ECSA requirements, a team project in an engineering module would be the ideal opportunity for students to develop individual and teamwork skills. Furthermore, the practice of educational objectives (specifically engineering, leadership, and teamwork related) gave students a better understanding of the outcomes to be achieved. Furthermore, it forced them to utilise problem-solving processes during the project, thus increasing their readiness for employment.

2.2 Benefits of teamwork

Team assignments provide an opportunity for students to engage in peer-to-peer learning which will enhance their ability to clarify and share knowledge, and develop their problem solving abilities and leadership skills (Almond, 2009) [9], (Johnson & Johnson, 2005) [10], (Burdett and Hastie) [11]. Other benefits could include higher-level learning, better communication, conflict management, and greater understanding [9]. At the same time, according to Candy et al., (1994) [12] skills that are transferable to the work environment such as teamwork, time management and interpersonal skills could be developed.

Burdett and Hastie (2009) [11], found that students do not always regard team assignments positively because dissatisfied students could inhibit and impede the performance of other team members and this could result in a poorer outcome. However, because students need a solid knowledge of fundamental principles, a domain of refined strategies for problem-solving, capacity to think and act in independent ways and to work and learn in teams, teamwork is a valuable approach [5].

Because of the associated benefits, effective learning associated with teamwork could lead to more competent practising engineers. This is especially important in light of more service and production industries indicating *competence* as the most important factor for competitiveness [6].

3. METHODOLOGY

A compulsory semester module in an Engineering programme was selected as a module that lends itself to a cooperative learning approach with a focus on developing teamwork and leadership skills. A project brief explaining all requirements was discussed with students prior to commencement of the project. As part of the teaching and learning objectives of the module, students were required to work in teams. These teams could consist of between four to five students and teams elected team leaders [3].

On completion of the project, team leader interviews were conducted. These team leaders were asked questions to determine not only their team members' commitment and involvement in the project, but also other issues that had an effect on the completion and success of the project. Team leaders were also asked to recommend changes for future team projects.

3.1 Interviews

Over a two-year period, team leaders were interviewed to obtain feedback regarding their experience as team leaders. Interviews were scheduled after the final assessment had been completed on the projects. It was not compulsory for team leaders to attend or partake in the interview session.

Year	Number of teams	Number of team leaders interviewed
Year 1	11	11
Year 2	8	5

3.2 Interview protocol

Year 1

All eleven team leaders attended the interview session. Fifteen questions were asked during the interview. Responses were coded into eleven categories. Table 1 shows the categories of the questions.

Table 1: Qualitative interviews

Categories assigned to the project process	Corresponding interview question number
1. Selection of team members	11
2. Team leader election	8 and 10
3. Change of leadership	9
4. Project analysis	3
5. Coordination of tasks	2
6. Time management	1
7. Delegation	4,6,14
8. Delegation of tasks and leadership	5
9. Conflict	12 and 13
10. Combination of males and females in the team	7
11. Project improvements	15

All the team leaders attended the interviews. Certain team leaders were present but did not participate in the interview session.

Year 2

Five team leaders participated in the session, although eight teams participated in the project. Four extra questions were included in Year 2 that led to two new categories. The new category numbers are 6, and 13 as listed in Table 2.

Table 2: Qualitative interviews

Categories assigned to the project process	*Corresponding interview question number*
1. Selection of team members	5
2. Team leader election	6, 12,18
3. Change of leadership	11
4. Project analysis (size of the project)	4
5. Coordination of tasks	2
6. Planning (project)	3
7. Time management	1
8. Delegation	8, 9, 15
9. Delegation of tasks and leadership	7
10. Conflict and getting rid of team members	13, 14
11. Team dynamics and gender in the team	10
12. Project improvements and improvement of the quality of the finished project	16, 19 17
13. Effect of lab technician	18

Feedback was then further categorised into planning, organising, leading, and controlling.

4. FINDINGS AND DISCUSSION

For the purpose of this research, the responses from team leaders in Year 1 and Year 2 of the project have been combined and are reported below. Feedback was summarised into management principles identified in the ECSA range statement for Exit Level Outcome 8 (The ability to manage a project should be demonstrated). Accordingly, feedback is reported in the following categories as defined by ECSA [7]:

Planning: set objectives, select strategies, implement strategies, and review achievement.
Organising: set operational model, identify and assign tasks, identify inputs, delegate responsibility, and authority.
Leading: give directions, set an example, communicate, motivate.
Controlling: monitor performance, check against standards, identify variations, and take remedial action.

Selection of the teams and team leaders
Students selected their own teams. The students that were not assigned to any teams were either teamed together or placed in a team that had capacity. No student was forced into a team. Over the two years, only one team leader was self-elected while other team leaders were elected by their teams.

The feedback captured in the interviews showed that the students prefer to choose their own teams and select their own leader. Some team leaders indicated that previous team leaders had been changed during the course of the project because of the following perceived issues: lack of self-esteem, lack of confidence, inability to guide the team or the level of maturity.

This indicated that some of the students displayed the necessary maturity in dealing with potentially awkward situations that could lead to conflict and loss of friendships. Furthermore, it indicated that they viewed the successful completion of the project in a serious light.

Planning: Coordination of tasks and time management
In most cases, the team leader was responsible for planning all the activities associated with the project execution. Setting priorities and developing action plans at the beginning of the project helped some teams to manage the project. Delegation of responsibilities assisted teams in achieving their goals. However, underestimating the complexity and time required executing the project, the amount of input, team involvement, time management, and last minute changes to the finished product were issues that all teams indicated as obstacles for successful project completion.

The feedback indicated that team leaders in general were aware of their responsibility of managing their teams to complete the project. It also became apparent that team leaders needed regular support and guidance from the lecturer.

Organising: Project analysis and delegation
A unanimous response from team leaders was that they underestimated the size and duration of the project. From the interviews, it became apparent that team leaders did not always organise tasks and deadlines effectively. Poor quality of work resulting in teams falling behind schedule placed pressure on team leaders. If team leaders did not schedule time with the laboratory technician to use certain of the equipment, it also resulted in bottleneck situations in the laboratory, which led to tasks not completed on time.

Delegation of tasks by team leaders, irrespective of age or gender, did apparently not pose any problems. However, team leaders felt that they worked harder than their team members did. This is because the majority of the team leaders indicated they had to redo either work delegated to others, or that they had to do the work themselves from the start. Certain teams did comment that age and gender had an effect on who was appointed as the team leader. They felt that the older students with work experience might be better leaders.

The feedback from the team leaders thus indicated certain shortcomings in their organisation of work. Possible reasons are that they were unfamiliar with the processes and the associated required laboratory time.

Leading: Conflict
All teams interviewed, apart from one team, experienced conflict in their team. Conflict was thus a common occurrence in all the teams. In general, team members because of the following reasons caused conflict:

- non-attendance at the briefing session
- not understanding the project requirements
- not pulling their weight
- not taking the project seriously

- a negative attitude towards the project
- not willing to get involved or unwilling to be a team player.

Any conflict was handled within the teams; this was done by scheduling team meetings to discuss the issues at hand. In extreme cases, the team leaders had no option but to expel team members not willing to cooperate. All the team leaders reported that the responsibility to complete the project fell on the team leader's shoulders.

The majority of the teams thought it good to have a mix of both males and females in a team, but they also reported that the gender of the team members was not important. The team leaders felt that the way team members contributed to the completion of the project in terms of management, team dynamics, capability, and other skills was important from a teamwork perspective.

Controlling: Project improvements and quality of the finished project
All the project requirements as stipulated in the project brief were explained in class. Some team leaders indicated that a lack of understanding of the brief was because either students were not in class or they did not pay attention during the briefing.

The team leaders indicated that the closer the due date, the more responsibility fell on them to complete the project. This resulted in team leaders having to complete tasks allocated to team members. Team leaders realised that this was due to poor time management, organisation, and control of the project schedule.

Laboratory technician
In Year 2, a laboratory technician was employed and overall improvements in the final products produced from Year 1 to Year 2 were clearly visible. The laboratory assistant, experienced with all the laboratory equipment required for executing the project therefore had a positive effect on the products produced in Year 2. Team leaders indicated that the laboratory assistant was very involved in assisting and guiding teams and displayed the relevant knowledge of the equipment utilised in executing the project. They were appreciative of this dedication and felt that a laboratory technician was definitely beneficial to the successful outcome and completion of the project.

Feedback from the team leaders clearly indicated the relevance and need for dedicated technical assistance in executing their projects.

5. RECOMMENDATIONS

Based on the study's findings, recommendations are made that mostly pertains to improving students' general and project management and leadership skills.

The team leaders felt that they did not require any extra training in managing projects. However, it is recommend that leadership training prior to a major teamwork project could assist to reduce the amount of conflict encountered throughout the duration of the project. Leadership training could assist team leaders to understand the tasks and duties associated with being a team leader. Training can include the stages of team formation, motivating the team, setting deadlines, planning, and assessing team members' strengths and weaknesses to allocate tasks accordingly. The process of getting to know team members and organising tasks according to individual strengths would teach valuable management, self-knowledge, and interpersonal skills to both team leaders and team members.

A major shortcoming on the part of team members and team leaders appeared to be a lack of time and project management. Teams need to understand the concept of breaking jobs into manageable parts and assigning realistic time values to these tasks whilst planning for contingencies and rework. They need to understand that constant feedback, communication, and control are requirements for successful project execution. Detailed project briefings and assisting teams in planning and setting control measures such as peer review meetings could assist in this regard. Team leaders recommend that more emphasis is placed on understanding the project brief and that it should be made compulsory for all students to attend the project briefing.

Furthermore, it became apparent that a peer review system for individual parts of work executed by team members could lead to improved quality of work and therefore meeting deadlines. Regular peer reviewing could also minimise the workload of team leaders and the resultant pressure from redoing team members' work.

Team leaders recommend a bi-weekly report back session with the lecturer for a progress report from team leaders. Team leaders would then obtain feedback from the lecturer and peers on their progress and guidance on dealing with difficult situations. Team leaders would then provide feedback to their teams. Team leaders felt that they needed support from the lecturer so that the importance of timeous work and scheduling would be emphasised to team members. The feedback meetings will also allow team leaders to compare their project progress and serve as an indicator for teams if they were falling behind schedule.

The assessment rubric included peer assessment marks for team member participation. This proved successful where students had the courage to assign lower marks to team members who did not meet their deadlines or successfully execute their tasks. It is this recommended that students understand the importance of this measure and that peer marks are allocated honestly, fairly and responsibly.

The introduction of a laboratory technician had a positive effect on teamwork and project execution. The teams who enjoyed the benefit of a dedicated laboratory technician produced higher quality projects and felt that the laboratory technician played an important role in successful project execution.

6. CONCLUSION

General benefits that can be attributed to this team project are the understanding of productivity and performance, skills development within the team, better self-knowledge and improving teamwork and project management skills. The aim of this research was to investigate how team leaders experienced and managed teamwork. The investigation particularly referred to the Engineering Council South Africa's (ECSA) Exit Level Outcome 8 (Engineering Council South Africa, 2012) that specifies individual and teamwork requirements for engineering programmes. Based on the feedback from team leaders, they practised and enhanced their planning, leading, organising, and controlling skills in the execution of this project in an engineering module. Even if many further opportunities for development were identified, due to a possible lack of maturity and experience, students were given the opportunity to work in teams and develop skills associated with being part of a team or leading a team.

This investigation could thus enhance future project briefs or instructions issued to students by including regular scheduled progress reports with teams. This could assist the team leader to understand, develop, and improve their leadership skills. Furthermore, it is anticipated that this research can contribute to the way team projects are designed, developed, managed, and assessed to improve the quality of the team experience for individual team members. This can result in improving their readiness for life and the world of work.

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Development and implementation of an advanced mobile data collection system

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ABSTRACT

This paper describes the development and implementation of a generic data collection tool. The Mobile Information Collection and Verification System (MICAVS) provides users with a generic platform to create application specific data collection questionnaires. During the data collection phase, the system uses an Android™ application to display relevant questionnaires and interfaces. The application thus utilises modern smartphone technology to aid data collection, ensure data traceability, perform tests on said data and guide users. After collection, the collected data are exported to a range of reporting systems. Case studies of successful system implementations in numerous industries are also discussed.

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1. INTRODUCTION

1.1 Challenges within South Africa's industrial sector

Many large industries in South Africa rely on electricity as primary energy source. Historically South Africa enjoyed low electricity tariffs, which led to a high reliance on electricity. However, by 2016 the cost of electricity has risen to 527% of what it used to be in 2006 [1], [2]. This caused a sudden increase in operational expenses and has a significant impact on the profitability of large electricity consumers. Industries affected by this increase include, but are not limited to: cement manufacturing, steel producing, water utility and mining.

Companies within these industries stand to gain significant benefits by improving energy efficiency. Energy service companies (ESCOs) are therefore often contracted to assist these companies with energy related projects. Typical services offered by these ESCOs during energy interventions include energy investigations, funding arrangement, infrastructure upgrades and project management. Selected ESCOs also offer maintenance programs, in order to ensure that system performance is sustained for an extended period of time.

Meetings with ESCO clients in various industries revealed the need for a cost effective mobile data collection system. These clients described their data requirements and unique challenges they face with collecting relevant data. Details surrounding these challenges are provided in the following section.

1.2 Mining industry challenges

One of the primary industries that ESCOs focus on is the mining industry. South Africa has some of the deepest gold and platinum mines in the world, including the world's deepest gold mine, with a current depth exceeding 3800m [3]. Mining at these depths presents many unique challenges with regard to service provision and maintaining of safe working conditions. These services require advanced systems that increase energy consumption and associated expenses.

Growing operational expenses reduce the profitability of mining activities. Furthermore, the increased operational expenses coupled with declining commodity prices and ore grades, raise the need for mines to investigate cost effective methods to reduce expenditure per ton of product delivered. This creates the demand for energy efficiency improvement and ESCO services. Reduced energy consumption will result in reduced energy expenses and will produce significant drop in overall operational expenses.

Studies have shown that proper maintenance offers great efficiency improvements that offer cost savings in return. However, ESCO projects and funding initiatives require large amounts of data. Infrastructure expansion to gather data is often expensive and do not guarantee a return on investment. Therefore the developed system will provide mining companies with a cost effective data collection tool.

1.3 Water industry concerns

In addition to escalating electricity prices, large industries are placed under pressure by several resource constraints. One limited resource is water. Water forms a crucial part of operations in many industries. South Africa is currently in the early stages of a water crisis. Some parts of the country are already burdened with an inadequate water supply [4].

Dr. J. Dabrowski [4] stated that over 98% of South Africa's available water resources have already been allocated across various sectors. Furthermore, estimations indicate that by 2025 the country will have a water deficit of between 2% and 13% based on expansion and economic performance. This is a major concern for the country and creates the need to implement proactive water management strategies.

Water suppliers rely on large pump sets and piped networks to transport the water. Baird [5] states that, a failure in such a piped network will have significant financial, environmental and social impacts. Brent and Haffejee [6] further expand on this by raising the concern that not only the water supplier will be affected, but also the consumers within the service area.

In addition to water loss concerns, the large pump sets used in the industry are high electricity consumers, which relate to high electricity expenses [7]. On average 657 kWh electricity is consumed per Mega litre of water supplied [8]. Due to the heavy reliance on electrical pumps, water distribution can be considered an energy intensive industry. Some ESCOs have thus started offering their resource management strategies to large water networks.

A reduction in system losses offers the supplier many financial advantages by reducing electricity and water treatment expenses. Additionally, the environmental impact of operations is reduced and precious water resources are preserved. These advantages motivate the need for improved maintenance structures and accurate maintenance information. Energy efficiency and maintenance projects on water systems require the collection of large amounts of data and therefore supports the demand for a mobile data collection system.

1.4 Maintenance data management

ESCO services typically include projects targeted at reducing energy consumption. These projects typically include infrastructure upgrades and improved control systems. In addition to this, ESCOs provide performance reports to the end user to ensure that the intervention operates as intended.

It was found that proper maintenance helped achieve target energy savings [9]. Furthermore, reducing wastages in pumped water schemes and on compressed air networks offer great energy saving opportunities. Complete and accurate data is however required to construct finding reports and identify system inefficiencies. Thus, the maintenance personnel responsible for these systems need tools to gather and manage maintenance data.

Maintenance staff needs effective methods to manage maintenance data. However due to economic constraints industrial users may also have difficulty funding these tools. A cost effective data collection system will therefore help industrial users to collect the data used to compile finding reports that will aid management to develop better maintenance structures.

1.5 Paper contents

The challenges described in the preceding sections indicate that clients in a range of industries share similar data requirements. Therefore, the data collection needs for a range of industry applications can be addressed by a single generic data collection system. A novel data collection system was consequently developed to satisfy the requirements described by ESCO clients. The following sections describe how this need was addressed through the investigation, development and implementation of a new data collection system. The following topics are addressed in ensuing sections of the paper:

- Evaluation of existing data collection methods;
- Design considerations for a mobile data collection system;
- Data validation structures;
- User guidance functionality;
- Case studies in the South African industrial sector;
- Concluding findings and comments.

2. EVALUATION OF DATA COLLECTION METHODS

2.1 Data collection systems

Digital data capture enables the collection of metadata, which is used to authenticate data, without placing additional responsibility on users. Computerised systems have the ability reduce data faults caused by human error. Furthermore, computerised systems offer users a range of features which ensures complete data sets, as well as validation data. Data collection systems exists, but present many shortfalls or restrictions. In this section three data collection methods are considered. These methods are: Supervisory Control and Data Acquisition (SCADA) systems, manual data recording and mobile applications.

2.2 SCADA systems

SCADA systems are the preferred method used for system control and data collection since these systems reduce the required amount of human intervention. Furthermore, these systems are utilised to achieve maximum cost saving potential offered by energy efficiency interventions by ensuring reliable system operation [10]. SCADA systems typically rely on PLCs for control and data acquisition at remote locations in order to ensure reliable operation. A Programmable Logic Controller (PLC) is a computational device and is used for industrial control and data collection in industrial applications [11].

Unfortunately the cost of implementing a PLC system is very high. In 2006 D. le Roux [12] estimated the implementation cost of a PLC system between R250 000 and R800 000. PLC installation costs are further escalated by software development and commissioning requirements [12]. The range of hardware components that form a complete PLC system includes:

- cabling for both power and communication purposes;
- junction boxes;
- a uninterrupted power supply (UPS);
- a human machine interface (HMI);
- circuit breakers.

Industrial applications, particularly mining, also require the use of high quality cables and instrumentation to withstand the extreme environmental conditions. These communication networks often span across large areas. This creates the need for very long cables and further increases the network cost. An additional downside of a SCADA system is that the system only monitors a rigid collection of variables. System expansions are required to add new sensors and add them in the system. These expansions are costly and also serve only targeted purposes. Additionally, these expansions have integration problems due to different suppliers and systems.

2.3 Mobile applications

The development of handheld computing devices such as smartphones and personal digital assistants (PDAs) provide new data collection opportunities. Many applications have therefore been developed to collect data. Each of the listed applications presents a unique combination of features, as well as its own list of shortfalls. Therefore, none of the other applications satisfied the combined set of requirements that this study is based on. Table 1 provides a summary of the existing applications and their features.

Table 1: Data collection application comparison

		Momento database [13]	Momento [14]	Goformz [15]	Nexticy [16]	Formetize [17]	Pushforms [18]	Devicemagic [19]	Magpi [20]	Doforms [21]	Flowfinity [22]	Epicollect plus [23]	Gis_cloud [24]	Poi_mapper [25]	Prontoforms [26]	Keel [27]
Configuration	Authorised user accounts		•			•	•	•	•	•	•		•	•	•	•
	Authorised user linking				•	•		•	•	•	•			•	•	•
	Data structure versioning													•	•	
	Auto update user configuration								•		•			•	•	
	Auto update data structure configuration	•		•	•	•	•	•	•	•	•		•	•	•	
	Offline configuration management	•												•		
	Kiosk mode device limitation					•										
	Licencing and authorised access to group data					•				•	•			•	•	
Data collection	Customisable input linking	•		•		•	•	•	•	•	•	•	•	•	•	•
	Code scanning	•				•	•	•	•	•	•	•	•		•	•
	Photograph with annotations					•		•		•	•				•	
	Document scanner															
	Signature capture	•		•	•	•	•	•		•	•				•	•
	Sketch pad			•		•		•		•	•				•	•
	Sound level measurement													•	•	
Verification	Historic data access on device	•	•								•		•	•		
	Geo location capture	•	•	•		•	•	•	•	•	•	•	•	•	•	•
	On device calculations	•		•	•	•	•		•	•	•		•	•	•	
	Customisable data validation tests	•					•				•	•		•		•
	Validate according to historic data										•					
	Customisable summary		•	•											•	
User assistance	User guidance on input form	•	•			•	•			•						
	Automated data set detection															•
	Workflow support via conditional sub forms	•		•	•	•			•	•	•	•	•	•	•	
	Manual task assignment	•	•	•		•	•	•	•	•	•				•	•
	Customisable map overlays												•	•		
	Review previous readings offline	•	•								•					
	Customisable validation messages					•										
Data	Customisable report integration	•	•	•		•			•		•		•	•	•	•
	Data encryption	•	•			•		•	•		•				•	•
	External system integration	•	•			•	•	•	•	•	•		•		•	•

2.4 Manual human recordings

Manual data recording is practiced in many industries. This method of data collection allows great amounts of flexibility and does not require expensive infrastructure upgrades. In some applications users are guided by forms they have to complete. However, in other cases employees do not have formal data collection structures.

Therefore, although this method is quick and easy to implement, there are significant shortfalls. The largest shortfall is inaccuracy due to human error, since during this process humans interact with data on various levels and each point of interaction creates a possible fault from human error. Possible errors can be made while: reading the meter, writing the meter reading down, reading handwritten notes, typing values into a computer and creating custom reports. It is thus clear that manual data collection has numerous human interactions and that each interaction can be considered an integrity risk.

Clients who made use of manual data collection identified additional system flaws during meetings. During manual data collection exercises employees often visit harsh environments and there are many difficulties using a pen and paper in these non-ideal conditions. These difficulties include insufficient paper support, stationary failure and harsh environmental conditions.

3. DESIGN CONSIDERATIONS FOR A MOBILE DATA COLLECTION SYSTEM

3.1 Introduction to a generic data collection system

Due to the shortfalls of the traditional data collection systems, a new system was developed. The system is designed to provide a generic data collection platform that is usable across multiple industries and applications. The primary component of the Mobile Information Collection and Verification System (MICAVS) is therefore a mobile application.

The application provides infrastructure that allows users to create custom data collection sets. These data sets can then be customised from within the application and exported to other devices without the need for further development. During configuration ingress activities are linked to items within the data set and stored in the database. During execution, the application dynamically creates user interfaces based on database entries.

When data sets are created, the set of collection variables can be personalised to address the user's specific needs. A range of data ingress activities have been created to allow the collection of various data types. During configuration, a specific data ingress activity is linked to each item in the data set. This aids users to enter appropriate data entries for each data field that they defined. Data fields can be marked as required to ensure that records are complete.

3.2 Operating system selection

The core of the MICAVS relies on an Android application which is used to create and manage log entries. Android was chosen as the best suited operating platform for the system due to the following factors. The principal factor was that Android has significant market penetration in South Africa, consequently many consumers already own Android devices [28]. These users are thus able to make use of the application without investing in new hardware.

Many ruggedized mobile devices are also commercially available. These devices are better suited for harsh operation conditions. Rugged devices can withstand risks including drops, as well as dust and water exposure factors better than standard mobile devices. Furthermore, selected rugged devices are certified for use in potentially explosive areas.

Most of these commercially available ruggedized devices employ either the Android or Windows mobile operating systems. No Apple® devices are available in ruggedized packages and are therefore not suitable for this application. Device availability and market penetration were thus considered and revealed that Android is the preferred platform for the MICAVS application.

3.3 Database

Android supports SQLite databases and therefore, the developed application utilises a SQLite database to manage data. Without root access, the database is isolated by Android so that only the associated application can access and modify the database. MICAVS uses the relational database to provide structure to the application. The database can thus be summarised in three categories namely: constants values, configurations settings and recorded data.

Constants are defined during compile time and cannot be modified on the device. These values are used to provide structured options and default values. Although these entries generate fixed outputs that offer users access to structured options, it offers developers a platform to quickly access and update crucial application options.

Configuration table values are used to manage variable interface options and predefined lists. These values can be configured on the device or using a configuration tool. During execution the application uses these tables to dynamically construct interface elements and populate lists as defined by the administrator.

Lastly data tables are used to manage recorded data. The database structure allows users to manipulate input options, by adapting the configuration tables. These changes affect the storage tables that accommodate unique configurations and thus stores data accordingly.

3.4 Interfaces

One of the key elements of the MICAVS is customisable user interfaces. Various interface elements have therefore been created. These elements include layouts for interfaces such as the main menu and sub-menus. The next and arguably most important element is the display cards. Lastly, various data ingress interfaces with fixed layouts were also created.

Interfaces are constructed dynamically from the database when the application is executed. Menu cards items including images, headings and support text are constructed from database entries. A collection of user access tables contains links between user access options and menu items. Therefore, only privileged users have access to specialised menu options such as the management interface. The MICAVS main menu with privileged user access is shown in Figure 1-A.

When creating a new log the application detects the appropriate mode and then compiles a list of data fields assigned to that particular mode. Card elements are then created based on the compiled list. Figure 1-B, shows the data input interface with a card for each data set entry. These cards contain links to the appointed data ingress interfaces. To add data the user must press on the appropriate card and use the data ingress interface to enter the relevant data. Figure 1-C, shows the numeric data ingress dialog.

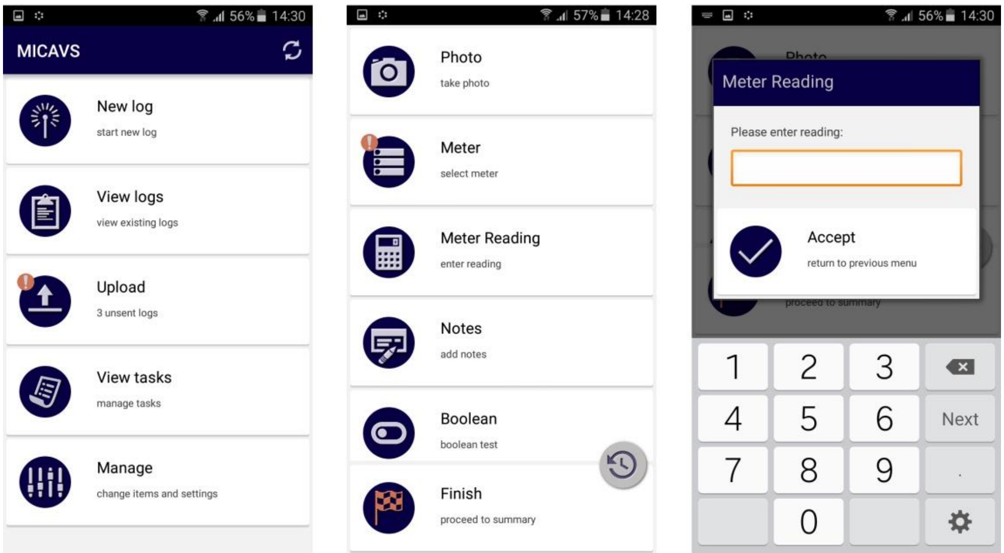

Figure 1: MICAVS customised interfaces

After all the required data fields are completed the user is allowed to finish the log. A log summary is then created by selecting *Finish* from the data input menu. This summary contains the logged data along with additional data including GPS location, timestamp and verification test results. Some data fields also have support interfaces that allow users to view the captured data. One example is the map view that shows a map with a pin where the log was created.

Test results displayed in the summary are created dynamically. If no tests are linked to the data field, a normal summary card will display only the captured data. Conversely, if tests are linked to a specific data field a detailed summary card will be displayed. These tests are discussed in more detail in section 4. The user is also notified if the captured value exceeds the test parameters.

Figure 2 shows examples of review interfaces in the MICAVS application. Figure 2-A shows an example of a summary interface. In this case an average test was executed on *Meter Reading*. The field is emphasised by displaying a highlighted card item. In this case the test failed and an exclamation is displayed. A failure message can be seen by selecting the *Meter Reading* card. Figure 2-B, shows an example of the customisable failure message dialog.

Certain selected data ingress types have support interfaces. For instance, *Location* entries can be viewed on a map. Figure 2-C shows an example of the reading location as a pin on a map. The map type can also be modified to show either a satellite image, normal map, hybrid map or terrain view. Images can also be reviewed in a similar interface. These support interfaces are invoked by selecting the grey buttons on the right hand side of the interface shown in Figure 2-A.

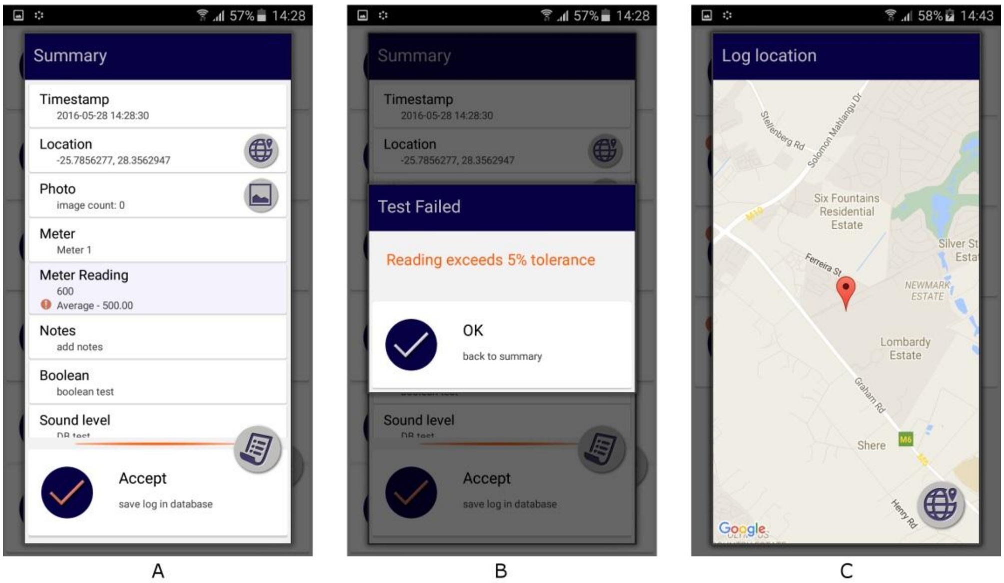

Figure 2: MICAVS review interfaces

3.5 Data transfer

The ability to transfer data is required in order to extract the full potential of the data collection system. Existing log entries can be filtered and viewed on the device. To allow customisable reports, the MICAVS exports data to remote servers in order to process the collected data. The MICAVS has been integrated with both internal and third party data processing systems to satisfy a range of user requirements.

The MICAVS was initially developed for an ESCO that provides various energy services to clients across multiple industries. To enable this, many internal systems were developed to receive, process, store and report on data collected on site. The MICAVS was therefore integrated with internal systems. The application sends structured data files to these systems via an internet connection both automatically and upon user request.

The integration enables the internal ESCO systems to receive data from the MICAVS application. The received values are then archived along with supporting data for traceability purposes. Furthermore, this integration allows the construction of custom reports and provides a platform to perform additional tests on data based on the client's needs.

A specific ESCO client also has an internal system used to track maintenance requests. The developer therefore collaborated with a team from the client in order to develop a data transfer strategy between the two systems. This strategy was conceived and implemented successfully. This allows the MICAVS application to communicate directly with the client system and enables automatic maintenance work order creations without the need for additional human intervention.

3.6 Data verification

The MICAVS provides users with a unique data verification platform. This platform provides clients with the ability to perform different data verification tests at three different stages of the data collection process. Firstly, there is a generic data validation component in the application. This component allows users to select one of multiple verification tests and apply it on a data field of their choosing. Unique test parameters can then be defined for each test. The application also has the ability to select historic data entries connected to the data field in question and compare the new entries with said historic data.

During the second verification stage, recorded data that are uploaded to the server are saved alongside metadata such as pictures that prove certain data elements. This stored data can then be used for verification for audit purposes by requesting raw data from the ESCO.

Lastly, the exported data are received by a reporting system which generates reports which can be customised according to the client's needs. This allows users to manually verify the data against previous collections or predefined values. A Microsoft® Excel template also allows users to perform advanced mathematical calculations on the dataset and use these values in automated reports.

3.7 User guidance

One of the unique functions of the MICAVS is user guidance. When the researcher joined ESCO clients during various field tests, the client made use of a note sheet that shows previous reading. New readings were compared with previous readings in order to verify that readings fell within acceptable limits.

After viewing these tests, the application was expanded to include this functionality. Users now have the ability to view previous readings while making new log entries. Users can therefore perform a manual verification that the values fall within an acceptable range.

When the user selects *Finish*, a log summary is also generated and the MICAVS performs linked tests on the data. A warning flag is displayed if any of the tests exceed the specified parameters. The user can then select the summary item to see a detailed description of the test result and verify that the entered values are correct before saving the log entry.

4. SYSTEM IMPLEMENTATION

The MICAVS system was implemented at three client sites. Client 1 is a large water supplier in South Africa and used the system to manage maintenance data. The second client is in the mining industry and used the application to manage water meter readings. Lastly, the application was used by ESCO personnel to perform an audit on a compressed air system in a goldmine.

4.1 Implementation 1: Water network maintenance

A large water board in South Arica relies on an extensive pipeline network to transport water to clients. The majority of this pipeline network is underground and totals to a combined length of 3600km [29]. These pipelines are subject to corrosion and other factors that decrease its life expectancy. According to the American Water Works Association similar pipelines have a typical lifespan of 70 years [5]. The network in question can therefore be considered mature which increases the risk of failure.

Due to the size of the network it is impractical to replace large sections of pipelines that do not present immediate risks. However, it is difficult to predict when and where pipelines will fail. According to Kahn [29], a pumped water loss between 4% and 5% was recorded for the network. This equates to 210 million litres of treated water that is lost on a daily basis. Furthermore, Kahn [29] raises the concern that the exact location of these losses are unknown, due to the fact that pipeline leaks are not accurately recorded.

These losses are a serious concern due to limited water resources in South Africa. Furthermore, these losses have significant impacts on other systems and the environment. Most of the lost water is potable water. It can therefore be deducted that 210 million litres of water received treatment without cause. The client therefore had the need for advanced data collection to record pipeline failures within their network.

Previously they relied on a manual system whereby the general public would call and report water leaks. A maintenance representative from the district was then sent out to investigate the report. If the leak was found on their network the investigator would report the fault and open a work order request.

The client had two powerful software systems, but did not utilise their potential as loads of manual labour was required to open work requests. In addition to this, according to maintenance personnel leak descriptions were not accurate. Furthermore, the collected data was inconsistent and varied according to each responder's personal preference. Reporting structures did not support structures used to collect Global Positioning System (GPS) data or photographic evidence.

The first of the software systems was used to manage maintenance requests. After a maintenance issue was created the system generated a work order and assigned a responsible person. The responsible person then had to find the leak with limited information available and perform the required maintenance with limited prior details of what the scope of work would entail.

The second system was used to manage Geographic Information System (GIS) data. Data stored in this system has the ability to show regions where frequent maintenance is required. Unfortunately this system was not utilized, because responders did not have access to a tool that can capture GPS locations and photographs and support data. Furthermore, no automated structures were in place to process inspection findings.

When the MICAVS was provided to the client, special data import functionality was added to the MICAVS to enable communication with the client's system. Additionally, a custom data set was defined for the client. The data set formed an inspection checklist which contains user specified inputs in combination with photographic evidence, GPS locations.

After initial implementation the client distributed the MICAVS system to maintenance representatives in each operation region. The regional representatives use Android devices equipped with the MICAVS application to create detailed issue logs. These logs are then uploaded to the client servers where they are processed. The client servers receive the log data and automatically open work orders. Detailed descriptions thus provide maintenance staff with a better indication of work required.

In addition to this the GIS system could be utilised for marking locations where leaks occurred. High risk areas can therefore now be identified based on geographical similarities. This enables maintenance management to identify problem pipelines and sections and replace only limited sections of the pipe network. This improved information structure therefore enables the client to make more informed maintenance decisions and reduce expenditure.

4.2 Implementation 2: Water meter readings

In this case the client was responsible for gathering water meter reading data. To do this the client traditionally relied on manual pen and paper methods and would physically visit a predetermined list of sites and write down readings. Most of these locations were outdoors; therefore weather conditions had a serious impact on operations.

The client was supplied with the MICAVS application and a unique setup was created according to the user's needs. After the system was implemented trial tests were performed and data verification tests were developed and the system was updated with an improved configuration. Part of this improved configuration included adding additional users. Due to security concerns, selected meter readings had to be assigned to personnel who could take the readings while escorted by security personnel.

The MICAVS system is capable of detecting specific components and user modes based on predefined identification codes. These codes can be in the form of barcodes or QR codes and must be unique. The client therefore obtained barcode tags and assigned the codes to specific meters. By utilising this functionality the possibility of selecting the wrong meter was removed.

Currently meter readings are recorded on a monthly basis. The application allows the user to access previous readings during data collection inspections. A detailed summary after every log contains on device calculations that indicate possible data errors and alert the user of any discrepancies while still on site. The users record data on site and then synchronises the collected data with the ESCO's server. Next the data is backed up for traceability purposes and custom reports are generated according to user specifications.

4.3 Implementation 3: Compressed air network audit

As previously mentioned South African gold mines often operate at depths exceeding 3800m [3] which presents many unique challenges. Specialist systems have therefore been developed to allow operation in these conditions. To illustrate this, consider the compressed air network used in mines. Compressed air generation can make up between 20% and 50% of a mine's electricity consumption [30], [15]. Botha [31] continues that compressed air generation expensive and one of the most inefficient means of energy distribution in mining operations.

Part of the ESCO services includes energy audits on client premises during which ESCO personnel identify inefficiencies and system faults. These results need to be recorded accurately in order to be used to construct finding reports. Potential saving opportunities or maintenance requirements can typically be addressed if these reports are used.

In this case the ESCO used the MICAVS system to perform an audit on a mine compressed air network. Recordings were made if any leaks or misuse of compressed air systems were observed. During this investigation 18 significant air leaks were noted on a single level within the mine.

These leaks have a major impact on system performance and induce significant cost implications since the compressed air networks rely on large electrical compressor systems. If leaks are managed properly less supply from the compressors is needed and electricity costs can be reduced.

5. CONCLUSION

This paper presented a generic data collection and verification system that was developed and implemented as part of a study. The developed system relies on an Android application for data collection and integrates with various support systems. The integrated systems offer users a unique platform to create custom data gathering structures.

The data requirements for the system were therefore obtained through a combination of discussions with clients and previous ESCO experience. This prompted the development of a new data collection system. The new system allows users to create multiple custom data collection interfaces accompanied by verification and data tractability functions.

The collected data is captured using a fully customisable Android application. The application offers user guidance and data verification tools to assist users to collect accurate data. After collection the data are synchronised with support systems which are used to store the data, generate custom reports and perform additional verification tests.

The system was successfully implemented on three separate industrial sites in South African. The users reported great advantages from using the system. Custom reports have also been generated, based on the client's specific needs. These reports aid clients to make better informed decisions. Additionally, recorded data and metadata are backed up and are available for further processing and audit purposes upon request.

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ENGINEERING THE FACE OF THE FUTURE FACTORY

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ABSTRACT

People are the next critical link in world class manufacturing facilities within South Africa. There needs to be a complete paradigm shift in terms of how we train our engineers who will design and manage these facilities as well as how we upskill operators and technicians within the facilities. This combined effort needs to focus on an active learning environment centred around problem solving and continuous improvement. This paper describes a very unique partnership between a university and industry partner which aims to revolutionise the way in which undergraduate engineers are trained and operators are developed. This paper will discuss the structure of this exciting new programme, the anticipated benefits and challenges experienced during its first year.

1. INTRODUCTION

The training of excellent engineers always has been, and remains, a partnership between industry and academic institutions

Academia without industry is paralysed. Industry without academia is blind.

It is often mentioned that graduate engineers have little practical experience, particularly of working in a factory environment. This is largely a consequence of engineering graduates seeking "clean" office jobs; with those organisations that expose graduates to real operating environments tending to experience high turnover and difficulty in recruiting engineers. As such graduates are rarely exposed to the shop floor environment, and certainly not on a sustained basis, at the very least because the cost to company of a graduate does not justify long term deployment to the shop floor.

Out of this emerge graduates who have little understanding of the practicalities associated with the operating environment, including low levels of familiarity with plant, and also the human factors that affect working environments.

To overcome the post graduate stigma associated with very valuable practical experience, Wits[1] entered into an innovative internship scheme with Unilever's newly commissioned Homecare Liquids factory, Khanyisa in Boksburg.

This partnership was set up as a long-term strategic programme to develop young engineering leaders in South Africa with first hand operational experience and excellent academic education. Simultaneously, this project aimed to function as a medium for transferring best practice to the operators at the factory.

Thirty engineering students were recruited out of their second and third years of study, to spend a full year, working as operators on the line as operators at Khanyisa. During this time, students would be exposed to elements, such as shift work, overtime, repetitive work and interacting with the workforce on the shop floor.

2. LITERATURE SURVEY

The predominant theories that underpin this initiative are the philosophy of a learning organisation supporting continuous improvement as well as the importance of problem-based learning within an engineering curriculum. A learning organisation supports the idea of developing and uplifting the base skills of the workforce while work-integrated learning is used to justify the benefit of the programme to students. These theories will be unpacked briefly in this literature survey.

2.1 A Learning Organisation

A learning organisation is introduced by Senge [1] as one where people are "*continually learning to see the whole together*". He believes that the only competitive edge that companies have is their ability to learn faster than their competitors. Ballé et. Al. [2] frame Toyota's famous production system as *The Thinking Production System,* emphasising the importance of thinking people in making organisations competitive. Ballé et al [2] introduce four frames which guide this Thinking Production System. Three of these frames speak directly to the importance of developing and involving people: creating a problem awareness culture, teaching people how to solve problems and developing people. They also discuss the importance of individual and team effort, aligned towards a common goal and constantly learning, challenging and experimenting.

2.2 Problem based learning (PBL) and Work-Integrated learning (WIL)

The concept of problem-based learning (PBL) was first introduced in the field of medical education; proposing that students learn best through immersion in a discipline-based problem [3].

In traditional learning, students are taught the fundamentals and are then given a problem to solve making use of this material. The learning objectives and principles for the problem are given to the students. In this form of learning, students often only learn what is required to pass [4]. In contrast, PBL makes use of a problem in which students are required to learn the fundamentals to find a solution to the problem. By making use of relevant problems, students' retention of learning can also be improved [5].

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PBL can be team based or individual (self-directed). It has been shown that a team based approach results in better learning [6]. Polanco et al [7] introduce three pillars for the effective implementation of PBL: student questioning, interdisciplinary method and teamwork. Savage et. al. [4] discuss the importance of integrating teamwork and systems- level thinking throughout their PBL projects.

To address the concerns associated with poor student performance in higher education and to improve the attributes of graduates, the Council on Higher Education [8] has recommended a participative and real-world approach to learning. They term this approach, work-integrated learning (WIL). The main driver behind WIL is improving student learning. Other benefits include improved academic performance, motivation to learn, improved teamwork, communication and collaborative skills as well as the development of positive work ethic and values and clearer career clarification [8].

Literature strongly supports the idea of giving students an opportunity to learn in a work-integrated and problem-based environment. There are many thoughts on how best to integrate these and it would be worth exploring how this approach aligns with other approaches in future work. The idea of developing shop floor employees to support continuous improvement is also well supported by literature. This unique approach by incorporating student learning and shop floor learning will lead to results that can enhance thinking in this space.

3. DESIGN OF THE PROGRAMME

The programme was designed as a multiyear agreement between the University and Unilever. Annually thirty students are to be recruited from the second and third year streams within our School (See Footnote 1). The programme has support from a dedicated lecturer and the students enter the internship on a full time basis. During this time, the students, the support lecturer and other staff of the School will be involved in process improvements at the Khanyisa factory. It is intended that these savings will fund the programme.

3.1 Consultation

We consulted widely in designing the programme. This included focus groups with undergraduate students, and discussions with Unilever and University staff.

The focus groups were conducted with forty-five randomly selected students from the School registry. This gave valuable insights into the student needs. The major emerging theme was fear; fear of delaying career entry, fear of not graduating with friends and fear that a “year off” would cause them to become “unfit” as students.

These themes were included in the programme design as far as possible.

3.2 Timelines and approach

The programme is intended to run over five years, with an initial one year pilot to establish baseline feasibility. After five years, it is hoped that the structure will have stabilised and the programme will become self-sustaining in the long term. Figure 1 shows a rough plan of the management elements needed in the various years.

	Work Package	**Year of Project** 1	2	3	4	5
0	Integrated Process Planning	●	○	○	○	●
1	Market Research	●		◦		◦
2	Marketing	●	●	●	○	○
3	Recruitment	●	●	●	○	○
4	Mentoring	○	●	●	●	●
5	Setting up and managing internship projects	●	●	○	○	○
6	Supervision of projects on site		●	●	●	●
7	Ad-hoc short term projects	○	○	○	○	○
8	Monitoring of the transfer of problem solving and improvement skills from students to operators		○	●	●	●
9	Ongoing monitoring and improvement of the programme	○	○	●	●	○
10	Provide input on global best practice, trends and expert analysis.	○	○	●	●	●

Key
◦ Refresher Study
○ Minor Activity
● Major Activity

Figure 1: Annual Plan

3.3 Academic programme support.

It was deemed impossible to run this programme without dedicated support, for which the University recruited a staff member tasked with managing and curating the Unilever partnership. This included being the official liaison between the partners, supervising student projects and coordinating the functions shown in Figure 1.

3.4 Funding

Apart from initial seed funding, the cost of the program is derived from savings generated as a result of student projects and other interventions supported by the University. A proportion of these savings is allocated to the University at quarterly review meetings. These funds are used amongst others to fund the position of the Unilever lecturer. The funding model aims ensure cost neutrality, a priority for the sustainability and replicability of the programme.

The Chemical Industries SETA (CHIETA), subsidises the student bursaries, thus assisting with the financial sustainability of the program. Student salaries are funded from the factory's operational budget as students fill required roles in the factory.

3.5 Students

3.5.1 Recruiting

Recruiting takes place from July in the year preceding the deployment of the students to Unilever. This includes several marketing events and roadshows, leading to one on one mentorship and guidance, which often also involves discussions with parents or existing bursary companies.

3.5.2 Cohort

The group consists of thirty students selected from applicants within the School. Students who have completed third year are preferred; however (with just a year to go) these students are difficult to recruit, so numbers are made up from students who have completed second year.

Returning students retain programme support, and as such by year three, there will be as many as ninety students in the system continuously – the current year of deployed students, and the returned students from the preceding cohorts. For greater clarity, see Figure 2.

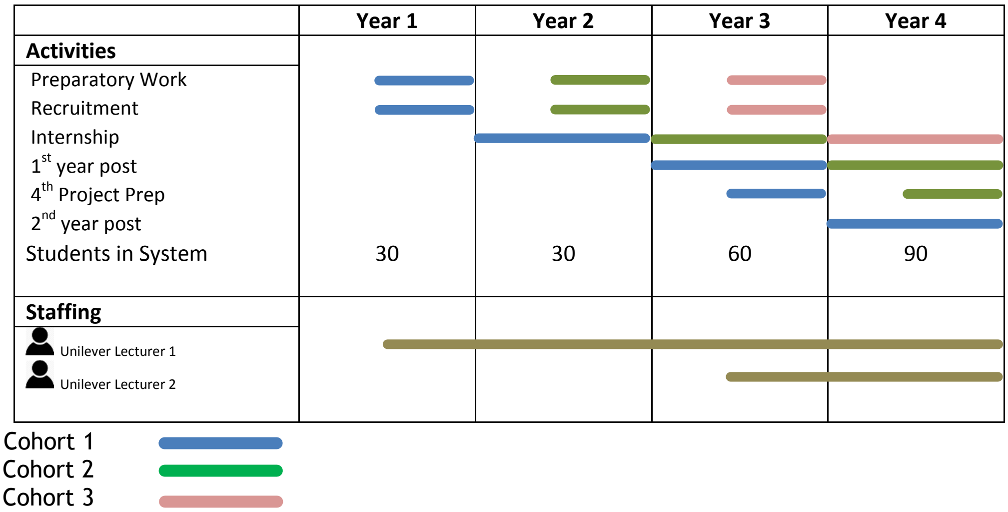

Figure 2: Phasing of people on the programme

3.5.3 Financial Support

During the year of deployment, students on the programme are paid a standard operator's wage. Upon completion of their year's deployment, the student returns to University where the remainder of their anticipated student fees are paid for. Students furthermore continue to enjoy the mentorship of the Unilever lecturer during their remaining years at University.

There is no obligation for the company to employ any of the students upon completion of their degrees, however top performers may be recruited.

3.5.4 Pre Programme

Prior to deployment to the shop floor, the students are sent on a third party work readiness programme, which is designed to bridge the academic programme and the working world. This is a rigorous boot camp, that includes shift work, a heavy load of assignment deadlines, and emotional and self-awareness training.

3.5.5 Working as Operators

Students spend the year working as operators in budgeted roles. During this year, it is a priority that the students integrate into the work teams and the workforce and are not separate in any way. Additional programme activities are designed as "after hour" activities, as student absence from the workplace is problematic.

3.5.6 Improvement Projects

Students working in the factory are tasked with identifying, investigating, and implementing improvement projects within their work area and the organisation. While these projects will be facilitated by the University, the expectation is that students will find and execute improvement projects independently.

3.5.7 Formal Learning

Formal learning time, including safety training, standard operating procedures, and technical operator skills will be provided by Unilever.

Recognising the student need to remain "intellectually fresh" the University provides formal learning material, lectures and assignments, to support improvement, and ensure a smooth return to university on completion of the program.

3.6 Benefit

The programme is designed to meet three key objectives; of creating a cohort of future engineering leaders with an awareness of the practical side of Engineering, who will excel at their remaining studies as a result of their exposure, and whilst deployed, transfer their skills to the existing factory workforce, creating an organisation, that in Senge's [1] words *keeps learning together*, which is the face of the future factory.

3.6.1 To Unilever

Unilever may leverage the University, her access to skilled professionals and strong students to assist with process improvement and generate savings. Unilever further gains early access to potential future leaders. Key as part of the relationship is the skills transfer from students to existing operators, essentially upskilling the workforce through these inputs.

3.6.2 To Wits

The University benefits by having students, of whom it is hoped, will graduate faster. An experienced cohort of students may be able to relate abstract academic concepts to a working environment, increasing their chance of success in future studies. It is also hoped that they will act as leaders amongst students, creating a stronger qualification. In addition to this, the funding contributions made through this scheme are of considerable benefit to the institution.

3.6.3 To the students

Problem based learning gives students the ability to relate concepts learned at University into practice and back again. This gives them “hooks to hang ideas on”, hopefully enabling them to graduate faster and with deeper more embedded insight. Students additionally benefit considerably from the financial security provided in part by the year of working as well as from the guarantee on study fees in their remaining years of study. Students further learn independence, grit and a structured work ethic.

4. INTERIM OBSERVATIONS AND DISCUSSION

4.1 Educating the future engineers

Poor pass rates and high dropout rates currently plague the higher education system with engineering being highlighted as one of the degree programmes that are worst affected [9]. This shift into higher education is also often compounded by financial and engagement challenges faced by students, but academic factors are seen as being the key to improving student success [9]. The poor success rates at South African Institutions is affected by poor student preparedness specifically related to key learning transitions that are required throughout the degree [9]. The program is designed to address these challenges while simultaneously preparing engineers for the currently unknown face of the future factory.

The primary educational objective for the work experience year is not the instruction of core engineering topics, but rather the provision of ancillary knowledge (such as; people skills) and the context in which engineering knowledge is required. For example, no mechatronics will be taught, however, student exposure to automation and control systems may provide context to link theory and practice once they return to university.

Participation in the programme is not graded. This aims to instil students with accountability to decide how much experience, exposure and benefit they choose to obtain. The students could just work as operators for a year, or they can take full advantage of their access to the organisation and show initiative to add value through improvement projects.

4.1.1 Student placement in the factory

Students are allocated to machine operator roles where tasks are fairly repetitive yet their presence is required to ensure continuous production. Examples of student roles include; packaging product, offloading raw materials onto the line and the operation and monitoring of automated equipment. Students are, for the year, not students but a fundamental part of operations.

The issues that students experience while performing operator roles should provide deeper understanding of work. It is believed that the hard work required by repetitive manual tasks may inspire student engineers to design better systems in their future careers. In addition, this provides a platform for bottom-up continuous improvement.

The operator’s role given to each student for their year of work plays a role in how much a student *perceives* they are learning. Students believe the manual, labour intensive roles they are performing are not preparing them for the completion of their degree or a career as an engineer. This is however a critical step in developing the face of the future factory, where future management has not only witnessed but experienced the plight of shop floor work and are therefore better equipped to design, manage and improve the systems of the future; and this, through the experience gained here, in consultation with those doing the work.

4.1.2 Improvement Projects

Practically realising improvement projects within the factory has been a challenge. This can be attributed to three key factors

1. Time and Motivation
2. Knowledge
3. Self-Empowerment

Students are responsible for their jobs as operators. These shift roles take up the work day yet students are also expected to complete improvement projects, expose themselves to other areas of the factory and study in their own time. The adjustment to shift work is a challenge for students who feel fatigued, especially when they are on night shift. Students are also traditionally motivated by marks, and the risk of failing. On the program students have to adopt an internal locus of control, motivated by their own learning and ambition. There are no rewards or incentives for completing improvement projects. Other assignments asked of the students have also been poorly executed or have low submission rates, owing, in part to the non-educational environment the students are in and the absent threat of failure.

Students participating in the program have had limited exposure to engineering application and are at different stages in their degrees. For example, students who have completed 3rd year Industrial Engineering are in a far better position to autonomously scope and execute improvement projects than a student who has only partially completed the second year.

Knowledge however is not as critical a challenge as student's lack of self-empowerment. Students are positioned at the bottom of the organisation's hierarchical structure and do not feel empowered to take action, make suggestions or illicit support from individuals at higher levels. Students, just like other employees, need to be empowered if they are going to make a positive contribution to improving an organisation.

The progress of student projects presents a major opportunity to students' learning, as this is the space in which they can take their experience as operators and apply themselves as engineers and problem solvers to improving that experience.

4.1.3 Formal Learning

This component keeps students academically engaged to ease their return to full time study. Classroom time together also allows students to reflect on workplace challenges and their learning. The formal learning component has experienced challenges in scheduling, given that students are on different shifts. Without the threat of failing, it is difficult to ensure all students engage in lecture material, and the associated assignments. This is compounded by operational demands of the factory which often requires overtime and the full focus of student operators, detracting from the learning objectives of the program.

4.2 Skills transfer to shop floor

The program encourages students to learn from operators, who are now their colleagues, many of whom have more than 10 years of experience in their roles.

The program is working towards skills transfer from students to operators. The first step towards this; is shown in the strong relationships that have already been built between student and traditional operators. Operators claim to enjoy having the students around and appear to appreciate the contribution the students are making.

Apart from the transfer of skills and knowledge, it is expected that students will share their career ambition (privileged to them by being in an operator role for one year and not for life and their future prospects as engineers) with their co-workers. Students make up approximately a third of the operational roles at the factory. The cross pollination between age and education levels is expected to encourage operators to continue learning and believe that they can break the 'glass ceiling' of their roles. In the long term this is expected to enable the shop floor to play an active role in decision making and improvement and allow the organisation to promote from with-in, enabling a bottom-up management approach and creating a learning organisation.

4.3 Measuring success

The primary goals of the program are to prepare engineers (who are more successful at their studies) for industry, simultaneously uplifting the workforce of the organisation. It is difficult to quantify success in these three areas. Moreover, the concept and partnership is a new one and participants still need to complete their year of work experience and return to university and finish their degrees before joining industry. It would be difficult to quantify programme success without a longitudinal study on participants' careers. We intend to monitor the cohorts whilst completing their degrees. Quantitative analysis of students' academic performance controlled against their peers. Qualitatively, students, independence, grit and ability to cope with academic work will be tracked through interviews and surveys.

The success of the program will also be shown through the overall financial benefit the students and academic partnership bring to the factory through improvement initiatives and shop floor engagement. With significant cost savings it is hoped that it can be proved that: *The right thing to do, is also the profitable thing to do.*

4.4 Summary

The program's three learning components together with the theory that each component relates to is summarised in Table 1. The current benefits and challenges being experienced are also detailed.

Table 1: Learning Components, Theory, Benefit and Challenges

Program Component	*Related Theory*	*Benefit*	*Challenges*
Students Working as Operators on 8 hour shits	Learning organisation Work-integrated learning	- Students are a critical part of operations - Students 'live' the operator experience - Exposure to operational problems - Information and knowledge share between students and operators - Students develop a deep understanding of process - Exposure to working world	- Repetitive work makes student tired and demotivated - Lack of time for learning, reflection and improvement initiatives - Students do not make a clear link to engineering or degree - Students are used to fill labour gaps, being treated as general workers
Continuous Improvement projects	Problem based learning	- Learning continuous improvement - Partnership sustainability (add real value) - Employee engagement, promoting improvement from shop floor - Development of operators	- Time for projects after shift - Lack of incentive - Lack knowledge and experience to deliver results - Students do not feel empowered to take actions, lacking self-belief
Lectures and assessments	Formal learning	- Keep students academically engaged - Support improvement projects - Close knowledge gaps	- Limited time for lectures after shifts - Industrial Engineering focused - Operation issues take over - Poor assignment submission

5. CONCLUSION

We believe that South Africa's future depends on the development and growth of the country's industries. Sustainable and real growth comes not only from great, highly schooled leaders, but also from an engaged, committed, respected and collaborative workforce.

This initiative aims to strengthen both: training good engineers and uplifting the skills and motivation of shop floor workers, making a start towards creating a learning organisation.

While the programme is in its infancy, positive feedback and signs are already evident. This includes the strong relationships between student and traditional operators and some simple improvement projects. Areas for future improvement include improved metrics, and refining the formal learning elements.

In designing the face of the future factory, Wits and Unilever are changing the way in which students become engineers and leaders.

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DEVELOPMENT OF A MODEL FOR ROAD TRANSPORT FUEL MANAGEMENT

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ABSTRACT [1] [2] [3]

Road transport is responsible for 76% of cargo movement in South Africa; at the same time transport cost in Sub-Sahara Africa forms a much higher fraction of the total cost of landed goods compared to the rest of the world. Fuel represents the single biggest operational cost for road transport operators; efforts towards improved fuel efficiency are therefore a priority within this sector. As fuel usage depends on many factors, including engine size, vehicle fabrication, driver behaviour, payload, traffic conditions and route inclinations, it is not a trivial exercise to create accurate consumption benchmarks for a specific operation. This paper investigates various factors that are known to impact fuel utilization with the aim of quantifying the relative importance of the contribution of each. Fuel usage data was collected for a representative set of trucks covering all major routes in South Africa and for various cargo categories over a 3 year period. This data was filtered based on different criteria, including driver identity, route and vehicle model. Comparisons were drawn between consumption figures derived from manually recorded refuel events and figures derived from measurements that are automatically performed by on-board vehicle sensors. It was concluded that driver behaviour and the possible siphoning of fuel from vehicles seem to be a major factor and would justify further actions towards curbing fuel losses. At the same time route inclination, payload and vehicle model also play an important role and should be incorporated into costing models used to determine how different routes and trips are priced.

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1. INTRODUCTION

Road transport forms a backbone of the African economy, due to the limited availability of rail infrastructure [1]. Road transport is responsible for 76% of cargo movement in South Africa [2]. Compared to the rest of the world the cost of transport in Africa is however much higher as a fraction of the total cost of delivered goods - transport represents as much as 18% of GDP in many African countries, compared to a global average of less than 10%. Fuel cost is the single biggest contributor to the cost of road transport operations, not only due to the high price of diesel but also due to unacceptable levels of fuel theft experienced by transporters: practical figures obtained from industry players indicate that this figure may be as high as 15 to 20 % of total fuel consumption if not more [4] [3]. At the same time those factors that cannot be avoided, like payload and route inclinations, must be properly accounted for when costing specific routes and trips to ensure that all routes and customers are serviced on a profitable basis; the alternative would be that some customers are unknowingly subsidizing others. Previous research in the field of fuel consumption modelling identified the primary factors that impact on consumption [5] [6] [7]. In order to restore the competitiveness of the African road transport industry it is therefore essential to find solutions, not only for efficient fuel management, but also for the effective prevention of fuel theft.

Figure 1 below displays a histogram of fuel consumption collected over more than 280,000 trips undertaken within the boundaries of South Africa. It can be seen that the consumption varies quite widely, from around 0.5 km/l up to more than 5 km/l. It is furthermore noticed that the statistical distribution seems to contain more than one mode, which is indicative of more than one independent underlying cause for the observed variations. The first mode centres around 2 km/l, which is generally regarded as the average consumption rate that should be expected for long haul road transport; the other is much higher at around 4 km/k, which seems unlikely to be caused only by normal factors. This provides additional motivation for a study of this nature.

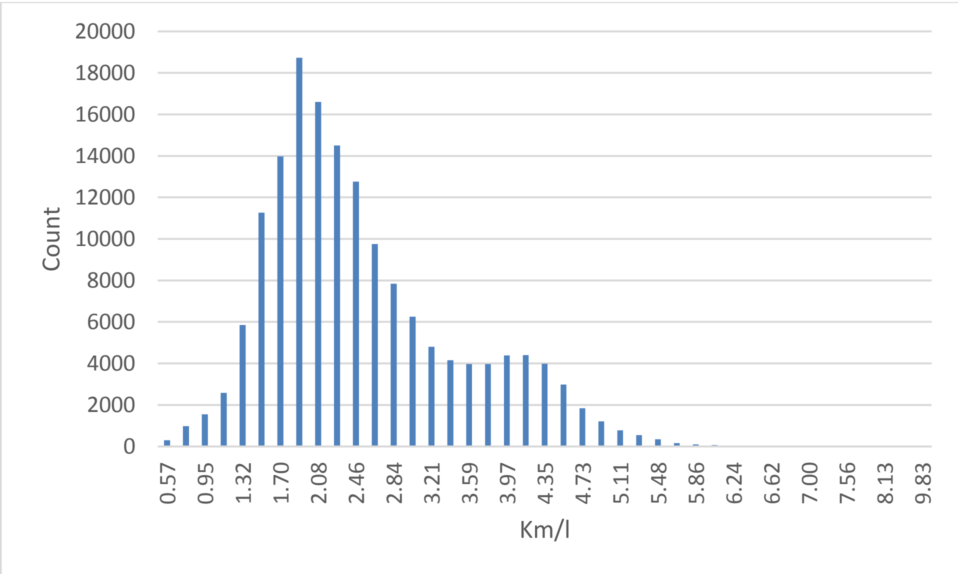


Figure 1 Histogram of fuel consumption over approximately 280,000 vehicle trips

Effective fuel management requires a system solution that can operate at different tiers: tier 1 comprises of sensing capabilities reflecting the current status of the vehicle and its fuel (e.g. GPS coordinates, valve open status, fuel tank level, etc.); tier 2 consists of local intelligence on the vehicle to collect and interpret sensor data and communicate with the home base if necessary (typically in the form of a tracking unit with different communications capabilities); tier 3 will be the management system that collects data from a number of vehicles and provides supervisory functions (e.g. for fuel consumption benchmarking).

In a previous paper we demonstrated that it is possible to deploy a telematics solution for improved road freight transport fuel management, and that with limited savings achieved (typically 1% of current fuel consumption) such a system will generate a positive return on investment, even if it requires the installation of new hardware for that purpose [8]. The obvious question from the perspective of a road freight transport operator is what level of improvement, compared against current fuel costs, can realistically be achieved should additional measures be imposed. The answer to this question will largely depend on the underlying causes for currently excessive consumption, and whether such causes could be eliminated. A variety of underlying reasons contribute towards non-ideal fuel consumption; these include driving practices (e.g. speeding), fuel theft, deviating from prescribed routes, excessive idling at points of loading and offloading, spending significant time in congested traffic and others. The identification of the actual reasons for excessive consumption and the quantification of the contribution of each is not a trivial problem to solve; even if a telematics system is in place that captures raw data related to fuel consumption the answers are typically hidden within stacks of collected data that still requires detailed interpretation.

The focus of our current research work is to create relevant benchmarks for fuel consumption that can be used by road freight transport operators to evaluate their own fuel performance. To achieve this objective we need to firstly quantify the actual fuel consumption for a sufficiently large number of trips over a representative set of routes within Southern Africa. This data set must include observations that cover all of the suspected primary determinants of fuel consumption as listed above. Secondly we must develop a methodology that can be applied to mine large sets of consumption data in order to identify the primary factors that explain differences in fuel consumption between different trips and to quantify the contribution of each. This will allow the realistically achievable improvements to be quantified and benchmarks to be created at levels that will challenge the status quo but that will still be practically achievable.

In this paper we describe the process that was followed to create a fuel consumption database and to categorize fuel consumption for different scenarios that represent the impact of some of the primary determinants of fuel consumption. We identify the obstacles that were encountered and that complicated the correct interpretation of the data, and describe the approaches and methods that we developed in order to overcome these. We then proceed to illustrate typical results that were obtained in terms of average consumption within specific categories, the difference in consumption between categories and the relative contribution made by each of a number of explanatory variables that impact upon fuel consumption.

The rest of the paper is structured as follows: section 2 details existing literature with relevance to our study, whilst section 3 provides an overview of the process that was followed to collect a representative set of fuel consumption data and section 4 describes the different routes that were covered by the available data set. In section 5 we draw a comparison between manually recorded refuelling figures and the consumption figures as collected by on-board vehicle sensors. We then proceed to investigate the impact of driver behaviour in section 6. Section 7 focuses on the impact of vehicle model on consumption, while section 8 describes a case study that investigates the impact of route inclination and payload. In section 9 we conclude and make recommendations for future research work.

2. LITERATURE STUDY

An investigation into fuel consumption in the commercial vehicle industry will be of value to both the logistics sector (from a cost reduction and performance management perspective) as well as for environmental agencies (from an emissions control perspective). It has been found that road transport is responsible for as much as 93% of carbon emissions in urban areas, while at the same time fuel costs represent between 25 and 40% of overall logistics transport costs [9]. From both perspectives the primary objective is to reduce the amount of fuel that is required to achieve a specific economic objective; in the case of the freight logistics industry this is the transportation of goods from points of production to points of consumption.

In order to pursue the above objective it is necessary to firstly identify the primary determinants of the fuel consumption of commercial freight vehicles (mostly trucks) when engaged in economic activities; the activities of all vehicles in the population must be sufficiently similar to those of other vehicles in the population to allow comparisons and the generation of performance benchmarks. Once all the primary determinants have been identified and their relationships with fuel consumption and emissions have been characterized it will be possible to develop a mathematical model that can be used in scenario analysis to study various possibilities towards improvement of the status quo. Previous research in the field of fuel consumption modelling identified the primary factors that impact on consumption [5] [6] [7]. These include vehicle engine type and size, payload, road inclination, wind strength and several others. In this study we focus on those factors that can be extracted from the available set of data reflecting the trip plans for a fleet of vehicles as well as their GPS tracking coordinates and fuel consumption per trip.

The determinants of fuel consumption can be broadly divided into three categories: vehicle specific attributes (those that determine the fuel efficiency of a specific model), the characteristics of the assignment to be completed (the route distances and inclinations and the times of day of week when goods must be delivered), and driver specific attributes (how effectively the vehicle is controlled by the driver and the accuracy of execution of the assignment by the driver). While each of these categories of factors have been studied separately before we could find no literature where factors from all three categories were studied collectively.

The first set of factors is fairly well understood as explained by [6] and many other research papers that focus on the fuel efficiency of different vehicle makes and models. The second set of factors have been studied from the perspective of characterizing the nature of commercial vehicle movements through the national and provincial road networks [10] [11]. It has furthermore been demonstrated that freight traffic can be simulated under different traffic conditions and policy measures [12]; such results can be combined with a fuel usage model to predict the amount of fuel that vehicles will use under different circumstances.

Other studies [13] derived personal trip data from GPS devices embedded into Smartphones; these techniques are however limited to the characterization of the movements of different sectors in the population without knowing the mode of transport that was used or the impact of behaviour on fuel consumption. While focusing on the establishment of models for vehicle movements in order to support traffic simulation models, the above studies did not address the impact of vehicle activity chains on fuel usage.

The third set of factors relate to the behaviour of truck drivers from a fuel efficiency perspective. Previous studies [8] have shown that within the African context not only inefficient driving styles but also illegal practices like the siphoning of fuel play a large role in determining the overall cost of fuel to the transport operator. While only some of these behaviours, like speeding and excessive idling, directly impact emission level they all add to the overall cost of the logistics operation, hence contributing towards the cost of goods delivered to the consumer [1][4].

3. OVERVIEW OF THE COLLECTION OF FUEL CONSUMPTION AND RELATED DATA

The purpose of our fuel usage data collection exercise was to ensure that we cover all the aspects to be investigated in this study. In order to simplify the process we started off with a fleet of approximately 400 vehicles that covers most of the major routes in South Africa. This would allow us to generate a significant amount of statistics on routes that include widely ranging inclinations (e.g. relatively flat from Johannesburg to Cape Town versus uphill and downhill from Durban to Johannesburg and back where passes over the Drakensberg range have to be crossed). This fleet also includes more than one vehicle make, allowing consumption of different engine designs to be compared.

As the primary long term objective of our research is the creation of a reliable set of fuel consumption performance benchmarks, it is important to collect data in a manner that support direct comparisons between different sets of data. This requires the available data to be subdivided into subsets per major routes that are covered. Different fuel performance levels can be expected to be achieved on different routes based on the number of expected stops, the likelihood of encountering congested traffic and the average incline. As the fleet of vehicles did not cover a defined set of standard routes the major routes had to be derived from the GPS tracking data itself. This is discussed in more detail in section 4 below.

Our initial focus was to reconcile fuel dispensed to vehicles according to refuelling records and fuel actually used by vehicles based on on-board sensing devices. For this reason we collected the refuelling records per truck over a period of one calendar year that covers all seasons, which is important as the road transport industry tends to be cyclic with peaks reached in the months leading up to the Christmas season, and a slump in business early in the new year. As the vehicles involved in the study are not always refuelled once per trip but as needed, we had to reconcile fuel dispensed with fuel used over periods of time than covered more than a specific trip.

The GPS tracking system used by these vehicles collects fuel usage data via the CAN bus system. While fuel usage is measured almost continuously by way of a flow meter, most of the installed units of this system were configured to only store and communicate the aggregate consumption as from when the engine was switched on until it was switched off again; this is done mostly to save on communication costs. The actual fuel usage reports were matched with the fuel dispensed reports by using the vehicle registration numbers that were present as vehicle identifiers in both lists.

It is important to also match trips with drivers, as driver behaviour is one of the primary determinants of effective fuel consumption, both in terms of driving skills and the tendency toward fuel shrinkage. In this case drivers were identified in two ways: in the trips plans drivers should be identified; this field was however missing for 44.8% of recorded trips. In addition drivers have to identify themselves by way of an ID tag that is inserted before a truck is started; this field was available for a larger fraction of trips (76.7%). The missing 23.3% may be ascribed to the fact that driver identification is not enforced on some vehicles, or can be overridden by a manager.

Another important aspect to take into consideration is the impact of route inclination on fuel usage. As could be expected fuel consumption is much higher on inclines compared to flat portions of the route; given the limit on the speed of a truck on downhill stretches this increased consumption level is not all made up on the downhill sections. In order to quantify the impact of inclines integrated over the entire route the inclines were extracted from Google maps by using the route descriptions as defined by the set of GPS coordinates representing each route [9]. While there may be other sources of inclination data the inclines obtained from Google maps were sufficiently accurate for the purpose of this work.

The final determinant of fuel usage that was investigated is payload. The load carried by a vessel has a major impact on its fuel usage over a specific route, specifically for routes that include steep inclines. The vehicles that were available for this study were however not always weighed before departure; we therefore had to use another approach to characterize the impact of payload for at least a subset of the total data set. For this purpose we analysed data on a two-way trip from a depot to a sugar mill where trucks travelled empty in one direction and full in the other. This allowed us to measure the impact of payload for the same set of vehicles.

4. IDENTIFICATION OF MAJOR ROUTES TO BE USED FOR COMPARISON PURPOSES

In order to achieve the objectives of this study it was necessary to identify routes that were regularly travelled by a significant number of vehicles and that would reflect the impact of all the major determinants of fuel consumption as identified above. As the number of locations where weigh bridges are present is quite limited it was decided to use the availability of a frequently visited static scale as one of the primary considerations in this choice. This would allow us to incorporate payload as determinant for fuel usage in the analysis, at least for a subset of vehicles that visited the weighbridge during the trip.

Table 1 below lists the Sanral weighbridges where vehicle from the fleet were observed from time to time; this list was compiled by searching the entire database of weighbridge data for the list of vehicle registration numbers present in the fleet. The most frequently visited weighbridge by fleet vehicles is Heidelberg just south of Gauteng on the N3 on the road corridor between Durban and Johannesburg; this is also known to be the busiest road freight corridor in South Africa. We therefore decided to firstly consider vehicles that use this route.

Table 1 Sanral weighbridges where fleet vehicles were observed

Site identifier	Name	Number of Occurrences
GAUTHEID	Heidelberg	1463
MPUMFARR	Farrefontein	700
KZNLMIDW	Midway	561
MPUMMDLE	Mid-East	555
MPUMMACH	Machado	523
KZNLMKON	Mkondeni	276
MPUMMDLW	Mid-West	138
MPUMKOMA	Komati	54
GAUTDONK	Donkerhoek	48
MPUMMDWT	Polokwane Zebediela	9

Figure 2 below displays the trip start positions for all trips included in the available data set. It can be seen that many of these are present along the N3 between Johannesburg and Durban, which confirms our choice. Figure 3 below displays the map for the N3 route as well as the elevation profile. It can be clearly seen that several steep inclines have to be mounted from Durban to Johannesburg; once the route has passed Harrismith it is relatively flat till the final destination is reached. For this route it will therefore be possible to characterize the fuel consumption over a relatively large sample of vehicles of which a percentage were weighed en route and that travelled across upwards and downwards inclines as well as flat sections.

We proceeded to refine the search for the most commonly used route by listing the loading and offloading points. Firstly we listed the most frequent loading points and selected from the list those that were in close proximity to the N3. For this most frequently visited loading point the list of most frequent offloading points were determined. In this way we identified the most frequently travelled single route from Redhill, Durban to Illovo, Johannesburg for which 323 trips were available within the available data set. We also identified the list of vehicles that had planned journeys between these points; 14 vehicles were identified that complete this route at least twice during the period covered by the data set.

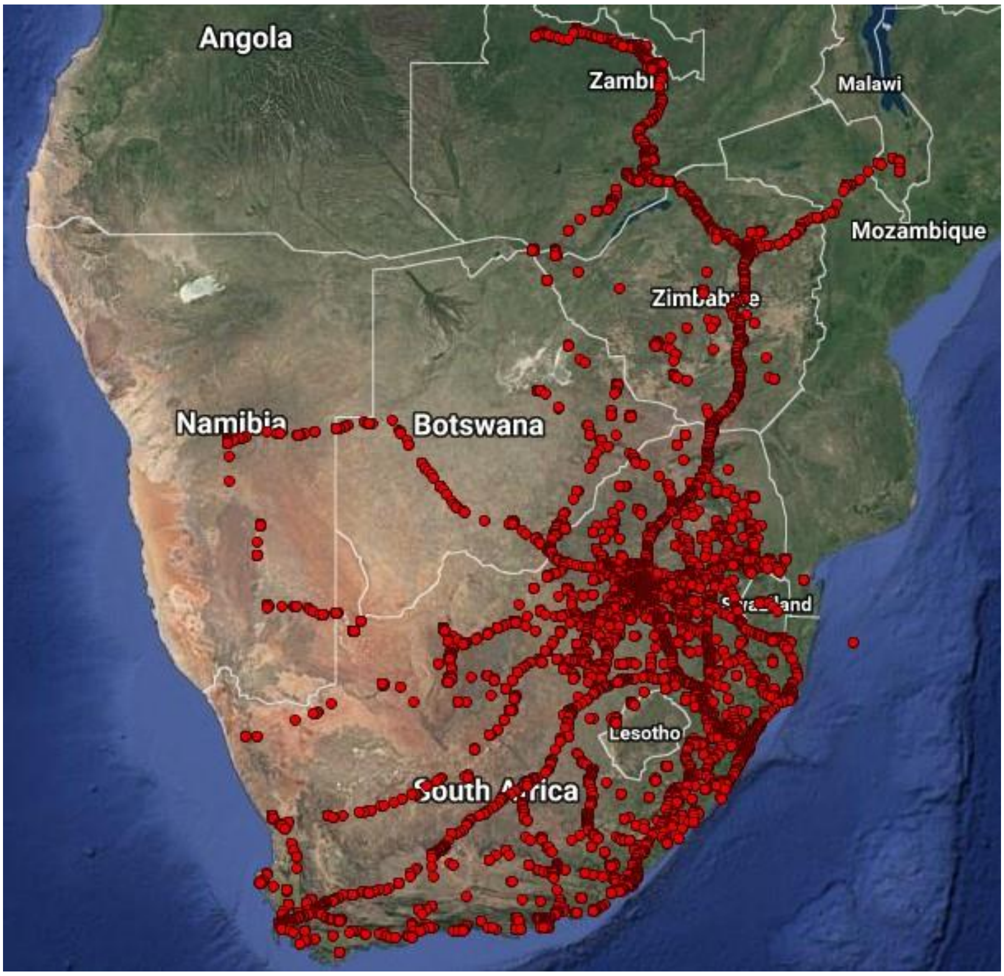


Figure 2 Trip start positions for all trips in the study

5. COMPARISON BETWEEN REFUELING AND FUEL CONSUMED FIGURES

As mentioned above, one of the primary objectives of the study was to compare fuel dispensed to vehicles against fuel actually used by the engine. This part of the investigation would serve several purposes:

- It can be used to calibrate the fuel flow gauges used inside the engines. It is quite possible that these gauges may have a calibration error which need to be corrected before the results can be used for comparison purposes. It can be expected that for a significant fraction of trips the fuel dispensed is correctly recorded. In such a case the fuel dispensed vs fuel consumed can be used to verify if the fuel usage gauge produced accurate results.
- It would indicate what fraction of fuel dispensed to a vehicle was not used in the engine – if both measurements were accurate it would imply that the remaining fuel was removed (in all likelihood stolen). Once it is known during which trips most fuel disappeared in this way it could be determined where trucks made unplanned stops that could potentially be associated with efforts towards fuel theft.
- It would indicate how accurately fuel dispensing records were maintained – if there are many cases where the engine used more fuel than what was dispensed to the vehicle based on fuel records it would imply that some records of fuel dispensed are not accounted for – this can potentially be correlated with the responsible driver to determine whether negligence played a role.
- If however the general tendency is for fuel dispensed to exceed the amount of fuel used by vehicles, and at the same time manually recorded distances exceed distances based on the automatically sensed odometer reading, it may imply that these records are deliberately manipulated to hide the fact that fuel is siphoned from the system and that recorded distances are overstated to show acceptable consumption figures.

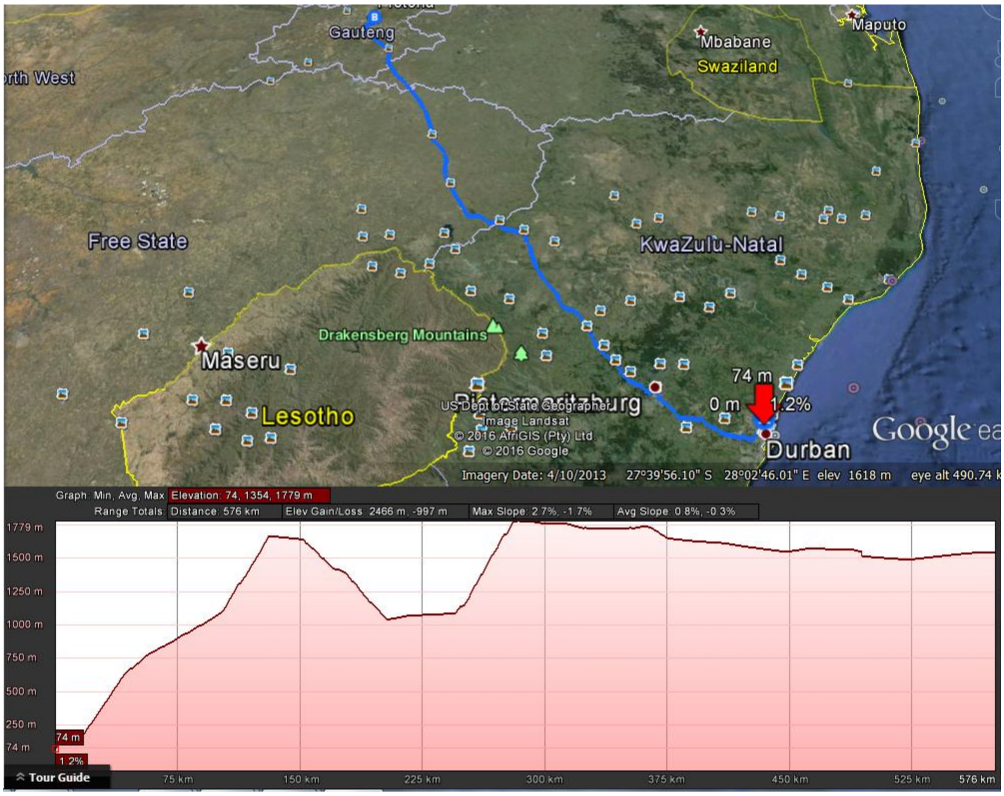


Figure 3 Map and elevation profile of the N3 Johannesburg-Durban route

The fuel records show that for the majority of trips vehicles are refuelled at the main fleet depot and that vehicles are most of the time filled up rather than partially refuelled. E.g. for one specific vehicle it was refuelled 137 times during the course of a year, 89 times at the main fleet depot with only 5 partial refuels. From the fuel records, which provide the date and time of the activity, and the GPS tracking data, it can be determined exactly where the fuel pump was located, as the vehicle had to be stationary for a period of time at this location.

In order to allow direct comparison between refuel and fuel consumption records we selected calendar periods during which vehicles always refuelled only at the main fleet depot, as this also corresponded with the end of the current trip and start of a new trip. Some instances of such comparison displayed discrepancies of up to 15% where the fuel dispensed was less than the fuel consumed – this indicated missing refuel records; this was confirmed by comparison of the distance logs as in the same case the vehicle odometer recorded a 19% longer distance covered compared to the distance extracted from the refuel records.

Two further case studies are displayed in Table 2 below for vehicles that were refuelled only at the main depot. OBC refers to information available from the on-board computer based on measurement of distance and fuel consumed made available via the CAN bus system of the vehicle [8] [9] [10], while manual corresponds to records maintained during refuelling of the vehicles.

Table 2 Case studies: refuel vs fuel consumed records

Item	Trip 1	Trip 2
Start date / time	2016-02-02 22:29:25	2016-02-01 09:55
End date / time	2016-02-04 14:44:21	2016-02-02 22:19
Distance travelled	905 km	1221 km
Fuel consumed	450 l	640 l
OBC distance / manual distance	99.8%	99.84%
OBC fuel / manual fuel	88.8%	100.82%

From the above experiment we can make the following conclusions:

- In all likelihood the good correspondence between distance covered and fuel consumed for Trip 2 provides proof of the fact that the OBC measurements are very accurate and that discrepancies due to faulty gauges are limited to a fraction of 1%.
- In the case of Trip 1 there is accurate correspondence between the distances but 11.2% less fuel was consumed than dispensed – in all likelihood this represents a case of fuel theft.

We performed a more complete comparison between fuel dispensed and consumed for a particular vehicle. In order to make accurate comparisons we excluded data where there were suspected missing refuel records. While some partial refuel records were encountered, this would average out over a sufficiently large number of observations. Table 3 below displays a comparison between OBC and manually recorded data over a full year of data.

Table 3 Comparison between OBC and manual fuel records over one year

Vehicle FMID	Refuel distance travelled (Km)	OBC distance travelled (Km)	Refuel fuel dispensed after trip (L)	OBC fuel consume d (L)	OBC Km / Refuel KM %	OBC L / Refuel L %	OBC vs Refuel accuracy %
1340	86 891.00	84 937.70	43 415.07	42 312.74	97.75	97.46	99.70

As can be seen from the above table, the refuel logs indicate that the vehicle travelled slightly further that the OBC recorded and that slightly more fuel was dispensed than consumed. This may indicate that some trips were not properly logged by the OBC, which will be investigated further. However, taking the ratio between the fuel dispensed based consumption rate and OBC fuel consumed based consumption rate (both in km/l) yields 99.70% correlation, indicating that good accuracy is being achieved in the fuel dispensed and fuel consumed categories.

Extending this to all vehicles, the average results over 148 vehicles are shown in Table 4 below. A few further conclusions can be drawn from this comparison:

- In general manually recorded distances are overstated; this may be to try and make up for dispensed fuel that was not consumed by the vehicle but stolen.
- Significantly more fuel is dispensed to vehicles than actually consumed by the engines; this difference is close to 20%.
- Even when accepting the possibly overstated distance travelled there is still a discrepancy of almost 10% between the fuel consumption rate in l/km between OBC and manually recorded fuel levels – this can be accepted as the minimum estimate for fuel shrinkage.

Table 4 Averages of comparisons between OBC and manual fuel records over 148 vehicles

Total refuel distance travelled (Km)	Total OBC distance travelled (Km)	Total refuel fuel dispensed after trip (L)	Total OBC fuel consumed (L)	OBC Km / Refuel KM %	OBC L / Refuel L %	OBC vs Refuel accuracy %
69 432.92	63 524.19	35 985.61	30 161.00	90.6	82.9	91.3

6. IMPACT OF DRIVER BEHAVIOUR

The results from the previous section show that major discrepancies exist between distances and volumes of fuel consumed as measured by the vehicle sensors and similar figures as recorded by drivers and fuel pump attendants during refuelling of vehicles. It confirms that driver behaviour, and more specifically manipulation of recorded figures by drivers, most likely in order to hide the siphoning of fuel, justifies more in-depth investigation.

For this purpose we calculated the following figures across all drivers and all routes:

1. The fuel consumption rate in km/l based purely on OBC measurements calculated over the full calendar year for each vehicle.
2. The fuel consumption rate in km/l based on manually recorded figures during refuelling events, for the same calendar period.
3. The fuel consumption rate in km/l calculated as OBC distance divided by dispensed fuel – this is a figure that in many cases will be used by transporters to determine their average fuel efficiency levels, should they use the aggregate odometer readings for the entire fleet over a year as well as the total fuel expense of the company.
4. OBC distance as fraction of recorded aggregate distance during refuel events, to provide an indication of the overstating of actual travel distances as recorded by drivers.
5. OBC fuel consumed as fraction of fuel dispensed, to provide an indication of the fraction of fuel dispensed but not consumed by the vehicle, i.e. the best estimate of the level of fuel theft.
6. Standard deviations for all of the above, to provide an indication if larger deviations occur within the manually recorded figures compared with the OBC recorded figures – if the manually recorded figures were manipulated it could be expected that larger deviations would occur within those sets of figures opposed to the OBC based figures, as it would be difficult to always siphon the same proportion of fuel between each refuel event.

These figures were calculated both as normal averages over all drivers as well as by weighting the contribution of each driver based on the OBC distance associated with that driver. The use of weighted averages will prevent large deviations that may occur within the figures for drivers that drove only small distances, from skewing the overall figures. We furthermore removed outliers that were beyond the 3 sigma limits and where the distance driven by that driver was very low, as it could be assumed that, in the case of drivers for whom only a few refuel events are available, one unintentional mistake in the recording of a refuel event can result in a totally unreliable figure. Amongst the 203 drivers 10 observations were removed for this reason; this represented approximately 5% of the total distance travelled by all drivers.

Table 5 Comparisons between OBC and manual fuel records over 193 drivers

	OBC Km / Refuel km %	OBC l / Refuel l %	Refuel based km/l	OBC based km/l	OBC km / Refuel l	Refuel km/l vs OBC km/l %
Average	86.027	81.516	2.010	2.117	1.723	95.211
Weighted Average	90.574	82.251	1.942	2.156	1.754	90.828
Standard Deviation	18.384	20.637	0.389	0.241	0.463	15.500
Variance	337.958	425.889	0.151	0.058	0.214	240.243

From the above set of figures we derive the following conclusions:

1. Distances travelled are overstated by approximately 10%, in all likelihood to hide the fact that fuel is siphoned.
2. Consumption in km/l based on recorded figures is 5% lower than actual consumption based on OBC figures - drivers claim, based on their own recordings, to achieve approximately 1.94 km/l, whereas the OBC average is 2.16 km/l. The trucks therefore actually perform better than claimed by drivers, the latter figures once again manipulated to hide the fact that fuel is removed from the system.
3. The consumption figure that the fleet owner will arrive at by only using overall distance travelled based on odometer readings and overall fuel paid for is even worse (1.75 km/l) than what is effectively claimed by drivers.
4. The argument that manually recorded figures are manipulated is strengthened by the standard deviation figures: for the OBC based consumption, which is mainly impacted by factors like route inclination,

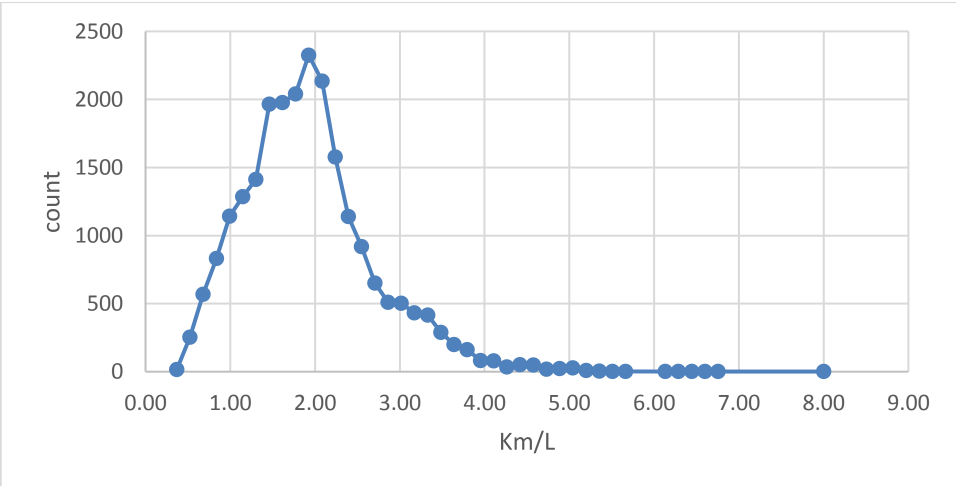
payload and idling times, the standard deviation is 0.24 km/l, whereas for the figure based on OBC distances and dispensed fuel the standard deviation is 0.46 km/l. For stochastic processes where different independent causes contribute to the same outcome, the relative importance of each are normally measured in terms of variances, as for normally distributed processes the total variance can be calculated as the sum of the variances caused by the contributing factors. If we therefore compare the variance within the OBC only km/l set with the variance where dispensed fuel is used, the latter has a variance that is between 3 and 4 times larger; differently stated the factors that should explain variance in fuel consumption in a system that is not manipulated (inclinations, payload, etc.) explain only 27% of the observed variation – the remaining 73% is caused by inaccurate recording and/or fuel theft.

5. For both normal and weighted averages the OBC fuel consumed is approximately 18% less than recorded fuel dispensed – this confirms that fuel theft is a significant problem, and that it is most likely the single biggest determinant of deviation between actual and ideal fuel cost.

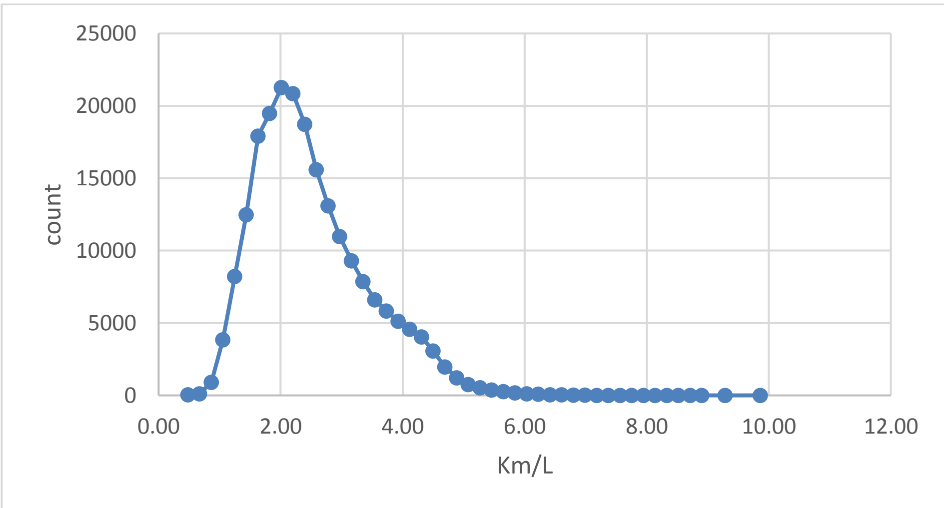
7. IMPACT OF VEHICLE MODEL ON FUEL CONSUMPTION

The choice of vehicle model is a further important consideration for transport operators as it is known that not all models perform equally well in all conditions. For this reason we separately calculated the average OBC based consumption of each vehicle model over all routes and all drivers. In Error! Reference source not found. **below we show the histograms of fuel consumptions for two different vehicle models. The average figures for a larger number of models appear in**

Table 6 below; we also show the number of trips over which the calculations were performed. A large difference can be seen for different models; this may be partly explained by the fact that different vehicle models may be used over different routes, a factor that has not yet been removed from these figures.



(a) Fuel consumption for Model 1



(b) Fuel consumption for Model 3

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Figure 4 Histograms of fuel consumption for different vehicle models

Table 6 Fuel consumption for different vehicle models

	Number of trips	Weighted Average km/l
Model 1	23140	1.76
Model 2	19876	2.53
Model 3	215611	2.51
Model 4	10206	3.07
Model 5	17952	2.62

8. CASE STUDY: IMPACT OF INCLINATION AND PAYLOAD FOR A SPECIFIC ROUTE

Section 6 and 7 provided evidence that factors that can be managed to reduce overall fuel consumption indeed play a very significant role. This does however not mean that other factors, including route inclinations and payload, should not be further investigated. In a system where the unwanted phenomena have been largely eliminated, these factors should be the primary determinants of fuel cost, and should therefore be used not only to measure the performance of vehicle models and driver proficiency, but also to correctly price each route and each trip based on actual cost.

In order to investigate the impact of inclination and payload a route was selected that displays large difference between inclinations between the two directions of travel, and where the payload also differed significantly as trucks travelled empty in one direction and fully loaded in the other. The route selected was the Pietermaritzburg – Noodsberg route where trucks moved between a sugar refinery and an offloading point for processed sugar. In Figure 5 below the inclination of the route is displayed, showing on average uphill from Pietermaritzburg to Noodsberg but with mostly empty trucks and downhill the other way but with loaded trucks.

When studying the routes travelled by trucks between these destinations is was observed that for a portion of the journey two different routes were used; for the purpose of the analysis only trips that took the most travelled route were included. When the average OBC based consumption was calculated for the two direction the rather surprising result was obtained that the unloaded trucks traveling mostly uphill on average achieved a figure of 2.14 km/l, while the loaded trucks traveling mostly downhill could only achieve 1.59 km/l – a difference of more than 25%. As these figures were not based on recording of fuel dispensed but purely on OBC measurements it could be assumed that they reflect the true average performance of trucks on these routes.

This provides evidence that factors such as inclination and payload do play a very significant role in fuel consumption and should be incorporated into a pricing model on a per trip basis. Should in this case different customers be serviced in each direction, and should the uphill leg have involved a larger payload compared to the downhill leg the applicable fuel consumption for each leg would have differed by an even larger amount than the 25% recorded above. Given that fuel cost represent approximately 40% of the overall cost of a road transport operation, and that margins are often only a few percent, the implication is that the differential fuel cost for each customer specific trip can make the difference between running at a healthy profit or a significant loss.

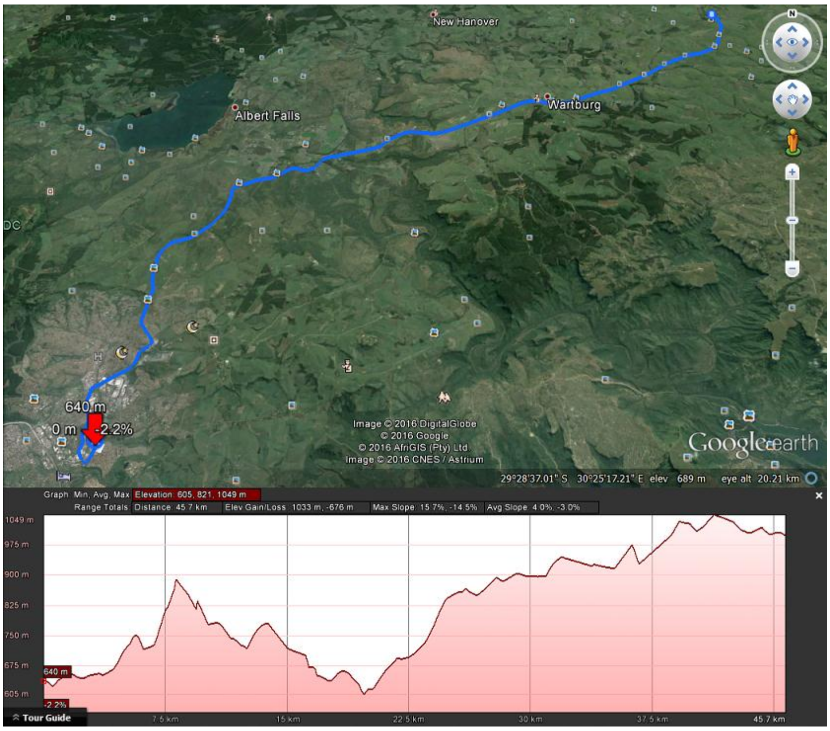

Figure 5 Map and elevation profile of the Pietermaritzburg - Noodsberg route

9. CONCLUSION

In this paper we investigated different factors that impact upon fuel consumption of trucks operated on a variety of routes around South Africa. Fuel consumption and related data was collected from a fleet of approximately 400 vehicles over a calendar year during which more than 280,000 trips were completed. We found that large discrepancies exist between distances travelled and amounts of fuel consumed as recorded by the on-board sensors of the vehicles versus those that were manually recorded. While some of these may be due to negligence, the errors are mostly skewed towards larger amounts dispensed than what the vehicles actually consumed. More detailed investigations into cases where deliberately introduced mistakes were most likely absent indicates that the on-board sensors produce errors of less than 1%, leaving us with the conclusion that in most cases where significant discrepancies occur the manually recorded figures are manipulated in order to hide the levels of fuel siphoning that appear to be present. Based on a comparison between fuel dispensed and fuel consumed it would appear that the level of fuel theft is approximately 18%, in line with estimated figures that were obtained from various industry players. This finding suggest the need to improve the level of control over the way in which fuel figures are recorded as well as improved measures to physically prevent fuel theft from vehicles. If these figures are calculated and reported to managers on a per trip basis it should be possible to act against the offenders immediately after the completion of a trip.

We further investigated other factors that influence fuel consumption, and found that vehicle model also has a significant impact, justifying current practices to select specific vehicle models for specific types of routes based on average inclination. It was also demonstrated that payload and inclination plays a big role and should be incorporated into costing models to determine suitable pricing for specific routes and for vehicles carrying specific payloads. The primary application areas for the results of this work would be the evaluation of the performance of truck drivers and of different truck models, as well as the accurate costing of trips based on a combination of the distance to be covered, the characteristics of the route in terms of inclination and rural vs urban, as well as the payload to be carried.

Further work will refine this study by determining the trips and geographical locations where most fuel siphoning appears to occur, and to match these incidents with suspicious stops that are made in unauthorized locations along such trips. This can provide further evidence of the prevalence of fuel theft and provide motivation for the implementation of additional preventative measures. Weights obtained from Sanral weighing scales will be combined with vehicle GPS and consumption data to determine the impact of payload on consumption for similar vehicle models on similar routes. Routes will furthermore be characterized in terms of their average inclinations and the results incorporated into a fuel consumption model that can estimate the expected consumption per route, supporting more accurate benchmarking of fuel efficiency and assisting efforts towards more accurate costing of specific routes.

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DEVELOPMENT OF A DECISION SUPPORT MODEL FOR AN OPTIMAL RUN, REPAIR OR REPLACE POLICY OF CAPITAL EQUIPMENT FOR A SOUTH AFRICAN RETAILER

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ABSTRACT

In this paper a methodology is presented for determining an optimal run, repair or replace policy for capital equipment in the retail industry. A decision support model is developed to assist the retailer's decision making process. The model incorporates both dynamic programming recursion and discounted modelling which assist in selecting the optimal sequence of decisions over a period of ten years which results in the lowest accumulated cost over the time period. A needs gap analysis is also performed to determine decision criteria currently not measured by the retailer.

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1. INTRODUCTION

The constant growth in the local retail industry has led both large and small South African retailers, to seek competitive advantages in order to minimise cost and maximise profits. Asset intensive retailers have recently identified that monitoring costs incurred with respect to capital equipment (CE) may lead to an increase in profits.

This paper originates from the need of a retailer with substantial investment in CE (such as generators, air-conditioners and refrigeration systems) to reduce expenditure in the pursuit of competitive advantage in their industry. Currently, the retailer's decisions to run, repair or replace (RRoR) CE are based on past experience and intuition. Since this decision making process is predominantly subjective, there is a likelihood that the current RRoR policy is not optimal with respectto minimum cost incurred and minimum time called. Decisions about CE should not be based on intuition but rather on scientific economic policies [3].

To improve the RRoR decisions regarding CE, this paper addresses the retailer's need for a decision support model (DSM). The objective of the (DSM) is to minimise resources (cost and time) invested by the retailer over the decision time horizon.

To successfully address the need of improved RRoR decisions certain assumptions are necessary in order to formulate a mathematical model for optimising the retailers RRoR policy. These assumptions delimit the scope of the project, but ensures focus on the intended purpose. The development of the DSM is subject to the following assumptions:

- The modelling only considers the decision to either run, repair or replace CE. As these are the decisions the retailer is face with when it comes to their CE.
- Explicit focus is placed on the *monetary value* of the CE with respect to the cost incurred by the retailer over the planning horizon. This assumption is made based on the goal of research done.
- The unit of measurement used in the DSM is years and a total time period of 10 years is considered. The measurement and period chosen is based on the preference of the retailer.

2. LITERTURE REVIEW

2.1 Capital Equipment Costs and Run, Repair or Replace policies

A RRoR policy is implemented by an organisation or by an individual to ensure optimal use of CE which is determined from the optimum economic life of the CE. The optimum economic life of CE, also known as optimum replacement age, is the time at which the total annual cost of the CE is at a minimum value [2]. In addition, the operating costs, as well as the purchase price of the new CE are required to determine the optimum economic life of CE [2].

Two errors should be avoided when determining RRoR policies:

1. Repairing or replacing the CE too soon, and
2. Repairing or replacing the CE too late.

These errors are avoided by making the right decision (whether to run, repair or replace) at the right time (period).

The outcome of making one of the two aforementioned errors is illustrated in Figure 2.1. Additionally, the figure depicts the influence that ownership, operations and fixed costs have on the optimum replacement age. These three costs add up to the total cost and the optimal replacement age is the pont in time when the total cost curve reaches it's minimum. In other words the optimum replacement age is where the gradient of the total cost curve is zero.

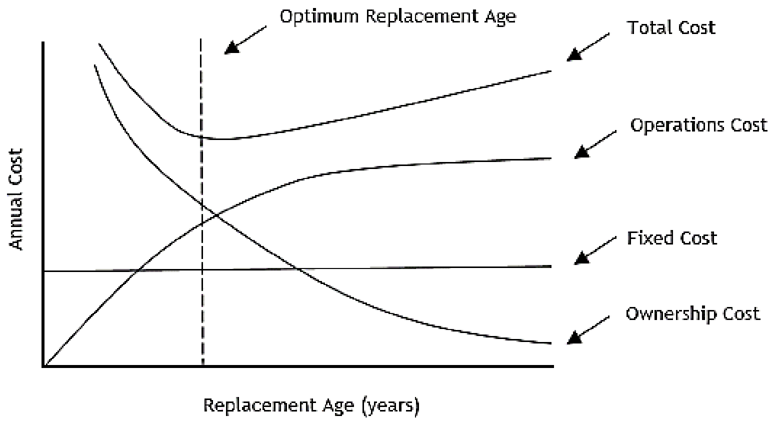

Figure 2.1: The classic economic life conflict of CE

Adopted from [2]

When the economic life of the CE increases, the operations cost per unit rises while the ownership cost decreases [2]. Ownership cost of CE is defined as the purchase price minus the resale value at the replacement time, divided by its economic life [2].

Operating cost consist of standing and running cost. In this paper standing cost is defined as depreciation and running cost is defined as maintenance costs.

Fixed cost is made up of costs such as insurance and licensing. These costs are omitted from the DSM development since these costs have no effect on the economic life of the CE due to it being independent of the age at which the CE is replaced.

2.2 Models for Determining Run, Repair or Replace Policies

Various models for determining repair or replace policies are available in literature. These models vary in application and complexity and include the *limiting maintenance cost*, *limiting accounting cost* and *historical data* models. Each of these models have its own limitations [12].

There exists a relationship between the cost of performing maintenance and the value of the equipment at any point in time [4]. Furthermore, a limit should be determined for the cost of maintenance, the so-called *limiting maintenance cost* model. If this limit is met or exceeded, no further repairs should be performed and the CE should be replaced [4]. This cost limit will become a lower value as the CE ages while the probability of replacing the CE will increase. The maintenance cost limit is not ideal for determining a RRoR policy due to the assumption that maintenance cost is a function of time rather than a function of utilisation [5].

The *accounting limit* model calculates an optimal point of replacement by taking the cost of maintaining the CE as well as the resale value into account [5]. The model considers the point in time where the cost of maintenance intercepts the resale value as the minimum cost point. This point is considered a suitable point for replacement and occurs where the total cost is at a minimum value [5].

The *historical data* model considers historical data for determining an optimal replacement policy [6]. By using historical data, the effect of the CE's age and usage can be determined. This model focuses on identifying a replacement policy that replaces the theoretical limits of ownership which are set initially. This model is applicable to both the age and utilisation of CE. For example, a retailer can set a policy (based on historical data) which states the CE should be replaced when it is five years old or when it has been in use for a specific number of hours or years. The outcome of this policy is dependent on which limit is reached first.

2.3 Factors Influencing Run, Repair or Replace Policies

Various studies and approaches have been documented suggesting factors which should be considered when approaching the critical issues of determining optimal RRoR policies. For the purpose and scope of this paper the following factors are considered: *resale book value*, *age*, *maintenance and repair* and *inflation*.

According to Jardine an Tsang [2] the *resale book value* of CE is a function of time and decreases as time increases. The actual income incurred from selling the used CE depends on the age, utilisation and the general condition of the CE.

The age of CE is an important factor to take into consideration with resale. The resale value of CE can be defined as the current market rate of the depreciated CE value.

The decision to replace CE cannot be accurately predicted and therefore making use of a repair limit should not be the sole indicator of the RRoR policy for CE. Estimates of the replacement time can be made based on the predicted routine maintenance costs. Nonetheless the instance of the occurrence and the costs associated with the non-routine maintenance cannot be predicted.

Inflation is known as one of the factors that cannot be controlled to achieve a desired result in the national economy. Inflation is taken into account when determining operating costs to ensure realistic overall cost is calculated over the specified time period. In general, investigations and calculations that incorporate in historical costs have to be adapted for inflation to provide reliable outcomes.

It is evident from the background information presented that the recording of appropriate data and the quality of such data are important considerations for determining a RRoR policy for an organisation's CE. As part of this case study a need gap analysis is performed to identify limitations in the data collection practices of the retailer at which the case study is performed, followed by the development of a DSM for the retailer.

3. NEED GAP ANALYSIS FOR AN OPTIMAL RUN, REPAIR OR REPALCE POLICY

A need gap analysis along with the principles of maturity modelling were used to identify data that are required for the RRoR DSM, but were not previously collected or measured by the retailer.

A need gap analysis is defined as a method of assessing the difference in current and desired performance [7]. The gap between the potential and actual performances is referred to as the area between "where one wants to be" (future state), and "where one is" (current state). Figure 3.1 illustrates the procedure for constructing a need–gap analysis [7]. The need-gap analysis consists of three steps:

1) Future state: Identify the objectives needed to be achieved.
2) Current state: Analyse the current state for each of the identified objectives.
3) Describing and bridge the gap: Comparison of the two states in order to identify gaps. If there are gaps, they are described together with specific solutions to remove the gaps.

In summary the three steps can be summarized as:

$$Gap = Future\ State - Current\ State$$

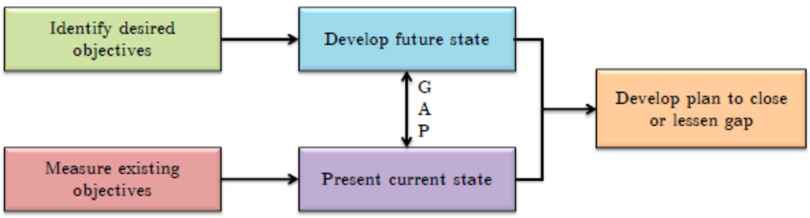

Figure 3.1: An overview of the three steps of constructing a need-gap analysis

Adopted from [6]

Maturity models are defined as: "descriptive stages through which systems, processes or organisation's progress evolve as they are defined, implemented and improved." [8]. Therefore, a maturity model is a method used to scale the maturity of the processes or areas of a business. The concept of levels is a fundamental building block of a maturity model. A level is considered as an extent, measure or degree of intensity [8], [9]. A maturity model consists of different maturity levels, which are used in this study to assist in identifying the different areas of improvement for closing the gaps which the need-gap analysis will reveal.

3.1 Constructing the Need-Gap Analysis

The ideal future state is identified by incorporating the factors that typically influence a RRoR policy and the objective of the model of minimising the resources (cost and time) invested by the retailer.

For this study, the analysis of the current state is performed by means of a questionnaire which the retailer completed. The questionnaire, shown in Figure 3.2, was created according to the procedure devised by Diem [9].

Gap analysis questions for Capital Equipment (CE)

Please complete the table of questions below by ticking the appropriate answers (Yes/No).

Questions	Yes	No
Maintenance Cost: costs incurred to keep an item in good condition and/or working order.		
1. Maintenance costs are tracked and documented on a monthly basis.		
2. Maintenance is done on scheduled dates.		
3. Maintenance is done based on CE failure.		
4. A work order is completed before maintenance is done.		
5. Unscheduled maintenance is documented (documentation of date).		
6. The date(s) of the scheduled maintenance are documented.		
7. The date(s) on which the scheduled maintenance are completed are documented.		
8. The costs incurred due to the parts/material needed to complete maintenance are documented.		
9. The labour costs incurred for completing maintenance are documented.		
Consequence Cost: costs incurred due to CE being replaced or idle.		
1. Replacement costs are tracked and documented on a monthly basis.		
2. Reason(s) for replacement is documented.		
3. Documentation is made of the date on which the replacement is done.		
4. Documentation is made of the date on which the replacement is completed.		
5. Cost of new CE is documented.		
6. The labour costs involved for the replacement are documented.		
7. Downtime costs are tracked and documented.		
8. The failure date(s) of the CE are documented.		
9. Documentation is made of the downtime period.		
10. Documentation is made of the production loss (costs).		
Repair Cost: cost of labour and material needed to fix the broken CE and get it to operate again.		
1. Repair costs are tracked and documented on a monthly basis.		
2. Reasons for repair(s) are documented.		
3. The repair period(s) are documented.		
4. The performance of the production of the CE is documented.		
5. The costs incurred due to the parts/material needed to complete the repairs are documented.		
6. The labour costs incurred for completing repairs are documented.		
Operating Cost: the cost incurred of working the CE.		
1. Operating costs are tracked and documented on a monthly basis.		
2. The costs of consumptions (e.g. oil and fuel) are documented.		
3. Operating costs are documented under descriptive/categorised headings.		

Figure 3.2: Need-Gap analysis questionnaire

With the questionnaire completed by the retailer, an analysis could be performed in order to determine the current state. This was done by means of a percentage scheme. For example, for each "yes" answer for questions one to nine of the maintenance cost section in Figure 3.2, a 11.1 percent contribution is recorded in the current state. This means that if the retailer answered "yes" three times, the current state is calculated as 33.3 percent compared the ideal future state which is represented by 100 percent. The same method is used for the consequence costs (10 percent per "yes" answer), repair costs (16.16 percent per "yes" answer) and finally the operating costs (33.3 percent per "yes" answer). As can be seen in the percentages, each section's answers are independent from the other sections, yet each section's final contribution is dependent on the individual questions within the respective section.

An example of a completed need gap analysis is shown in Figure 3.3. It can be seen that for the maintenance cost there is no gap and the current state meets the future state. This results in the fact that no actions are needed for further collection of maintenance related data. For the consequence, repair and operating costs there exist gaps between the current state and the future state. Actions are required to close these gaps. The amount of detail of the need-gap analysis is based on preference and may be altered to show more or less information. The consequence cost is broken up into replacement cost and downtime cost. This is done to provide more detail of where the gap is within the consequence cost.

Need-Gap Analysis				
Data Required	**Current State**	**Future State**	**Gap**	**Action needed**
Maintenance Costs:	100%	100%	No gap	No action needed
Preventative	20%			
Condition Based	0%			
Corrective	100%			
Consequence Costs:	-	-	-	-
Replacement Cost	0%	100%	100%	Process implemented and documentation needed
Downtime Cost	60%	100%	40%	Documented needed
Repair Costs:	40%	100%	60%	Documentation needed
Operating Costs:	0%	100%	100%	Process implemented and documentation needed

Cost Definitions	
Maintenance Costs:	costs incurred to keep an item in good condition and/or working order.
Consequence Costs:	costs incurred due to CE being replaced or idle.
Repair Costs:	cost of labour and material needed to fix the broken CE and get it to operate again.
Operting Costs:	the cost incurred of working the CE.

Figure 3.3: Completed Need-Gap analysis

Using the output of the need gap analysis, the input data required for developing the DSM is determined. In addition to, the actions needed to obtain the input data are also highlighted.

4. DECISION SUPPORT MODEL FOR AN OPTIMAL RUN, REPAIR OR REPLACE POLICY

A DSM was developed to determine an optimal RRoR policy for the retailer. The DSM incorporates dynamic programming recursion (DPR) and discounted modelling (DM).

4.1 Mathematical Model

DPR is used to determine an optimal RRoR policy. DPR can be used to solve optimisation problems [1]. In addition a DPR problem is said to be in a given *stage* that simply consists of all the possible *states* that the system can occupy.

The stages are defined as the different time periods *t*, *t+1*, *t+2*,...*t+9* and the states are defined as the different decisions being evaluated as shown in Figure 4.1.

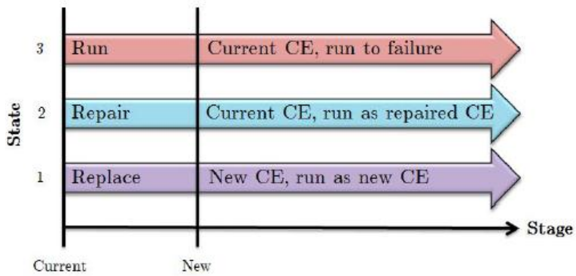

Figure 4.1:The Transformation of the evaluated states (decisions) over the different stages (current or new)

The application of DPR is aimed at finding the shortest, or longest, path which joins two points in a network [1]. This means that the shortest, or longest, path is determined by comparing the lengths of the paths. With the objective of minimising costs incurred and time spend, the shortest path will result in the optimal solution. Each decision made has an impact on the path, thus each decision should be compared to one another for the optimal sequence of decisions to create the shortest path.

A model for the optimal replacement interval of CE with the objective of minimising total discounted costs are used for developing the DSM, and are formulated as 4.1:

$$f_t(n) = min\begin{Bmatrix} \frac{A_c r^i + \sum_{i=1}^{n} O_i r^i}{1-r^i} & \ldots run \\ \frac{(R_i + A_c) + \sum_{i=1}^{n} O_i r^i}{1-r^i} & \ldots repair \\ \frac{(A_c - S_i + A_n) r^i + \sum_{i=1}^{n} O_i r^i}{1-r^i} & \ldots replace \end{Bmatrix} \quad (4.1)$$

where A_c is the initial acquisition cost of the current CE. A_n is the initial acquisition cost of the new CE. O_i is the operating and maintenance costs, r is the discounting factor, R_i is the repair cost at time i and S_i is the resale price of the CE at time i.

4.2 Using the Decision Support Model

The DSM was developed in Visual Basic for Applications (VBA) in Microsoft Excel. The model consists of three sheets which are available to the user. The worksheet labelled "READ ME" informs the user of all constraints and requirements regarding the DSM, as shown in Figure 4.2. Figure 4.3 shows the worksheet labelled "Historical Data". This worksheet allows the user to submit historical data (costs incurred) of the considered CE for the different time periods. It is intended that this worksheet be updated with historical data when such data becomes available. Finally, the optimal RRoR policy is displayed in the worksheet labelled "RRoR policy" as depicted in Figure 4.4.

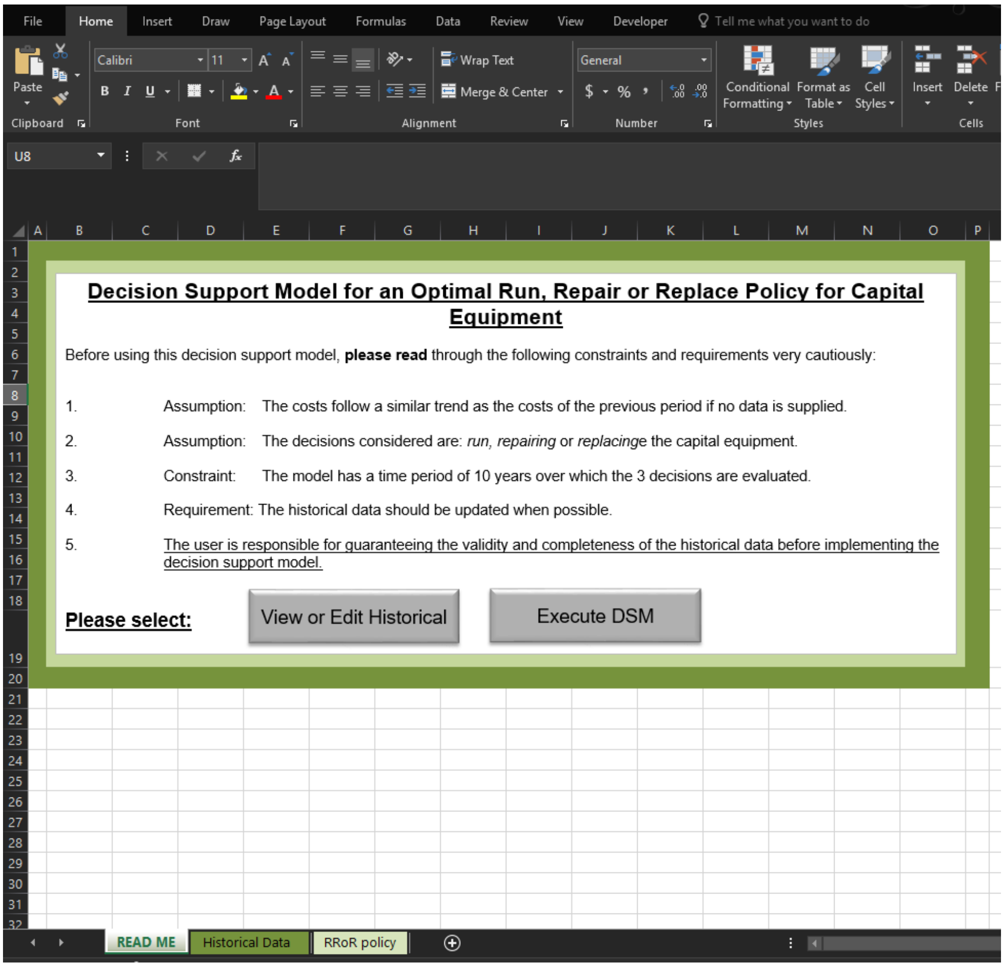

Figure 4.2: The general layout of the first worksheet labelled "READ ME" related to the DSM

4.2.1 Assumptions, Constraints and Requirements

Some assumptions, constraints and requirements were considered during the development of the DSM. The assumptions pertain to the costs incurred and the decisions considered in the DSM (Figure 4.2). Due to the limited amount of historical data available (which was identified through the need-gap analysis), it is assumed that new CE incurs costs following a similar trend as in the past. This trend can be rationalised if more data becomes available or when updated costs are recorded in the model. The second assumption considers the decisions evaluated as shown in Figure 4.4. The decisions evaluated are to run, repair or replace the CE. The number of states (decisions) at each stage (point in time) increases with a factor of the state to the power of stages. In other words, the number of decision routes considered at each point in time is calculated as the three to the power of the point in time. For example, in year two; 9 decision routes are evaluated. The DSM is developed to compute an output of infinite periods, however, Microsoft Excel does not have the capacity to compute decisions for periods of more than 10 years. Up to the tenth year 59 049 ,(3^{10}) possible decision routes are evaluated for the optimal RRoR policy.

Users should first familiarise themselves with the assumptions, considerations and requirements to ensure they understand these before attempting to use the DSM. After reading the sheet labelled “READ ME”, the user may choose to either submit data or execute the DSM algorithm.

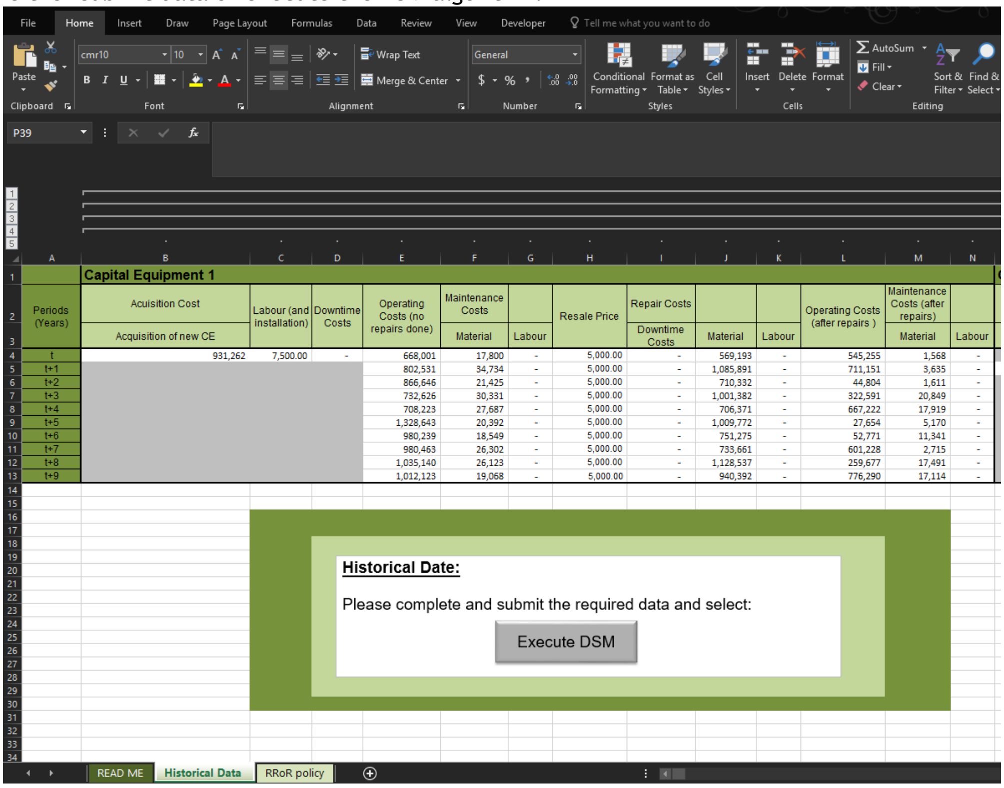

Figure 4.3:The general layout of the first worksheet labelled "Historical Data" related to the DSM

4.2.2 Submitting and updating Historical Data

The user can:

1. Update/enter data in the worksheet and execute the DSM, or
2. View the data and then execute the DSM.

Figure 4.3 shows the data required for the execution of the DSM for determining an RRoR policy.

Table 4-1: The data required for the DSM

Acquisition Costs This cost can entail purchase price of new CE, installation costs, downtime costs and even commission.
Resale Price This is the price at which the CE will be sold.
Repair Costs The costs incurred to repair a component or components of the CE.
Operating Costs Two forms of operating costs are needed, the first are operating cost if no repair is done and the second is operating costs after repairs are done to the CE.
Maintenance costs These costs can comprise of material and labour. As with the operating costs, two similar forms of maintenance costs are also required.

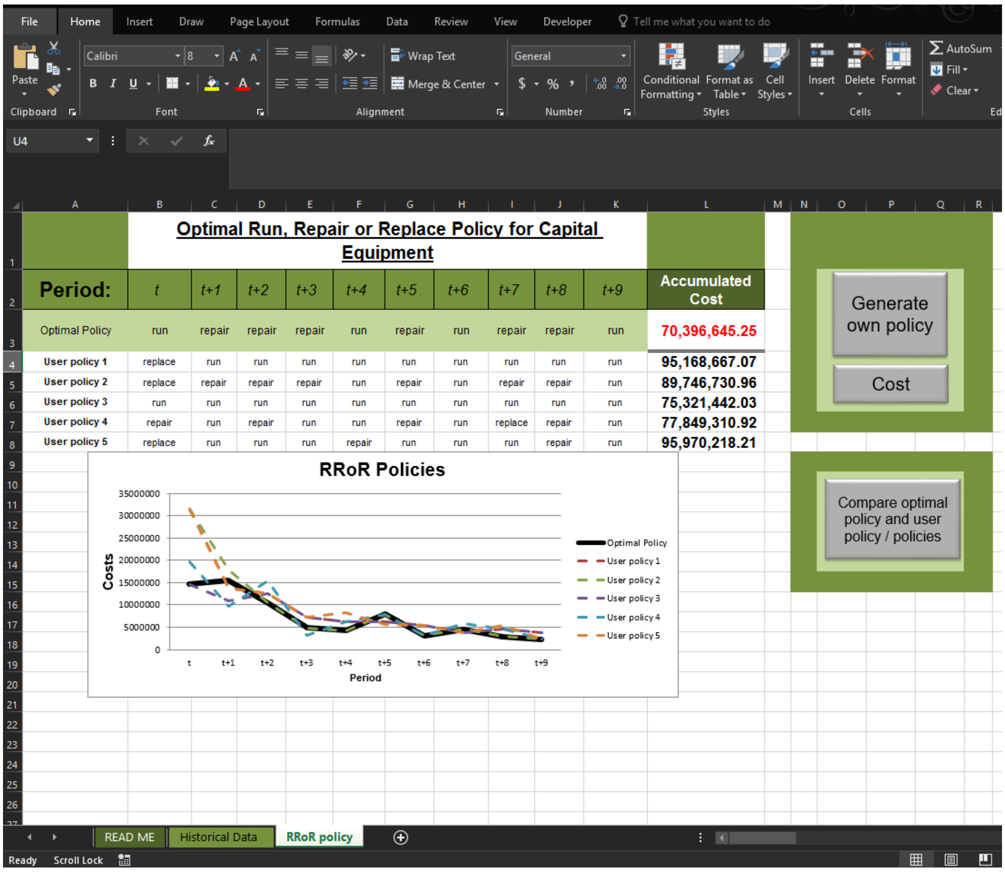

Figure 4.4:The general layout of the first worksheet labelled "RRoR Policy" related to the DSM

4.2.3 Output of DSM

The optimal RRoR policy as determined by the DSM is presented in the worksheet labelled “RRoR policy”, as shown in Figure 4.4. Additionally, the user is given the option to alter the decision at the different periods. The impact of these alterations is shown in the form of a graph created by the DSM (shown in Figure 4.4). The user may create up to 10 custom or user RRoR policies. After the user has generated the custom policies, a graph is created facilitating comparison between the optimal and custom RRoR policies. The optimal RRoR policy is shown in black and the custom policies in various colours (Figure 4.4).

The DSM was validated by means of face validation and a hypothetical case study. The face validation was performed in the form of a questionnaire completed by the involved retailer. The effectiveness of the DSM was judged through the following questions to the retailer. Following the questions, the responses given by the retailer are presented.

1. **Considering the methodology developed to determine an optimal RRoR policy for CE, what is your opinion on the potential of the DSM developed?**
   - *“The DSM has potential, but the heavy dependence on data makes the DSM cumbersome and unlikely to be used in practice.”*
   - *“Significant improvements in data capturing will need to be made for the model to successfully determine a replacement strategy.”*
   - *Although the DSM has many favorable attributes, in the short to medium term there is little probability that the model could be employed successfully.”*
2. **In your opinion what are the strong points of the DSM developed?**
   - *“Ability to handle exception price scenarios. The model can be run for a cheaper unit available immediately.”*
   - *“The model has flexibility in that users can generate their own policy and compare the costs to that of the optimal solution. This will be useful in instances where future cash flow restrictions are known, or refurbishments are scheduled and down time can be minimized.”*
3. **In your opinion what are the weak points of the DSM developed?**
   - *“The DSM is data intensive.”*
   - *“There is not an option to compare similar types of equipment with one another.”*

- *"The DSM does not consider depreciation."*

4. **Please comment on the following aspect of the DSM by giving a rating of 1 to 4; 1 being *poor*, 2 being *fair*, 3 being *good* and 4 being *very good*:**
   - Graphical modelling approach: *"2"*
   - Presentation of results: *"3"*
   - Asset management and retail terminology used: *"3"*
   - Model consistency: *"2"*
5. **Base on the comments given previously, in question 4, how do you think it is possible to improve the DSM for determining an optimal RRoR policy?**
   - *"Expand the model to compare different types of equipment."*
   - *"Simplify the model by reducing the data requirements."*
   - *"Increase the processing speed of the model by either reducing the computational expense, or use computing methods to improve the calculation speed."*
   - *"Include reliability considerations."*
6. **Please comment on the overall impression of approach to solving the optimisation problem (determine what decision to take at each period in time) presented by the student.**
   - *"The model provides an interesting perspective on the run, repair or replace decision."*
   - *By being able to view the decision at discrete points in time in offers flexibility and facilitates modification of the optimal strategy based on the company's needs."*
   - *"However, the strong theoretical basis of the solution with multiple decisions in the future makes the model fairly complex to unpack."*
   - *"Finally due to the lack of actual data, it is difficult to gauge the validity of the decisions."*

Insufficient data was available to test DSM at the retailer, therefore a hypothetical case study is created to assess the validity of the DSM. The cost incurred in the hypothetical case study are justifiable as the retailer assisted in formulating this case study along with the assumptions made regarding the CE. The assumptions made with respect to the case study is tabulated in Table 4-2.

Table 4-2: Hypothetical case study assumptions

1. CE Considered A 600KVA generator with a prime rating set at 70%
2. Downtime Cost It is assumed that the installation and repairs are done after trading hours which means the retailer does not incur any downtime costs.
3. Acquisition Costs (installation of new CE and commission) Installation costs consists of ZAR 5,500 for delivery and rigging plus ZAR 2,000 for commissioning when a new generator is installed.
4. Resale Price The generator is sold for its value in kilograms of metal. This value is assumed at ZAR 5,000 plus inflation.
5. Repair Cost The most severe failure that occur is motor failure. The assumption is made that if a part of the generator would fail and repair is needed, this would be the motor. The motor will be replaced While the alternator and switchgear will not be replaced. It is assumed that ZAR 569,193 is incurred when the decision to repair is considered at a point in time.
6. Operating Cost It is assumed that the cost for operation is ZAR 668,001 for period t.
7. Maintenance costs (Repair Cost) An annual service period of t is required, at a cost of ZAR 17,800 which is incurred for maintenance.
8. Interest Rate The average interest rate is assumed to be 9% for the period t to $t+9$.

The resale price for the case study is constant throughout the full time frame and is only influenced by the average inflation. The installation costs, maintenance costs, operating costs and repair costs for periods $t+1$ to $t+9$ for the second to tenth generator considered for repairing or replacing is created by means of a Microsoft Excel random number generator.

The output of the model with the input data given as detailed for the case study is depicted in Figure 4.4. The optimal RRoR policy for the case study for the time period t to $t+9$ is to run, repair, repair, repair, run, repair, run, repair, repair and finally run for the respective points in time with the total incurred cost being ZAR 70,396,645 as seen in Table 4-3. This is a table of the results displayed in Figure 4.4.

Table 4-3:Optimal RRoR policy generated by DSM along with five user policies with total incurred cost per policy

Period	t	t+1	t+2	t+3	t+4	t+5	t+6	t+7	t+8	T+9	Incurred cost (ZAR)
Optimal	run	repair	**repair**	repair	run	repair	run	repair	repair	run	70,396,645
User 1	replace	run	**run**	run	run	run	run	run	run	run	95,168,667
User 2	replace	repair	**repair**	repair	run	repair	run	repair	repair	run	89,746,730
User 3	run	run	**run**	run	run	run	run	run	run	run	75,321,442
User 4	repair	run	**repair**	run	run	repair	run	replace	repair	run	77,849,310
User 5	replace	run	**run**	run	repair	run	run	run	repair	run	95,970,218

Five other user policies are considered and none deliver a lower accumulated cost than the optimal policy produced by the DSM.

5. CONCLUSION AND RECOMMENDATIONS

Determining an optimal RRoR policy is not a trivial task. Alternative decisions need to be considered, while ensuring the final decision is optimal. This decision is influenced by various factors which differ from retailer to retailer and are determined by the retailer's business objectives.

Each CE group exhibits its own unique trends and relationships when it comes to cost incurred over a period of time. This is due to different operating conditions and maintenance strategies. It is important to take these conditions and strategies into account when designing a RRoR policy. To account for these variations a run, repair or replace decision is required to be considered at the end of each period. The DSM makes provision for evaluating each decision made at each period, then selects the sequence of decisions with the lowest accumulated cost over the total time period.

In order to select the decision with the lowest cost, quality data is needed. Good quality data will ensure a higher degree of accuracy and reliability.

The need gap analysis identifies the data required for the model. As part of the study the retailer completed the need-gap analysis for determining how readily available the required data is from industry asset owners. The results of the need-gap analysis show that only some of the data is available. The problem is not so much the collection of data but rather the type of data which are recorded. Emphasis is placed on the financial aspects of CE and not on the condition, utilisation and lifetime data of the CE. Although only one need-gap analysis was performed it is expected that similar limits exist in the wider retail industry.

The following limitations are associated with the DSM in its current format and should be considered in the future use of the DSM:

- The DSM is dependent on the quality and availability of the historical data. Assumptions would need to be made if the required data are unavailable. If the quality of the data is poor, the optimal RRoR policy produced by the DSM would be compromised.
- The user of the DSM needs to have a basic understanding of RRoR policies and what they entail in order to interpret the computed results.

It is important to be aware of these limitations when using the DSM or when making run, repair or replace decisions.

The following recommendations should be considered for future research in the field of RRoR decision making:

- *Investigate other factors.* The factors investigated in this project are resale book value or resale price, age, maintenance and repairs and inflation. It may be useful to investigate decrease in value of CE over time (depreciation), as well as the reliability of the CE.
- *Additional features.* Currently the DSM does not include the option to compare similar types of CE for the lowest acquisition costs. Investigating and incorporating this may lead to a different optimal RRoR policy to be derived with a lower accumulated cost.
- *Limitations.* Investigating the limitations (DSM dependency on quality data of the DSM and user having a basic understanding of RRoR policies) may decrease the limitations of the DSM and create more opportunities for the application of the DSM.

Researching and investigating these recommendations will lead to the improvement of the DSM and consequently more opportunities and assistance in run, repair or replace decision making.

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EVALUATING LEAN IMPLEMENTATION IN SOUTH AFRICAN CASTING FOUNDRIES

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ABSTRACT

Manufacturing companies implement lean to enhance their competitiveness and meet the ever changing demands of the globalized markets. Literature suggests that when lean tools are correctly implemented, companies experience better productivity, improved worker morale and profits. However not much research has been done to evaluate lean implementation and the identification of best practices. This research paper evaluates and studies the implication of lean implementation in South African foundry environment.

Multiple case studies were carried out to evaluate lean implementation. These case studies involved a survey, where questionnaires were distributed to the foundries. The study focused on lean tools, techniques and strategy that companies adopt in the implementation of lean. The research showed that foundries have introduced lean manufacturing. The results revealed that foundries benefit from lean implementation. Some of the noticed benefits were improved quality, production, profitability and customer service. Barriers that hindered lean implementation were weak top management involvement, poor worker attitude and the non-availability of adequate resources.

This paper contributes to the body of knowledge in lean philosophy. To lean practitioners the paper highlights some of the critical factors that needs to be monitored for a successful lean implementation.

Keywords: Manufacturing, lean tools, lean implementation, foundry and productivity.

1. INTRODUCTION AND BACKGROUND

In today's competitive environment, companies are required to enhance their operations and strategically implement and design procedures which assist in improving product quality, reducing costs and improving delivery performance, [1]. Many industries have increasingly used lean manufacturing in order to improve performance, although, lean techniques were initially applied only to industrial operations, [2]. Womack, [3], describes lean as the most powerful tool available for creating value while eliminating waste in any organization. The implementation of lean tools has a significant impact on various industries, [4]. Lean tools have potential in assisting productivity improvements and reducing waste, [5]. According to Forbes and Ahmed, [6], manufacturing industries have greatly improved their competitiveness through the use of lean methods. Studies by Womack, [3], reveal that other organizations that have implemented lean manufacturing successfully have gained a competitive advantage. However, there are pitfalls for organisation's that attempt to use this powerful strategy without a thorough knowledge and understanding of the critical success factors of lean, [1].

Lean production emerged in the automobile industry, [1]. It originates from the Toyota Production System, [7]. The Toyota production system provides the basis of what is known as lean thinking by Womack, [3]. Many companies envy the way Toyota does its production, [1]. The Toyota system is really about growth and profit, [1]. Consequently, the successes of lean manufacturing principle were never questioned because Toyota had taken control of the market share in automobile production, [8]. A serious weakness with this argument, however, is that if lean is such a powerful approach and Toyota models it so well, why is it that few organizations are able to implement lean successfully. This implies that few companies succeed in the way Toyota did, [1].

The aim of lean production is to reduce waste using several tools and techniques. Different organisations have implemented lean manufacturing; therefore, lean principles can be applied in any industry, [5]. The key problem with this statement is that is it possible to apply lean in various industries where the traditions are different, [9]. The latter point has been critiqued by Womack, [3]. However he argued that it is essential to try. Chakravorty and Atwater, [10], defines lean manufacturing as "a philosophy, strategy or concept that depends on a set of practices or tools that are implemented to minimize waste in order to improve company performance".

Casting foundries in South Africa are challenged by highly regulated energy intensive processes, [11], however, there have been several investigations into reducing energy consumption. Lean tools and techniques have proven to be effective in improving casting foundry sustainability. As the foundry industry is an industry where efficient production and environmental impacts are strongly linked, Torielli and Abrahams, [11], suggests that foundries can become economically and environmentally sustainable businesses with the systems approach offered by implementing lean. He further suggested that, in an operation industry like casting the purpose of implementing lean is to reduce the production cost thereby eliminating non-value adding activities. Foundry plants which are small, medium and large in size should also be a place for lean implementation, [7].

Foundries in general face various barriers in lean implementation. Several authors have highlighted various barriers faced by foundries such as: top management and workers resistance, [12]; [13], lack of resource availability, [14]; [15], cultural differences, [16]; [17], lack of clear communication, [17], lack of top management involvement, [16], [18], lack of formal training for managers and workers, [14], [19]. These challenges are the motivation of this study.

Although success factors indicate that lean intervention in South Africa organisation has been successful, [1], literature suggests that many organisations are however finding that lean implementation is not easily achieved, [20]. Kanakana,[8], cited in Vermaak, [1], stated that, more than half of South African companies that have tried to implement lean have not even reached the standard of industry average. Some organizations adopt lean operations principles either as defensive strategy to stay competitive or as an offensive strategy to move ahead of competitors, [21].

This paper evaluates lean implementation in 3 casting foundries. Consequently in an attempt to eliminate non-value adding activities within the casting process, the paper investigates barriers faced by local foundries when implementing lean.

1.2 Research Objectives

The objectives of this research are:

- To evaluate how South Africa (SA) foundries have implemented lean.
- To identify lean tools that can help the foundries eliminate waste.

1.3 Research Questions

The research study seeks to answer the following questions:

- To what extent has SA foundries implemented lean?
- What are the barriers to lean implementation?
- To what extent has foundries benefited from lean implementation?

2 Literature Review

2.1 The Concept of Lean

Lean is a concept comprising a set of principles, practices, tools and techniques which, when implemented by following a systematic approach would improve resource utilization, quality and delivery with respect to products and services, [6]. It is a production philosophy which considers that any activity which consumes resources but not create value for the end customer is wasteful and therefore should be eliminated, [3],[13].). Consequently, lean production was developed in the 1950's to eliminate waste, [22], [1]. Waste in this context refers to overproduction, waiting time, excess inventory, defective goods or any other factor that can disrupt the even flow of goods along the transformation process, [23]. Lean production has an underlying philosophy that, by eliminating waste, quality can be improved and costs reduced, [22].

2.2 Lean Manufacturing Tools and Techniques

Lean manufacturing is carried out through a set of lean practices, [5]. The implementation of these tools and techniques identifies the elimination of numerous wastes which exists, [24]. In order to reduce waste lean manufacturing tools and techniques should be employed, [1]. The foundation of lean manufacturing includes the following tools and techniques:

5S

- This tool is a systematic method for organizing and standardising the workplace, [25]. It's one of the lean simplest tools to implement, [21]. The activities are (1) Sort out (2) Set in order (3) Shine/Cleanliness (4) Standardize (5) Sustain, [24].

Kanban

- A kanban system is an information system that controls the required parts at the required time, [5].

Kaizen

- Kaizen is the Japanese name for continuous improvement and it is central to lean operations, [17]. It is the process of identifying and eliminating wastes as quickly as possible at the lowest possible cost, [24].

Continuous improvement

- Continuous improvement can be defined as the planned, organized and systematic process of ongoing, incremental and company-wide change of existing practices aimed at improving company performance, [15].

Work Standardized

- Operations are organized in the safest, best known sequence using the most effective combination of resources, [24]. The job is broken down into elements.

Value Stream Mapping

- Value stream mapping is employed to identify the areas that need to be improved and to decide the wastes to be eliminated, [2], [5]. It provides a graphical flow of the process and supports the related value stream analysis tool. It also provides the scope for the project by defining the current and future states of the system, [24]. [5], agrees that, it facilitates a communication flow from customer to supplier and a resource flow from supplier to customer.

Total Productive Maintenance

- Total Productive Maintenance (TPM) is a maintenance program, which involves a newly defined concept for maintaining plants and equipment. The goal of the TPM is to increase production, increase employee morale and job satisfaction, [26].

Total Quality Management

- This is a management system used to continuously improve all areas of a company's operations, [2].

2.3 Barriers in Lean Implementation

Implementing lean manufacturing is not an easy task for any organisation, [18]. Despite the benefits from lean manufacturing, however, many companies are not successful in implementing lean, [27]. According to Jadhav et al., [12], numerous problems and issues regarding the implementation of lean manufacturing has been reported.

In general foundries face barriers in lean implementation. Several authors have highlighted these barriers as, [12], [18], [27]:

Top management and workers resistance

- The primary reasons for resistance are often a lack of clarity and uncertainty of the change, pressure and the challenge to learn something new, [28]. Furthermore, resistance from employees might be due to the fear factor of losing their jobs as Lean implementation eliminates non-value adding activities, [13].

Lack of formal training for managers and workers

- According to Miller, [29], the aim of training is to impart new knowledge, skills and attitudes on employees for the sole purpose of performance improvement. This was supported by Houshmand and Jamshidnezhad, [30], who reported that lack of training hampers the improvement process. Miller, [29], further argues that training must enable workers to adapt to the fast changing global competitive environment. Eswaramoorothi et al., [14], suggested that a lack of lean training in foundries leads to low levels of successful lean implementation.

Cultural differences

- The cultural barrier introduces challenges in implementing lean techniques, [9], [12]. Hines et al., [31], maintains that while organizations have introduced lean techniques relatively easily, they still find it difficult to achieve the organizational culture and mindset that provides the foundation of lean. Robinson and Schroeder, [9], reported that the workforce is usually difficult to engage in creating a culture of lean improvement. However, culture is deep-seated and difficult to change, but leaders can influence or manage an organization's culture, [12]. Respectively, defining lean culture is important in foundries.

Lack of top management involvement

- For any organisation to succeed in lean implementation, top management must take full responsibility in empowering all employees in lean activities. Lack of commitment may lead to limited access to resources, lengthy decision making processes and communication breakdowns, [32].

Lack of resource availability

- Lack of resources (financial, technical, and human) is a common barrier for implementing lean, [15]. According to Tracy, [23], some organizations avoid implementing lean as they believe that they do not have sufficient resources to invest in a lean program.

Lack of clear communication

- In foundries, employees need to be properly informed of the changes that are being implemented, [17]. Barriers to communication may lead to the termination of a lean project, [32].

2.4 South African Foundries

A foundry is a factory that produces metal castings from either ferrous or non-ferrous metals including copper, brass, bronze, aluminum, zinc, lead, nickel, and all their various alloys, [33]. They offer services such as, mould-making, melting, pouring, heat treating, surface cleaning and other finishing operations. Many foundries also offer welding and assembly services to achieve semi or finished products ready for use by customers or other manufacturing operations.

The Executive Director of the Aluminum Federation South Africa reported that, the foundry sector is one of the foundation stones for all manufacturing and tool and die making. About 80% of manufactured products have castings in them. Yet, South African foundries have been in decline for more than a decade, though there are still some centers of excellence, [34]. The local foundry industry has been earmarked as one of the manufacturing sectors with a significant potential for growth, in both the domestic and export markets. However, the South African Institute of Foundry men (SAIF) believe that growth opportunities for the industry lie in embracing technological development that will create new market opportunities.

The South African foundry industry is predominantly made up of small to medium sized companies. According to a study by National Foundry Technology Network, [35], smaller foundry companies that employ less than 100 people comprise 80% of the South African foundry industry. Foundries serve many markets and industries, including automobile, construction, agriculture, forestry, mining, pulp and paper, heavy machinery, air craft, municipal services, military, railroad, chemical processing and energy production. Hence a study on casting foundries' productivity improvement using lean methods is relevant for the South African economy.

3 Methodology

A case study methodology was adopted for this paper, [36]. The case studies focused on three Casting Foundries in South Africa. The case study consisted of a mixed methodology which included a detailed literature review on lean implementation, a mini-survey with a structured questionnaire and some interviews. From literature a questionnaire on lean implementation was adopted from the work of Mehta et al., [16], Wan and Hou [37] and Akugizibwe and Clegg [38]. The questionnaire focused on evaluating lean implementation in South African Casting Foundries by examining factors such as tools and techniques, strategies and barriers in the foundries. The questionnaire employed a 5 point Likert scale ranging from strongly disagrees to strongly agree. A copy of the questionnaire is attached as Appendix 1. An analysis of the lean implementation is discussed below. The analysis was done through a comparison of agree and disagree as shown in the analysis graphs. The respondents included managers, production supervisors and shop floor workers of the three studied foundries. The responses were analysed as percentages of disagree and agree.

4 Findings and Discussion of Results

A total of 18 questionnaires were distributed amongst managers, production supervisors and shop floor workers of the three casting foundries. 18 responses were received and used for analysis, Company A had 5, Company B had 7 and Company C had 6 responses respectively. 3 managers from the three foundries were interviewed. The results obtained from the research is presented in this section. All the data was grouped together and graphs were drawn showing the percentage of those who agreed or disagreed with the lean implementation themes covered in this paper: aims of implementing lean; tools and techniques used in implementing lean; strategies used to engage staff in lean projects and progress made in implementing lean. The data was used to analyse lean implementation in casting foundries.

4.1 Aims for implementing lean

Aims for implementing lean in the casting foundries were identified as cost reduction, quality improvement, customer satisfaction, quality improvement and reduction in lead time respectively. For example on cost reductions 17 responses, which gave 95 % as indicated in figure 1, agreed that cost reduction was achieved through the attempts made in removing the 7 wastes, [24]. All three foundries indicated a reduction of lead time that was achieved through improved manufacturing planning and the implementation of quality management systems. These efforts have had an effect of improved customer satisfaction, [26], and increased worker motivation, [15]. Information given by the three managers through interviews indicated that there was improvement in production due to quality improvements and cost reductions.

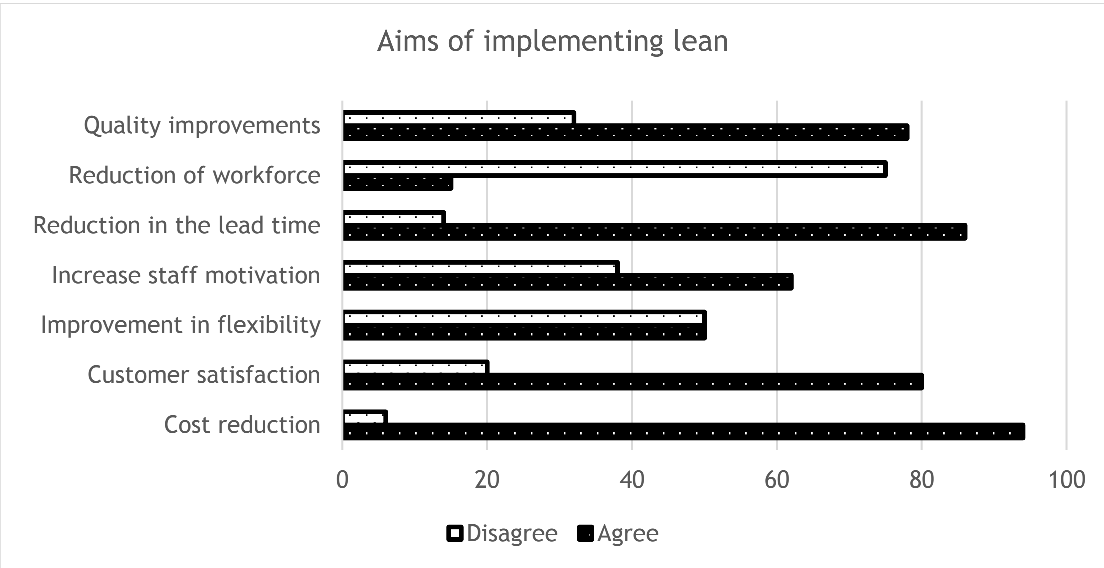

Figure 1: Aims for implementing lean

4.2 Tools and techniques used during implementation of lean

The foundation of lean incorporates set of tools and techniques into the business process. Vienazindiene and Ciarniene, [25], further stated that, these tools and techniques lead to improvement in five dimensions. These dimensions are elimination of waste, continuous improvement, continuous flow and pull-driven systems, multifunctional teams and information systems, [25].

The results in the figure below show effective tools and techniques that assists casting foundries in their sustainability. The most common tool used in the casting foundries was Kaizen, followed by Total Quality Management and Workplace Organisation in third place. Kaizen appears to be very significant. Mehta et al., [16], reported that "Kaizen can play a leading role in making lean process a successful one as it helps the organization to meet the challenge of doing more with the same or fewer resources". Interviews revealed that the casting foundries are also using other quality management tools in their plants other than lean tools. The managers indicated that they were familiar with quality improvement tools such as check sheets, Pareto, cause and effect diagram and both variable and attribute charts.

TQM implementation has helped management to deliver on organisational goals, targets and strategy. Worker empowerment was noticeable during the study period's visits to the foundries. This empowerment has improved team work, communication and commitment to organisational transformation. All the foundries are using fact based decision making through the appropriate use of data collection and analysis methods. Barriers to TQM implementation were avoided through education and training. Study interviews indicated that worker suggestions are now an acceptable norm by management. 5S has improved all the foundries workplace organization.

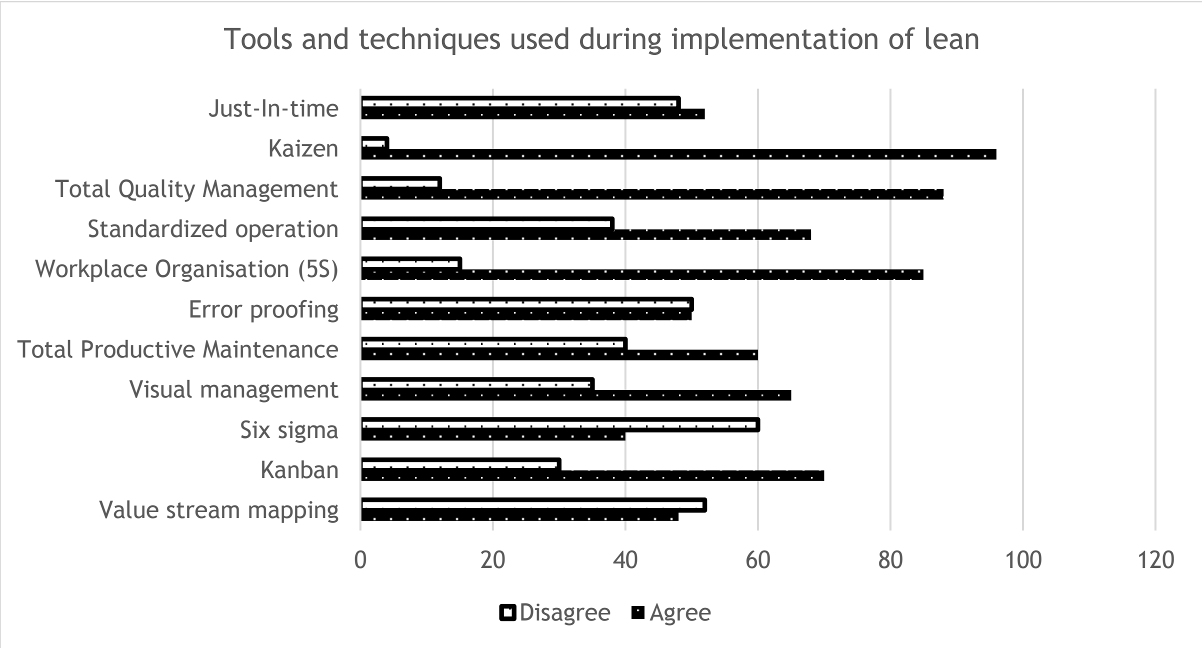

Figure 2: Tools and techniques used during implementation of lean

4.3 Strategies used to engage staff in the lean project

Lean manufacturing can be described as bundles of practices, [25]. It engages people in the act of continually increasing value creation. Hence, all production employees must work together. The most strategies which were used in the casting foundries to engage staff in the lean project were emphasis on training and skill building, employment engagement in identifying solutions and incentives. Through interviews, the research established that before lean implementation efforts, employees were not properly empowered to make contributions to their working environment. Lack of empowerment causes risks such as lack of morale, [29]. This has a negative impact on the lean project success. Interviews revealed that the staff was exposed to sufficient training and to appropriate lean education. Incentives of production bonuses served as a motivation to the adoption of lean in two of the studied foundries. Training that was offered to workers improved their knowledge, skills and attitudes. This helped in process improvements efforts. Training and skills building helps subordinates to understand their responsibilities, authority and accountability, [19], as they contribute in achieving the objectives and goals of the organization, [3].

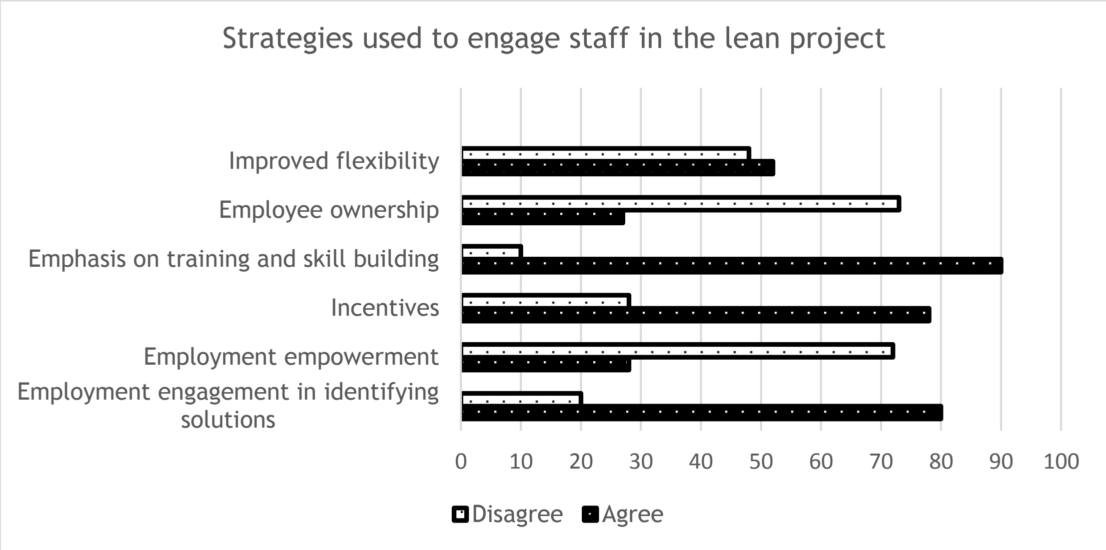

Figure 3: Strategies used to engage staff in the lean project

4.4 Progress made in implementing lean manufacturing

The study highlighted the progress that has been made in implementing lean in casting foundries. According to the empirical research conducted by Vienazindiene, [25], statistics shows that the most significant progress is seen in areas such as return on assets, on time delivery, machine availability, machine set up reduction, reduction in floor space and inventory reduction. The managers reported that the cycle time improved and lean implementation has been beneficial for their casting foundries.

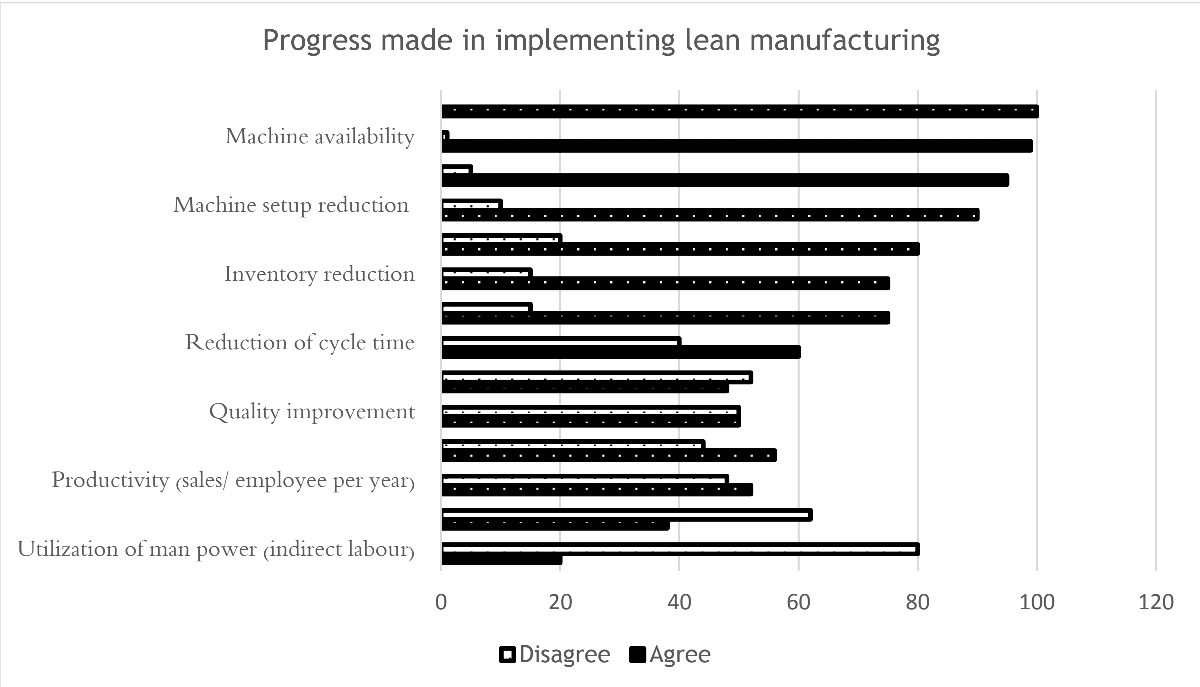

Figure 4: Progress made in implementing lean manufacturing

4.5 Barriers of implementing lean manufacturing

The barriers which were noted as preventing or delaying lean manufacturing implementation are shown in Figure 5. Barriers may differ depending on the sector of economy and specific company; however, 90% of the responses indicate that the main barrier was backsliding to old ways of working, [25]. This may be caused by the fact that, it was hard for employees to adapt to the new system and procedures. The managers indicated that the lean philosophy must be clearly understood before implementation and there must be ongoing commitment from both employees and management. The managers also indicated that lean project funding was a major constrain. They reported that the funding was not always adequate and undercapitalization of projects is a risk. Wan and Hou, [37], reported that undercapitalization was due to inaccurate cost estimates and exchange rate variability. The research also established that some of the resistance to changes was caused by lack of clear communication. This may lead to termination of lean project. However sustained efforts in education and skilling reduced the impact of most of the barriers.

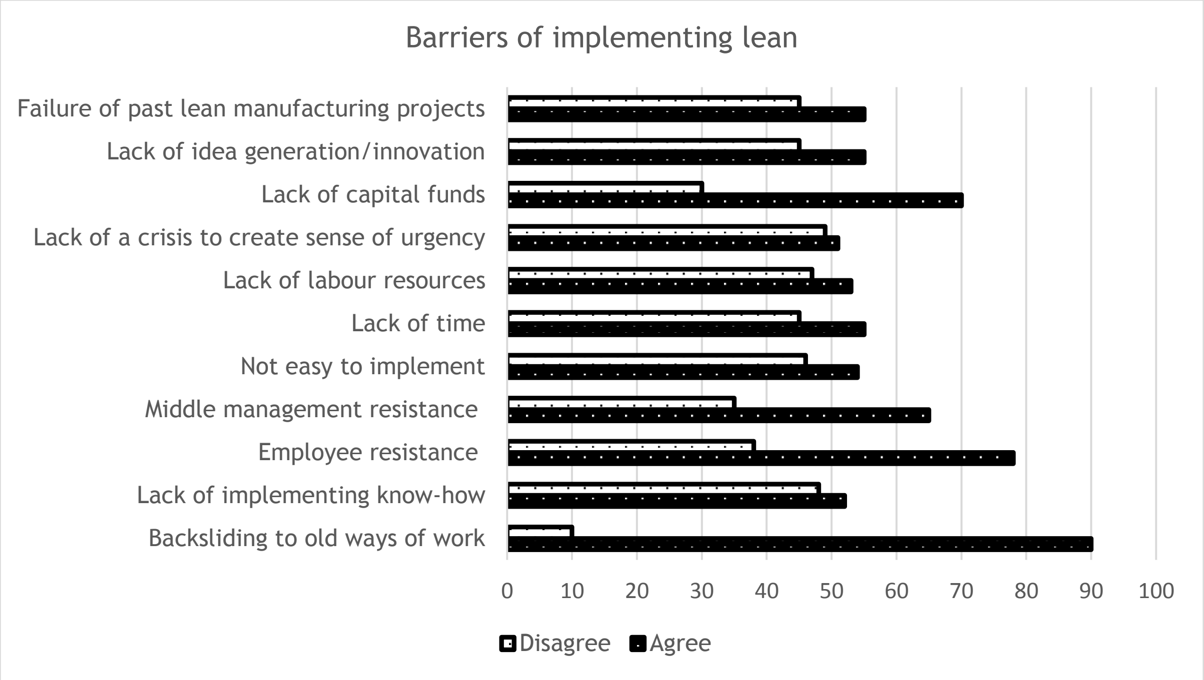

Figure 5: Barriers of implementing lean

5 Conclusion

The success of lean implementation can only be achieved through people's efforts. It is the people that bring the concept of lean to life. The interaction between top management and workers is important. All production employees must work together to eliminate waste. Senior managers in Casting Foundries were encouraged to directly involve and motivate all staff and provide necessary resources in the training and implementation of lean. Lean is a long-term process which includes many difficulties and requires commitment and resilience. Hence, senior managers were also encouraged to create the right conditions that assist openness and transparency that will result in good team building and better cohesion of team members. The research found that, the rate at which lean techniques are implemented depends on the circumstances of individual foundries, however, the most significant progress seen in both Casting Foundries were reduction of production costs which increased profitability and the development of employees and work environment. This proves that the lean concept can be applied in the casting foundry industry, thereby improving productivity.

6 Limitations

Only three casting foundries were studied making it difficult to genaralise these results. Financial figures before and after lean implementation were not obtained for analysis, hence detailed analysis of business results was not done. The effect of new technology and impact of new product development were not part of this study, but all these could give different results.

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APPENDIX 1

LEAN QUESTIONNAIRE

EVALUATING LEAN IMPLEMENTATION IN SOUTH AFRICAN CASTING FOUNDRIES

The purpose of this study is to evaluate Lean implementation in South African Foundries. This questionnaire will gather information on how South Africa (SA) foundries have implemented lean.

The information provided will be used for research purposes only.

1. AIMS OF IMPLEMENTING LEAN

What were the main aims for implementing lean? On a scale of 1 – 5, kindly indicate by inserting X against the level of importance of the lean project implemented.

Scale: 1-Strongly disagree;

Cost reduction	1	2	3	4	5
Customer satisfaction improvement	1	2	3	4	5
improvement in flexibility	1	2	3	4	5
Increase staff motivation	1	2	3	4	5
Increase staff contribution in decision making	1	2	3	4	5
Reduction in the lead time	1	2	3	4	5
Reduction of workforce	1	2	3	4	5
Quality improvements	1	2	3	4	5

2. TOOLS OR TECHNIQUES USED TO IMPLEMENT LEAN

What tools and techniques were used during the implementation of the Lean? Please indicate the tools and techniques which were either used or not used during the lean project implementation.

Value stream mapping	1	2	3	4	5
Kanban	1	2	3	4	5
Six sigma	1	2	3	4	5
Visual management	1	2	3	4	5
Total Productive Maintenance	1	2	3	4	5
Error proofing	1	2	3	4	5
Workplace Organization (5S)	1	2	3	4	5
Standardized operation	1	2	3	4	5
Total Quality Management	1	2	3	4	5

Kaizen	1	2	3	4	5
Just-In-time	1	2	3	4	5

3. STRATEGIES USED TO ENGAGE STAFF IN THE LEAN PROJECT

What strategies were used to engage staff in the lean project? Kindly indicate your rating by inserting a number of your choice from 1 to 5 as guided by the scale below how successful they were.

Employee engagement in identifying solutions	1	2	3	4	5
Employee empowerment	1	2	3	4	5
Incentives	1	2	3	4	5
Emphasis on training and skill building	1	2	3	4	5
Employee ownership	1	2	3	4	5
Improved flexibility	1	2	3	4	5

4. PROGRESS MADE IN IMPLEMENTING LEAN MANUFACTURING

What progress has been made in implementing lean in your organisation? Kindly indicate your rating by inserting a number of your choice from 1 to 5 as guided by the scale below how successful they were.

Utilization of man power (indirect labour)	1	2	3	4	5
Reduction of defects per year	1	2	3	4	5
Productivity(sales/employee per year)	1	2	3	4	5
Increase in the current capacity	1	2	3	4	5
Quality improvement	1	2	3	4	5
Utilization of man power(direct labour)	1	2	3	4	5
Reduction of cycle time	1	2	3	4	5
Delivery lead times	1	2	3	4	5
Inventory reduction	1	2	3	4	5
Reduction in floor space	1	2	3	4	5
Machine setup reduction	1	2	3	4	5
On time delivery	1	2	3	4	5
Machine availability	1	2	3	4	5
Return on assets	1	2	3	4	5

5. BARRIERS OF IMPLEMENTING LEAN MANUFACTURING

What have been the main barriers of implementing lean manufacturing in your organisation? On a scale of 1 – 5, kindly indicate by inserting X against the barriers of implementing lean manufacturing in your organisation.

Backsliding to old ways of work	1	2	3	4	5
Lack of implementing know-how	1	2	3	4	5
Employee resistance	1	2	3	4	5
Middle management resistance	1	2	3	4	5
Not easy to implement	1	2	3	4	5
Lack of time	1	2	3	4	5
Lack of labour resources	1	2	3	4	5
Lack of a crisis to create sense of urgency	1	2	3	4	5
Lack of capital funds	1	2	3	4	5
Lack of idea generation/innovation	1	2	3	4	5
Failure of past lean manufacturing projects	1	2	3	4	5

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TECHNOLOGY TRANSFER TO UPCOMING COMMERCIAL – COTTON FARMERS IN THE MAKHATHINI REGION

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ABSTRACT

Abstract - Makhathini Farmers have produced cotton for over 10 years at subsistence level despite utilizing related technology extensively; the farmers' mission remains to produce cotton at commercial level. The technology mentioned in the study is available worldwide, as well as locally. The technology accessed is readily available to the local farmers. Against the above background the research problem was formulated as: "How is technology deployed to upcoming commercial - cotton farmers in the Makhathini region to support sustainable cotton production in this specific area. A stratified random sample was drawn from the upcoming commercial - cotton farmers based in Makhathini. To ensure representivity of data and to allow the researcher to generalize findings to upcoming commercial - cotton farmers in South Africa, factors such as farm size were considered. Representatives of 13 Famers' Associations were interviewed and a response rate of 13/13 (100%) was obtained. The findings indicate overwhelming utilization of technology by the farmers. Yet an issue that is unresolved is why farmers are not producing at a commercial level despite the aid of technology. Cronbach's Alpha is an instrument used to measure reliability. Calculating alpha has become widespread practice in comparison to other index of reliability. The alpha was used in SPSS programme.

'n Profiel van die katoen tegnologie gebruik in die Makhatini streek word aangespreek in die navorsings artikel. Die fokus van die artikel is gerig op die mate van ondersteuning beskikbaar aan die boere in die streek. Die klein boere in die streek verbou katoen die afgelope 10 jaar. Die verbouing van katoen is meer gerig op oorlewings boerdery maar dit is ,n oogmerk van die boere om in die toekoms katoen op ,n komersieële vlak te verbou. Die tegnologie waarna verwys word in die artikel is globaal sowel as plaaslik van toepassing in die verbouing van katoen. Die tegnology is vrylik beskikbaar aan die boere in die streek. Gestruktureerde onderhoude is met boere van 13 plaaslike Boere Verenigings gevoer. Die navorser het daarin geslaag om n 100% reaksie behaal met vraeluste se beantwoording. Die bevindinge dui daarop dat boere in die streek tegonologie gebruik in die verbouing van katoen. Die onbeantwoorde vraag is dan waarom die verbouing van katoen nie op n komersieële vlak plaasvind nie. Cronbach se Alpha kofficient instrument was gebruik om die betroubaarheid te meet. Dit is algemene gebruik in navorsing om die Cronbach Alpha aan te wend om vergelykings vir betroubaarheid te toets. Die Cronbach Alpha was gebruik deur middel van die SPSS program.

Key words: Accessibility of technology; adoption of appropriate technology; technology diffusion theory and transfer.

1. INTRODUCTION

The literature review will focus primarily on types of technology available in the cotton industry in South Africa. Comparison will be made of technology used in different countries. Modalities of technology transfer, Challenges or obstacles to utilizing technology faced by cotton farmers, and support mechanism for the formation of sustainable small and medium-sized for farmers to reach fully commercialized business will be outlined.

Cotton farmers in the South African Development Community, including the South African cotton farmers, face a common problem having to compete internationally. The advent of free-trade resulted in countries like China and India taking advantage of the market gap that exists

Cotton S.A has revealed its plans to support upcoming commercial - cotton farmers to produce 30% of the South African crop by 2014. Verryne[19], reports on ARC-IIC a five-point plan that has been drawn up:

- to familiarize upcoming commercial - cotton farmers with the nature and characteristics of cotton plant;
- to demonstrate best practice for farming management;
- to device a practical method of transferring information to all the farmers even if they are illiterate;
- to prepare the incumbent farmers with the basic knowledge for second level training which involves Sector Education and Training Authority courses in cotton cultivation and management Verryne[20] adds that farmers should be encouraged to move away from subsistence cotton farming to commercialize cotton farming.

2. THEORETICAL FRAMEWORK

This chapter will focus on theories that seek to explain the reason for utilizing technology within the context of upcoming commercial - cotton farmers among whom the empirical study was conducted. The results of the study conducted indicate that the farmers use technology, yet they are still farming at subsistence level. The theories will include among others: Theory of technology; Classification of technology; Framework for adopting technology and Comparative cotton technology. Application will be drawn from the following countries: United State of America, China, India, and South Africa.

2.1 THEORY OF TECHNOLOGY

Rijk[15], states that the need to improve agricultural labour productivity has in recent years become a forceful reality. Even more so, mechanization of agricultural labour productivity impacts on various aspects, namely:

- increased labour productivity where labour is substituted by machinery to facilitate cultivation of a larger area or serviced by the same labour force;
- increased labour productivity where there is faster turn-around time to achieve higher cropping intensity; and
- decreased costs of production where the machine introduced has a longer run at lower cost which offsets initial capital outlay.

2.1.1 Classifications of technology

Technology can be classified according to the following categories:

2.1.1.1 Codified technology

Business has to convert technology capabilities into saleable units that meet customer needs Pries & Guild[14]. For the benefit of the organizations, tacit knowledge can be packaged as technological terms of manual Hall[8]. Knowledge based on know-what, know-how and know-why form the domains of technology which is seen as standardized content which could be shared or used to develop and train personnel Hall[8].

2.1.1.2 New technology

According to De Coster & Butler[5] new technology refers to technology that is utilized for the first time by a firm or organization, even though it may have been in existence for long time. Its utilization impacts on the old way of achieving the company's objectives. Although it may have been on the market, it is new to the organization. Often its utilization impacts on cost and time-based competitiveness.

2.1.1.3 High technology

High technology companies generally focus on deploying an overall technology approach to business. They constantly seek to develop new technologies that are superior to those of their competitors. They have diverse technology portfolios. In particular, these organizations pursue technology with high intensity to gain technology-based competitive superiority Lichtenthaler[11].

2.1.1.4 Emerging technology

Emerging technology refers to technology that has not yet been utilized to its optimal potential or not commercially exploited. The use of it could be limited by certain government policy restrictions. The level of its utilization depends on the impact of knowledge proximity and economic stability of the country with emerging technology. The European Union has developed technology framework that is based on cognitive science, health-ageing and emerging knowledge–based economy. The policy makes provision for healthy ageing, namely extended healthy life years, and improved health care support system, improvement of quality of life of the elderly and reactivation of social participation Rijker-Defrasne et al[15].

2.2 APPROPRIATENESS OF TECHNOLOGY

According to Duan, Deng & Corbitt[6], appropriate technology is a concept more prevalent in Small and Medium Enterprises. These Small and Medium Enterprises different widely and have distinctive characteristics in the adoption of technology. They are generally more prone to taking risks in the adoption of technology rate of failure after adopting is high.

2.3 COMPARATIVE COTTON TECHNOLOGY UTILISATION

2.3.1 Technology utilization in United States of America

As the United States of America is a highly developed country in terms of technology utilisation, many countries benchmark use to evaluate areas that are similar. The level of technology utilization in the United States of America puts it at a competitive level in all the spheres.

2.3.1.1 Use of organic cotton

Pantagonia is a manufacturer, designer and distributor of top-level quality outdoor wear and sportswear. The firm was founded by a mountaineer called Yvon Chouinard. It is based in Ventura California in the United States of America. It sells sportswear for mountaineering, rock climbing, skiing, fishing, kayaking, long-distance running (marathons) and mountain biking. In 1994 the company decided to manufacture apparel from organically produced cotton cloth. In 1996 the firm used well certified cotton Casadesus-Masanelm et al[3].

2.4 TECHNOLOGY UTILISATION IN CHINA

2.4.1 Impact of use Bacillus theringieusis on cotton

2.4.1.1 Molecular marker technique

According to Preetha and Raveendren[13] molecular markers have played an important role in cotton-breeding research. There are various marker techniques. Some of them include: Restriction Fragment Length Polymorphism (RFLP), Random Amplified Polymorphic DNA), Amplified Fragment Length Polymorphism, Simple Sequence Repeats, Inter Simple Sequence Repeats and Sequence Related Amplified Polymorphism.

This technique refers to variations among individual cotton lengths of Deoxyribonucleic Acid clusters that are produced by restricted enzymes that cut Deoxyribonucleic Acid at selected sites.

2.5 TECHNOLOGY UTILIZATION IN INDIA

Application of bacillus theringieusis crops has helped to reduce chemical pesticide utilization. The application of this technology has had positive environmental, economic and health results Krisna & Qaim[10]. Emerging countries have experienced a decrease in marginal returns due to yield that has stagnated should look to adopting organic agriculture. The organic technology has been successful in India, Eyhorn, Ramakrishma & Mäder[7].

2.6 TECHNOLOGY UTILIZATION IN SOUTH AFRICA

2.6.1 Introduction of genetically modified cotton in South Africa

In South Africa, **genetically modified** cotton was introduced in 1997 Verryne[19], some African countries saw it as a panacea to ensure sustainable development. Reaction to argument ranges from outright rejection to enthusiastic acceptance. This technology has lively discussions all over the world. According to Yang[22] scholars in this field are widely optimistic about the benefits that GM technology holds for the agricultural industry. Sceptics deny the benefits could hold for developing countries, let alone small-scale farmers Clover [4]. Scepticism is unavoidable, but what does seem certain is the fact that the world population is increasing by 81million people per year. The total population is expected to increase from the present figure of 6.6 billion to 9 billion by 2050 Morse & Mannion[12].

2.7 FRAMEWORK FOR ADOPTING TECHNOLOGY

According to Sousa and Voss[18] technology is adopted for a number of reasons inter alia: products have reached maturity; the products are at the stage where sales are stagnating or close to becoming obsolete; inadequate technologies as well as market resources or access constraints; excessive product development costs; absence of sales techniques and market research; and an information gap between marketing and production. Singh, Garp & Deshmukh[16], postulate that market conditions usually dictate the parameter used to decide on strategies and priorities to be employed.

2.7.1 TECHNOLOGY TRANSFER MODALITIES

2.7.1.1 Mentorship

The mentorship programme for the Cotton industry was launched in 2006. Since then Cotton SA has been the accredited presenter of on-going skills training programmes to small-scale farmers. It does this to support the National Cotton Strategy (NCS). Accreditations of courses are granted by the Education and Quality Assurance (ETQA) body. Effective and fair standards are regulated by South African Qualification Authority (SAQA). The AgriSETA is responsible for funding the training programme.

2.7.2 Extension officers

The ARC-IIC has introduced a strategic plan to improve competitiveness among upcoming commercial - cotton farmers. This curriculum is aimed at training of the trainers. This means that the cotton extension officers and field technical advisers have to be trained to in turn train the farmers. Knowledge of pests, diseases and Integrated Pest Management (IPM), Best management practice, waste reduction, market access and strengthening of relationships with local stake holders. The aim is to improve efficiency, utilize resources efficiently and to become profitable Bruwer[1].

2.7.3 Training programme

The training programme entails basic unit standard of 10 units representing 43 credits. The units are grouped into four modules according to the growing season. Module I: covers: pre-planting activities, such as financial planning and management of agri-business. In this module, topics covered include: acquisition of production credits; basic business plan; cash flow management and record keeping.

Module II covers field preparation such as the establishment of cotton plant; application of fertilizers and weed control within six weeks after the first growth. Module III covers pest management, cotton and symbiotic insect life cycle, as well as symptoms and control of pests. Module IV covers preparation for harvesting, harvesting methods, limitation of contamination, grading and marketing. Bruwer[2] reports that up to 724 small farmers have received formal skill development certificates between Makhathini and Tonga which is situated in Mbombela. The credits involved certain number of units at NQF level 1.

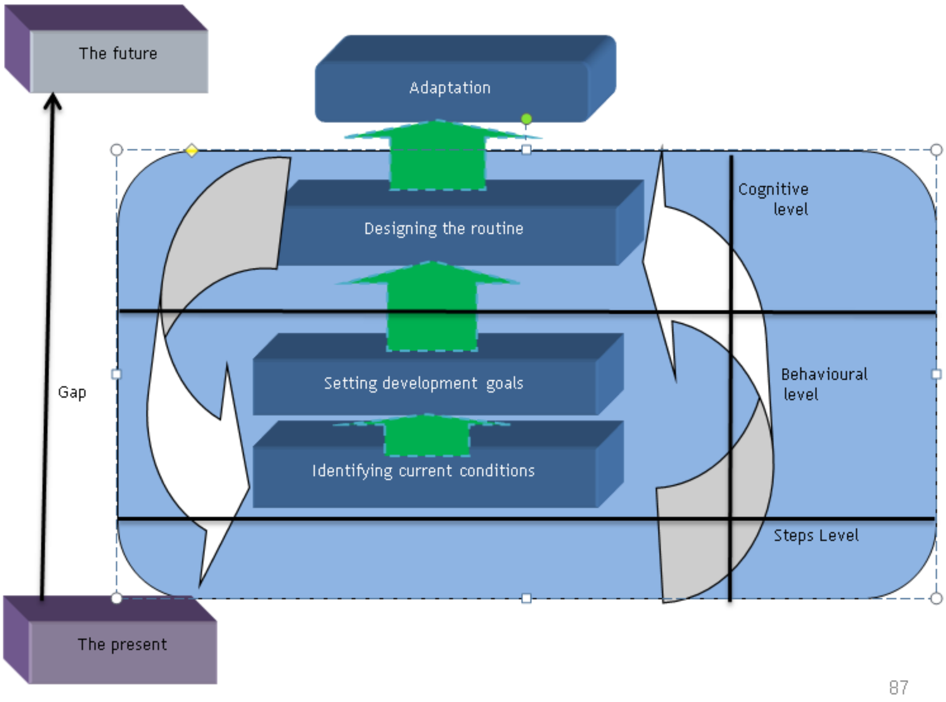

Figure 1: A model of strategic planning for transferring technology Weiwei[21]

Weiwei[21], indicates that goals that are set should include not only current conditions but also Technology Organizing Environment (TOE) framework as a tool that could be considered for identifying factors influencing the adoption of technology to during the strategic planning process. Three factors are identified namely: technological factors, environment and the organization itself. The technological factors are those technologies that are relevant to the company. The environment is the macro area in which the company trades, competes and is subjected to government regulations.

3. RESEARCH DESIGN AND METHODS

This study intends to investigate the problem statement: "How is technology deployed to upcoming commercial - cotton farmers in the Makhathini region to support sustainable cotton production?" Based on the problem statement, a secondary question is phrased as:

To what extent are respondents aware of cotton technologies and information?

The principal objective is to make a theoretical and practical contribution to the situation of the upcoming commercial - cotton farmers and other stakeholders in the cotton supply chain with regard to using technology deployment as a means of facilitating quicker reaction to customer needs, meeting expectations and improving profitability.

3.1 SIGNIFICANCE OF THIS RESEARCH

The research is particularly important because it aims to identify factors hindering the deployment of technology to upcoming commercial - cotton farmers in the Makhathini region and to propose solutions to them. The solutions will be benchmarked against factors or models that have made other commercial farmers successful.

3.2 HYPOTHESIS

The first hypothesis test whether respondents are aware of technologies related to cotton picking, planting genetically modified cotton, use of integrated pest control and latest technologies applied by the cotton industry. The generic hypothesis can therefore be formulated as:

H_0: No significant difference exists between small-scale upcoming commercial - cotton farmers who are aware of cotton technologies and small-scale upcoming commercial - cotton farmers unaware of cotton technologies.

H_1: More small-scale upcoming commercial - cotton farmers are aware of cotton technologies than those that are unaware.

The second hypothesis will test access to technology in terms of picking machines, modified seed, pest control systems and equipment.
H_0: No significant difference exists between small-scale upcoming commercial -cotton farmers that have access to technology and small-scale upcoming commercial-cotton farmers that do have access to technology.

H_1: More small-scale upcoming commercial - cotton farmers have access to technology than those that do not have access to technology.

The Cronbach Alpha reliabilities for technology awareness, and utilization were all above 0.85, the outcomes of the measuring instrument proved to be reliable. The reliability of the qualitative data was ensured by ensuring that the chairperson of each Farmers' Association was always present during the fieldwork to confirm or to provide a better perspective of respondents point views. The chairperson also played a useful role of interpreting areas of the questionnaire that were not clear to farmers.

3.3 RESEARCH DESIGN AND METHODOLOGY

The research will follow a survey research design to describe the conditions of the farmers. Based on the empirical research findings the researcher will be able to explain the farmers' level of preparedness to transform their operations from subsistence cotton production to commercial cotton production.

3.3.1 Description of population and region

Makhathini Cotton is a black economic empowerment firm with 65% black empowerment holders. In 2002 this firm invested about R50 million in a cotton ginnery. Currently there are approximately 90 to 120 small-scale farmers involved in this project. In 2002 the Kwazulu-Natal provincial government committed itself to providing production inputs to approximately 2 100 cotton farmers.

Smale et al[17], state that an estimated 3 000 farmers are organized into 33 farmers associations). It can therefore be assumed that the population size of upcoming commercial - cotton farmers in Kwazulu-Natal province is in the vicinity of 2 500. In the Makhathini region there are 30 cotton farmers' associations representing 2 000 farmers. As this study focuses on the Makhathini region a sample will be selected from this population.

3.3.2 Sample Frame

During the planning phase of the research, and with the support of the President of the Farmers' Association of the Makhathini region, the researcher was able to obtain access to the contact details of 13 Farmers' Associations representing a sample frame of 1 210 small-scale farmers' eligible for selection.

3.3.3 RESEARCH ASSUMPTIONS

If it is established from the findings that of the 121 farmers that were available to answer the questionnaire, 50% plus 1 utilized technology, a conclusion can be drawn that more farmers utilize technology in growing cotton.

4. RESEARCH FINDINGS

Figure 2, indicates that the majority of the respondents obtained their cotton seed from Cotton SA (n=56; 46%), whereas 39% (n=48) and 12% (n=15) both forming 51% representing the extent of technology (or genetically modified seed) that the respondents are getting from Monsanto and Vencan respectively. Figure 2, further indicates that the Kwazulu-Natal Cotton Growers Association is responsible for soil management and IPM (n=35; 29%).

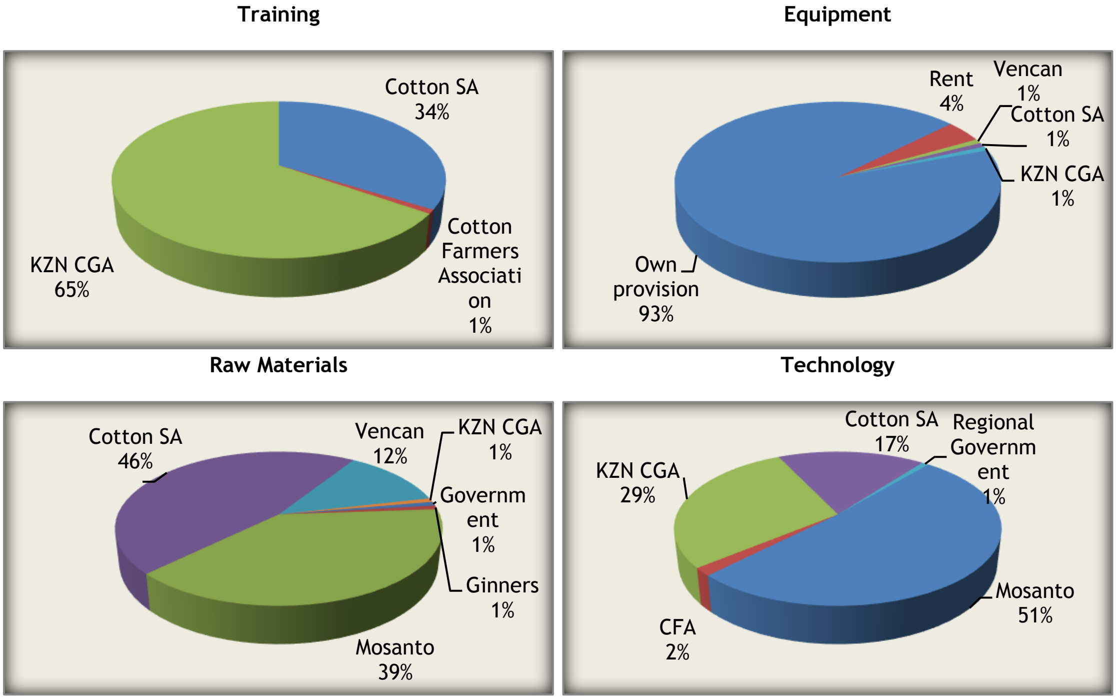

Figure 2: Access and assimilation of technology

The kind of training provided by both institutions named above is shown in Figure 2, and relates to the extent to which technology is utilized. Monsanto seems to be responsible for providing the greater extend of technology in the form of cotton seed, while the Kwazulu-Natal Cotton Growers Association provides guidance on soil management. Cotton SA serves as a link to pass on information technology. Figure 2, further indicates training provided by both the Kwazulu-Natal Cotton Growers Association and Cotton SA. However, 98% of the respondents have less than 8 years of formal education. This does not seem to be viable.

The overwhelming majority of the respondents (n=113; 93%) indicated to be in possession of cotton farming equipment. This gives an indication of the extent of self-reliance and availability of collateral security. There seems to be consensus among the respondents that the Government or Cotton SA should assign mentorship programmes to upcoming commercial - cotton farmers in Makhathini (Figure 2).

Response	Frequency	Percentage	Valid Percentage	Cumulative Percentage
Valid 1.00	117	96.7	96.7	96.7
2.00	3	2.5	2.5	99.2
4.00	1	.8	.8	100.0
Total	121	100.0	100.0	

Table 1: Utilisation of biologically modified seed

Table 1 shows that an overwhelming majority of respondents are utilising biologically modified seed, with frequency of (n=117; 96.7%). Relatively few almost negligible respondents still use conventional seed with a frequency of (n=3; 2.5%)

Variable	χ^2	Sig.	χ^2 (Critical value)	Df	H_0
Use information and communication technology	0.997	0.05	7.82	3	Accept
Use mechanical cotton picking machines	3.1788	0.05	7.82	3	Accept
Plant biologically modified seed	1.000	0.05	7.82	3	Accept
Follow an integrated pest control strategy	0.999	0.05	7.82	3	Accept
Use mechanical devices to farm cotton	0.999	0.05	7.82	3	Accept
Process seed cotton	1.3751	0.05	7.82	3	Accept
Have the knowledge and skill to grade and classify cotton	7.2995	0.05	7.82	3	Accept
Access information on market prices on a regular basis	7.6101	0.05	7.82	3	Accept
Make use of training opportunities to support knowledge of farming	0.999	0.05	7.82	3	Accept

Table 2: Chi-square test for utilization of technology

Results in table 2 indicate that the H_0 hypothesis should be accepted, implying that small-scale upcoming commercial - cotton farmers do utilize technology to improve their cotton yield and the profitability of their farms.

5. CHALLENGES OR OBSTACLES TO UTILIZING TECHNOLOGY FACED BY COTTON FARMERS

- It was indicated that the current technology deployment process is constrained by an industry benefitting approach instead of a real focus on a commercialization transition that needs to take place at individual farming business level.

- An information gap exists between Cotton S.A sales forecasts and the Ubongwa Association currently active in the Makhathini region. Association leaders need to be taught forecasting techniques used and to understand how they can be used to provide reasonably accurate production estimates. Volume and market penetration take considerable time to develop.

- Training of more Association leaders is recommended in order that these leaders could monitor sales trends and recommend the right time to sell cotton to the gins as international prices are used. At the moment there is only one trained person in this area.

6 SUPPORT MECHANISM FOR FORMATION OF SUSTAINABLE SME'S

Familiarize upcoming commercial - cotton farmers with the wonderful creation that the cotton plant is. Explain all the components of the plant and the development of the crop.
Devise a methodology to demonstrate best practices of cotton production and how each activity contributes to the yield that can be obtained by the producer. Device a methodology that not only literate, semi-literate as well as a person that did not have the opportunity to attend formal teaching would be able to understand. Preparation of the farmers with basic knowledge of cotton production to be ready to attend SETA courses in cotton cultivation and management. Lastly demonstrate good quality by differentiating between bad and good quality of cotton with samples.

7. CONCLUSIONS AND RECOMMENDATIONS

At this point, it is necessary to revisit the research questions posed in section 3. The principal research question was: "How is technology deployed to upcoming commercial - cotton farmers in the Makhathini region to support sustainable cotton production in this specific area?" Based upon the principal research question, the secondary question was formulated namely:

To what extent are respondents aware, have access and utilise cotton technologies?

An overwhelming majority of the respondents were aware and had access to available technology as per figure 2. However, the goal of commercialization of cotton eluded them. In the view of the researcher, too much emphasize was placed on the internal conditions of upcoming commercial - cotton farmers while too little emphasize is placed on the synchronization of internal and external conditions in which the farmers operate. Failure to synchronize these conditions could impede the transition of upcoming commercial - cotton farmers. This view is also supported by the theories put forward by Knott[9] discussed in the theory section. It is therefore recommended that deliberate plans be put in place to equip farmers for bigger transitional space to commercialisation. A paradigm shift in approach be adopted in which interventions focus on commercialization of individual upcoming commercial - cotton farmers to enable them to compete successfully in the competitive internal and external commercial market.

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PREVENTATIVE MAINTENANCE IN PUBLIC HOSPITALS

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ABSTRACT

This is a summary of eight research projects done by students as required for partial completion of their B-tech qualification. The purpose was to determine the manner in which maintenance was performed and to suggest possible improvements. Students evaluated radiology and diagnostics departments. The maintenance technicians were interviewed to determine the maintenance strategy and the effectiveness thereof. Nurses and a hospital representative were also interviewed in this regard. The purpose of maintenance is to keep equipment in working order and to prevent equipment failures. The maintenance strategy has a significant impact on the functioning of a hospital. Literature suggests that about one third of maintenance costs are wasted. Unexpected failure of equipment has a large impact on a hospital. The Government has a maintenance plan in place for public hospitals and every year a number of public hospitals are evaluated for compliance. The research indicated that most maintenance was managed by suppliers of equipment and that equipment was generally in good working condition. The current system can probably be improved on by using mobile devices for work orders, daily checks and uploading information onto a database.

Keywords

Preventative Maintenance, Public Hospitals, web-based systems, mobile devices

1. Introduction

In South Africa public health care is marked by an inadequate supply of medicine, deteriorating infrastructure, equipment failures, shortage of staff and misuse or misallocation of funds [1]. The quality of public health care differs greatly between the various hospitals and within certain areas. Rural areas in South Africa typically have the greatest constraints in all aspects but also in availability of equipment [2]. Benatar [3] claims that South Africa has the capacity to train skilled, caring practitioners who provide quality care with the highest professional standards. According to an article in Health 24 [4], the Free State lost 177 doctors due to difficult working conditions in 2015. One aspect that has a significant impact on operation of public health care is the inadequate functioning of equipment. It also has an impact on the working conditions of the staff. This paper focuses specifically on maintenance of equipment which will ensure that the necessary equipment is available when required.

An average to large sized hospital has 5 000 to 10 000 different types of medical equipment [5]. Statistics accumulated by The Joint Commission (TJC) [[6] Feb 2016) in America and Canada showed that faulty or absent medical equipment was involved in patient incidents that resulted in serious injuries or death. No information could be found with regard to the correlation between equipment failure and patient health in public hospitals in South Africa. It is critical to ensure that equipment is maintained for a reliable medical service [7]. The purpose of maintenance is to keep equipment in working order and to prevent equipment failures [8]. Careful management of the associated cost is especially important in public hospitals because of severe financial constraints

It is important to note that the cost of maintenance over the life span of medical equipment often exceeds procurement costs. Many modern medical devices are complex and sophisticated which further escalates their maintenance costs [9].

2. Objective

The purpose of this paper is to evaluate the manner in which maintenance is performed in public hospitals in Gauteng and suggest ways of possible improvement.

3. Literature Review

Rastegarie and Salonen [10] define maintenance as “the combination of all technical, administrative and managerial actions during the life cycle of an item intended to retain it in or restore to, a state in which it can perform the required function”. Maintenance strategies can be based on several alternatives such as failure based, time-based, risk based and condition based [11]. Typically these strategies can be divided into two main categories, preventative or corrective maintenance [10]. Figure 1, illustrates the relationship between these two main categories. Organisations need to select a maintenance strategy that is optimal to the functioning of the company. Selecting the correct maintenance strategy can improve productivity and profitability.

Maintenance strategy selection can be considered as a complex multiple-criteria decision making problem [11]. Failure data needs to be collected for each piece of equipment in order to determine the effectiveness of the maintenance strategy. In addition consideration must be given to the available resources for these strategies.

It is important to measure maintenance performance so that it is possible to determine the value of maintenance performed [12]. Literature has identified [13] several different maintenance performance measures, these measures can be divided into three categories:

- Measures of equipment
- Measures of cost and
- Measures of process performance

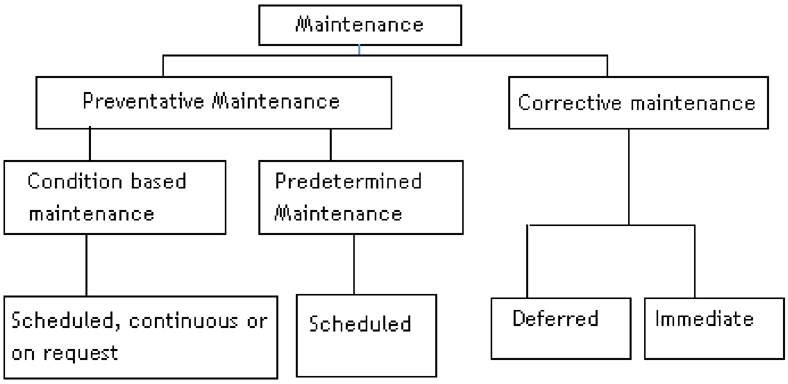

Figure 1: Maintenance types [10]

3.1. Corrective Maintenance

One main approach to maintenance is corrective maintenance. Corrective maintenance is an approach whereby equipment is allowed to run to failure and then repaired. Corrective maintenance is also called reactive maintenance. This maintenance strategy is sometimes supported because it can be argued that no maintenance cost is incurred until the point of failure. Often organisations do not shut down equipment for repair as they have the perception that they do not have time for preventative maintenance. We will never be able to completely eliminate corrective maintenance but it needs to be minimised. [14].

It is important to ensure that the technicians responsible for reactive maintenance are well prepared. This includes ensuring that they have the correct tools, replacement parts, training and transport [15]. It is easier to manage reactive maintenance if technicians are assigned to do the maintenance of specific equipment. Consideration must also be given the process of dispatching work orders. It is also worth spending time to decide how work orders will be dispatched. Work orders should provide a detailed description of the work required and the priority of the work.

The consequences of failure should influence the decision of whether or not corrective or preventative maintenance is utilised for a specific piece of equipment [16]

3.2 Preventative Maintenance

Preventative maintenance is the alternative approach to maintenance is; see Figure 1. This type of maintenance requires maintenance to be completed before failure **occurs.** Most preventative maintenance is based on a predetermined interval irrespective of the condition of the equipment. These intervals can be time based or based on usage [11].

The maintenance cost is less than with reactive maintenance [17]. The extent of the damage of equipment that has failed is usually significant and the unplanned downtime can incur other unexpected costs. Preventative maintenance is however more difficult to coordinate because it necessitates careful planning.

There has been criticism of preventative maintenance as it includes implementation of unnecessary maintenance. The weakness is that it is seldom done at exactly the right time.

Advantages and disadvantages of preventative maintenance according to Hansen [17]:

Advantages:

- Cost effective in many capital–intensive processes
- Flexibility allows for adjustment of maintenance periodically
- Increased component life cycle
- Energy savings
- Reduced equipment or process failure
- Estimated 12% – 18 % cost savings over reactive maintenance program

Disadvantages:

- Catastrophic failures still occur
- Labour intensive
- Includes performance of unnecessary maintenance
- Potential for incidental damage to components in conducting maintenance

It is therefore important to choose a successful maintenance program. Technicians should be well trained and scheduling should be done effectively. Preventative maintenance Includes condition based maintenance.

3.2.1 Condition Based Maintenance

Condition based maintenance can be defined as a set of maintenance processes and capabilities derived from real-time assessment of the equipment condition from various sources e.g. embedded sensors and external tests. The goal of condition based maintenance is to only perform maintenance when there is evidence of a need to do so and thus increasing the availability of the asset [18]. According to Rastegarie and Salonen [10] condition based maintenance falls under Preventative maintenance.

3.3 Improving Maintenance Effectiveness

Concepts for increasing the effectiveness of maintenance strategies that are frequently discussed in the literature are:

- Reliability Centred Maintenance (RCM) and
- Total Productive Maintenance (TPM).

3.3.1 Reliability Maintenance

Reliability centred maintenance, analyses the functions and potential failures of equipment with a focus on preserving system functions, rather than preserving the equipment. Reliability centred maintenance is used to develop scheduled maintenance plans that will provide an acceptable level of operation, with an acceptable level of risk, in an efficient and cost-effective manner [19]. The consequence of breakdowns is taken into account.

3.3.2 Total Productive Maintenance

Total Productive maintenance is designed to maximise equipment effectiveness by doing maintenance with as little as possible interruption of production, preferably doing maintenance during production. With this approach everyone is involved in the maintenance process, from top management to shop floor workers. [20]

3.3 Biomedical Technicians

In South Africa there are biomedical technicians and technologists as well as medical equipment maintenance professionals. These individuals are trained to maintain medical equipment. These careers are similar to biomedical engineers, clinical engineers or "medical equipment maintainers" these technician are referred to in other countries s

Malkin and Keane collected [21] evidence in a number of countries, to support the need for maintenance of laboratory and medical equipment in resource-poor settings. Engineering or engineering student volunteers visited 60 resource poor hospitals to gather data on out of service equipment in these hospitals. Of these hospitals only seven had some planned preventative maintenance and only three had complete preventative maintenance programs. The volunteers had a basic toolkit; they had access to internet and had to purchase replacement parts locally for no more than US$50. They were allowed to **travel to get parts as long as they could use public transport.**

When analysing the repair request data it was determined that eighty nine percent of the repair requests were for medical equipment. The engineering volunteers were able to put seventy two percent of equipment back into service. This contradicts the belief that getting hold of spare parts is one of the major constraints as to why medical equipment is out of service in resource poor areas [21].

On analysis of the skills required to fulfil the repair requests an opportunity for a new curriculum for individuals to repair medical equipment (within different fields and different levels of complexity) was identified. Basic skills were defined as that of a person who could read, write and do math through fractions. These individuals could learn what is required for the successful completion of the desired task within 1-2 hours without them having any prior knowledge of medical equipment. It was found that 107 basic skills were used to put 66% of the medical equipment back into service in resource poor settings [21].

4. Methodology

Eight students from the University of Johannesburg went to five different medical institutions to research this topic of maintenance in public hospitals. The research project is required for partial fulfilment of their B-tech qualification. Differing methodologies were employed. Students used either a survey or studied available data or interviewed staff. Students surveyed the maintenance technicians. Others surveyed staff working with equipment or looked at maintenance records. Most students used a quantitative research approach. One student went to the radiology department at the University of Johannesburg. The remaining students went to four different public hospitals and a clinic. A radiology department, diagnostic equipment and other critical equipment were investigated. Of the equipment scrutinised some were maintained internally by maintenance technicians and others externally by the supplier. The capture and analysis of maintenance data was also investigated.

5. Findings

5.1. Maintenance of Equipment and Facilities in South African Public Hospitals

The maintenance of equipment and facilities in South African public hospitals is assessed according to the "Hospital Standards for Accreditation". This is a checklist completed by an inspector in order to determine whether or not hospitals comply with their requirements. The inspector is employed by the government in order to fulfil the Public Service commission (PSC) Act, 1997, Section 9[22]. After inspecting a hospital the inspector can suggest improvements or decide to continue or cancel the hospital's licence to operate. One of the aspects covered in this checklist is the maintenance plan of the hospital [23]. There are six main questions asked regarding maintenance:

1. The hospital has a maintenance plan.
2. The maintenance and repair manuals are in one location.
3. There is a master record of each piece of equipment in the hospital.
4. There is an action record that details the scheduled maintenance to be performed for each piece of equipment on a regular basis or schedule.
5. Defective parts for electrical systems are routinely inspected and replaced if indicated.
6. There are routine inspections, oiling and replacement of defective parts of mechanical systems.

5.2. Radiology Equipment

In the radiology departments, checklists need to be completed daily, monthly, quarterly, bi-annually and annually. Fluoroscopy has visual checks that have to be performed daily, monthly, quarterly and annually and sonography equipment has visual checks that have to be performed daily monthly and annually. The checklists are completed and kept as proof. If problems are detected during these checks necessary adjustments are made by the operator. For problems that the operator cannot correct, the maintenance technicians are contacted. In both radiology departments investigated equipment was regularly maintained as per the manufacturer's specifications. In interviews the radiographers in these departments indicated that they had never had a complete breakdown but they had experienced minor breakdowns that were repaired quickly and did not cause equipment to be out of service for any length of time. Several public hospitals are using their suppliers to maintain the equipment and this function is negotiated as part of the sale.

5.3. Medical Technicians and Assistant Technicians in Public Hospitals

Based on an interview with a medical technician at one of the public hospitals it became apparent that the hospital had a preventative maintenance program and the maintenance team was responsible for this program. The purpose of this program was early detection of problems and routine maintenance in the diagnostic department. The maintenance department set up the schedule and generated work orders; the completed work orders were then filed.

Most equipment was under a maintenance contract for maintenance by professional inspectors. The diagnostic imaging equipment had the most downtime due to load shedding. Not all public hospitals had an in-house maintenance department responsible for the proper continued operation of medical equipment in the hospital.

In the survey of hospital technicians it was identified that daily, weekly and monthly inspections were conducted. During these inspections technicians needed to determine whether there was malfunctioning of equipment. Data was captured manually which made it difficult for technicians to monitor life cycle and maintain traceability of equipment.

Operators' satisfaction was compared when machines were maintained in-house or by external contractors. Operators seemed to be able to make adjustments to equipment that was maintained in-house. The student found that operators were not satisfied with the maintenance whether it was done internally or externally.

5.4. Data Capturing and Planning

Most data was captured manually and filed. Daily, monthly, quarterly, bi-annually and annually checks were completed on forms and filed. None of the students found an electronic system in place. Reporting of maintenance problems was done by a phone call. The biomedical technicians were of the opinion that there would be many benefits when using an electronic system.

It could be possible to implement an electronic preventative maintenance program to assist hospitals in providing good quality services. To set up an electronic system to manage preventative maintenance the following would be required:

- Complete equipment inventory: The medical technicians in the hospital can assist with the identification of equipment that needs to be included in the inventory.
- Identification: It must be possible to distinguish equipment by its function. Identification could be developed in line with electronic system needs.
- Data of maintenance requirements as per supplier's instructions.
- Data of performance of equipment and failures that do occur.

In the public sector some clinics in Tshwane provided nurses and community healthcare workers with mobile devices sponsored by Vodacom. These devices cannot be used as a phone but has applications and data. An application was downloaded onto the device and this was linked to a database with all of the patients' information. When a healthcare worker examines a patient, the database can be accessed. The database provides some broad guidelines, e.g. this patient should be checked for TB. The healthcare workers can consult with the nurse via the system and make appointments to see the nurse for advice. When patients are released from hospital there is also a person who needs to inform the nurse that the patient is going home and that a healthcare worker needs to see them. Currently some problems have been encountered with this system as not all individuals are computer literate but it remains a very good system.

6. Conclusion

Of the public hospitals and clinics evaluated, preventative maintenance was used by most of them. In some areas the operators were not satisfied with the maintenance whether performed by internal or external personnel. Many of the institutions had an agreement with the suppliers to tend to the maintenance of the equipment.

There is currently no system to do maintenance performance measurement to determine the value of the existing maintenance strategy.

There are many benefits that can be realised from a web-based system specifically for maintenance of medical equipment. The cost can be minimised by looking for sponsors as was done with the healthcare workers. Training is extremely important. It cannot be assumed that all staff, whose responsibility it is to report faults of medical equipment, is computer literate. The employees need to be trained in the use of the web-based and mobile applications.

In conclusion it seems beneficial to develop a new curriculum for medical technicians that are not as extensive as the current curriculum requires and use these individuals to tend to the need in rural areas.

7. Recommendation

It is recommended that a system be developed or an existing system is bought to manage and maintain medical assets and equipment. Several local and international companies are developing systems that use mobile devices with web-based applications and databases to manage their assets. It would be possible to use similar systems with the same mobile devices that healthcare workers are using currently.

In such a system it will be easier to set up a maintenance schedule and assign tasks to the relevant technicians, depending on their skills and the task requirements. The technicians should download their tasks to their mobile devices and perform the maintenance. As maintenance is completed the task results must be uploaded. All failures and maintenance information (e.g. time taken to perform each task) will be available to determine whether the best asset management strategy is being followed. In this way the value of the maintenance can be determined.

A new curriculum could possibly be developed for medical technicians responsible for maintenance of medical equipment. Specialist advice could be made available via an electronic system. Hopefully these individuals could tend to some of the needs in the rural areas

A maintenance performance measurement system could be implemented. Such a system would also be easier to manage if an online system exists with maintenance data. This system should monitor value added by maintenance.

Further study should be done on the cost of using internal or external maintenance technicians and whether it truly is the best strategy to follow the manufacturer's guidelines for maintenance.

Further study should be done as to how the maintenance strategies in public hospitals can be improved and possibly standardised as there are quality issues with regard to maintenance.

8. Acknowledgement

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AN EVALUATION AND COMPARISON OF BUSINESS SIMULATION SOFTWARE

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ABSTRACT

Various simulation programs are available today to perform business related simulation. A simulation model is useful for making decisions, e.g. in project, maintenance and operations management, or to understand the dynamic behaviour of business systems. This paper presents the results of a project to evaluate and compare a number of simulation programs. The output of four Monte Carlo simulation programs and two discrete event simulation programs were evaluated with the same input data and number of trials. The difference in output from the four simulation programs was found to be quite small. Engineers and managers can therefore use any these programs with confidence for similar type of problems as investigated in this study.

1. INTRODUCTION

1.1 Background

Various software packages are available today to perform business related simulation, e.g. @Risk [1], Crystal Ball [2], XLSim [3], SimVoi [4] and RiskAMP [5], or standalone software like Arena [6], GoldSim [7], BlockSim [8] and Raptor [9]. Simulation models are useful for making investment and other financial decisions, for optimising engineering designs or to understand the dynamic behaviour of business systems. These programs are often used in projects and in maintenance and operations management.

This paper presents the results of a study to evaluate and compare a number of simulation programs mentioned above. The functionality of simulation programs differ with more costly programs that usually have more functions for the user. The low budget options like RiskSim [4] and XLSim provide a limited number of probability distributions whereas @Risk and RiskAMP provide more than 40 built-in probability distributions.

Simulation programs can be applied to various business related problems and a comprehensive comparison of simulation programs would require a study of the performance and output of various problems. For this study only two cases were selected, i.e. the simulation of the total duration of a project when a number of tasks are performed in series or parallel and secondly a simulation of the availability of a system comprising a number of components in a series or parallel configuration.

1.2 Objective

The primary objective of this research study was to determine whether a number of simulation programs or add-ins for MS Excel provide similar outputs for the same inputs and number of trials. The use of spreadsheets with simulation add-ins to perform Monte Carlo simulation (MCS) to model project cost and schedule uncertainty has become quite popular in project management, risk management and financial management. It was therefore decided to model the total duration for a project comprising a number of individual activities to achieve the main object stated above. The following proposition was formulated.

The distribution for the total project duration if performed using the XLSim, RiskAMP or GoldSim simulation programs do not differ significantly from the distribution for the total project duration obtained with the RiskSim add-in software.

Two discrete event simulation programs, i.e. Raptor and BlockSim, were also applied to determine the availability of a multi-component system and the following proposition was defined.

The characteristics of the interval availability of a system as determined with the BlockSim software does not differ significantly from the availability as determined with the Raptor program when the same Weibull distributions are used as the failure distributions of the individual components.

2. LITERATURE

2.1 Monte Carlo Simulation

Monte Carlo methods were initially practiced under the names 'statistical sampling' or 'probability simulation'. Fermi used the method in the 1930's to calculate neutron diffusion in nuclear reactions. The name 'Monte Carlo Simulation' was used by Ulam and Von Neumann (Eckhardt, [10]) who modelled nuclear fission in the 1940's during the Manhattan research and development project. MCS is a 'static' simulation that uses random sampling to evolve an overall outcome distribution. It has become popular in project management to incorporate the uncertainty in cost or schedule in quantitative risk analysis (Schuyler [11], Grey [12]). The output in this application is typically a total cost or schedule distribution for the project.

MCS for modelling cost and schedule in projects has been used and applied by many project managers and researchers, e.g. Raydugin [13] explains how MCS could be used to determine a project cost reserve as well as a project schedule reserve or buffer. He also focuses on the value of MCS in decision making in projects. Cooper et al. [14] also discuss in some detail how the uniform and triangular distributions can be used to model general uncertainty in cost and schedule estimates as well as the impact of specific events on the cost and schedule distributions. He also explains how correlation can be included in simulations.

2.2 Discrete Event Simulation

A discrete event simulation models a system for which some variable 'changes only at a discrete set of points in time' (Banks et al. [15]). A repairable system could typically be in an operational or running state and when a failure occurs, it changes to a stopped or down state. When a repair or replacement is completed the system changes to a running state again. The interval availability of a repairable system is a function of reliability and maintainability and is determined by means of the uptime and downtime over a specific interval, e.g. one month or 720 hours of operation. A discrete event simulation (DES) is useful to model failures and repairs and to determine the availability from the failure times and repair times. Two discrete event simulation programs were used to model a repairable system, i.e. Raptor [9] and BlockSim [8].

2.3 Probability distributions

2.3.1 Uniform distribution

The uniform or rectangular distribution is continuous and bounded on the left and right. It has two parameters, the lower bound, a, and the upper bound, b, and the range is therefore $a \leq x \leq b$. Random variates for the uniform distribution can be determined using the Excel function RANDBETWEEN(a;b) or the simulation software's built-in distribution function for the uniform distribution.

2.3.2 Triangular distribution

The triangular distribution is bounded on the left and right and can be symmetric or skew depending on the values of the three parameters that determine the shape of the distribution. The three parameters of the triangular distribution are typically:

- a = lower bound (minimum)
- m = most likely value (mode)
- b = upper bound (maximum)

The random variates for the triangular distribution can be determined from formulas provided in literature (Evans et al. [16]).

2.3.3 Normal distribution

The normal distribution, also known as the Gaussian distribution, is a continuous and symmetric distribution defined by two parameters, i.e. the mean value, μ, and the standard deviation, σ. The density function of the normal distribution is defined over $-\infty$ to $+\infty$ and care should be taken when using this distribution in simulation where the variable is only defined from 0 - ∞, e.g. duration of an activity which cannot be negative. Random variates for the normal distribution can be calculated with the NORMINV(RAND(),μ,σ) function of Excel.

2.3.4 Lognormal distribution

The lognormal distribution is a continuous, non-symmetric distribution that is often used to model the duration of activities or tasks. It applies mostly to novice artisans or workers that have to perform non-standard and complex tasks. These tasks often take longer especially when something goes wrong. It has two parameters, i.e. the mean value, μ, and the standard deviation, σ. Random variates can be calculated using the Excel built-in function LOGNORM.INV(RAND(),μ,σ).

2.3.5 Gumbel distribution

The Gumbel distribution is continuous and also known as the Smallest Extreme Value (SEV) distribution (Type I) as well as the logWeibull distribution. It has a location parameter $\mu > 0$ and a scale parameter $\beta > 0$. A random variate, T, for the Gumbel distribution was calculated using equation 1. This distribution is mainly used in the analysis of extreme values, e.g. flood levels and earthquake damage.

$$T(\rho, \mu, \beta) = \mu - \beta \cdot LN\left[LN\left(\frac{1}{\rho}\right)\right] \quad (1)$$

where ρ is a random number.

2.3.6 Weibull distribution

The Weibull distribution is well known for modelling reliability of physical assets and humans due to its versatility with regard to failure rate. The 'shape' parameter, β, determines whether an item exhibits a decreasing, constant or increasing failure rate. The second parameter, η, is known as the 'characteristic life' when used in reliability applications.

The Weibull distribution is also useful to model task or activity duration in projects since it is one of a few distributions that is skewed towards the left, i.e. a negative skewness factor, if the shape parameter is larger than 1. The general assumption is that the distribution of task duration is skewed to the right and therefore some historical data is needed on specific task durations to warrant the use of the Weibull distribution. A random variate, T, for the Weibull distribution was calculated using equation 2.

$$T(\rho, \beta, \eta) = \eta \cdot \left[LN\left(1 - \frac{1}{1-\rho}\right)\right]^{\frac{1}{\beta}} \quad (2)$$

where ρ is a random number.

2.3.7 Gamma distribution

The gamma distribution is continuous over the range 0 - ∞ with scale parameter, $b > 0$, and a shape parameter, $c > 0$. Random variates can be determined using the Excel built-in function GAMMA.INV(RAND(),b,c) or the simulation software's own defined function if available.

2.4 Comparison of simulation programs

Willis [17] performed a study in 2000 to compare a number of simulation programs for reliability and availability simulation. Ten capabilities that were regarded as important for mission reliability simulation were defined and nine simulation programs were tested against these criteria. This study is quite old now and many of the simulation programs might not be available any more. Some of the popular software that that are still available today are AvSim, BlockSim, Relex RBD and Raptor. The software was not compared in terms of the output of simulations.

3. METHODOLOGY

3.1 Overview

A Monte Carlo simulation can be done with MS Excel without additional software or add-ins using standard functions provided, e.g. RAND() for generating random numbers between 0 and 1 and FREQUENCY(Array1,Array2,) to produce a histogram of random variates. The variates can be sorted from smallest to largest and cumulative distribution values can be determined. However, the simulation add-ins or standalone software that are commercially available automate the simulation process and is more convenient and faster to use.

Two project activity networks were selected for Monte Carlo simulation study, i.e. a 'series' network where all activities are performed in sequence and a 'parallel' network where some activities take place in parallel.

3.2 Schedule simulation for a series network

Eleven activities that are performed in sequence were selected and the parameters used for the different distributions are shown in Table 1.

Table 1. Distribution parameter values for activity duration for a series network

Activity	Triangular			Uniform		Normal		Gumbel	
	a	m	b	a	b	μ	σ	μ	β
A	5	7	14	5.325	12.008	8.667	1.929	7.798	1.504
B	5	6	12	4.990	10.344	7.667	1.546	6.971	1.205
C	6	8	16	6.258	13.742	10.000	2.160	9.028	1.684
D	5	7	14	5.325	12.008	8.667	1.929	7.798	1.504
E	4	5	10	4.060	8.606	6.333	1.312	5.743	1.023
F	6	7	14	5.918	12.082	9.000	1.780	8.199	1.387
G	6	8	16	6.258	13.742	10.000	2.160	9.028	1.684
H	7	10	18	7.646	15.687	11.667	2.321	10.622	1.810
J	5	6	12	4.990	10.344	7.667	1.546	6.971	1.205
K	6	7	14	5.918	12.082	9.000	1.780	8.199	1.387
L	7	10	20	7.520	17.147	12.333	2.779	11.083	2.167

The 'most likely' or mode values (m) for the triangular distribution were randomly selected between 5-10 time units (typically days). The lower bound (a) and upper bound (b) were chosen to provide a right skewed distribution. This is quite typical for the subjective estimates of task duration in projects since tasks sometimes take much longer than the average and would very rarely take much quicker to complete.

3.3 Schedule simulation for a parallel network

The project network with parallel activities that was used in this study is illustrated in Figure 1 below.

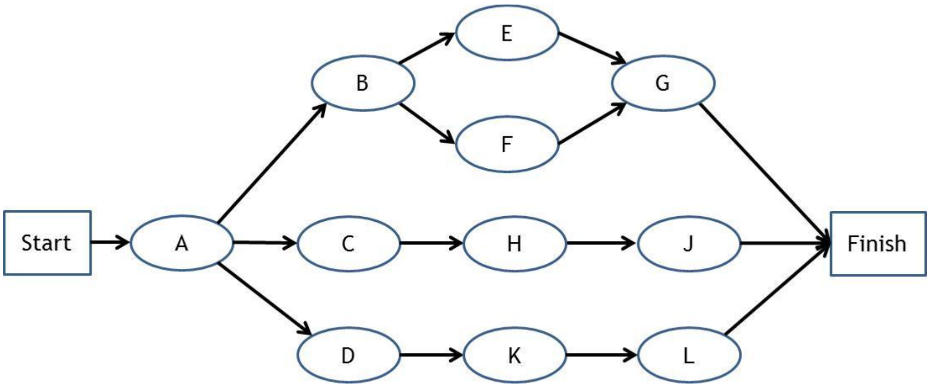

Figure 1. Activity network for parallel case investigated

The dependency of activities that are performed in sequence and parallel should be accommodated in the Excel spreadsheet. For example, the start time for activity G is the maximum finish time of activities E and F. Similarly, the project is only finished when the activities G, J and L are all finished.

The output of the four simulation programs were obtained for four different input distributions. The mode values for the triangular distribution were also selected randomly between 7-15 time units and values for the parameters a and b were chosen to give a right skewed distribution. The values used for the other distributions were calculated from the mean and standard deviation values as shown in Table 2.

Table 2. Distribution parameter values for activity duration for a parallel network

Activity	Triangular			Lognormal		Weibull		Gamma	
	a	m	b	μ	σ	β	η	b	c
A	13	15	18	15.333	1.027	15.783	18.450	222.737	0.069
B	8	9	12	9.667	0.850	10.035	13.910	129.385	0.075
C	6	8	10	8.000	0.816	8.351	11.896	96.000	0.083
D	7	9	13	9.667	1.247	10.194	9.285	60.071	0.161
E	9	12	17	12.667	1.650	13.363	9.192	58.939	0.215
F	11	13	17	13.667	1.247	14.206	13.377	120.071	0.114
G	6	7	10	7.667	0.850	8.030	10.905	81.385	0.094
H	9	12	18	13.000	1.871	13.783	8.265	48.286	0.269
J	5	7	10	7.333	1.027	7.764	8.505	50.947	0.144
K	13	16	20	16.333	1.434	16.955	13.932	129.784	0.126
L	10	13	18	13.667	1.650	14.368	9.964	68.612	0.199

3.4 Discrete event simulation

A system with 20 components was defined to test the two software programs that performed the discrete event simulations, i.e. Raptor and BlockSim®. The reliability block diagram for this system is shown in Figure 2 below.

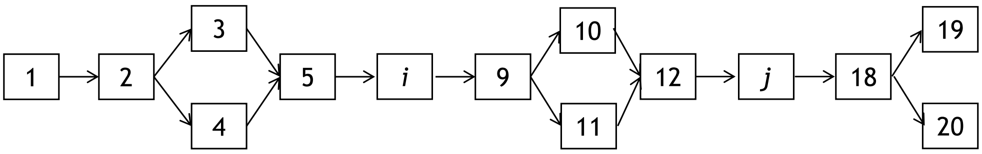

Figure 2. Reliability block diagram for 20 items

A Weibull distribution was selected to describe the failure behavior of all 20 components. The shape parameter for the Weibull distribution, β, was randomly selected between 2 and 6 and the characteristic life, η, was randomly selected between 5000 and 15000 hours. A normal distribution with a mean replacement time of 50 time units and standard deviation of 5 was chosen to model the repair behavior of all the components.

4. RESULTS

4.1 Overview

The RiskSim and GoldSim software provide the raw data, i.e. the random variates calculated for the total project duration, as well as percentiles at 5% intervals and other statistical data. The XLSim and RiskAMP software do not provide the raw output data but the percentiles at 5% intervals and some statistical data are provided. The values of the total duration at 5% intervals of the percentiles were therefore used as comparison of the output of these software programs.

Most software also provides some statistical data of the output distribution. RiskSim and GoldSim also provide graphical output, typically the probability density and cumulative distribution function of the output distribution.

The results are provided separately for the two cases, i.e. the series network and the parallel network. The descriptive statistics are given for the RiskSim add-in only since GoldSim does not provide all this detail. The P80 and P90 duration values are compared against the triangular distribution to assess the effect of the tails of the input distributions.

4.2 Distributions provided by software

Simulation programs provide a number of distributions to be used for uncertain inputs, e.g. the cost or duration of an activity in a project. Table 3 shows the functions included in the software and that were used in this research project. The different distributions in the standalone GoldSim software are just selected by name from a drop-down menu.

Table 3: Distributions provided by software

Distribution	RiskSim	XLSim	RiskAMP	GoldSim
Uniform	RandUniform	gen_Uniform	UniformValue✓	✓
Triangular	RandTriangular	gen_Triang	TriangularValue	✓
Normal	RandNormal	gen_Normal	NormalValue	✓
Lognormal	RandLognormal	gen_Lognormal	LognormalValue	✓
Weibull	X	X	WeibullValue	✓
Gamma	X	X	GammaValue	✓
Gumbel	X	X	X	✓

For those distributions not provided by the specific add-in software, the built-in functions of Excel were used with the function for the uniform distribution to provide a random number between 0 and 1. For the Gumbel distribution the formula in equation 1 was used to calculate the random variates.

4.3 Simulation software for project duration

4.3.1 Project with activities in series

The descriptive statistics for the total duration as provided by the simulation software are given in Table 4 for the triangular distribution only.

Table 4. Statistics for total duration distribution for triangular distribution inputs

Parameter	RiskSim	XLSim	RiskAMP	GoldSim
Mean	101.027	101.042	100.951	101.108
Std Dev	6.527	6.560	6.510	6.515
Skewness	0.133	N/A	0.126	0.182
P25	96.488	96.469	96.445	96.533
Median	100.879	100.937	100.791	100.824
P75	105.432	105.423	105.350	105.408

The values for the four software programs agree very well and the only noticeable difference is the skewness that varies from 0.126 – 0.182. This could be due to different random number generators used by the software or the interpolation algorithm. The skewness value is not provided by the XLSim software.

The total project duration using the RiskSim add-in was used as reference and the difference in duration was determined with the XLSim, RiskAMP and GoldSim software at 5% intervals of the percentiles. A graphic result for the triangular distribution as input is given in Figure 3.

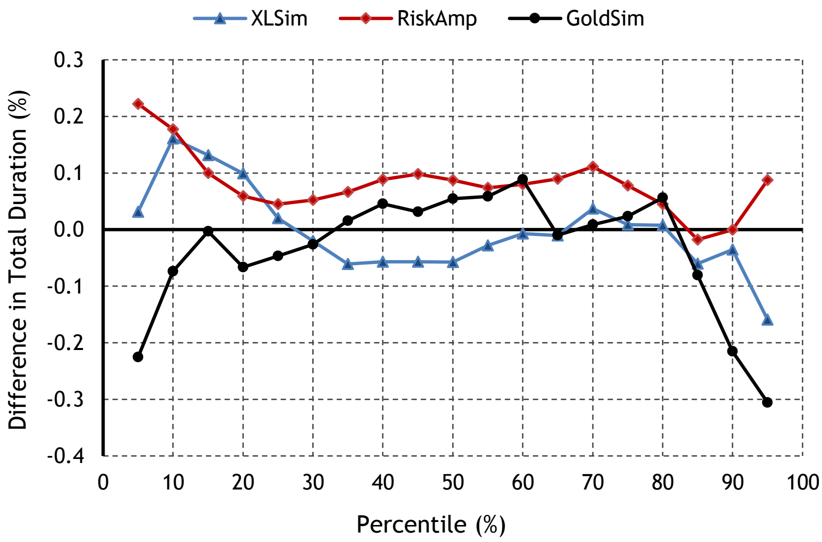

Figure 3. Difference in total duration with triangular distributions as input

From Figure 3 it is seen that the difference in total duration is very small in the 20-80% region, typically less than about 0.1%. In the regions 5-20% and 80-95%, the difference is larger but still less than about 0.3%. This was expected since different simulation software use different algorithms for random number generation as well as different interpolation and extrapolation algorithms. The difference in total duration for the other distributions was also less than about 0.3% over the 5-95% range. The RiskSim and GoldSim programs produce the values of the random variates and a two-sample t-test with unequal variance was performed on this data to compare the output distributions for the triangular distribution as input. The output distributions are so similar that a p-value of 1.0000 was obtained with the t-test. This indicates, at a 95% confidence level (p-value > 0.05), that the two distributions are not significantly different.

The P80 and P90 values are of particular interest to the project or risk manager and are often used for reporting the certainty duration values at various stages of a project. The comparison of P80 values for the series network is shown in Figure 4 and the comparison of P90 values in Figure 5.

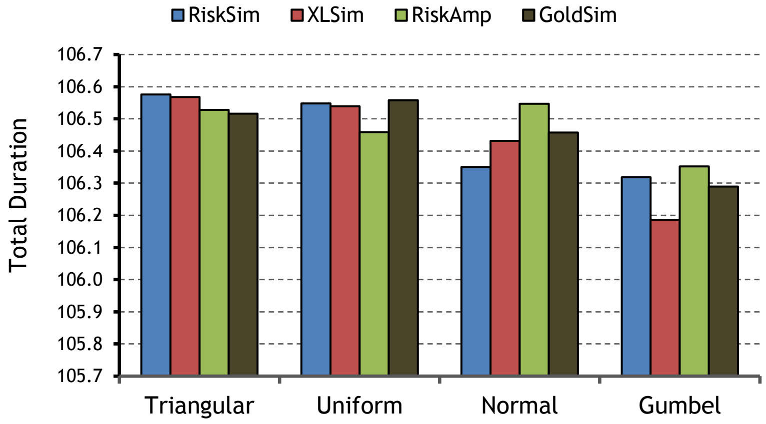

Figure 4. Total duration for 80% certainty and different distributions as input

The total duration at P80 for the four software programs and the triangular and uniform distributions are very similar. There is slightly more variation for the normal and Gumbel distributions. It should be remembered that the normal distribution is a symmetric distribution while the input distributions were non-symmetric.

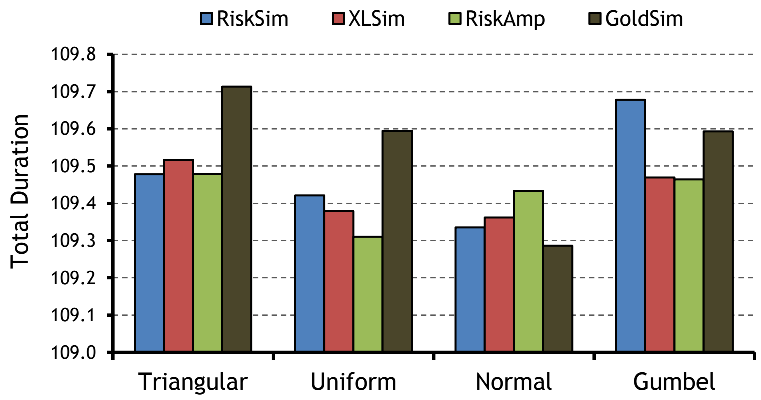

Figure 5. Total duration for 90% certainty and different distributions as input

The total duration at P90 shows more variation than at P80 as could be expected. The GoldSim software gave a noticeably longer duration than the other three programs but only 10000 trials were used with GoldSim while 20000 trials were used with the other programs. It is interesting to note that the duration values were very similar for all four programs when the normal distribution was used.

4.3.2 Project with activities in parallel

The simulations were repeated for the parallel network and the descriptive statistics for the total duration distribution are given in Table 6 for the triangular distribution only.

Table 6: Statistics for total duration for parallel network with triangular distribution inputs

Parameter	RiskSim	XLSim	RiskAMP	GoldSim
Mean	55.013	55.031	54.969	55.010
Std Dev	2.721	2.724	2.718	2.724
Skewness	0.103	N/A	0.038	0.079
P25	53.096	53.137	53.040	53.049
P50	54.954	54.962	54.918	54.966
P75	56.873	56.884	56.849	56.926

The values obtained with the four different simulation programs are in good agreement, except for the skewness that varies from 0.038 – 0.103. The skewness value is not provided by the XLSim software.

The total project duration using the RiskSim add-in was used as reference and the difference in duration was determined for the XLSim, and GoldSim programs at 5% intervals of the percentiles. The graphic result for the triangular distribution only is given in Figure 6.

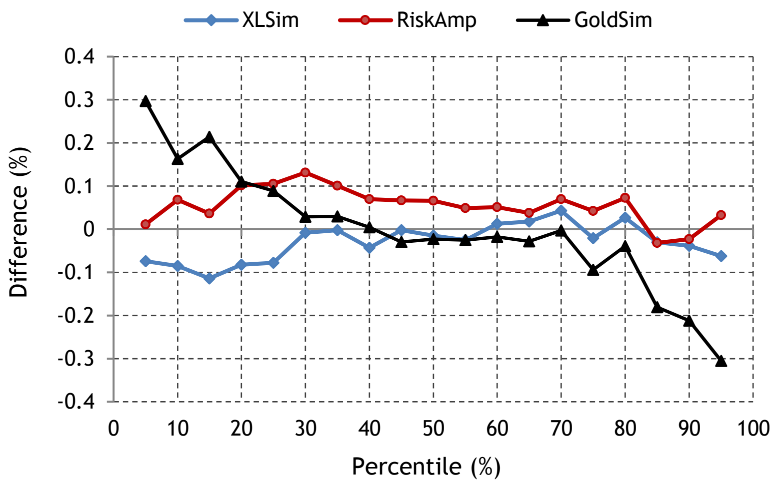

Figure 6. Difference in total duration with different software with triangular input distributions

As was noticed for the difference between software programs for the series network, the difference for the parallel network is also quite small, i.e. less than about 0.1% for the 20-80% region. For the 5-20% and 80-95% regions, the difference is larger but still less than about 0.3%. The difference in total duration for the other distributions was also less than about 0.3% over the 5-95% range.

The comparison of P80 values for the project with some parallel activities is shown in Figure 7 and the comparison of P90 values in Figure 8.

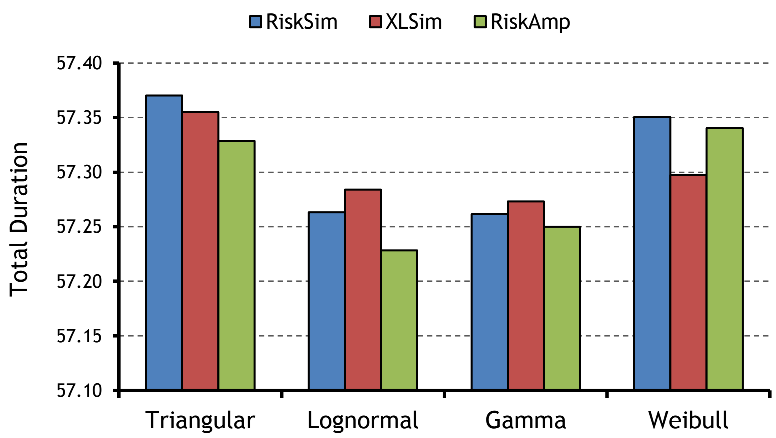

Figure 7. Total duration for P80 with different software and different distributions as input

The total duration values for the four simulation programs investigated are quite similar with the largest differences noted for the lognormal and Weibull distributions. It is also interesting to note that one specific program did not have the largest or the smallest values for all four distributions.

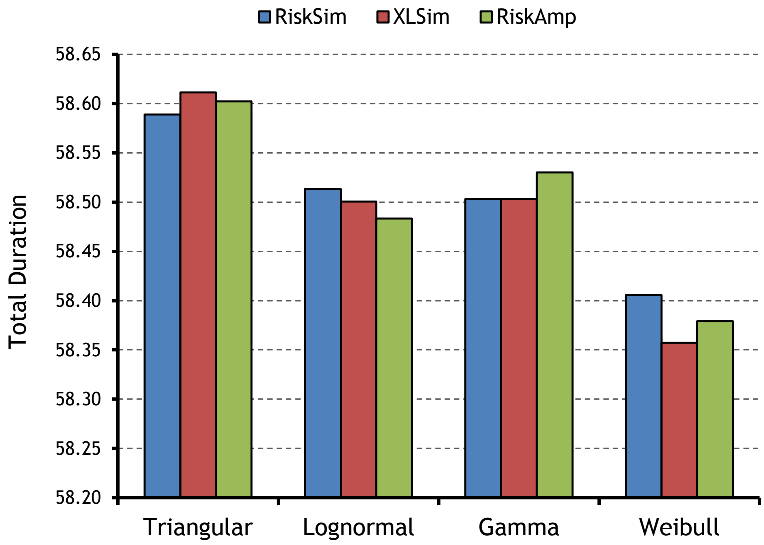

Figure 8. Total duration for P90 with different software and different distributions as input

The P90 values agree remarkably well for this case. Even the difference in total duration is quite small for the different input distributions although there is more variation than for the P80 values which is to be expected. The best agreement between the different software and different distributions is obtained in the 20-80% range. One might have expected that the different skewness and tails of these distributions would cause a notable difference in total duration.

The results for the series and parallel networks support the proposition that the output distribution for the XLSim, RiskAMP and GoldSim programs do not differ significantly from the distribution for the RiskSim program for all the different distributions investigated.

4.4 Software for reliability and availability of a system

The Raptor and BlockSim programs were used to perform 1000 trials at time intervals of 720 hours which was taken as one month of operation. One output of both programs is the average availability since the start of operations. This was used to calculate the interval availability at each time interval of 720 hours. Only the Weibull distribution was used for each of the 20 components of the total system. The interval availability for the total system for both software programs is shown in Figure 9.

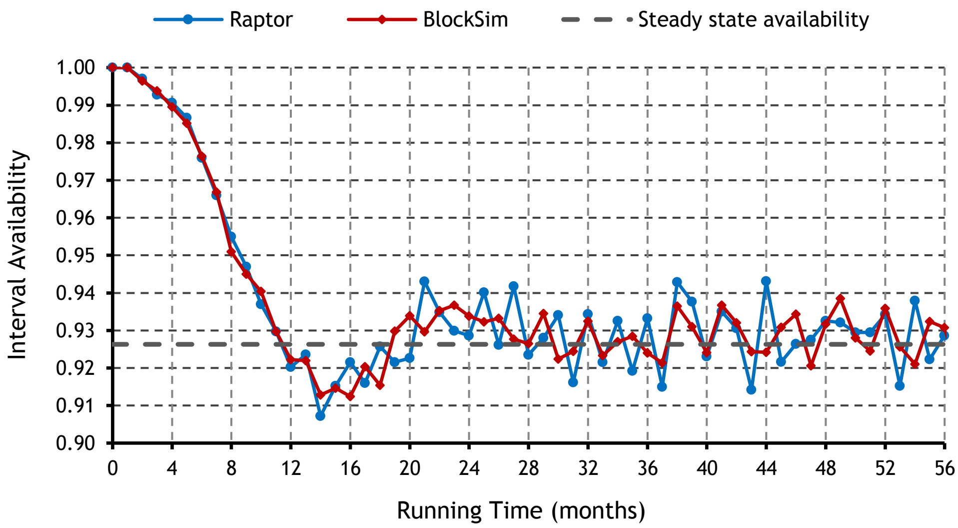

Figure 9. Availability comparison of Raptor and BlockSim simulation programs

The interval availability plots for the two simulation programs agree fairly well but there are some minor differences. The zig-zag pattern observed with the Raptor software was not as prominent with the BlockSim software. At times the maxima and minima for the two plots coincide, e.g. at 32, 38, 41 and 52 months for the maxima. However, there are examples where the minima and maxima do not occur at the same time, e.g. at 30, 44 and 54 months. This could be due to different random number generators used by the two programs.

Descriptive statistics of the availability plots were determined for the steady state period of 18-56 months and are shown in Table 7.

Table 7. Statistics for availability values obtained with Raptor and BlockSim software

Parameter	Raptor	BlockSim
Ao (average)	0.929	0.929
Std Dev	0.0077	0.0057
Ao (minimum)	0.914	0.917
Ao (maximum)	0.943	0.943

The average, minimum and maximum values for availability for the two software programs agree very well and the only major difference seen in Table 7 is in the standard deviation. The standard deviation with the BlockSim software was 26% less than the standard deviation as determined with the Raptor software. The variation of the interval availability values around the mean value when steady state was achieved were used to perform a two sample t-test with unequal variance and a p-value of 0.83 was obtained. This supports the proposition that the results with the two simulation programs are not significantly different.

The random variates for the Weibull distribution are calculated by means of the inverse of the cumulative distribution function (equation 2) and both software programs would use the same formula. The difference in standard deviation might be due to different random number generators used by the software. The BlockSim software uses the Mersenne Twister pseudo random number generator (Matsumoto & Nishimura [18]). The random number generator algorithm for the Raptor software is not known.

5. CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The distribution for the total project duration for a project with eleven activities in series as well as a project with some parallel activities was determined using four different Monte Carlo simulation programs and seven different input distributions. The results indicate that there is very little difference in the outputs of the four simulation programs even though only 10000 trials were used for the GoldSim program as opposed to the 20000 trials used for the RiskSim, XLSim and RiskAMP add-ins. The values for total project duration differed by less than about 0.3% over the 5-95% percentile range. Over the 20-80% percentile, range the difference in total duration is less than about 0.1%. The difference in total project duration for the 95-100% percentiles was not determined since extrapolation from a limited number of data points is inaccurate and should not be used by project and risk managers.

The results confirm the proposition that different simulation add-ins for Excel or standalone Monte Carlo simulation software can be used with confidence by project and risk managers for project cost and schedule simulation. The subjective estimates by experts for the parameters of input distributions are far more uncertain than the small differences obtained for different simulation software.

Two discrete-event simulation programs were also compared by determining the interval availability at intervals of 720 hours for a multi-component system. A two sample t-test for the difference between the availability as determined with the simulation and the theoretical availability confirmed the proposition that the results of the two programs are not significantly different.

5.2 Recommendations

Two test cases, one for a series and one for a parallel network were used to test the proposition. These test cases should also be investigated with highly skewed distributions and perhaps higher standard deviations. Right skewed triangular distributions where the value of $(b-m)$ is 4 to 5 times the value of $(m-a)$ could be assumed for the input and the output of the software compared.

There are also other add-ins or standalone simulation programs that could be tested, e.g. @Risk, Crystal Ball and RiskSolver. It could also be interesting to run a larger number of trials, e.g. 50000 for the spreadsheet simulation and 5000 for the discrete event simulation, and the output compared for the difference software.

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IDENTIFYING BARRIERS FACED BY KEY ROLE PLAYERS IN THE SOUTH AFRICAN MANGANESE INDUSTRY

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ABSTRACT

South Africa has abundant manganese ore deposits. Yet, it fails to capitalize on this resource and reach possible levels of economic benefit in this commodity's industry. This paper aims to identify the barriers to economic growth for key role players in the manganese industry. The manganese value chain is mapped out to determine the different manufacturing processes, role player dependencies and factors shaping the value chain. Representatives from the various sectors in the value chain were interviewed in order to identify, categorise and rank the barriers according to their impact on economic growth. This enables areas for improvement to be identified in order to promote the development of the local manganese industry.

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1. INTRODUCTION

The manganese industry is an integral part of South Africa's well-established mineral and commodity sector. It is well endowed with natural reserves and has developed local technical expertise in producing value-added products i.e. manganese ferroalloys since 1937 [1]. Together with many other well-established mineral industries in South Africa, the manganese industry has served as a catalyst for the advancement of an extensive physical infrastructure in the country and similarly made significant contributions to research and development, technologic advancements and market relationships throughout the various sectors in the manganese value chain.

South Africa's vast mineral wealth has long served as an attractive option for large capital investments. This natural wealth is the driving force for the development of an integrated mining industry, due to the sharing of infrastructure and the overlap of shareholder interests. The mining industry has formed a dominant part of the country's economy and is responsible for revenues earned through trade in global markets [2]. The establishment of mining-related activities, together with the promotion of downstream beneficiation by government through various policies and strategies, has placed focus on unlocking economic value further downstream from mining to other activities, such as further processing, refining and fabrication of high value products [2]–[4].

The steel and manganese industries are closely related and regularly influence each other. The outlook of the steel industry is essential for manganese for the following four reasons:

1. Manganese is primarily used in steel manufacturing, which accounts for approximately 90 % of the total manganese demand [5]–[8].
2. It is used as an alloying material.
3. There are no suitable alternatives for manganese in steel production [5], [8], [9].
4. Vertical integration in the global manganese value chain (which means leading steel companies are to some degree involved in manganese production) [5], [10].

South Africa is a leading player in the international manganese ore and manganese ferroalloys industry. It is the largest producer and exporter of manganese ore and a major role player in ferromanganese production and global trade of these alloys [1], [11]. The abundance of natural resources, relatively low electricity costs and cheap labour are historical factors that have contributed to this dominant position in the manganese value chain [1], [12].

There are numerous factors that have progressively grown during the past couple of years which has had detrimental effects on the manganese industry and threatened the country's dominant position. These factors include [1], [12]:

1) New legislation affecting the mining and minerals industry;
2) A shortage of local suitable reductants;
3) Depletion of surplus electricity generation capacity with resultant threat of escalation of electricity prices, and;
4) Pressure resulting from the recent fall in the manganese commodity market.

Furthermore, the manganese ore and alloy production capacity added during the commodity boom cycle (between 2001 and 2007 when the manganese commodity cycle was at a peak [13]) has declined, resulting in the current market remaining oversaturated and in ample overcapacity of manganese ore and alloys [14]. As a repercussion, manganese is presently one of the worst performing commodities with prices at its lowest point, not seen since the 90's [14].

It is evident that the manganese industry like so many other metal and mineral industries, has entered an extremely difficult period. This has led to the industry shifting focus to address challenges not only in terms of short term gain, but to ensure long-term viability [1]. These measures include appealing for a review of specific legislative policies in the mining and mineral market to improve support from government, improvement of operational efficiency, development of port and rail infrastructure, as well as initiatives to expand electricity generation and coke production capacity [1].

1.1 Research objective

The aim of this study is to establish the importance of various factors that impede economic growth throughout the value chain in the South African manganese industry. This aim is supported by three research objectives, namely:

1. Determine the different stages and branches of the South African manganese value chain;
2. Identify the barriers faced by the role players within each of these stages and branches with regards to economic growth, and;
3. Rank these barriers according to their impeding effect on economic growth.

1.2 Literature gap to be addressed

The published literature pertaining to the South African manganese industry provides a detailed layout of the manganese value chain and how the country relates to the global market [1], [5], [10], [12]. Much of the literature, however, is slightly outdated, relying on sources published before the sharp rise in electricity tariffs were implemented, the regular occurrence of unreliable power supply, the manganese commodity cycle facing a record low point, increased labour disputes in the mining sector, and government policies implemented to support beneficiation initiatives. All of which gained traction in the mid to late 2000's.

Furthermore, there is a void in this research pertaining to the major problems and constraints faced by the different role players in this industry with regards to economic growth and the impact that these constraints have on their businesses. There also is a lack of information pertaining to the impact that these role players exert one another and how these constraints affect their relationships. At present, there is no research available where the main barriers to economic growth of individual role players in the manganese value chain is identified and ranked according to their impact on the business. This paper addresses these issues by providing an update of the current state of affairs of the South African manganese industry and its position in the global value chain, as well as identifying the current constraints faced by the various local role players and the impact these constraints have on their economic growth.

2. INDUSTRY BACKGROUND

South Africa hosts about 75 to 80 percent of the world's identified manganese resources and approximately 24 per cent of the world's reserves [12], [15]. Over 90 per cent of the reserves are located in the Kalahari Manganese Fields (KMF) which is situated in the Northern Cape and has an estimated 4 billion tons of manganese reserves [12]. There are two main types of manganese ore present in the Kalahari deposit, namely low-grade primary sedimentary Mamatwan-type ore and high-grade Wessels-type ore [12], [13]. The Mamatwan type contains between 20 to 38 per cent (less than 40%) of manganese in its ores, while the Wessels type, which only makes up 3 per cent of the total ore body, contains 45 to 60 per cent manganese [16], [17]. The manganese ores of the KMF are characterized by their low phosphorus content, which makes it a suitable feedstock for the steel industry.

The country produces high-grade ore, features increasing mining operations and is a significant producer of manganese alloys. The manganese supply and demand closely follows the iron and steel market trends due to manganese's primary use in steel manufacturing, but is also used in numerous other applications. Manganese is the 12th most abundant element in the earth's crust and the 4th most abundant of the metals in commercial use [9].

Manganese ore is obtained in the form of manganese oxide and must undergo numerous forms of processing in order to be converted into alloys. The most important manganese alloys are high carbon ferromanganese (HC FeMn), refined ferromanganese (RF FeMn) and silicomanganese (SiMn) alloys [5], [9], [12]. Manganese has properties which makes it an ideal input for alloy manufacturing and thus plays a significant role in the steelmaking process as an alloying element [7]. Therefore the three industries of manganese, iron and steel are intricately linked [5]. There is no adequate substitute for manganese in steel which contains all of its technical benefits and its relatively low cost [9]. The second most important application of manganese is portable dry cell batteries [7].

2.1 The manganese value chain

It is clear that the world demand for manganese and ferromanganese products have a direct dependence on the outlook of the steel industry, which in turn is driven by housing construction, the automobile industry and general infrastructural constructions [5]. To understand South Africa's position in this industry, the context of the country's role, where the barriers lie to economic growth, the global value chain of manganese, and manganese related products are examined. According to Gereffi [18], for many countries, especially low-income countries, the ability to effectively insert themselves into the global value chain is a vital condition for their development. The manganese value chain is closely related to the beneficiation process. According to Maia [2], beneficiation can be defined as the transformation of minerals, through chemical or metallurgical processes, to higher value added products for domestic or export markets. Different stages in the value chain are defined in Table 1, using examples applicable to the manganese value chain.

Through inspection of the manganese global value chain, it is evident how the industry is organized by examining the structure and dynamics of the different role players involved. Since this mineral commodity, like so many others, is globally integrated with complex industry interactions, examining the value chain is a useful tool to trace the shifting patterns of global production. It is also convenient for associating geographically dispersed activities and role players, and to determine the role they fulfill [18]. The global value chain focuses on the sequences of value addition within the industry and examines the technologies, standards, regulations, products, processes, and markets which provide a holistic view of the global industry.

Table 1: The different stages of beneficiation, as defined by Maia [2], with examples applicable to the manganese value chain

Stages	Raw material	Stage 1	Stage 2	Stage 3	Stage 4
Metals	Ore	Smelted or refined products	Fabrication alloys and metals	Semi manufactured articles	Fabricated articles
Example	Manganese ore	Ferromanganese	Stainless steel	Long and flat products	White goods, pumps, valves

2.2 South African manganese industry

The first two stages of Maia's beneficiation process are dominant in the South African manganese industry namely, the mining and procurement of the manganese ore and the fabrication of alloys, metals and other intermediate products. The manganese value chain does, of course, stretch much further than only these two sectors (see Figure 1); but these are the main aspects directly pertaining to the current South African manganese production activities. South Africa's position in the global production and consumption of these manganese products are summarised in Table 2.

Table 2: South Africa's global production and consumption of manganese products [11]

Product	Production			Consumption		
	Global rank	Volume (mt)	% of Total	Global rank	Volume (mt)	% of Total
Mn Ore	1	4,640	24.9	9	325	1.8
HC FeMn	3	457	10.1	28	27	0.56
Ref FeMn	5	102	5.9	31	10	0.59
SiMn	14	134	1.0	30	30	0.22
Steel	21	7,220	0.45	-	-	-

Where Vol = Volume (000 mt Mn Units), % = Percentage of global total, Rank = Global ranking

2.3 Local role players of the manganese industry

It is evident from Figure 1 that the manganese industry consists of various sectors, each utilizing specific types of ore, intermediate products, processes, upstream inputs and role players. This summary was created to provide the reader with a better understanding of the context of the production scale of the various manganese products and to present the different sectors of the manganese value chain. There are currently five major manganese mining companies in South Africa, namely [5], [19]: South32 (formerly BHP Billiton/Samancor Manganese), Assmang Limited, Kalagadi Manganese, Tshipi Manganese and United Manganese of the Kalahari (UMK). BHP Billiton is the world's largest manganese producer while Assmang Limited is fourth. Together these two companies dominate the local manganese production market in South Africa [5]. Smaller producers include Kudumane, Metmin and National Manganese Mines, as well as many other BBBEE companies that have entered the market [19].

The country has four manganese alloy producers that are classified as stage 2 role players in Maia's beneficiation process. These ferroalloy producers are: Metalloys (South32), Assmang, Transalloys and Mogale Alloys [12], [19]. Of these four, Transalloys is the largest producer of silicomanganese (SiMn) in Africa. Mogale Alloys a smaller producer of SiMn and the other two producers supply ferromanganese. With the increase in electricity tariffs and unreliable supply thereof in recent years, together with the oversaturated market, many of these suppliers have drastically slowed down production or halted their operations altogether [20]. South Africa also has producers of electrolytic manganese dioxide (EMD) and electrolytic manganese metal (EMM).

The latter generally accounts for between 6% to 10% of the total manganese ore usage [21]. All of South Africa's manganese resources are located in the Northern Cape Province in a zone stretching northwards over a distance of 150km, from south of Postmasburg to the Wessels and Black Rock Mines north of Hotazel, known as the Kalahari Manganese Field (KMF) [10]. It is the largest single manganese depository in the world and accommodates all of the country's manganese mines. The manufacturers of manganese related products, present higher in the value chain, however, are situated closer to the eastern coast in industrial areas in the Mpumalanga, Gauteng and Kwa-Zulu Natal provinces.

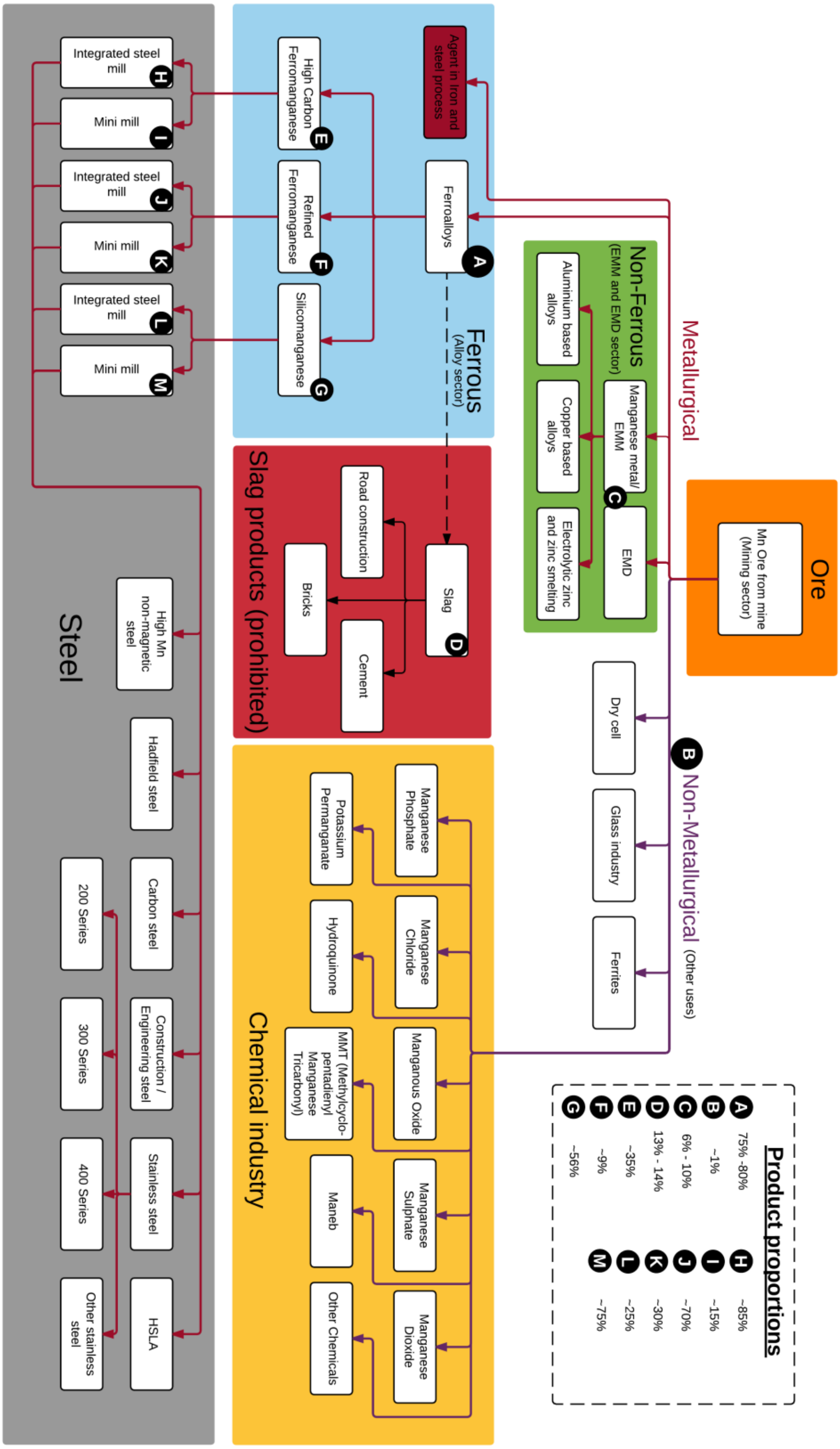

Figure 1: South African manganese value chain [5], [8], [21], [22]

3. RESEARCH METHODOLOGY

Due to the exploratory and descriptive nature of the study, a qualitative research approach was followed as shown in **Error! Reference source not found.**. A qualitative approach predominantly affirms an inductive approach to the relationship between theory and research, in which the emphasis is placed on information generation [23]. Since the focus of the study is on providing insight on the multiple role players in the manganese value chain and the various barriers that they face to economic growth, a qualitative study, is suitable for this research.

3.1 Research Approach

The principle data required for this study, is the ranking of the main barriers that different role players in the South African manganese industry face to economic growth. The research methodology followed for this study consists of 3 phases, with the first entailing the identification of data sources and method sampling. This phase addresses research objective 1 by providing an in-depth overview of the local value chain. The second phase is data collection, which includes drafting an interview guide, conducting interviews with relevant company's respondents, and reviewing reports and other forms of secondary data. This phase addresses research objective 2 and 3 through the identification of barriers by industry experts and ranking the barriers according to their responses. The final phase is the analysis and validation of the collected data and results. The phases and underlying activities are shown in Figure 2.

3.2 Data collection method

Multiple data collection techniques were used in the research methodology to reinforce the triangulation of data and therefore establishing the qualitative outcomes of the research. Various forms of data triangulation are employed through the use of qualitative research, the collection of specific operational data (such as electricity usage, when operational delays occur, productivity of the workforce, etc.) to corroborate the qualitative data gathered from the barrier discussions in the interviews. Furthermore, it supports the credibility, reliability and validity of the findings through cross verification of information [24]. This study incorporates triangulation with the following two approaches:

1) **Data source triangulation:** Evidence from different data sources (primary and secondary research) was collected. This includes interviews with relevant companies' respondents, questionnaires, company documents, public records, literature review and observations.
2) **Methodology triangulation:** Multiple methods to gather data was combined and utilised. This included conducting both conversational interviewing and semi-structured question interviewing to determine the barriers faced by companies. The results are compared with barriers gathered during company reports, news articles and relevant publications on the manganese industry.

The applied data collection tools for primary data collection includes document reviews and semi-structured interviews with the help of an interview guide which allowed for specific topics to be covered, yet allowed for questions to be added in accordance with responses provided by the interviewees. Open questions were used to ensure that the interviewee had leeway in how to reply and to allow for the interviewee's levels of knowledge and understanding to be tapped in order to explore new areas of research which has previously been limited [23]. The questions were exploratory in nature, prompting the interviewee to identify barriers that specifically affect them and which potentially have not yet been mentioned in public records. The interviews gave stakeholders the opportunity to voice their opinion on the level of interaction between different industry players. The questions also allowed for their perspectives to be shared on the future of the industry and where they believe the major barriers for economic growth lie.

Secondary data was also collected in the form of literature reviewed throughout the study, company publications such as annual and other reports, and publicly available data which is relevant to role players and barriers in the manganese value chain. In order to obtain a broader opinion on the various constraints faced by the role players, a questionnaire was prepared and emailed to numerous experts in the fields of mining, ferroalloy production and other production of manganese products (see Table 3).

The interview and questionnaire covered issues including current operations, logistics, technology, electricity and energy usage, raw materials and pre-treatment thereof, environmental issues, relevant legislation and policies, by-products, economic aspects of operations, exports and sale of products. An interview guide was sent to the respondents before the interview was conducted, presenting an overview of the various aspects that will be covered. It also explicitly requested the biggest barriers that they face in terms of economic growth. After the interview was conducted, a follow-up questionnaire was sent for soliciting specific information on content areas in order to identify and elaborate underlining barriers from the respondents.

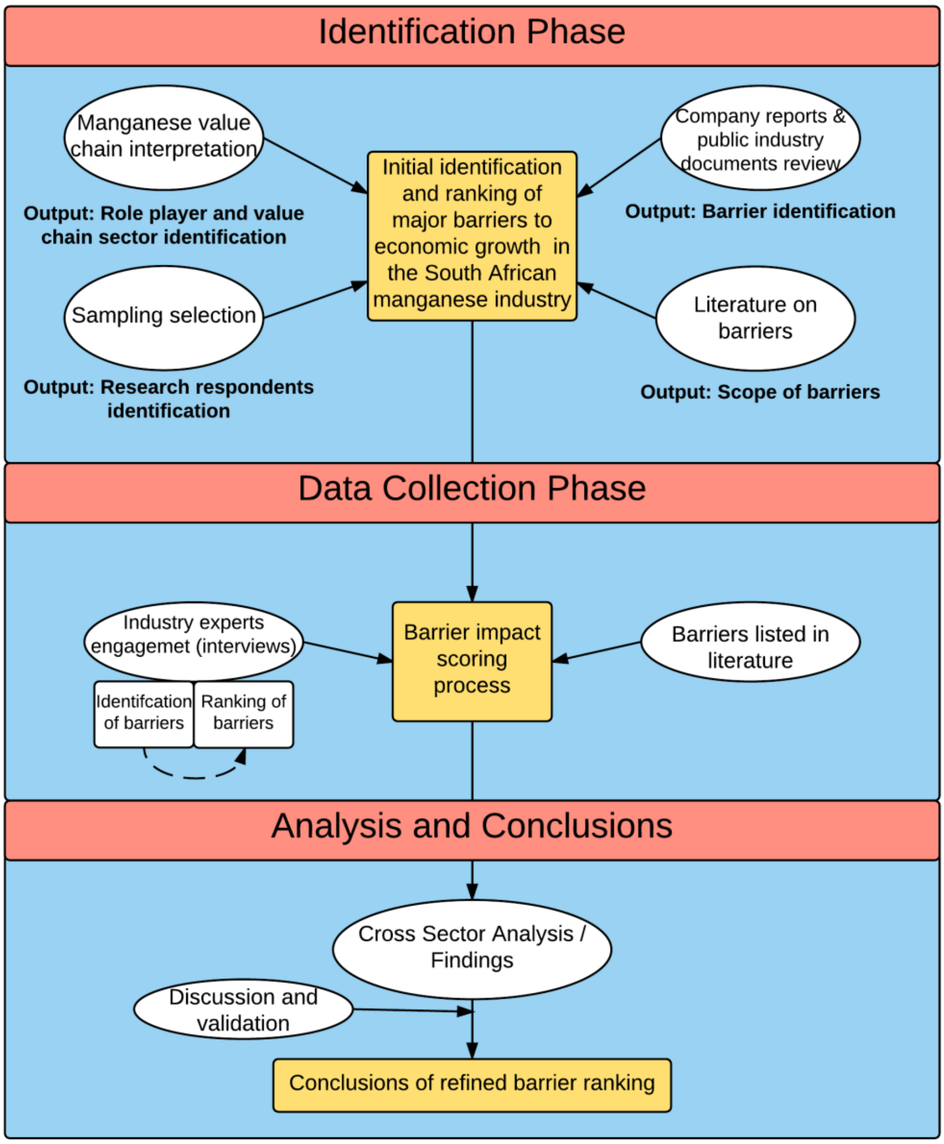

Figure 2: Research phases of the study

3.3 Sampling method

Semi-structured interviews were conducted with the aim of gaining comparable views of the most pressing issues in the industry faced by various role players in different sectors of the manganese value chain. It was thus necessary that potential respondents from the different sectors in the value chain were approached for the study. The input from these various industry experts have allowed for the constraints to be ranked according to severity which in turn makes it possible to assign a level of priority to each constraint. All interview responses were used to identify major operational barriers and the scope of its impact.

The list provided by the DMR [19] of manganese mining companies and manganese-related product manufacturers, as well as relevant companies listed in literature [5], [12], [25], identified 23 companies in the South African manganese value chain. Seven of these companies were disregarded, since their operational focus on manganese were negligible or they could not be reached for comments nor were any of their company documentation available. The remaining role players varied in business size, operation field, time in market and size of their market share. From the relevant candidates, three types of role players could be identified, namely those in mining, alloy production and lastly manganese related product manufacturers such as EMM and EMD producers. In order to cover the majority of the local value chain, it was important to have representatives from each sector participating in the study. Smaller sectors such as the specialized usage of manganese in chemical applications, which only accounts for approximately 1% of manganese usage, is not as crucial for this research purposes and were therefore excluded from the study.

Interviews were conducted with representatives of two of the largest manganese mining companies in the world, two of the four South African manganese alloy producers, gaining perspectives in both ferromanganese and silicomanganese alloys operations, and the world's only non-China based producer of electrolytic manganese metal and Africa's only producer of premium-quality electrolytic manganese dioxide.

Table 3: Sampling and sourcing of data

Role player Type	Interview	Questionnaire	Public records	Could not reach	Identified role players in sector
Mining	2	2	6	10	**16**
Alloy production	2	2	4	0	**4**
Other	2	2	2	1	**3**
Total sources	**6**	**6**	**12**	**11**	

Table 4: Companies from which the respondents were surveyed

Company	Role / Sector	Operation phase	Interaction type
1	Mine	Running	Interview / Questionnaire / Publications
2	Mine	Running	Publications
3	Mine	Running	Publications
4	Mine	Running	Interview / Questionnaire / Publications
5	Mine	Running	Publications
6	Mine	Running	Publications
7	Alloy	Production decreased	Publications
8	Alloy	Production decreased	Publications
9	Alloy	Production decreased	Interview / Questionnaire / Publications
10	Alloy	Production decreased	Interview / Questionnaire / Publications
11	EMM	Running	Interview / Questionnaire / Publications
12	EMD	Process of closing	Interview / Questionnaire / Publications

3.4 Data analysis techniques and interpretations

Barriers are initially identified through observations in company reports and other literature. It was accepted and elaborated upon further through primary sourcing in the form of questionnaires and interviews conducted with experts in the manganese field. The barriers were ranked according to the sectors they occurred in the value chain by the respondents' feedback on each barrier's respective impact on economic growth. A score was assigned to each ranking as follows:

- Ranked 1st = 5 points
- Ranked 2nd = 3 points
- Ranked 3rd = 2 points
- Mentioned = 1 point

The barriers are ranked according to the highest accumulative score between the respondents in the same sector in order to identify the major barriers faced by role players in the manganese mining, alloy production and other related product manufacturing.

Examining the results can help determine how the barriers influence each business and where bottlenecks occur which hinders progression. This analysis thus reveals which barriers cause the greatest restriction on economic growth. The results from the respondents were compared to secondary data from published company reports to determine if there is a degree of consensus. The literature corroborated the findings.

4. RESULTS

Through primary and secondary sourcing, numerous barriers in the manganese industry were identified, stretching from lack of proper infrastructure and energy supply to labour issues and the implementation of new policies by the government. It is also clear that the barriers provided by role players in the same sector had a strong correlation, but sometimes differed from role players in other sectors. An example is the unreliable energy supply identified in the energy-intensive alloy, EMD and EMM production sector, but does not have as a significant impact in the mining sector. In some instances, some barriers were ranked together by the respondents (such as both the unreliable supply and rising cost of electricity), in which case these barriers shared the respective ranking. From the responses and literature review, a total of 31 barriers were identified. In order to protect the anonymity of the various companies and their representatives, the barriers are not explicitly linked to specific individuals.

Table 5: Scoring of barriers

MINING SECTOR					
Ranked barriers	**1st**	**2nd**	**3rd**	**Other**	**SCORE**
1) Low market price	1	1			8
2) Industry fragmentation	1				5
3) Lack of rail capacity			2		4
4) Electricity (unreliable supply)		1			3
4) Electricity (rising cost)		1			3
MANGANESE ALLOY SECTOR					
Ranked barriers	**1st**	**2nd**	**3rd**	**Other**	**SCORE**
1) Low market price	2				10
2) Electricity (unreliable supply)		2			6
2) Electricity (rising cost)		2			6
3) Low productivity of workforce			1	1	3
4) Volatility of workforce			1		2
5) Cost of labour				1	1
EMD SECTOR					
Ranked barriers	**1st**	**2nd**	**3rd**	**Other**	**SCORE**
1) Oversupply of product	1				5
2) Anti-dumping duty		1			3
3) Electricity (unreliable supply)			1		2
3) Electricity (rising cost)			1		2
EMM SECTOR					
Ranked barriers	**1st**	**2nd**	**3rd**	**Other**	**SCORE**
1) Electricity (unreliable supply)	1				5
1) Electricity (rising cost)	1				5
2) Lack of rail capacity		1			3
3) Lack of government support			1		2

4.1 Identified barriers in the manganese value chain according to sector

The top three barriers of each sector is ranked according to the impact it has on the economic growth of the role players in the respective sector.

4.1.1 Barriers in the manganese mining sector

1) Low market price

Commodity prices are often affected by external factors which many times cannot be controlled by producers. All commodities are subject to wide fluctuation, especially minerals used for alloy and steel manufacturing. Manganese supply and demand are closely dependent on the iron and steel market with all manganese products following a similar trend to these resources. Price volatility has an adverse effect on a company's operating results, asset values and cash flows. If commodity prices remain weak for sustained periods, it can lead to growth projects no longer being perceived as viable options. China's dominance in the steel market also determines many trends in the industry.

The added manganese ore and alloy capacity during the commodity boom years is now in the market, resulting in considerable overcapacity in the market. As a consequence, manganese is one of the worst performing commodities today [14]. Companies in some instances have rejected additional rail capacity to transport their ore when prices were too low for export. The weak market conditions for manganese products, has caused mining companies to lower production and only consider the cheapest forms of transport or risk making a loss.

2) Fragmentation / rise in internal competition

The fragmentation of the local industry structure has lead to a significant rise in internal competion. The barriers to entry in the manganese ore market have traditionally been relatively high, which allowed for a limited number of players in this sector, but this changed after the government started issuing

new mining licenses to numerous companies. This has caused the mining sector to be condensed with numerous companies all competing for the same resources in the same market.
When the market consisted of less ore producers, rivalry was contained and the price could be regulated by these few entities. At present, many mines are situated together competing for the same rail and port capacity, customers and other resources. The rise in competition between mining companies which is constantly on the rise, has lead to decreased profit margins in order to remain in the market and attract customers. The market conditions are thus becoming less attractive for ore producing companies.

3) ***Rail capacity***
Ports and the freight system in South Africa is currently suffering from inefficiencies rendering most of the manganese ore incapable of being optimally distributed to domestic and international markets. Since the country's transport infrastructure has been found inadequate of supporting higher export volumes to the international market, greater efforts are to be made to improve the efficiency of South Africa's ports and rail utilities. Accelerated economic growth and lack of adequate maintenance and upgrading, however, have rendered the transport system in urgent need of corrective measures.

In both interviewed cases, the mining company's production rate is higher than what can be transported via rail to its various destinations, causing a bottleneck to occur. When the market price for manganese ore was still high, it was profitable to transport the ore via road transport such as trucks, but with the current weak economic position the commodity faces, this is no longer the case. Many mining companies, situated in close proximity to one another, have to vie for rail allocation to transport their ore. If enough rail capacity cannot be provided, then mining production is lowered. The logistic costs of transporting ore to ports for export, as well as from the ports to the final customer, are the highest expenditure for these companies. All interviewed mining companies have scaled down production in order to match their rail allocation. If more is produced, the ore needs to be transported via trucks on the road, which greatly increases the cost per ton and will lead to a loss of profit.

4.1.2 Barriers in the manganese alloy sector

1) ***Weak market conditions***
Currently all manganese ferroalloy producers are shutting down or are in the process of shutting down production, primarily due to the weak market conditions. The market demand is too low to justify operating the energy-intensive furnaces. There was a time when a bottleneck occurred between the mines and the smelters where the supply of ore did not fulfil the demand, but this is no longer the case.

The current commodity recession has consequently lead to a downward trend in the demand for manganese ore and alloys. Steel manufacturing is inherently a primary economy which drives the demand for alloys and is currently in decline. It was not expected that this commodity slump would have continued for so long, which resulted in many producers having continued with operations while hoping for the conditions to change. All along enduring the difficult economic conditions that it entailed.

2) ***Unreliable electricity supply and rising cost (ranked together)***
The second major constraint faced by alloy producers is electricity availability and rising cost. With production lowering due to the weak mineral economy, the supply has become sufficient, but at normal production rate the interrupted supply causes many operational setbacks and the rising tariffs are cutting into profits. Where South Africa used to have very inexpensive electricity, the country has lost its international competitive advantage in this regard. Furthermore, it seems that these prices may still be on the rise in the coming years, while other countries prices remain relatively consistent [26]. In recent years, power has seen a massive jump in price which had a significant impact on operation costs of all alloy producers.

Energy-intensive alloy producers also regularly experience power containments where energy consumption in the company must be lowered for a duration of time in order to lighten the burden on the national electricity grid as per agreement with Eskom. Consistency is key for these producers and their furnaces need to remain continuously running for as long as possible to attain ideal operating conditions. Power containment and interrupted supply, drastically decreases efficiency and increases the operating costs of the furnaces.

3) ***Volatile and unproductive labour force***
South Africa's weak economic growth, rising costs, high unemployment and numerous socio-economic challenges have resulted in many problems and unrest in labour cost and efficiency. This extreme financial pressure has been evident in extended strikes in metal industries. Unrest among workers has led to decreased labour productivity which undermines companies' profitability and threaten the sustainability of the business.

Strikes also regularly occur with employees demanding larger wages, which further decrease productivity. According to respondents, similar facilities abroad are operated by a workforce much smaller in size than locally, with the same work being done by a smaller group of people. This is due to better qualified staff, as well higher productivity of workers abroad. Labour costs are on the increase, adding to the already large operational costs.

4.1.3 Barriers in the EMD sector

1) ***Oversupply in EMD market***
EMD is a niche market with various producers all over the world. Due to the large number of EMD producers and a reduction in demand, especially local demand in Africa, and the market is in oversupply. It is thus likely that a global producer must close down operations. Since local demand is much smaller than abroad, it is likely that South African producers' market share will shrink. This was the case for Delta EMD.

2) ***Anti-dumping duty***
South African producers have not always found it economic to exploit rising demand for manganese products due to its distance from the markets, despite the existing excess production capacity to do so. Competitors that are located closer to the markets have traditionally had a competitive advantage over producers from abroad. Anti-dumping claims have been made against South Africa by companies in Europe stating that South Africa is dumping EMD products abroad and selling it for less than the production cost. This to the South African company being forced to pay a 20% duty fee in order to export its products to Europe which was not a viable option. The same company lost its share in American markets, when the USA decided to terminate its contract and rather support a local producer.

3) ***Unreliable electricity supply and rising cost (ranked together)***
Electricity was another major barrier for this industry. Load-shedding which unpredictably took place and halted operations is a major concern. Many of the machinery had to be prepared more than two hours in advance to ensure that no damages occur to the equipment and the product. If the necessary precautions were not made beforehand, the entire batch being prepared was ruined and ended up as waste. Since an electrolytic process is used, a constant electricity supply is required for optimal working conditions. The sharp annual increases in electricity tariffs in recent years, has placed immense pressure on these companies and drastically increased their overall production costs.

4.1.4 Barriers in the EMM sector

1) ***Unreliable electricity supply and rising cost (ranked together)***
(See *Barriers in the EMD sector*)

2) ***Lack of rail capacity***
The freight system and ports in South Africa are currently suffering from inefficiencies rendering most of the manganese products incapable of being optimally distributed to domestic and international markets. Since the country's transport infrastructure has been found inadequate of supporting higher export volumes to the international market, greater efforts are to be made to improve the efficiency of South Africa's ports and rail utilities. Accelerated economic growth and lack of adequate maintenance and upgrading, however, have rendered the transport system in urgent need of corrective measures.

3) ***Government support***
Companies are making substantial changes to align their businesses with new policies implemented by the government to promote beneficiation, yet these companies do not receive the support or advantages, such as subsidies, as they expected by the government. Furthermore, the constant delays in national infrastructure developments adds to the mismanagement factor constraining economic growth of the businesses involved.

5. CONCLUSIONS AND RECOMMENDATIONS

This study has affirmed the current state of affairs of each sector which comprises the manganese industry of South Africa. An in-depth overview of the manganese value chain was presented, which provides context to how South Africa's local industry fits in with the global market. Furthermore, first-hand data was collected in order to identify the current major barriers faced by role players in different sectors of the value chain, as well as ranking the top three barriers in each sector. The results provide the barriers to economic growth that cause the greatest impedance on the various role players in the mining, alloy manufacturing and EMD and EMM production sectors.

These barriers were up to now, not explicitly identified and ranked according to severity by various role players in different sectors of the South African value chain. This provides significant insight by experts in the field of mining, alloy manufacturing, as well as the production of other manganese related products such as EMM and EMD on where operational bottlenecks in the manganese industry occurs. This study allows for further investigation as to how these major barriers to economic growth can optimally be addressed in South Africa, as well as forecasting the possible risks that these barriers could have on the different role players in the value chain.

Despite all of the research objectives being met, there are still some recommendations for future related work, including expanding the list of identified barriers to include more barriers. A severity score for each barrier could also be added, in order to quantify the extent of the impact of each of the barriers as experienced by each of the respondents.

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SUPPLY CHAIN MANAGEMENT: PERFORMANCE BENCHMARKS FOR SOUTH AFRICAN COMPANIES

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ABSTRACT

In a fast-paced competitive business environment, it is essential to be able to gauge performance, not only for companies to track their progress over time, but also their relative performance to others in their own environment. Understanding where you are in terms of performance, can set the stage for improvement and developing competitive capabilities. A study was conducted to determine firstly which performance measures are considered important by South African businesses and secondly if this is an acceptable way to measure performance for benchmarking purposes. The objective of this project is to construct and test a tool to benchmark performance in the context of the South African supply chain environment. The benefit of determining these differentiating factors will be that clearer direction can be given to companies in terms of supply chain factors to improve their chances of success. This could be used as a guide to companies on a continuous improvement journey. A process of designing those measures was done by a focus group involving seven industry experts, where after a rough survey was conducted to test the reaction of the industry to those measures. The research shows a selection of 16 measures that the industry experts consider important to measure resulting from thorough debate. It also includes some segmentation questions that the experts considered important. The research also indicates which measures are used and which people from industry are willing to respond to. These form the basis of a better scorecard to measure supply chain performance, from the three perspectives of input, output and process. This will enable businesses to gauge their performance in relation to their competitors comparing the same indicators. It is recommended that these tested measures be rolled out into industry so that South African businesses can benefit from this research. It will require a mechanism that could form the basis of further research.

Keywords: Supply Chain, benchmarking, performance, measurements, South Africa

1 Introduction

Global competition has forced all businesses to become more competitive and there is a growing need for global performance standards to be understood [1, p. 452]. South African companies are competing with cheap imports from Eastern countries like China and Vietnam, while struggling to hold onto a dominant position in Africa. According to the Global Competitiveness Report [2, pp. 340-341], South Africa is performing relatively well in the African region, although there are certain areas like education, health and labour relations that need serious attention. This indicates that South Africa does have the capability to compete globally, but has special circumstances and challenges to deal with.

One of the key challenges of South African businesses is that they do not have benchmarking information of similar businesses to compare themselves with in the same environment. They can compare themselves with other countries in Europe or the USA, or even the other BRICS countries, but there is no exclusively South African study to show what the other manufacturing businesses are experiencing. An example of an international tool for benchmarking is the Baldridge Criteria for Performance Excellence that has been in existence since 1987. Companies in the US use it to improve practices, capabilities and results, facilitate communication and serve as a working tool for improvement [3, p. ii]. It is a long questionnaire that is self-assessed and only takes American requirements into account.

The reason why differentiation is needed between South African businesses and those in other parts of the world is that South Africa deals with a number of unique challenges that make the situation different to other regions. Even with the same type of product, value, mission, strategy and objectives, performance in different parts of the world will be different [4, p. 45]. Some of those challenges are the labour laws, the large pool of unskilled labour, the distances to other markets, long procurement lead times from other countries, our legislative environment, connectivity and bandwidth limitations, and preferential procurement policies. These differences are not necessarily supply chain related, but have a profound influence on the way companies do business, their results and performance.

Companies are often looking for other similar companies in the same environment to compare themselves to, especially with reference to the operational measures that ensure successful operation. One such example is forecast accuracy. It is well known that accuracy differs according to product type and group, but what are the accuracies associated with a specific group?

There are many surveys that attempt to provide answers, like the State of Logistics survey [5], done by the CSIR and Imperial Logistics, and the Supply Chain Foresight survey [6] run by Barloworld Logistics. None of these focus on specifically operational measures, the challenges they face and benchmark information they can compare themselves to. Most companies are still focused mainly on financial measures [7, p. 611] when they measure themselves.

No similar research to this study could be found. The closest was a study done in 2003 titled "Benchmarking Supply Chain Management Practice in New Zealand" by Basnet et al. [8]. South Africa shares a few of it challenges with New Zealand, like the geographical remoteness, and the relative small size compared to world markets [8, pp. 63-64], but cannot be compared directly. This was also an older study that has lost some relevance in the light of the global economic developments of the last 10 years.

2 Literature and Conceptual Method

In the current business environment, companies are in competition with each other not only horizontally, but also vertically in the same supply chain. Often misalignment of common goals can negate the best effort of those in your same team. They remain dependent upon one another in the supply chain for cooperation and understanding of common issues and challenges and collaborative partnering for best business results. This is called "competitive interdependence" by Gulledge & Chavusholu [9, p. 754]. Thus it is not necessary to just be concerned with what your competition is doing, but also those in your own chain as they may have an effect on your performance, which in turn will affect competitiveness with outside chains. Lai [10] performed a study evaluating performance measures for extended enterprise (EE) in China. He found that extended enterprises are more focused on customer processes, thus place more emphasis on collaboration with customers than with suppliers [10, p. 701], and are more likely to benchmark the associated activities.

Although businesses may produce or distribute vastly different products, the processes they employ may be similar and a possibility for benchmarking. As such, it needs not be industry specific, and may be less likely to be seen as a threat from a competitor wanting to spy. Codling [11, p. 26] uses the example of two concert pianists performing the same work, but with different interpretation. A process will similarly be executed with a company's own interpretation. It is very seldom that processes can be copied exactly between companies, even as competitors. Each will add its own methods and culture to its interpretation.

Moffet et al. [12, p. 377] found that the benefits of benchmarking extends to improvement in strategy, customer service, performance and processes. According to Randall & Farris [13, p. 450], being able to capitalise on opportunities for better management of supply chains, both within and between companies, effective performance measurement and benchmarking are required. Through successful measuring and benchmarking, performance, decision making and accountability can be enhanced in the supply chain [14, pp. 35-36]. A benefit of benchmarking found in a study of Randall & Farris [13, p. 456] was that measuring the right metric can result in pinpointing the cause of the problem and give direction for improvement. There are significant operational and financial benefits to being best in class [15, p. 12]

The drivers of supply chain management need to be understood and prioritised. There may be some that will be more important to benchmark than others [4, pp. 55,60]. The main drivers include facilities, inventory, transportation, information, sourcing and pricing. According to Golec [16], Table 1 outlines the categories of tactical decisions that will help an organisation achieve its goals.

Table 1: Categories for making tactical manufacturing decisions [16]

Tactical decision category	Plan Areas
Capacity	Type, size, balance, forecasting, technology
Facility	Layout, capacity, location, focus
Process technology	Type, integration, productivity, flexibility
Process management	Goal, effectiveness, efficiency, competitive
Manufacturing infrastructural	Analysis, design, planning, control, integration, inventory, quality, information
Human resources	Competence, motivation, recruit, deployment
New product launch	Design, innovation, customisation
Supply chain management	Inventory, timing, quality
Customer relationship management	Timing, delivery, service, satisfaction

One of the shortcomings of supply chain benchmarking in the past, has been the lack of integration of performance measures to form a holistic view [17, p. 34]; [18, p. 72]. The respondents in the interviews done by Camerinelli also indicated that alignment between functions is lacking [19, p. 58], and that there is a need for a model to integrate them. The Data Envelopment Analysis (DEA) research aims to level the field and create a single index. [20] [21]

The major weakness of benchmarking in general is that not all aspects are quantifiable and comparable between different businesses. In the Balanced Scorecard Impact Model (BSC –IM), they attempt to overcome this limitation by making use of Impact Charts and Impact Matrices [22, p. 796]. A major challenge in benchmarking is finding a single number index of performance, and most methodologies cannot cater for comparison between companies [23, p. 36].To overcome this, ratios are sometimes used, but it is still a challenge to combine ratios into a single measure [23, p. 38]. It is the opinion of Li et al. [24, p. 2919] that it is unrealistic and not beneficial to try and measure complete supply chains, but to rather identify those smaller components to use for measuring and benchmarking as they exist in complex competitive and collaborative relationships and cannot be reduced to having one measurable outcome. The common purpose of a supply chain is of course to satisfy the end customer requirement, but how can you compare different aspects if only that is measured? Li et al. [24, p. 2919] thus concludes that a supply chain can be compared to an ecological system or community with symbiotic relationships and abiotic factors and cannot be reduced to only one measure.

Madu & Kuei [20] focus mainly on the efficiency of the conversion processes and take the view that relative efficiency is necessary for comparison. They employ a linear programming-based approach called Data Envelopment Analysis (DEA) to describe the relationship between inputs and outputs. Some benefits to this approach [20, p. 322] [21, p. 5098]:

- Individual companies can be assessed, so not dependent on sample size.
- It produces a single measure for a company.
- Multiple input and –output scenarios can be accommodated.
- There is no restriction on the form of inputs and outputs.
- No weights or costs need to be assigned.
- It does not focus on central tendencies.
- It can create a threshold level for performance.
- Qualitative and quantitative measures can be assessed simultaneously.

Two basic orientations exist – input reduction and output augmentation [20, p. 322]. This is similar to the manufacturing measure of productivity or the financial measure of Return on Investment (ROI). This could be used to rank companies on a scale to identify the best performer in the benchmarking context. Shafiee et al. [21, p. 5093] also used this concept and combined it with the Balanced Scorecard to give a more integrated view.

Numerous attempts [25], [19], [26], [27], [21], [28] have been made to classify, quantify and model these processes of which The Oliver Wight Class A Checklist for Business Excellence, Balanced Scorecard (BSC), The Supply Chain Operations Reference Model (SCOR) and The Economic Value Add (EVA) Model are some. These were selected to studyfor this research. Although there are many such models available in the literature, there is not enough research on the link between performance measures and the objectives and motivations in entities in the supply chain [29, p. 703].

2.1 Oliver Wight Class A checklist for business excellence

In 1983, Oliver Wight and George Plossl, two manufacturing gurus first introduced the checklist as a map to manufacturing excellence. The current Oliver Wight Class A checklist for Business Excellence [27] is currently in its sixth edition. It contains nine chapters with ten main subjects in each chapter with a number of definitions of excellence each. It works towards world class performance, and advocates 19 milestones along the way. Each milestone has a number of definitions with driver and support measures to score. The status at each milestone is reported and used to indicate the areas to be targeted for improvement. It aims to give a checklist for companies to see where they are in the road to excellence. However, if all companies adopt this, it could be useful to compare, but the cost and time required to go through this exercise is just too large to be seen as worth the result. It usually needs guidance from the Oliver Wight consulting team, which is very expensive. The other criticism of this methodology is that it is not quantitative, and as such based on a subjective assessment of the level of activity of a business aspect. This is very susceptible to bias and manipulation.

Although a very well accepted and useful tool, for the purposes of this study, it is too long, complicated and expensive to adopt in its entirety. The search continued for a model closer to the goals of this study. This brought us to the Balanced Scorecard which is discussed next.

2.2 Balanced scorecard

As originally published by Kaplan and Norton [30], the Balanced Scorecard methodology is probably the most popular and cited of all measurement methodologies today as it not only measures financial aspects, but "balances" the functional perspectives to give better integration for full business performance. It takes the balanced view of not just regarding the tangible measures important, but also those that are considered intangible.

According to Shafiee et al. [21, p. 5093], the biggest benefit of the Balanced Scorecard is to provide a link between strategies and processes, illustrating cause and effect. A number of studies based their further development work on the Balanced Scorecard as discussed below.

Bhagwat & Sharma developed a balanced scorecard for supply chain management because simple financial measures are not giving meaningful direction for improvement in modern day supply chains, and proper measures for success may be of a more intangible nature [25, p. 44]. They based a large part of their research on the work of Gunasekaran et al. [18] who constructed a very thorough framework for measuring the performance of a supply chain. They classified measures into categories: Strategic, Tactical and Operational as well as financial and non-financial [18, p. 83]. They also aligned their framework to the SCOR model processes but added the outcome of customer satisfaction and some measures for that [18, p. 85]. In their conclusion they [18, p. 86] argue that people should be held accountable for the success of the business as a whole, and not just the area they work in. This paved the way for other models that aim to be more integrated. Shafiee et al. [21] conducted further studies combining the Balanced scorecard with Data Envelopment Analysis, another method not in the scope of this study.
Another way to view the Supply Chain through the Balanced Scorecard model, is as proposed by Franceschini et al. [22, p. 788] specifically for manufacturing firms. Their reference model is called the Balanced Scorecard Impact Model (BSC- IM) and is expanded into analysis criteria and summarised in Table 2 below:

Table 2: Balanced Scorecard Impact Model [22, p. 790]

Basic dimensions	Analysis criteria
Financial	Sales Revenue Cost of human resources Cost of raw materials, goods and external services Other costs Investments Amount of debt
Customer	Communication

	After sales service Perception of final product or service Organisation image
Internal business process	Quantitative production level Cycle time Qualitative production level (final products) Qualitative production level (incoming products) Delivery Stock level Capacity utilisation Expansion Satisfaction of human resources Productivity of human resources Security of human resources Environmental impact
Learning and growth	Product variety Research and development on products Research and development on process Competitiveness Response time Conformity to customer requirements Rationality in setting and development of projects Education, training and qualification of human resources Self-learning

Lai [10, p. 695] developed a performance measurement model for the extended enterprise, looking at performance from the perspective of the customer, supplier, management and employee, to measure aspects of finance, technology, operations and the environment [10, p. 695], in a manner similar to the BSC.

All the above are attempts at finding a more balanced and complete view of business. However, like the Oliver Wight checklist, it had a largely functional focus. The search continued and led to investigating the SCOR model, which has more of a process focus.

2.3 The Supply Chain Operations Reference (SCOR) model

The SCOR model was developed in 1996 and endorsed by the Supply Chain Council, now part of APICS, The Association for Operations Management. The precursor to the SCOR model was the series of benchmarking studies done between 1992 and 1994 by a company called PRTM (Pittiglio, Rabin, Todd & McGrath), subsequently acquired by PriceWaterhouseCoopers (PWC). It evolved into a complete model developed by industry for industry. It was selected for inclusion in this study because of its long history and industry wide recognition of being a valuable tool.

The APICS Supply Chain Council already has a number of best practices and metrics in place that can be used as a basis for benchmarking these processes. The basic framework for SCOR measurements is shown in Table 3 below:

Table 3: SCOR metrics [28]

Performance attribute	Definition	Level 1 metrics
Delivery reliability	The performance of the supply chain in delivering the correct product to the correct place at the right time, in the right condition and packaging, in the correct quantity with the correct documentation and to the right customer.	Delivery performance. Fill rates. Perfect order fulfilment.
Responsiveness	The velocity at which a supply chain provides products to a customer.	Order fulfilment lead times.
Flexibility	The agility of a supply chain in responding to marketplace changes to gain or maintain competitive advantage.	Response time. Production flexibility.
Costs	Costs associated with operating the supply chain.	Cost of Goods sold. Total SC management costs. Value-added productivity.

		Warranty/ returns processing costs.
Asset management efficiency	The effectiveness of an organisation in managing assets to support demand satisfaction. This includes the management of all assets: fixed and working capital.	Cash-to-cash cycle time. Inventory days of supply. Asset turns.

This model has proven extremely useful, as a number of these measures comply with our requirement for simplicity and ease of calculation. Those measures will be included in the study. But the search continued to build the full picture. This led us to the EVA model.

2.4 The EVA (Economic Value Add) model

The SCOR model has been criticised to lack integrative synchronisation capability [17, p. 36]. In other words, one area may be operating very well according to the performance measures, but has a detrimental effect on a next process. In an attempt to overcome this, Camerinelli & Cantu' [19] draws an Economic Value Add tree and add performance metrics based on the SCOR model to indicate where each will contribute to the financial performance of a business. Below is an adapted version of their tree (Figure 1: EVA model with detail in Table 4).

From the below can be seen that a number of core measures give an indication of financial performance. As the goal of a business is to add economic value, these assist in translating operational measures into financial impact, not only of process performance, but also of proposed changes [19, p. 42]

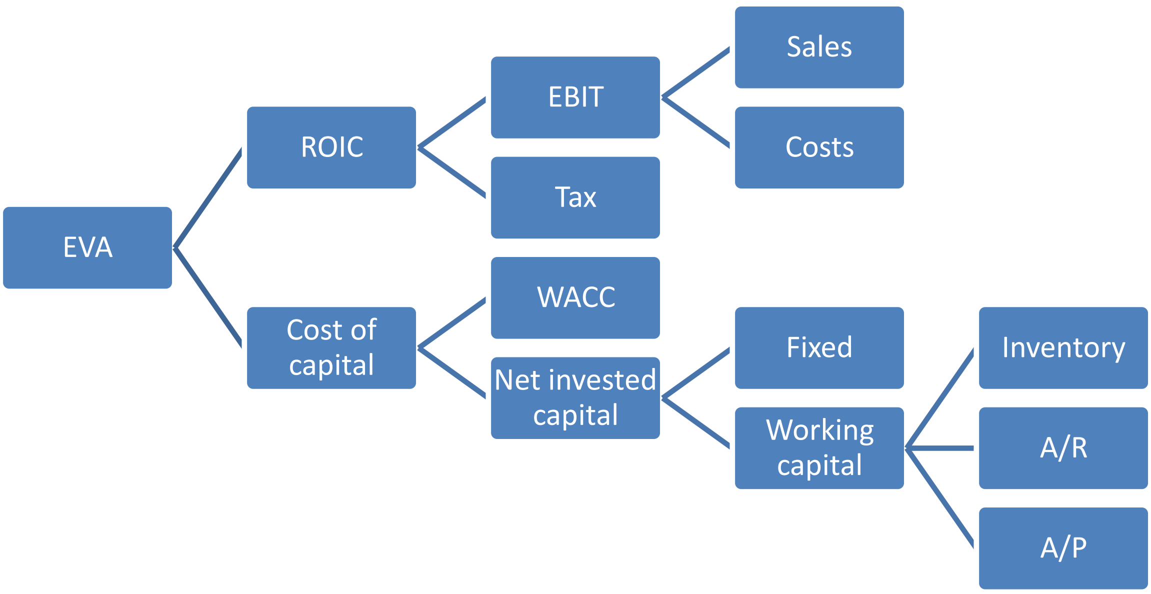

Figure 1: EVA model [19]

Table 4: Performance measures associated with EVA model elements [19, p. 57]

EVA element	Performance measures
Sales	Perfect order fulfilment Order fulfilment cycle time Return on Supply Chain Fixed assets COGS Return on working capital SCM cost Percentage in stock Forecast accuracy
Total costs	Perfect order fulfilment Order fulfilment cycle time Return on Supply Chain Fixed assets COGS

	Return on working capital SCM cost Percentage in stock Forecast accuracy Capacity utilisation
Fixed capital investment	Order fulfilment cycle time Return on Supply Chain Fixed assets Capacity utilisation
Working Capital	Perfect order fulfilment Order fulfilment cycle time Return on working capital Percentage in stock Forecast accuracy Capacity utilisation
Inventory	Perfect order fulfilment Order fulfilment cycle time COGS Cash-to-cash cycle time Return on working capital Percentage in stock Forecast accuracy Capacity utilisation

Accounts Receivable	Perfect order fulfilment Order fulfilment cycle time Cash-to-cash cycle time Return on working capital Percentage in stock Forecast accuracy
Accounts Payable	Perfect order fulfilment Order fulfilment cycle time COGS Cash-to-cash cycle time Return on working capital Percentage in stock Forecast accuracy

The literature study was used to create a list of measures with classifications into three groups; Input, Output and Process measures. Table 5 shows how the measures were classified into these groups. These indicate the possible measures to be included in the study. They also form the basis for the proposal to the focus group.

Table 5: Possible measures from the literature

Input measures	Process measures	Output measures
• Cost (Franceschini et al. 2014) • Debt (Franceschini et al. 2014) • CoGS (Camerinelli 2006, SCOR 2012, Franceschini et al. 2014) • % in stock (Camerinelli 2006) • Forecast Accuracy (Camerinelli 2006) • Investment (Franceschini et al. 2014) • Working capital • Employee training (Anderson 2004) • # of new product introduced (Bititchi 2012)	• Cycle time (Camerinelli 2006, SCOR 2012, Franceschini et al. 2014, Anderson 2004, Stewart 1995, Gunesekaran 2001, 2007) • Stock Level (Franceschini et al. 2014) • Capacity utilisation (Camerinelli 2006, Franceschini et al. 2014, Stewart 1995, Bhagwat 2007) • Cash-to-cash cycle time (Randall & Farris 2009, Camerinelli 2006) • Productivity (SCOR 2012, Franceschini et al. 2014, Anderson 2004, Bititchi 2012) • Response time (SCOR 2012) • Scrap % (Gunesekaran 2001, 2007) • Adherence to schedule (Atilgan)	• Sales (Franceschini et al. 2014) • Revenue (Franceschini et al. 2014) • Perfect order fulfillment (Camerinelli 2006, SCOR 2012) • Fill rates (SCOR 2012, Franceschini et al. 2014) • Asset turns (SCOR 2012) • Gross Profit (Franceschini et al. 2014) • Net Profit (Franceschini et al. 2014) • Inventory carry cost (Stewart 1995) • Customer query time (Bhagwat 2007) • # of customer complaints (Anderson 2004) • Adherence to due date (Anderson 2004)

The conclusion from the literature is that if business follows the basic input-process-output construct, the inputs (lead) and outputs (lag) can be benchmarked through specific metrics and the process can be benchmarked through practices. It is also clear that there is no right or wrong answer and that the level of detail and number of methods and metrics is up to the specific party conducting the research. In other words, it can be made as simple or complicated as is desired. All of the methods and measures have advantages and shortcomings, but the challenge is to keep it simple and have a balanced view that gives an accurate assessment of performance, free of bias and manipulation to serve a specific agenda.

3 Research process

It is not clear to companies which measures are important for comparison with competitors and related performances. The following research questions were asked:

- What supply chain measures are important for companies to benchmark themselves against others?
- Can the accepted list be validated?

The research process is described by the diagram in Figure 2 and discussed below.

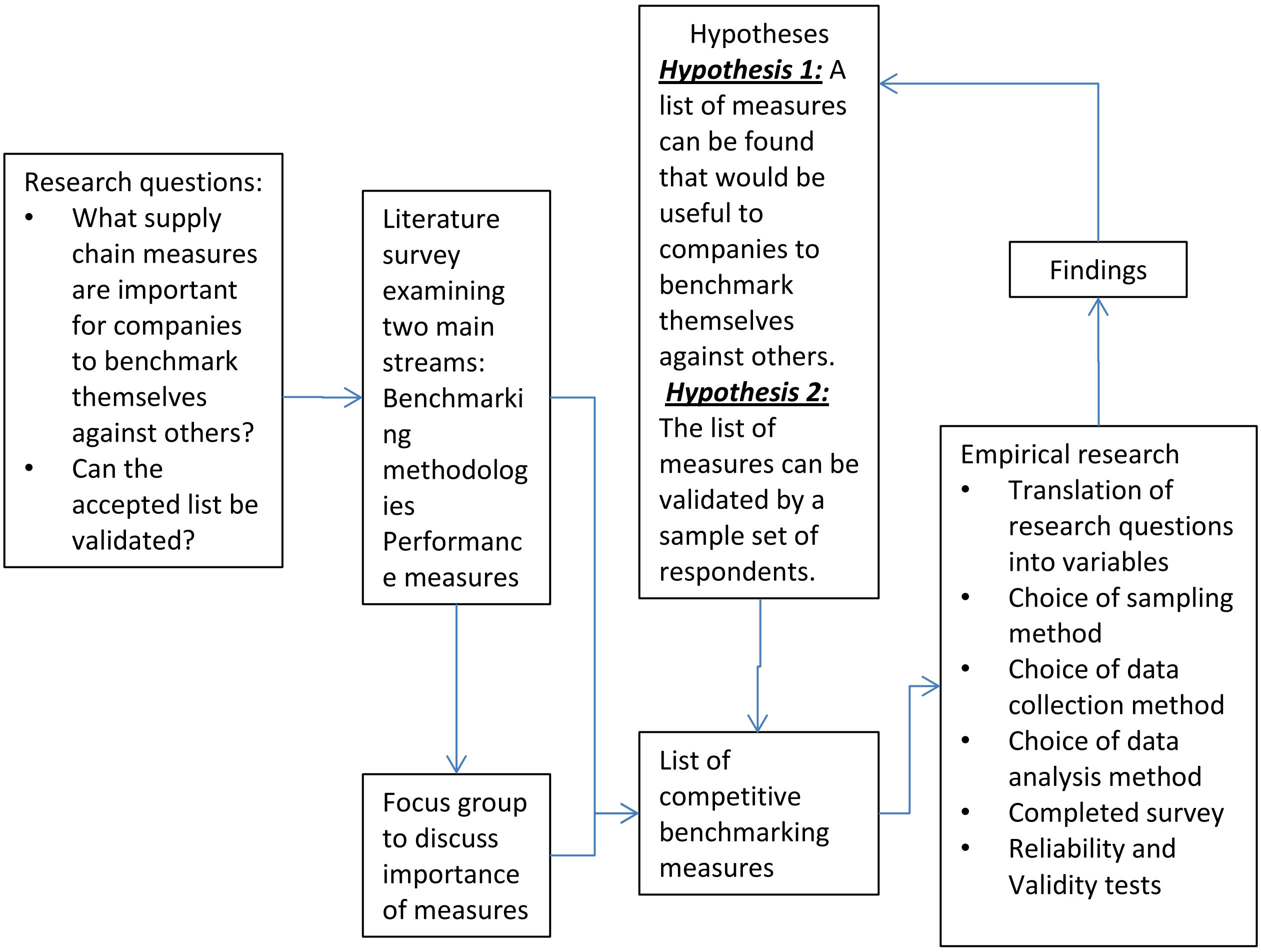

Figure 2: Synthesis of the research process

A thorough literature review was done to examine the existing theory of benchmarking and previous research done in this field. A number of methodologies were examined and a list of possible measures was compiled to serve as suggested measures to adopt. A selection of willing industry representatives was involved in a focus group initiative to explore the best selection of measures to do a study of competitive nature. The next step was to create a survey and get the survey to as many people as possible to test the validity of those measures. It was sent out to the databases of three industry organisations and a number of responses were received. The 10 most complete responses were selected for analysis. The population is the total business community in South Africa, while the frame was approximately 5000 high-level individuals in various positions in the supply chain space. The response rate was expected to be low due to the nature of the survey and the amount of information required, but the focus was on good quality feedback rather than quantity at that stage. A number of industry bodies were approached for distribution and support of the survey. Further analysis was done on the responses and analysed for results.

After the results were analysed, the findings were compared to the research questions and conclusions were made.

4 Results

During the literature survey, a list of measures were identified that could be presented to the focus group for discussion. A number of senior supply chain practitioners and consultants were invited to the focus group of which seven accepted the invitation to participate. Below a brief profile of the participants:

Table 6: Profile of focus group participants

Job title	Company type	Short description
General Manager: Business Process Optimisation	Explosives	Responsible for strengthening the Sales & Operations Planning process through improved Supply Chain visibility as well as tactical and strategic decision support tools and processes.

Consulting engineer	Transportation Engineers	Specialises in transport economics, logistics and supply chain management as well as education and training in those fields.
Warehouse specialist	Warehouse consultants	He has designed and implemented several hundred warehouse facilities in South Africa, Europe and the Middle East, and is seen as the leading authority in warehouse facilities design in South Africa.
GM Supply Chain	Machinery supplier	Design, implementation and management of optimisation projects across the supply chain. Expert in system enablement, contracting, procurement, maintenance, production planning, inventory and Sales & Operations planning.
GM Transport Operations	Leading retailer	Optimisation and management of retail network transport operations.
COO	Logistics consultants	Experience in consulting, systems integration and information technology. Former Director of Operations for a cosmetics company.
CEO	Bar-coding and warehouse enablement	Company specialising in enabling efficient warehousing solutions through hardware and software deployment.

During this session, there was a lot of debate around the measures, as one of the goals was to keep them as easy and simple to answer as possible. Due to the profile of people in the focus group, a lot of experience was utilised to arrive at the final list. The list was also refined to include the method for calculation that respondents should use. This would ensure that all measured something in the same way and that performance could be compared.

It was decided to include segmentation information for the purpose of industry comparison. Those questions included information on the industry sector, competitive priorities, their supply chain position, their number of employees and the number of stock keeping units (SKU's) in their system. Other background questions include the respondent's job title and whether they as a company have a sustainability strategy. At the end of the survey, respondents are asked to rate the usefulness of the survey as well as space to leave their contact details and comments.

A final list of 16 measures resulted and we could prove that a list of measures can be created. See the list and calculations below in

Table 7: List of measurements and calculations

	Position	Measure	Suggested calculation	Information required	Bucket
1	Input	Forecast accuracy	MAPE (Mean Absolute Percentage Error)	Calculated MAPE (Mean Absolute Percentage Error)	Year
2	Output	Inventory value/ turnover percentage	Average inventory value/ turnover X100	Average inventory value, turnover	Year
3	Output	OTIF (On time in full)	Number of Customer Orders Delivered On Time and in Full / The Total Number of Customer Orders x 100 (first customer commit)	Total number of customer orders received, number of customer orders delivered without any mistakes, shortages or late in relation to promise date.	Month
4	Output	Percentage returns	Number of items returned/ number of items sold X100 (finished goods)	Number of items returned, number of items sold	Year
5	Input	Percentage salary bill spent on training	Training spend/ salary bill X100	Training spend, Salary bill	Year
6	Output	Percentage late or back orders/ total orders	Number of Late or back sales orders/ Number of total sales orders X100	Number of late or back orders, total number of orders	Current
7	Input	Percentage new products in the	Number of products younger than a year/ total	Young products, Total number of products in item master	Year

		portfolio (younger than a year)	number of products (finished goods)		
8	Output	Stock turns	Cost of Goods sold/ average inventory value	CoGS, Average inventory value	Year
9	Output	Logistics costs as a percentage of turnover	Outbound Logistics costs/ turnover X100	Logistics cost, turnover	Year
10	Process	Supplier performance – Percentage orders delivered on time	Orders purchase orders received on time in full/ number of purchase orders X100 (initial commitment)	Number or purchase orders placed, number of purchase orders received on time and in full	Year
11	Process	Percentage active products on product master (movement in the last 12 months) SKU	Number of items moved in the last 12 months/ Total number of item number records (finished goods)	Items with transactions against them in the last 12 months, total number of item records	Year
12	Process	Percentage Inventory accuracy at last stock count	Number of stocked products with accurate records/ total number of stocked products (clarify)	Total number of item number records, Last month number of accurate records	Last count
13	Output	Percentage in stock	Number of positive stock values on active items/ number of active items X100 (finished goods)	Number of positive stock values on active items, number of active items	Last count
14	Process	Debtors days	Days for customers to pay	Average days for customers to pay	Actual
15	Process	Percentage local to total sourcing	Local / total sourcing value X100	Value of material sourced locally, value of all material sourced	Actual
16	Process	Creditors days	Days to pay suppliers	Average days to pay suppliers	Actual

In Table 8 below the responses are summarised. They are ranked according to the number of responses received per measure.

Of the sample, the response was analysed to understand which measures were worth including in future studies and which not. If at least half the respondents answered a question, it was considered well supported and worth keeping. In our sample, two questions had 80% response, five questions had a 70% response, and six questions had a 60% response rate. The remaining three only had a 40% response that indicates that they are not well supported in industry. The actual values are not important at this stage, as only the benchmarking instrument was tested. From these results it can be seen that 13 out of the 16 measures had a high response rate, indicating high use and acceptability in industry, while the other three had a low response rate, indicating low use and/ or acceptability in industry. For the purposes of this study, it is concluded that those three measures either have to be discarded from future benchmarking exercises, need to be reworked or explained better, or developed to gain better buy-in from industry. This resulted in proving that the list of measures can be validated.

Table 8: Summary of responses

	Position	Measure	Number of responses received	Average value
1	Process	Creditors days	8	40
2	Output	OTIF (On time in full)	8	93%
3	Process	Debtors days	7	37
4	Process	% local to total sourcing	7	72%

5	Output	% late or back orders/ total orders	7	11%
6	Input	% salary bill spent on training	7	6%
7	Input	% new products in the portfolio (younger than a year)	7	2%
8	Process	% active products on product master (movement in the last 12 months) SKU	6	83%
9	Process	% Inventory accuracy at last stock count	6	98%
10	Output	% returns	6	8%
11	Output	Stock turns	6	15
12	Output	% in stock	6	83%
13	Input	Forecast error	6	20%
14	Process	Supplier performance – % orders delivered on time	4	48%
15	Output	Inventory value/ turnover percentage	4	22%
16	Output	Logistics costs as a % of turnover	4	11%

The research shows which measures are used often and are thus well accepted by industry, and which ones are new to them. These form the basis of a better scorecard to measure supply chain performance, from the three perspectives of input, output and process.

5 Conclusions and recommendations

We can conclude from the literature that if business follows the basic input-process-output construct, the inputs (lead) and outputs (lag) can be benchmarked through specific metrics and the process can be benchmarked through practices. It is also clear that there is no right or wrong answer and that the level of detail and number of methods and metrics is up to the specific party conducting the research. In other words, it can be made as simple or complicated as is desired. All of the methods and measures have advantages and shortcomings, but the challenge is to keep it simple and have a balanced view that gives an accurate assessment of performance, free of bias and manipulation to serve a specific agenda.

The characteristics and features of the ideal performance management system are described by Gomes et al. [31, p. 523] as inclusiveness, completeness, timeliness, universality, measurability, consistency, integrity, flexibility and ethical.

It was found that certain measures are important to the supply chain community to measure (Research Question 1). Results were obtained for these measures indicating how many companies use them, and how viable they are in a benchmarking study such as this (Research Question 2). A small sample was used for this purpose, but it provided a great testing ground for the viability of future research in this area and the reception of something like this in the market. Some measures were responded well to, and this indicates that they are accepted and widely used. This could also indicate the level of measurement sophistication that the respondents have reached.

Others were not responded well to, and this can indicate that either the company is not aware of the measurement, not skilled at taking the measurement or does not understand the importance of measuring that aspect of supply chain performance. All three these scenarios present an opportunity for improvement.

Some measures present better value in a benchmarking exercise than others. Only forecast accuracy needs to be reconsidered in terms of how it is measured as it does not mean the same to everyone, and as such does not present good value to a benchmarking exercise. See Table 9 below for a summary.

Table 9: Benchmarking measures assessed

Position	Measure (Research Question 1)	Supported/ accepted (Research Question 2)	Good benchmarking value
Input	Forecast error	Yes	***No***
Input	Percentage new products in the portfolio (younger than a year)	Yes	Yes
Input	Percentage salary bill spent on training	Yes	Yes
Output	Inventory value/ turnover percentage	***No***	Yes

Output	Logistics costs as a percentage of turnover	***No***	Yes
Output	OTIF (On time in full)	Yes	Yes
Output	Percentage in stock	Yes	Yes
Output	Percentage late or back orders/ total orders	Yes	Yes
Output	Percentage returns	Yes	Yes
Output	Stock turns	Yes	Yes
Process	Creditors days	Yes	Yes
Process	Debtors days	Yes	Yes
Process	Percentage active products on product master (movement in the last 12 months) SKU	Yes	Yes
Process	Percentage Inventory accuracy at last stock count	Yes	Yes
Process	Percentage local to total sourcing	Yes	Yes
Process	Supplier performance – Percentage orders delivered on time	***No***	Yes

6 Implications for and contributions to theory and practice

This research has long-term and far-reaching implications on theory and practice. The results of the survey can give an overall indication of the "health" of a supply chain, and scope exists to build further on this idea of developing a "health check" tool to make it easier to self-assess and interpret, not only based on individual measures, but also their relationship and interaction between each other. There is also scope for some sort of predictive analysis based on correlation of variables.

As this tool has been developed and tested during this research, it can be expanded to include a wider audience. This can form the basis of further research.

If used correctly, the measures can give the following value to organisations:

Table 10: Value of measurements

Position	Measure	Value to the company measuring
Input	Forecast error.	Indicator of analytical ability and quality of market information.
Input	Percentage new products in the portfolio (younger than a year).	Indicator of pace of innovation in the company, indicator of life cycle of products and product risk.
Input	Percentage salary bill spent on training.	Indicator of commitment to employee development, could influence staff retention and morale.
Output	Inventory value/ turnover percentage.	Indicator of throughput productivity.
Output	Logistics costs as a percentage of turnover.	Indicator of transport efficiency.
Output	OTIF (On time in full).	Indicator of discipline and precision in the warehouse, an indicator of forecast and planning quality.
Output	Percentage in stock.	Indicator of lost sales potential.
Output	Percentage late or back orders/ total orders.	Indicator of how well order fulfilment is managed, indicator of cash recovery and cash flow, indicator of capacity management quality.
Output	Percentage returns.	Indicator of quality of processes and discipline in warehouse, indicator of quality of order management, indicator of product quality, indicator of security and dispatch checking.
Output	Stock turns.	Indicator of forecast accuracy, indicator of planning quality.
Process	Creditors days.	Information about cash flow, indication about control over payment procedures, indicator of risk around credit ratings.

Process	Debtors days.	Information about cash flow, indication of control over debt collection procedures, indicator of risk of write-off.
Process	Percentage active products on product master (movement in the last 12 months) SKU.	Cross-indicator of stock turn and aging, indicator of stock management quality, forecast accuracy, production planning and procurement competence.
Process	Percentage Inventory accuracy at last stock count.	Indicator of discipline and quality of processes in the warehouse, indicator of system integrity.
Process	Percentage local to total sourcing.	Information about the amount of local industry supported, indicator of transportation and sourcing risk, indicator of commitment to local industry development.
Process	Supplier performance – Percentage orders delivered on time.	Indicator of supplier reliability.

The table above is a valuable tool to understand the value that these measurements can provide in a business. It can provide the departure point for goal setting when a measurement is not rendering a good value. These areas also indicate the areas to go look for improvement in the supply chain.

The health of a supply chain cannot be assessed through only one or two measures, but a combination of measures. This can form the basis for further research, not only which measures influence each other, but also the strength of correlation between them.
Another implication is to structure a "best practice" set of KPI's for current supply chains in order to guide companies towards a more productive and useful scorecard to manage their supply chains.

It is recommended that the tool developed in this research be used in future benchmarking surveys, and include a formal structured program for annual benchmarking in South Africa.

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DEVELOPMENT OF A WAREHOUSE MANAGEMENT MATURITY MODEL FRAMEWORK FOR THE SOUTH AFRICAN WAREHOUSING ENVIRONMENT

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ABSTRACT

Warehouses play an active role in today's fast-paced and competitive global supply chains. They are utilized from collection of raw materials through to final dispatching of finished products. An efficient warehouse is necessary to achieve an efficient supply chain network with streamlined processes, quick response to market demands and overall high customer satisfaction. An inefficient warehouse on the other hand could result in high labour costs, duplicated and unnecessary processes, high inventory holding costs and even slow response to market demands compounding low customer satisfaction.

This paper aims to develop a Warehouse Management Maturity Model (W3M) framework applicable to the South African environment that will assist warehouse managers in achieving greater warehouse efficiency through improved quality of the various warehousing processes from receiving to dispatching of goods. To develop the W3M framework, three maturity models are studied via a literature review and a Delphi Method survey is conducted with warehousing experts to finalise the features of the framework.

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1. INTRODUCTION

In highly competitive business landscapes, companies are under pressure to compete for customers through mechanisms such as product features, price, quality and speed-to-market. In many instances, their survival strategy involves decreasing operational costs, with logistics costs related to warehousing and transportation along the supply chain often a key priority [1]. The South African logistics industry has not been immune to the pressure to compete for customers and has faced a number of challenges ranging from availability of supply chain skills and lack of overall supply chain strategy and tactics to ineffective processes and systems [2].

Rushton, et al. [3] states that with warehousing's key position in supply chains ranging from the distribution of raw materials, work in progress through to finished goods and spare parts storage, its efficiency is of high importance and therefore should not pose any risk to the functioning of the supply chain.

Inefficient processes in a warehouse could easily debilitate the ability of an organisation to fulfil its purpose thus risking the functioning of the rest of the supply chain. This research paper attempts to find answers to the following questions:

1. How can a warehouse be made more efficient?
2. How can warehouse staff be guided in the identification of strengths and weaknesses in the management of their warehouse?

The literature review in this research focused on maturity models which are a suitable tool for identifying strengths and weaknesses of processes as well as providing benchmarking information. It consists of a framework for assessing the quality of processes within an organisation by having its methods and processes assessed against best practices amongst similar businesses. Albliwi, et al., [4] firmly believes that the presence of maturity models in an organisation plays an important role in providing a platform for assessing their process maturity and making improvements. They also highlight the need for a process maturity instrument that is adaptable and ready to use.

The key factors and processes which are vital to achieving efficiency in a warehouse were identified using a Delphi Method survey. Once these key factors were validated in the iterative Delphi Method survey, a Warehouse Management Maturity Model (W3M) tool was constructed to provide a guide to achieving greater warehouse efficiency in the warehousing environment through improving the quality of the various processes.

2. LITERATURE REVIEW

The literature review presented the opportunity to deconstruct common maturity models to produce the framework and characteristics of the W3M. The intention of this research was not to radically innovate maturity models but rather draw on the success factors, structures and characteristics of practising maturity models to construct a tool which addresses the specific needs of warehouses in South Africa.

2.1 Maturity Models as a benchmarking tool

One may consider a maturity model as an auditing tool to aid organizations in implementing effective processes in a given management discipline so that they can evolve and become more efficient. Using industry best practices to improve and enhance the performance and improve efficiency of one's organisation is not a new concept and is applied to numerous fields [5].

Oyomno [6] describes the concept of "maturity" as *inspiring a sense of progress and growth* and infers that a maturity assessment is viewed positively to suggest a direction in which to grow and improve. Albliwi, et al., [4] states that the presence of maturity models in an organisation play an important role in providing a platform for assessing their process maturity and making improvements. They also highlight the need for a process maturity instrument that is adaptable and ready to use.

Judgev & Thomas [7] present a number of negative aspects of the practical use of maturity models, ranging from its inflexibility with respect to change management to its inability to solve problems and lack of consideration of the human element. However, they also clarify that despite the negative aspects, maturity models have made a considerable contribution to creating competency awareness. This is in the context of this study a very useful aspect of maturity models that allows one to see where weaknesses are present within an organisation in addition to defining the sequence in which they should be tackled.

2.2 Maturity models in industry

Maturity models were originally developed for the software industry in the 1970s, however in recent years they have been modified and applied in a multitude of different fields ranging from project management, telemedicine service maturity [8], accountancy maturity [9] and even government capabilities for e-government [6].

The two most common maturity models actively used in industry include the Capability Maturity Model® Integration (CMMI®) and Prince2 ® Maturity Models (P2MM). Following the lack of benchmarking tools in the

Warehousing industry specifically, Dr Jeroen van den Berg, a well-known expert in warehouse management, proposed a Warehouse Maturity grid where he describes four stages of maturity within which companies can fall.

The most common characteristic of all maturity models is that they have levels of maturity ranging from bad to good. Figure 1 describes the characteristics observed in organisations in each of the 5 levels adapted from Crosby's Quality Management Maturity Grid in 1979 [10]. Each level is described by a particular state ranging from uncertainty to certainty.

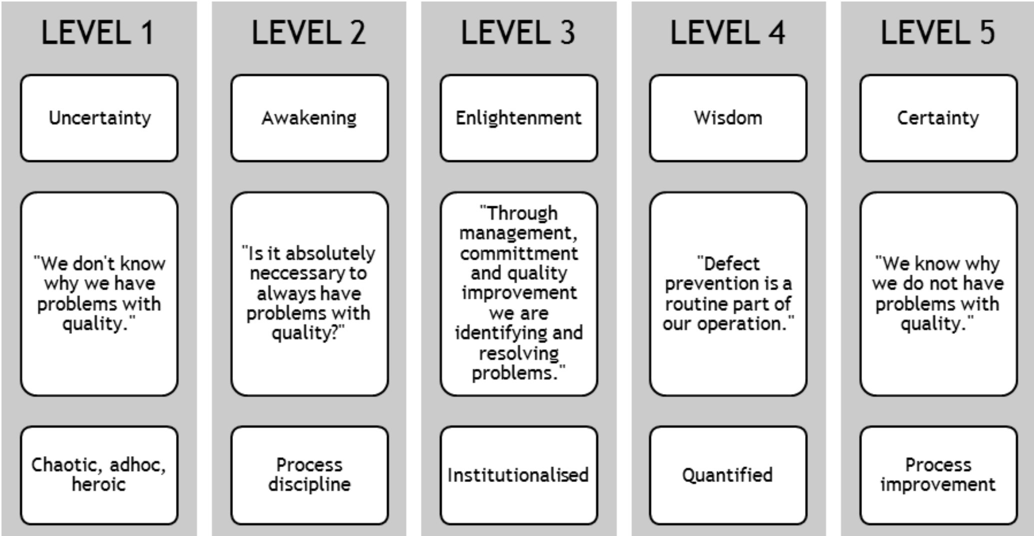

Figure 1: General structure and characteristics of a maturity model adapted from Crosby [10]

Table 1 describes the characteristics of three Maturity Models discussed in the review of these models. Similar to Crosby's levels, each level has its own characteristics and requirements. The common features of the three models are also summarised in Table 1.

Table 1: Summary and comparison of key characteristics of maturity models applied in industry

Maturity Model	Capability Maturity Model Integration [11]	Prince2© Maturity Model [12]	Warehouse Maturity Model [13]	Common feature
Common name	CMMI	P2MM	WM2	
Industry	Software development	Project Management	Warehouse Management	
Maturity Levels	5 levels	5 levels	4 Levels	5 appears to be the most common number of levels
Features associated with each level	**Level 1: Initial** Adhoc management of processes which are not defined. Control is lacking.	**Level 1: Awareness of process** Processes are not habitually documented. Organization is over-committed. Processes abandoned during a crisis, resulting in no repeatability of successes.	**Level 1: Reactive** This is the baseline level. Processes are unstructured and ill defined. Management reacts to same event that occur in the warehouse daily or even hourly. Individual heroics make things happen in this stage.	Processes are not in place. Crisis mode is the norm.
	Level 2: Managed Project planning, monitoring and control are exercised. Quality is important.	**Level 2: Repeatable process** Process discipline is not an organisational rule but basic management practices exist. Basic training in project management principles.	**Level 2: Effective** Management of the warehouse is standardised. The organisation is systematically structured. Goals are set. Cost and performance levels are identified. There is transparent analysis of bottlenecks.	There is an awakening to quality and processes which must be implemented. The WM2 model does not demonstrate an awakening stage

Maturity Model	Capability Maturity Model Integration [11]	Prince2© Maturity Model [12]	Warehouse Maturity Model [13]	Common feature
				where there a slow transition into implementing processes.
	Level 3: Defined The focus on processes is strong. Process definitions are available. Integrated project and risk management are in place.	**Level 3: Defined process** Processes are documented and standardized. Improvements are planned and controlled, and based on assessments. Training programme in place to support employees.	**Level 3: Responsive** Information Technology is used to increase performance. New planning and control principles respond in real-time to events.	Processes are defined and planning is the focus.
	Level 4: Quantitatively Project management is performed using quantitative techniques and process performance is tracked.	**Level 4: Managed Process** Measurement data is collected to improve overall performance.	**Level 4: Collaborative** The role of the warehouse in the supply chain is reconsidered. The warehouse is looked at as a part of the supply chain and not a separate entity. The focus is on improving the performance of the entire supply chain through better collaboration.	Quantitative techniques are used to measure performance.
	Level 5: Optimizing The organization has established organizational performance management.	**Level 5: Optimized process** Strong focus on optimization and forecasting. Processes are quantitatively managed.	There is no 5th level in Dr Jeroen van den Berg's model.	The focus is on continuous improvement. The WM2 does not have a 5th level.

A review of these three maturity models (CMMI, P2MM, the Warehouse Maturity grid) is presented in the sub-sections to follow. This critical review provided the basic framework for the conceptual Warehouse Management Maturity Model.

2.2.1 CMMI framework

CMMI model consists of 5 levels of maturity which provides an incremental step approach for making process improvements. An important feature of CMMI is that it uses 16 process areas to provide focal points for improvement. These areas segment the entire software development process into smaller more manageable and accountable areas which can be improved with greater precision. Another desirable characteristic of the CMMI framework is that it is adaptable as more process areas can be added to the model [8].

Höggerl & Sehorz [14] highlights the need for intensive training on the various terminologies and concepts required to conduct an audit using the CMMI framework which requires a considerable amount of effort to implement and often a shift in culture and attitude [15]. The CMMI framework is complex, multi-faceted and cannot be implemented by a layperson. It needs a team of appraisers with very specific skills and experience requirements to commit time to the appraisal.

Another characteristic of CMMI maturity levels is that all specific goals of the process areas and all generic goals for the respective level have to be achieved in order to advance to the next maturity level [11]. This holds some merit in that organisations are motivated to finalise all improvements in a certain level so they can progress to the next level. However it may also inhibit an organisation from focusing on potential improvements which are quick wins from the next level since they are so focused on the previous level as highlighted by Van den Berg [13]. It is suitable for large organisations with adequate resources to implement and appraise. The W3M model must steer clear of such requirements as it needs to be simple and easy implementable.

2.2.2 *Project Management Maturity Model*

Demir & Kocaba [16] indicate that maturity models in project management are becoming popular due to their versatility and ability to control time and cost parameters efficiently. While there are over 30 different variants of Project Management Maturity Models (PMMM) in the market today, each with their own focus, the most prominent one is the PRINCE2 Maturity Model (P2MM) which is a 5-maturity-level framework that organizations use to assess their current implementation of the PRINCE2 project management method. PMMMs are typically aligned with national or international project management bodies of knowledge like the Project Management Body of Knowledge (PMBOK) or PRINCE2. Some consulting firms and project management experts have also offered their versions of a PMMM. One such consulting firm is PM Solutions which combines Software Engineering Institute (SEI) type maturity measurement and the Project Management Institute's PMBOK guide industry standard in identifying key areas of project management to be addressed [17].

Organizations can obtain a P2MM assessment of their maturity either by self-assessment or a formal review conducted by consultants [7]. Self-assessment can be done by simply reviewing the model and assessing the organization using the attributes, or by using the P2MM self-assessment tool to gain a better insight [12]. Organizations have the option of obtaining a P2MM assessment of their maturity either by self-assessment or a formal review. Smaller organisations with limited funds can also use Project Management Maturity assessments.

2.2.3 *Warehouse Maturity Model*

Dr Jeroen van den Berg [13] describes his Warehouse Maturity grid as a growth model which guides the (warehouse) manager along the four stages in the maturity grid. Each stage in the maturity grid signifies the state of how processes are working. Completing each stage enables the warehouse to act successfully in the next stage as the quality of the processes improves [13]. No critical reviews of this model were available despite a thorough literature search. This may be due to the fact that the model is fairly new and not widely used in industry, let alone South Africa.

The warehouse maturity grid offers breakthrough improvements rather than incremental improvements. This is characterised by the four levels of improvement presented as opposed to the more common five. The step change between level 1 and 2 appears very dramatic. From having no process management to having standardisation and performance management in place is a big leap. These big leaps have a high probability of producing unpredictable results. Each preceding level should essentially act as a primer for each subsequent level. It is for this reason that this breakthrough improvement approach is not favoured in this research.

It is not a rule that you must advance from one level to the next. Dr Jeroen van der Burg structured this model such that opportunities from a higher level perceived as quick wins, could be seized in a lower level. This presents a chaotic approach to implementing improvements as it is not staged. More often than not, an improvement depends on another improvement. Again this offers unpredictable results.

3. RESEARCH METHODOLOGY

This research used the Delphi Method Survey to gauge the views of experts in the supply chain field. The Delphi Method survey is an organised research technique which uses an iterative process to reach consensus on survey responses [18] . The key outcomes of the Delphi Method Survey were to identify the organisational needs of the warehouse per level of the Maturity Model and build the features of the W3M.

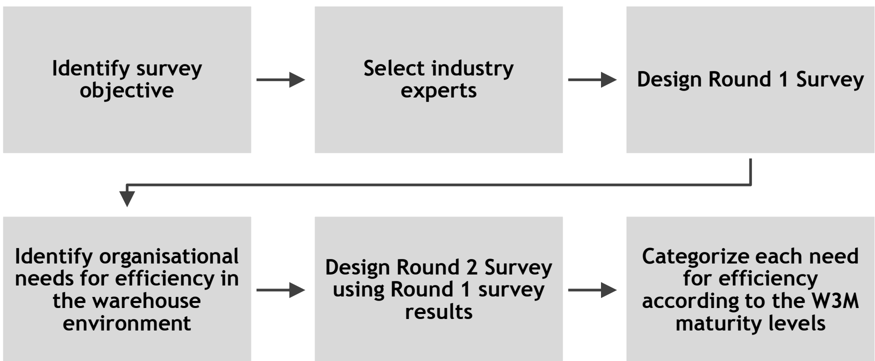

Figure 2: Objectives of each Delphi Method round of surveys

Two rounds of the survey were conducted. In order to be selected for the survey, participants were required to have been actively involved in warehousing for a minimum of 5 years. The level of seniority of the participant also played a role, in that the participant should have decision making power and the ability to drive change within the warehouse. Participants directly involved in daily operations of warehousing functions included Operations Directors, Warehouse Managers and Operations Managers. Professional Supply Chain Analysts and Industrial Engineers with experience in overall supply chain activities were also selected to gain an academic perspective on warehousing.

The objective of round 1 was to identify organisational needs for efficiency in the warehouse environment. An invitation to participate in the survey was sent out to 20 experts with working knowledge of warehousing. The 20 experts were from a selection of work colleagues as well as from participants who responded to a LinkedIn advert in the Warehouse Professionals group and the South African Institute of Industrial Engineers group. Of the 20 who were invited, 16 participants responded with completed surveys. Participant statistics are reflected in Table 2.

The results from round 1 were summarised and used to develop a round 2 questionnaire where 14 of the round 1 experts responded with their views on which need should be satisfied in which maturity level. The objective of the round 2 Delphi Method Survey was to categorize each efficiency need according to the W3M maturity levels. Participant statistics for each round are reflected in Table 2.

Table 2: Key participant statistics for Delphi Method survey

Designations	Round 1		Round 2	
	Total Number	Combined years of experience	Total Number	Combined years of experience
Operations	2	50	2	50
DC Manager	5	52	3	40
Operations	4	55	4	55
Supply Chain	2	45	2	45
Industrial	3	20	3	20
Total	**16**	**222**	**14**	**210**

4. RESULTS

4.1 Round 1 results

With the round 1 survey structured to find out what key decision makers in warehousing viewed as requirements for efficiency, participants were asked to answer two questions.

1. What does efficiency in warehousing mean?
2. What are the top 10 most important needs in warehousing to make the warehouse function efficiently?

The responses to the first question in the first survey highlighted how each participant had a different priority in terms of achieving efficiency. Responses which are listed in no particular order include the following:

- Performing and operating on a day-to-day basis with the least wastage of resources (labour, time, money, equipment etc.)
- Being able to store, pick, pack and dispatch items on time, in full and without any safety incidents in the given cycle time.
- Receiving the right product and dispatching the right product to the customer, in the right condition, at the right time using the least amount of effort and resources.
- Productive, happy staff members driving customer satisfaction
- The ratio of output vs. input. The input for warehousing should be looked at from an end-to-end perspective in terms of all resources (including time as a resource) vs. output (units/cartons). Often this can be measured as cost to process a unit/carton and lead time.
- Doing more with less, e.g. Using the least resources to get the highest output.
- Being able to store, pick, pack and dispatch items on time, in full and without any safety incidents in the given cycle time.
- Deliver customer orders on time, complete, without damage and with accurate documentation

Table 3 summarises the responses to the second question which yielded a comprehensive list of organisational needs which must be satisfied in order to achieve warehouse efficiency. In this research, each need was categorised according to its fit into one of the 5Ms (i.e. Manpower, Machine, Material, Method and Money) and then into Management Focus Areas. The result of matching efficiency needs with productivity elements and Management Focus Areas separately is that it is then possible to define productivity elements in terms of Management Focus Areas. Nine Management Focus Areas were identified. They include:

1. Demand Management,
2. Infrastructure Management,
3. Management Control,

4. Performance Management,
5. Process Management,
6. Project Management,
7. Quality Management,
8. Resource Management, and
9. Risk Management.

Management Focus Areas were carefully matched against each efficiency need. This was done to allow for easy allocation of appropriate person/s within the warehouse to own the improvement opportunities within that Management Focus Area. For example opportunities related to improving Risk Management within the warehouse will fall under the Risk Manager's responsibilities. The intention was to spread the responsibility of efficiency improvement opportunities amongst all staff within the warehouse. Improvements should never fall on the shoulders of a single individual as it could result in myopic solutions which have smaller impacts on efficiency.

Table 3: Round 1 results per Productivity parameter (5Ms) question 2

Productivity element	Organisational Needs from Delphi Method Survey
Manpower	**1. Effective resource management** - Adequate staff required to get the job done - Flexibility in resources for peak / off-peak periods - Motivated Staff - Incentives for reaching targets / goals - recognise and reward - Training and equipping staff with new skills / multi-skilling o Knowledge of what equipment can be used in which areas and what benefits can be achieved - Staff job descriptions in place – people know what is expected of them - Skilled staff who understand the warehouse system, the targets and operational processes - Placing the right people to do the right task at the right time - Using staff to brainstorm Continuous Improvement initiatives
	2. Management Style - Correct management structure to implement and supervise the process - Leadership that inspires and listens - Positive culture - Collaboration workshops with clients to improve service delivery
Machine	**1. Adequate and appropriate equipment and tools** - Material Handling Equipment - Hardware for WMS - Warehouse space

Material	- The right documentation
	- WMS systems
	    o Real time visibility and forecasting
	    o Data is used to enhance the warehouse capability to meet customer requirements
	- Stationery available

Money	- Money to make improvements - Faster decision making on spending of funds for improvements
Method	**1. Agile problem solving**
	2. Planning, Monitoring and Control - Communication/ Meetings/ Feedback - Control, planning, project management (Supervisors/Managers) - Planning, Scheduling of key tasks (Fail to plan is a plan to fail) - Clear goals and targets, including vision and mission of warehouse - KPI's for Managers/Supervisors to effectively manage processes - Management reports to measure performance and track progress - Continuous feedback on the progress made and checks on whether targets that have been met.
	3. Process management - Standard Operating Procedures (SOPs) in place - Sufficient process flow that works for the system - Embracing of lean principles o Zero waste culture

Productivity element	Organisational Needs from Delphi Method Survey
	4. Risk Management - Risk analysis – corrective action - Clear risk and safety procedures documented in a SHEQ policy - Good housekeeping - Preventative Maintenance

4.2 Round 2 Results

Round 2 consisted of two questions which evolved from a summary of the first round results. The survey described the characteristics of the levels in the W3M and asked the experts to give their view on what efficiency need must be met in a particular level in the W3M, for that level of maturity to be achieved. A summarised list of efficiency needs was provided from the first round answers. Participants were asked to pick their answers from the list and add new answers which they thought were missing. They were then asked if the characterization of the different levels were adequate.

The responses from participants are summarised in Table 4. Participant's had a fairly good understanding of efficiency needs required at each level based on the characteristics of that level. The difference in responses from the 14 participants was marginal.

Table 4: Round 2 results with warehouse management characteristics per maturity level

Maturity Level	***Characteristics of Maturity Model*** *(provided to experts in survey)*	*Survey Responses:* ***Categorisation of warehouse characteristics per maturity level***
Level 1	*Leaning towards adhoc management of processes resulting in chaos when the unexpected occurs.* *Organisation lacks control and planning. Focus is on just surviving the day.*	• *Inadequate resources to get the work done (staff, equipment)* • *No standard processes or SOPs* • *No Project management principles employed* • *Lack of role clarity* • *High absenteeism* • *Lack of leadership/ guidance* • *No clear understanding of process flow in warehouse* • *No strategy* • *Targets not set* • *Staff is untrained and no training plans in place* • *Communication is ineffective*
Level 2	*Organisation is awakened to the need for planning and control as well as effective process management. It is not organisation wide but on a department level and co-ordination is lacking. Basic training of staff.*	• *Adequate resourcing to get to job done* • *SOP's for high priority processes* • *Basic upskilling/ training of staff* • *KPI's for managers & supervisors* • *Align warehouse goals with the Company mission and vision statement* • *Effective communication* • *Planning instead of random implementation*
Level 3	*Strong emphasis on effective process management. Processes are standardised and documented across the organisation. Risk Management is in place. Organisation realises the benefits achievable from standardised processes, planning and control. The right people are doing the right tasks.*	• *SOPs for all tasks* • *Planning is a key requirement* • *Work targets are put in place* • *Risk assessments introduced* • *Measuring and reporting is emphasised* • *Training is commonplace* • *Communication is emphasised* • *Feedback loops installed/ Regular meets* • *Lean culture is encouraged*
Level 4	*Performance measurement is a focal point to further improve the organisation. Management is committed and actively involved in improvement initiatives. Information is a valuable asset for the organisation.*	• *Key performance indicators introduced to measure the outcome of all actions being taken* • *Lean and improvement culture embedded in leadership and senior supervisors* • *Implement software to enhance warehouse capability for tracking and data reporting* • *Data is used to enhance the warehouse capability to meet customer requirements* • *Roll-out lean training to leadership and supervisors*

Maturity Level	*Characteristics of Maturity Model* *(provided to experts in survey)*	*Survey Responses: Categorisation of warehouse characteristics per maturity level*
Level 5	*The focus is on optimisation. Performance management, forecasting and the use of technology is instrumental in the organisation's optimisation.*	• *Collaboration workshops with clients to improve service delivery* • *Lean and improvement culture embedded in workforce* • *Real time visibility and forecasting* • *Knowledge of what equipment can be used in which areas and what benefits can be achieved* • *Zero Waste culture* • *Using staff to brainstorm Continuous Improvement initiatives*

The second question tested the participants' level of agreement with the characteristics associated with each level. The level of agreement used a Likert Scale ranging from strongly agree, moderately agree and neutral, moderately, to disagree, and strongly disagree

As illustrated in Figure 3, the response from participants was very positive with 43% strongly agreeing that the characteristics of the model levels were adequately described and 50% moderately agreeing. This implies a 97% acceptance of the provided model characteristics. Only 7% were neutral in their responses. There were no disagreements with the description of the levels.

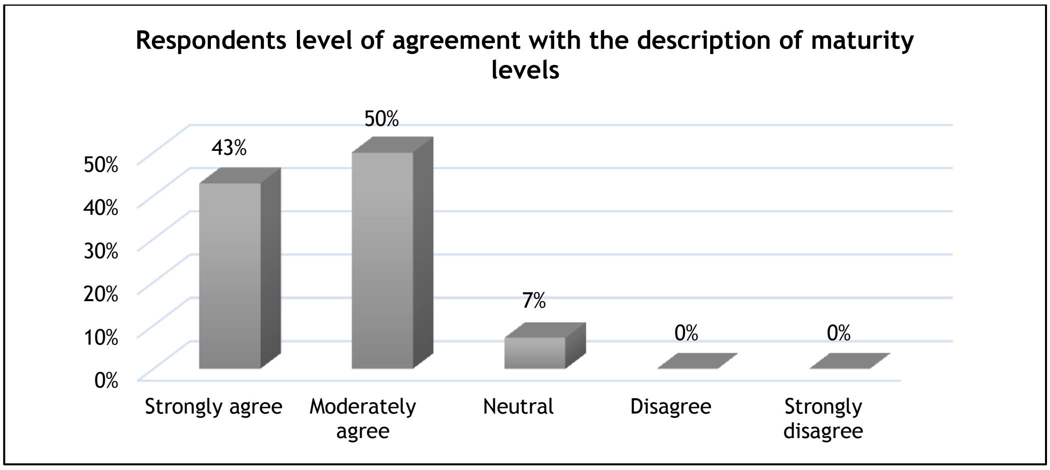

Figure 3: Responses from survey participants for Round 2, question 2

Conducting the Delphi Method Survey presented the opportunity to identify key needs for efficiency in a warehouse based on industry expert's understanding of efficiency in warehousing. This served as a reference point for what efficiency needs must be achieved in order to advance from one level of maturity to the next. It became evident that productivity elements could be represented as a function of Management Focus Areas, thus further allowing for a productivity score to be determined per productivity element. The benefits of this scoring are multi-fold in that:

1. This would give the warehouse manager an indication of how productive they are in using a certain element to achieve efficiency.
2. It will be possible to define a scoring dashboard which can be used for progress tracking, benchmarking; and
3. It could highlight the specific element which is not performing well in the warehouse and which management focus areas are weak.

There was a 97% agreement amongst the industry experts with the description of each maturity level and the overall framework presented (i.e. 5 levels of maturity ranging from level 1 where there is chaos to level 5 which is focused on continuous improvement).

5. CONCEPTUAL MODEL

There are predominantly 5 levels of maturity ultimately describing each state adapted from Crosby [10]. These 5 levels are

- Level 1: Uncertainty,
- Level 2: Awakening,
- Level 3: Enlightenment,
- Level 4: Wisdom, and
- Level 5: Certainty

Table 5: Round 2 results with warehouse management characteristics per maturity level

Maturity level	Question asked by organisation	Characteristics of organisation
Level 1: Uncertainty	*"Why are we not coping?"*	The organisation is leaning towards adhoc management of processes resulting in chaos when the unexpected occurs. The organisation lacks control and planning. Focus is on just surviving the day.
Level 2: Awakening	*"What can we do to survive?"*	The organisation is awakened to the need for planning and control as well as effective process management. It is not organisation wide but on a department level and co-ordination is lacking. There is also basic training of staff evident.
Level 3: Enlightenment	*"What can we do to cement our survival?"*	There is strong emphasis on effective process management. Processes are standardised and documented across the organisation. Risk Management is in place and the organisation realises the benefits achievable from standardised processes, planning and control. The right people are also doing the right tasks.
Level 4: Wisdom	*"How do we know what we are doing is good or bad for us?"*	Performance measurement is a focal point to further improve the organisation. Management is committed and actively involved in improvement initiatives. Information is a valuable asset for the organisation.
Level 5: Certainty	*"What can we do to improve our organisation?"*	The focus is on optimisation. Performance management, forecasting and the use of technology is instrumental in the organisation's optimisation.

Advancement from one level to the next without achieving the targets of the current level is not recommended. Knowledge areas are useful in categorising the different areas of management within a particular field. In the W3M framework, these knowledge areas will be known as Management Focus Areas.

Including the 5Ms used in root cause analysis as productivity elements will assist warehouse managers in pinpointing the specific resource area which is lacking, be it people, process, information, equipment or money related. In addition to the 5 productivity elements, there are nine management focus areas which are composed of specific attributes which must be met, namely:

1. **Demand Management** concerned with planning of resources to match demand profile of warehouse
2. **Infrastructure Management** focusing on appropriate design and layout of the warehouse and equipment upkeep
3. **Management Control** of warehouse in terms of decision making, support and guidance to staff, including setting of targets that are aligned with the company's strategy
4. **Performance Management** covering Monitoring and controlling of performance including tracking and reporting
5. **Process Management focused on** process mapping and analysis as well as ensuring that Standard Operating Procedures and times for key processes are adopted
6. **Project Management ensuring that a** structured approach to managing scope, schedule, budget and quality is in place
7. **Quality Management focusing on** Continuous improvement initiatives
8. **Resource Management managing** labour (training, well-being, role clarity), equipment, money (budget) and tools (e.g. WMS and MEH)
9. **Risk Management ensuring that** risk assessments and proactive mitigation of identified risks is conducted

6. W3M ASSESSMENT AND REPRESENTATION OF RESULTS

In order to evaluate the maturity of the warehouse processes in a warehouse, a W3M assessment must be carried out by the warehouse manager. As with any assessment, certain rules should be applied to allow for a fair and logical conclusion to the assessment. A W3M Assessment Tool will be used to determine the level of maturity of each Management Focus Area in a warehouse. The expected outcomes of each Management Focus Area's efficiency needs were identified in the Delphi Method Survey. To obtain the W3M Assessment Tool described in this section, it is suggested that the lack of that outcome is defined. Incremental improvements can then be devised to get to the next level of maturity.

Figure 4 depicts the W3M radar chart, which clearly shows the nine Management Focus Areas with the specific 5M productivity elements impacted. The W3M radar chart is able to provide a bird's eye view of the strong and weak Management Focus Areas in a process. The graphical W3M radar chart can be placed on a visible notice board in the warehouse and incorporated into meetings with staff so they are aware of the state of the warehouse and what needs to be done to improve its efficiency.

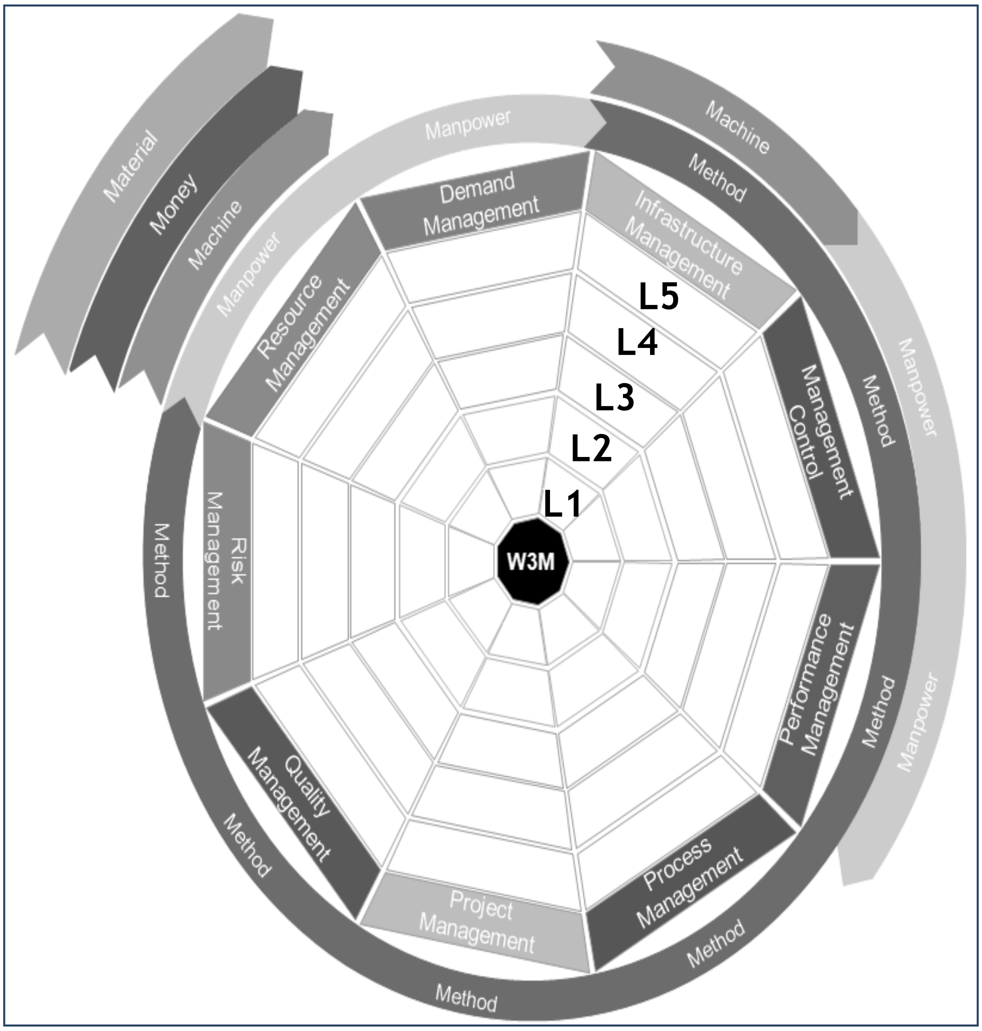

Figure 4: W3M radar chart (author's representation)

7. CONCLUSION

The research consisted of two objectives, namely identify efficiency needs in the warehousing environment and a method of guiding warehouse staff in the identification of strengths and weakness in the management of their warehouse. The first objective was achieved via the Delphi Method survey. The second objective was achieved by constructing a Warehouse Management Maturity Model (W3M) tool help warehouse staff assess the quality of processes in their warehouse, and ultimately highlight what deficiencies or gaps must be filled to achieve efficiency. By combining the maturity model frameworks from the Literature survey with the efficiency needs from the Delphi Method survey it was possible to categorise the various efficiency needs required per maturity level.

The W3M tool is composed of 5 productivity elements and there are nine Management Focus Areas to pin point the aspect of the warehouse that requires improvement.

The following conclusions may be made about the conceptual model:

1. An assessment will be required to determine the level of maturity of the warehouse.
2. A defined assessment process must be in place incorporating continuous improvement methodology.
3. Assessment results must be visually pleasing and reflect the maturity of the various Management Focus areas at a glance. A W3M radar chart will serve this purpose as illustrated in Figure 4.
4. A W3M Productivity score must be calculated to highlight the specific productivity element which is not performing well in the warehouse.

8. RECOMMENDATIONS FOR FUTURE ADVANCEMENT OF THE W3M TOOL

With the scoring technique adopted, similar warehouses can select process areas by which to evaluate their maturity. They can then compare their maturity. Warehouses can be evaluated against the W3M in tender processes by manufacturers and retailers.

The W3M has a very flexible structure that can be further developed to add more efficiency needs and possibly more Management Focus Areas. Some examples include Customer Service Management and Information Technology Management to address high customer satisfaction and access to information efficiency needs respectively.

CMMI calls for process assets to be produced to validate the claim that a certain level is true of the organisation. The W3M lacks this aspect and may make the model very subjective. A list of process assets should be compiled for each Management Focus Area's expected outcomes.

Each warehouse process can be evaluated to determine its maturity. Despite being time-consuming, breaking down warehouse management into the six processes identified will simplify the implementation of improvement initiatives as the efforts will be more focused. The process area team leaders/managers will conduct assessments for the process areas which they are responsible for, thus allowing the gaps to be pinpointed to a specific process area. Each warehouse process will have its own W3M radar chart.

A possible 6th level of maturity may be added to the framework involving collaboration of the warehouse with the rest of the supply chain. The impact on reducing costs can be assessed once the model is adopted and measured for success.

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SOCIAL MANUFACTURING BAMBOO BIKES FOR AFRICA

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ABSTRACT

Manufacturing methods constantly change to adapt to societal needs. However, there is a new method aimed towards value creation emerging. This method or manufacturing paradigm is described as social manufacturing, which combines manufacturing with open design platforms. This paper discusses a Bamboo Bikes for Africa case study where the open design process is used through an online community using social manufacturing techniques. The best design is chosen, manufactured and compared to benchmark process chains. This study proved that using crowd sourcing and co-creation, designs can be developed and improved to generate a significant amount of innovative designs.

[1,3,4 & 5]The author(s) was/were enrolled for an M Eng (Industrial) degree in the Department of Industrial Engineering, University of Stellenbosch

1. INTRODUCTION

The activity in which the form of raw materials is changed to create products is defined as manufacturing, and it ensures value creation from natural resources [1]. The evolution of manufacturing technologies has caused a paradigm shift and changed its emphasis from mass production and product variety a number of times since the industrial revolution [2]. Societal changes, as well as change in market imperatives are the major driving factors behind the manufacturing paradigm shift. We currently find ourselves at the brink of a new manufacturing revolution, called social manufacturing, and it includes the shared creation, distribution, trade, production and consumption of goods, resources and services by different people and organizations throughout the industrial and social spectrum [3]. Figure 1 illustrates these changes in manufacturing paradigms, with regards to economics of scale and scope, showing when the emphasis changed [4]. It also illustrates how social manufacturing links with the bamboo bicycle project sketch. With the invention of assembly lines, manufacturers were concentrated on producing large volumes of products, with low customisability. This was the era of craft production and mass production, however emphasis on producing larger volumes of products continued until the market became saturated around the 1970's. Many products were mass produced and society demanded greater variety, giving birth to the era of flexible production. This trend continues until around the year 2000, where manufacturing changed to a greater emphasis on customisation and personalisation. However social manufacturing is the new manufacturing revolution.

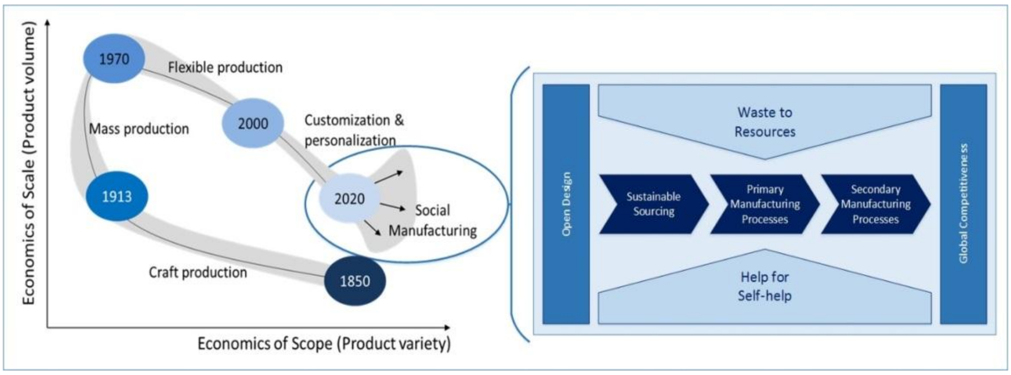

Figure 1: Manufacturing paradigm changes and how it links to the bamboo bicycle project sketch [4]

An industrial revolution, driven by the Internet of Things, has given rise to various manufacturing strategies worldwide [5]. Examples are Catapult in the United Kingdom, SIP in Japan, Industry 4.0 in Germany and NNMI in the United States [6]. Kagermann, et al. (2013) decribe this revolution as the convergence of the virtual world and the physical world in the form of Cyber-Physical-Systems (CPS). Changes in production methods, customer expectations and value creation will occur as a result of this era of manufacturing. This open design platform enables customers, local suppliers and small companies to develop products and social manufacturing helps manufacturers to produce these products.

A case study is required in order to understand the business model of social manufacturing. An experiment can be conducted where the community or industrial cluster is used within a manufacturing process. An industrial cluster is the "social community and economic agents" [7] that collectively strives to produce a superior product and/or service. A social community is an ever-changing body of people. Thus, by using a social media platform, their idea creation, knowledge and niche-spotting capacity could be harnessed to address seemingly overwhelming problems.

Bamboo is used, because it is a sustainable material that will contribute significantly to the manufacturing industry and local communities in Africa. This project does not aim to only give these people a means of transport, however the aim is to enrich their lives and businesses, therefore adding 'Swiss army knife' like technology to these bicycles to improve their way of living.

Because the rural parts of sub-Saharan Africa have a high poverty rate and declining road conditions, transportation issues in these parts impose a challenging environment to find sustainable solutions to uplift the economic and social conditions of individuals living in this strenuous environment. The ability of an individual to access jobs, healthcare and education directly affects their livelihood [8]. Transportation also provides access to various social networks throughout a country from where future job opportunities may emerge. By developing the skills of a population, sustainable economic growth can be reached through the alleviation of poverty and the reduction of inequality. This is proof that human development and economic growth is linked and mutually reinforcing [9].

Finding a way to address the transportation issues while reducing unemployment through human development will provide a sustainable solution that will diminish poverty and increase economic growth. Manufacturing and selling bicycle frames made mainly from bamboo could be a sustainable solution to provide rural Africans with a method of transportation, while facilitating skills development and job creation.

This paper illustrates the use of social media as a design platform. It uses a case study of a final year engineering class, tasked to design bamboo bicycle frames. An effective transport system is one of the major problems in Africa, therefore using this Bamboo Bikes for Africa Project to create bicycles for rural Africa is essential and it can change the face of transport in Africa.

2. SOCIAL MANUFACTURING

According to Koren [10], personal and social networking relationships can create value to organisations, by allowing them to utilise the resources within a network for their benefit. This is the premise on which social manufacturing is built. Social manufacturing is described as a new kind of networked manufacturing mode, integrating many distributed, socialised resources, and bundles enterprises into manufacturing communities [11]. This results in the formation of manufacturing communities by initial clustering and self-organisation. An enabler of this social manufacturing, or crowd sourced manufacturing, is web 2.0 technologies [12].

The ability to generate new knowledge can play a significant role in staying competitive. Open design platforms use this ability to change the manner in which knowledge is constructed around manufacturing, leading to new and faster methods to solve problems through co-creation [13] **and** [14]. Social manufacturing is predicted to be in use by 2020. Table 1 shows the intended business model, which implements a pull system (sale-produce-assembly). The resulting value chain causes a sustainable conscious society, with a demand for personalised products. The internet of things allows social manufacturing to be driven forward and can thus be seen as an enabling technology. Self-organising systems can be seen as a key technology, while information and knowledge processing is based on a cyber-physical system.

Table 1: Social manufacturing elements (Adapted from [4])

Paradigm	Social Manufacturing		Existing Social Manufacturing companies
Societal Needs	Personalised products on demand – Sustainability conscious		Opendesk
Market	Global production – demand fluctuation		Local Motors
Business Model	Pull (sale-produce-assemble)		Shapeways – 3D printing
Enabling Technology	Internet of things		WindowFarms
Key technology	Self-organizing systems		Blender
Information & knowledge processing	Cyber-physical systems		OpenStructures

Social manufacturing has the ability to create opportunities for internal related work or work with corporate partners. This is done by providing all involved parties with access to the relevant information, allowing them to transfer and share documents, and to automate tasks which were traditionally done manually. This results in an accelerated process and decision making.

While traditional manufacturing companies rely on internal design, social manufacturing companies allow any interested party with internet access to submit designs and ideas. An open database allows these designs and ideas to be shared, where other people can contribute by suggesting improvements or adding it themselves. The design period can be shortened by using increasing amounts of crowd sourcing. This is done by identifying patterns from emerging synthesis quicker, assisting in developing customer demanded products faster.

Furthermore, in social manufacturing, the manufacturing is done by the user or the market. Manufacturing capabilities are embedded within the online community platform database. This allows social manufacturing companies to both design and prototype products faster, utilising more human resources, at a reduced cost. This is illustrated in figure 2. Therefore, identifying and comparing the different business elements of social manufacturing and generating a generic business model for social manufacturing is essential to incorporate social manufacturing within current manufacturing companies.

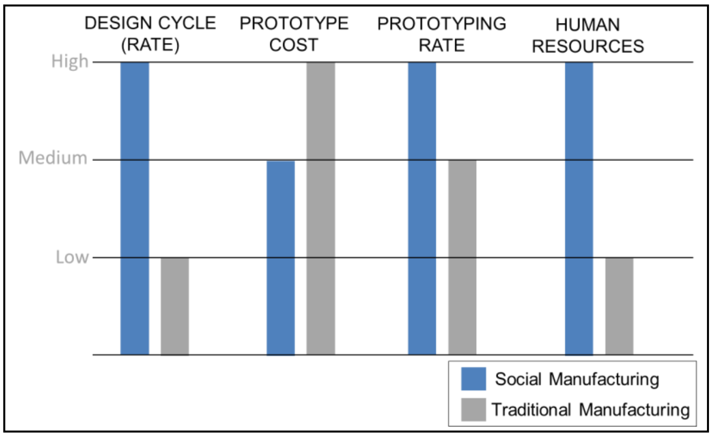

Figure 2: Comparing efficient utilization of social- and traditional manufacturing methodologies (not to scale - for illustrative purposes only) [4]

Ras et al [1] created a development lifecycle as seen in Figure 3. This lifecycle or process summarizes all the factors and at what phase of the product lifecycle these factors have to be taken into consideration.

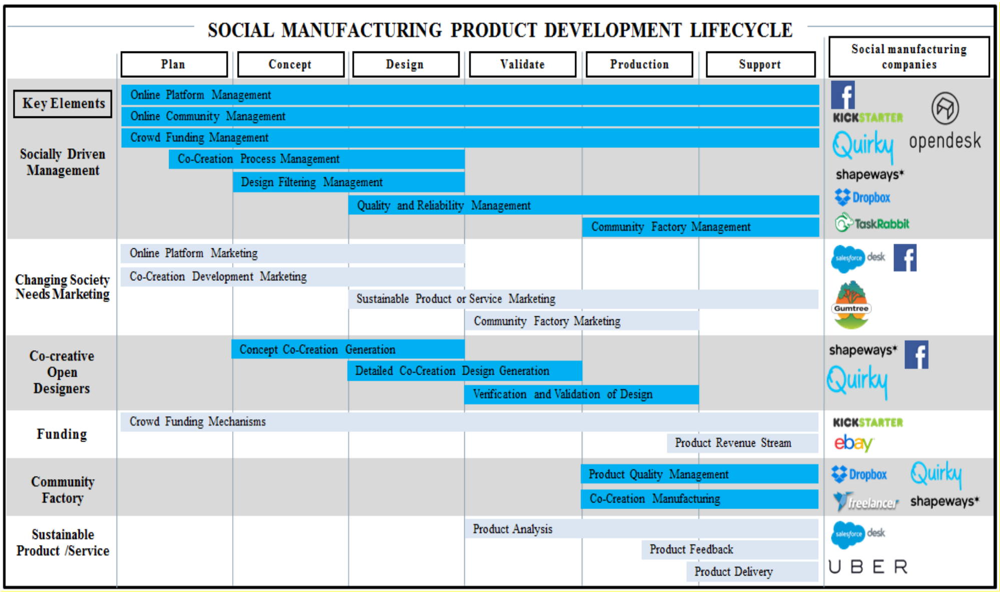

Figure 3: Social manufacturing product development lifecycle.

3. BAMBOO MANUFACTURING

3.1 Standardisation

Within the species great variation is observed in the diameter and the height of the culms. The lower the density of the culms the greater the diameter-at-breast-height (DBH) will be, but the lower the total biomass per unit area [15]. A high culm density will result in a reduced DBH and higher total biomass. Hence the culm density influences the diameter of the culms. The most effective agricultural methods, which facilitates easy harvesting must also be pursued [16]. An irrigation schedule will also be followed especially during the dry season.

Bamboo reaches its maximum strength when the culm is mature. This depends from specie to specie but is usually from the age of 3 years. If bamboo is older than 6 years, it might have suffered damage caused by insects [16]. Lopez suggests that the location of the bamboo has an influence on the strength properties of bamboo [3]. Research done on *Dendrocalamus* showed that the finest bamboo of this species grew in drier areas.

South Africa's only indigenous bamboo is *Thamnocalamus tessellatus*. The Bamboo source in South Africa that can be utilized is *Bambusa balcooa,* it was introduced to the country in the 1660's for paper pulp production and has since naturalized to South Africa's climate, although it's natural habitat is located in more tropical climate areas [17]. The plant itself can reach a height of 12m to 20m and a diameter of 6 cm to 15 cm [18]. In some circles *Bambusa balcooa* is also referred to as giant bamboo [17]. This offers a distinctive challenge when it comes to bicycle manufacturing which generally requires thinner diameter tubes especially at the chain and seat stays at the rear section of the bicycle.

Bamboo is harvested by selecting the most suitable culm, certain factors that are important to consider in the harvesting process are: the felling cycle; the intensity of the felling; the method of the felling as well as the transportation of the felled bamboo to the factory [15]. As previously argued, identifying mature bamboo is important. In year four, which is a good age to harvest, *Bambusa Balcooa* has the following characteristics. The culm covering is absent, branches have less leaves, most of the auxiliary and secondary branches transform into thorn like structures. Thicker branches are usually dead and shed, leaving scars on the culm. The culm has a smooth surface and is dark green. Black or rotten adventitious root ring can be present on the basal 1 to 2 nodes [16].

In the morning bamboo transports starch from the roots to the leafs as due to photosynthesis. The best time to harvest bamboo is early in the morning before sunrise from 12am and 6am, most of the starch is then in rhizomes at the roots [15]. The following advantages arise from harvesting bamboo in this manor: The bamboo is less attractive to insects, the bamboo weighs less for transporting purposes and the bamboo will dry faster.

The starch (sugar) content in bamboo is also high in the growing season considering this the best season for harvesting bamboo is after the rainy season. The culms will then be more resistant to biological degrading organisms [16].

Bamboo has less natural durability than most woods because of the absence of certain chemicals. The starch in the bamboo attracts beetles and fungi. Another factor that contributes to the bamboo's low natural durability is the hollowness of the bamboo. If an insect or fungi destroys 2mm of the outer layer of wood it is still in fair condition. Considering bamboo 2 mm is the quarter of the thickness in some instances. The hollow inside of the bamboo serves as a good hiding place for these agents of destruction [19].

Untreated bamboo typically has the following life, subject to the environment that it is in: 1-3 Years in the open air and in contact with soil, 4-6 years when it is under cover and not in contact with soil and 10- 15 years under very good conditions. There exist chemical and non-chemical methods to treat bamboo. The non-chemical methods can be conducted by unqualified villagers without technical equipment and with little cost. The non-chemical treatment can significantly increase the resistance against fungal and beetle attack. The real cost saving benefit of these methods with regards to long-term usability must be carefully evaluated [19].

Water- based chemical solutions are divided in non-fixing and fixing to the bamboo tissue and uses organic or inorganic salts. When the water from the solution evaporates the salts are left, which are either fixing or non-fixing. Non –fixing preservatives wash away in rainy conditions and are hence only suitable for use under cover in-doors or in dry conditions. There are different methods to apply chemical preservatives [16].

The drying of the bamboo is a step in the manufacturing process that improves the structural properties and the desirable appearance. Two major drying methods are: air drying and kiln drying.

i. Air drying: The moisture is removed by exposing it to atmospheric conditions. Stacking bamboo upright dries the bamboo in half the time when compared to stacking them horizontally. The drying time can range from several weeks, to several months. It goes without saying that air drying is quite dependent on the weather. A moisture content below 12% is required [16].

ii. Kiln drying: It is more efficient than air drying, the bamboo can be dried to the required moisture content in a much shorter time. Kiln drying produces high level results. It is a basic process of stacking bamboo culms or splits in a chamber where the air circulation and the temperature are maintained and controlled so that the moisture content can be reduced to the required level. Drying schedules are used to control the temperature and the relative humidity to the dry the bamboo in the shortest possible time with the least occurrences of degrades. Each bamboo specie has a unique drying behavior and therefore requires a unique schedule [16].

The identified process chain the bamboo follows before it is used for manufacturing are depicted in figure 4. The different strategies to standardize bamboo are listed below each step.

Grow bamboo
- Good management practices.
- Ecological and site condition.
- Culm density.
- Allow to reach optimal mechanical and structural properties. (3-5 years.)

Cut bamboo
- Harvest at the right time of day and season.
- Establish allowable diameter range.
- Identify mature culms.

Treat bamboo
- Low starch content.
- Correct treatment for the desired application.

Prepare for manufacturing (dry bamboo)
- Drying uniformly.
- Seal product after drying.

Figure 4: The four stages before the bamboo can be used for manufacturing and the accompanying standardizing strategies [15].

3.2 Manufacturing bamboo bicycles

The Bamboo Bicycle Club is situated in London and they help people who are passionate about cycling to build and ride their own bicycles. In addition to provide each person with all the necessary parts and tools to create their own bicycles, they also offer workshops to teach each person how the process works. The club generally uses one of the two most common species of bamboo for building bicycles, Mos or Tonkin, and source the product from an importer in the UK **[20]**. Both of the species, Mos and Tonkin, have good environmental performance and excellent strength properties, which makes them perfect for use in building a bicycle. Even though the bamboo is hand selected and treated at the source, they still recommend that it be coated with a protective layer to limit the movement of moisture and to protect the frame against the elements.

One of the most important steps in building a bamboo bicycle frame is to know which pieces of bamboo need to be used on which parts of the bicycle. After selection, the different pieces of bamboo are cut into the correct length according to the design that has been chosen. A hand drill with a circular hole cutter is used to cut the bamboo. This allows each piece of bamboo to fit snugly over the other. After cutting, a hand file and box cutter is used to complete the final shaping process.

The most important step of the secondary processes involved is the fiber and resin. This step determines the strength of the bamboo bicycle and is what keeps the frame the together. This could literally make or break the bamboo bicycle.

HERO bikes follows a contemporary approach to create a sustainable, socially conscious small business through the utilization of a locally grown bamboo [10]. HERO bikes cater for the DIY enthusiasts who want to manufacture their bicycles on their own. Not only do they sell bamboo bicycle kits that the customer assembles on their own, but they also have workshops which provides the customer with the opportunity to build their own bicycle in the HERO bike shop under the supervision of technicians. Included in the purchased kit is the jig used to assemble the bicycle. For the purpose of this study, only the building of the physical bicycle is considered, not the assembly of the jig itself.

A project was completed by the Engineering Materials Development Institute of Nigeria where they attempted to develop an eco-friendly bamboo bicycle by following these three steps: 1) outsourcing of the intricate parts; 2) heat treating the bamboo; and 3) jig design and assembly [21]. Since all the joints were outsourced, the manufacturing processes of these parts are overlooked. The drying process of the bamboo consisted of heating the bamboo evenly and slowly until the color transitioned from green to light brown, and then from light brown to dark brown. After heat treatment, the cutting process ensured that the bamboo was the required length according to the design. The third step is to mate the bamboo tubes with the brackets that were outsourced in step one. A large end mill was used to miter the tubes to roughly the size of the brackets they would be mated to, then a dermal was used to miter these tubes to perfection. After ensuring that all the bamboo fit perfectly with the joints, all the components were assembled in the jig, awaiting the fastening process.

4. RESEARCH METHODOLOGY

Figure 5 summarises the methodology that was followed to complete this project. Using the literature study to gain an understanding of social manufacturing and bamboo manufacturing, respectively, a validation experiment will be set up to use social manufacturing to develop various different bicycle frame designs and the best design will be chosen to manufacture a bicycle frame. The standardizing procedure and the manufacturing process chain of the bicycle will be evaluated and compared to the results obtained through the literature study.

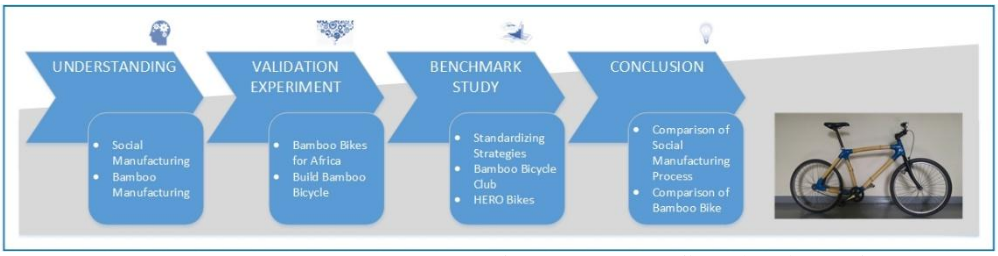

Figure 5: Research process steps followed in this study.

5. EXPERIMENTAL RESULTS AND DISCUSSION

Social Media will be the platform for the online community to simulate the social manufacturing experiment. In order to use Social Media data gathering is done by using social manufacturing in an industrial cluster, which is the 4th year students in the Advanced Manufacturing 414 course tutorial of the Industrial Engineering Department of Stellenbosch University. The tutorial is made up of 2 sections which should be finished in 2 weeks where the students are divided into 10 groups. The validation experiment followed the generic framework for social manufacturing.

The first week is the plan and concept generation phase from. In this phase the students must design free hand sketches of Bamboo Bicycles and upload these designs onto Social Media (Facebook, Instagram, Twitter and Dropbox for monitoring purposes). These designs must include attachments (Swiss army knife technology) that will improve the everyday life of someone living in rural Africa. These designs must then be promoted on Bamboo Bikes for Africa's Facebook-, Instagram- and Twitter pages. The design from each group with the most 'Likes' must then be used for the second week. This will act as the validation and marketing of the designs.

The second week the students will 3D CAD model the best design from week 1. This will act as the design phase (detailed design). These CAD models only include the frame of the bicycles along with the attachments (Swiss army knife technology). The students will then have to make a video around their design as to what makes it great. Both the video and 3D CAD model will then be posted onto Social Media to create awareness. These designs will then be used to manufacture the bicycles at Stellenbosch University and donate it to our local communities. The manufacturing process will be the production and support phases, however this is not in the scope of this case study.

A questionnaire was given to the students to determine their perspective and experience of social manufacturing. The questionnaire can give an indication to whether people would get involved with a social manufacturing company. The rest of the results captured in this study are based on the data from Facebook, Instagram, Twitter and Dropbox.

The next step is to analyse the data obtained from the students with regards to their designs and the data from the various social media platforms. From the 10 groups of students, they delivered 151 bamboo bicycle designs in one week. This meant that each group designed 15 bicycles on average.

The next step is to analyse the different Social Media platforms. The students were requested to promote all their designs on Facebook, Instagram and Twitter to see on which platform they could get the most Likes. Facebook got a total of 8472 Likes, Instagram 2013 Likes and Twitter 68 Likes. From these results we can see, because Facebook and Instagram focuses more on photos rather than text like Twitter, people reacted more to the photos rather than text.

In order to establish the amount of views of the page and posts the total reach is important. As illustrated in Figure 6, in 7 days the Bamboo Bikes for Africa posts reached 10552 people. This is significant as the students were only 89 people which transformed into a total reach of more than 10000. The total post reach proves the power of using Social Media as it is easy to connect to a very large online community in a short period of time.

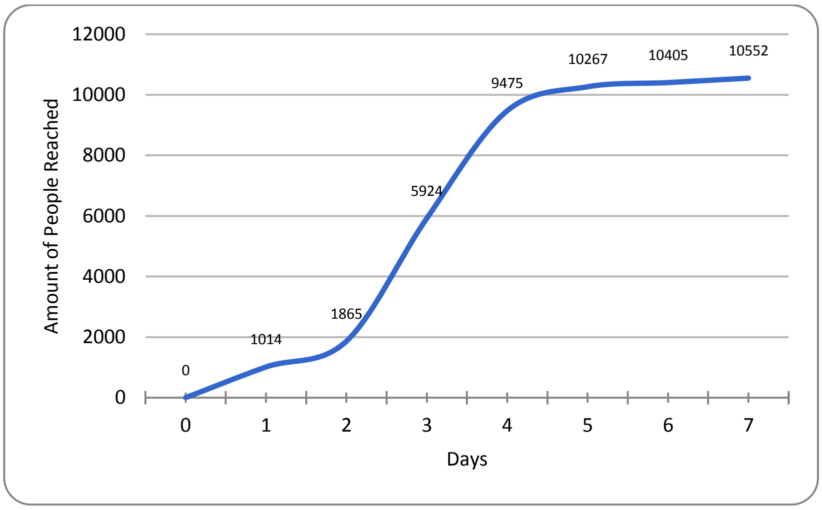

Figure 6: Total post reach on Facebook page [1].

Week 2 of the project was used for the students to 3D CAD model, on Autodesk Inventor, the design from each group with the most likes from week 1. The CAD process needs to only show the frame of the bicycle along with the attachments that gives the bicycle its 'Swiss army knife' like technology.

The best design was chosen for the final Bamboo Bicycle that was manufactured. This manufactured bamboo bicycle is seen in Figure 7. The entire bicycle frame was manufactured from bamboo and the joints were made of a combination of steel and fiberglass.

Figure 7: Manufactured bamboo bicycle [22].

In Table 2 the standardizing strategies identified in the four steps of the sourcing process chain are rated according to the influence it has on the diameter, wall- thickness and the shrinkage. These three factors must be standardized and acceptable variances must be adhered to in order to maximize the usefulness of the bamboo when it is used for manufacturing of the bamboo bicycle. The summarized comment explains the reasoning behind the allocations.

Table 2: The standardizing strategies are linked to the standardizing factors [15].

Strategy	Diameter	Wall thickness	Shrinkage	Comment
1. Good management practices	Low	Low		
2. Ecological and site condition	Medium	Low		Drier conditions lead to a smaller diameter [3].
3. Culm density	High	Medium		The density of the culms influences the diameter [16].
4. Allow to reach optimal mechanical and structural properties. (3-5 years.)		Medium		The age has an effect on the primary tissue, which influences the strength of bamboo [3].
5. Harvest at the right time of day and season.				This is related to the starch content which effects the preservation [16].
6. Establish allowable diameter range.	High			An allowable diameter variance for each tube.

7. Identify mature culms.		Medium		Bamboo reach their maximum strength when they are mature [3].
8. Low starch content				This effects the preservation of the bamboo.
9. Correct treatment for desired application				
10. Drying uniformly			Medium	If it dries uniformly like losing moisture on one side it will contract unevenly [29].
11. Seal product after drying.			High	Bamboo must be properly sealed off to prevent change in the moisture content [29].

The processes used to manufacture the bamboo bicycle was subject to available materials and machines at the University of Stellenbosch. It is therefore necessary to compare the process steps used with benchmark processes. The process steps utilized by each of the different process chains is displayed in table 3.

Table 3: Process steps utilized by each of the process chains (Adapted from [2] and [22]).

Process Steps	Bamboo Bikes for Africa 01	Bamboo Bikes for Africa 02	Bamboo Bicycle Club	Engineering Materials Development Institute	HERO Bikes
Heat treat the raw bamboo				x	x
Treat the bamboo with insecticide	x	x			
Dry bamboo	x	x		x	x
Bamboo selection	x	x	x	x	x
Prep bamboo for cutting	x	x	x		
Cut bamboo	x	x	x	x	x
Shape bamboo			x	x	
Rough bamboo					x
Remove bamboo material				x	
Outsource the joints				x	
Remove necessary joints from old bicycle	x				
Weld the parts to create the joints	x				
Sandblast the Joints	x				
Create joints using SLS		x			
Treat the joints	x				
Attach the lugs to the frame					x
Preliminary assembly	x	x	x	x	x
Shape the lugs					x
Assemble lugs					x
Apply fiber	x	x	x	x	x
Apply resin	x	x	x	x	x
Lug Preparation					x
Carbon-wrap					x
Filler	x				
Sanding	x	x	x	x	
Install brake bridge					x
Painting	x				
Varnish	x	x			x

Figure 8 shows the comparison of the manufacturing times between the different companies. It shows that HERO Bicycles and the Bamboo Bicycle Club have a very similar manufacturing time, while the first prototype of Bamboo

Bikes for Africa took substantially longer to complete. This can be attributed to the fact that the team had to remove the necessary components from an old bicycle before they could start the actual manufacturing process.

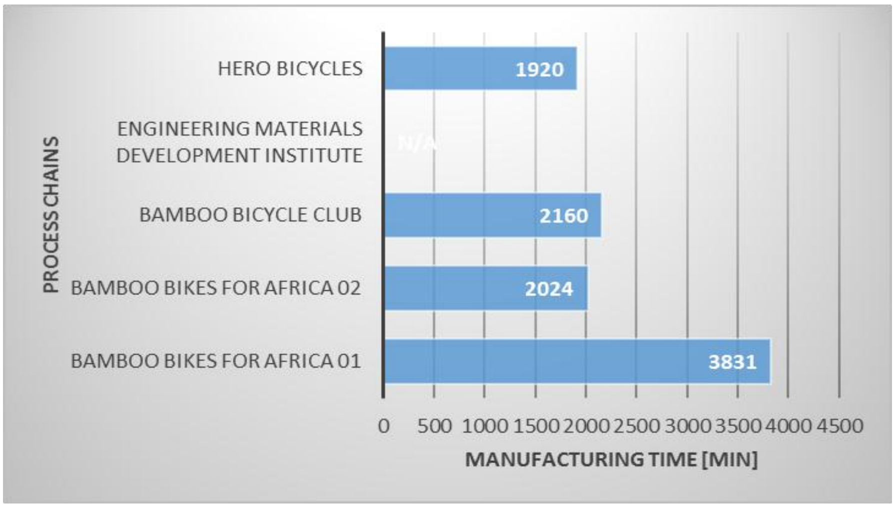

Figure 8: Comparison of manufacturing times between the different process chains [2]

There is a substantial cost difference between the Bamboo Bikes for Africa prototype and the rest of the process chains, as seen in Figure 9, even though the team had to purchase a bicycle to source all of the necessary components. This could be attributed to the fact that there is no markup added to the BBfA bicycle.

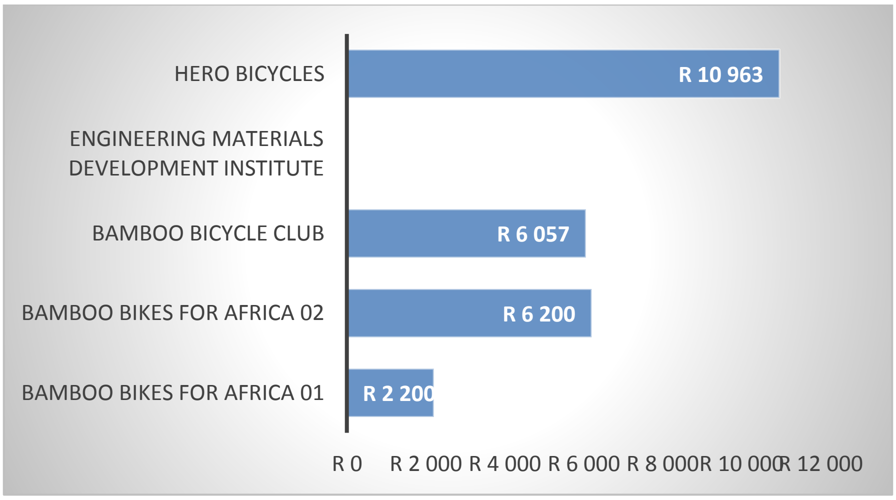

Figure 9: Comparison of manufacturing costs between the different process chains [2].

As the waste process could not physically be measured, the student distinguished between high or low waste during the manufacturing processes by using his own discretion through the knowledge he gained during the literature study. Because only the necessary components are used during the manufacturing process of the first prototype, the waste is high when manufacturing the joints. The 3D printing process has the lowest waste of all the stakeholders because every component is manufactured exactly to specifications. Figure 10 represents the material waste during the manufacturing processes of the different process chains.

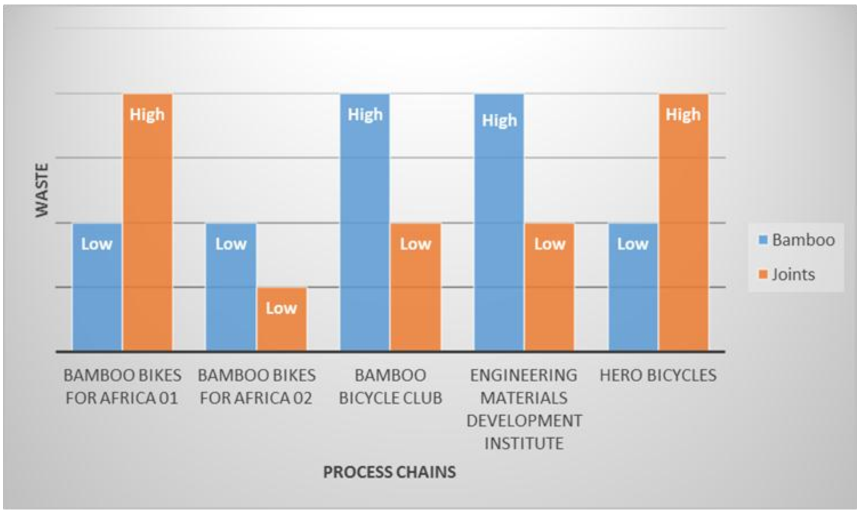

Figure 10: Comparison of material waste during the manufacturing processes of the different process chains [2].

6. CONCLUSION

The business model elements of social manufacturing were explored and compared to traditional manufacturing methods. The research and conceptual design phase of social manufacturing when compared to traditional design phases were much shorter. This case study proved that by using social manufacturing, the design phase could produce more designs in a shorter amount of time than a traditional design method. Through analysing the designs, it was shown that an even higher amount of quality designs was generated by improving the first example design that was shown to the online community. The case study showed that by using an online community, a social manufacturing company can involve significantly more people than with a traditional manufacturing process. A bamboo bicycle was designed and manufactured, which is competitive with existing approaches. This paper indicates the business benefit of crowd sourcing and using an online community in the design phase of a manufacturing company.

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FAILURE ANALYSIS OF LOCOMOTIVE ALTERNATORS USING THE SIX SIGMA METHODOLOGY

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ABSTRACT

The series 6E diesel electric locomotives use an alternator to produce power to the traction motors that are mounted to the bogies to drive the locomotive. Company XYZ is the largest repairer of the locomotive alternators which refurbishes an average of 675 locomotive alternators per annum. Locomotives are coupled with wagons to supply commodities such as iron and ore in South Africa. Company XYZ faced high failure rates due to locomotive alternators defects. These defects led to service issues and revenue losses. Therefore, the company embarked on a project to investigate strategic initiatives to reduce failure the rate. Six Sigma DMAIC methodology was identified as an initiative that focused on improving the quality of the locomotive alternator by reducing failure the rate. The current Six Sigma level was at 3.8 sigma with the defect per million (DPMO) of 11481 at 675 units annually. Of the 675 refurbished locomotive alternators produced annually, 18% had a failure rate. Through the implementation of the DMAIC methodology, insulation on an armature was the highest type of failure. A resolution was proposed that each locomotive alternator that had operated more than 12 months in-service must undergo complete armature insulation. This proposal reduced the failure rate to 6%, thus yielding improved Sigma level of 4.2 with a DPMO of 3457 at 675 units.

Key Words: Six Sigma, Product Quality, Variation, Product Defects

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1. INTRODUCTION

Mittle [25] opined that, in simple terms, a locomotive alternator or electrical alternator is an electrical machine whose main purpose is to convert electrical energy into mechanical energy. This locomotive alternator is also known as a synchronous electrical machine that belongs to the electrical rotating machine family which includes; generators, convertors, motors and transformers [5]. A locomotive alternator is a critical assembly component that results in the stoppage of a locomotive whenever it experiences failure.

The main parts that form a locomotive alternator are the; armarture, frame and end-shield, where the armarture is the rotating part of the alternator that has a shaft, and the stationary part of the alternator comprise the frame and end-shield as illustrated in Diagram 1 below.

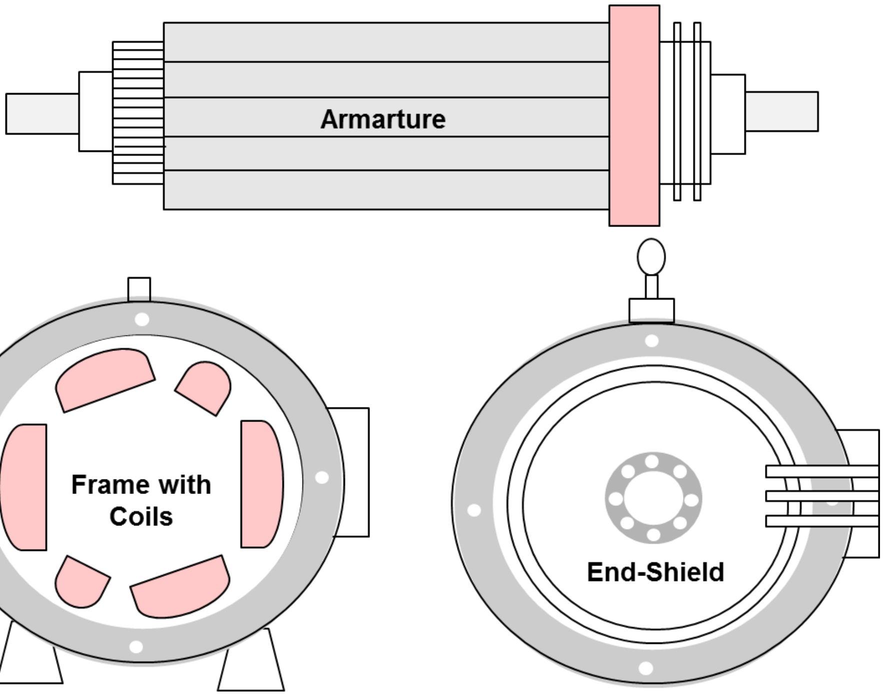

Diagram 1: Locomotive alternator assembly

Whenever the failure occurs with a locomotive, the customer updates the failure on the non-conformance report system. Due to a high prevalence of locomotive failures recorded on the non-conformance report system, data was extracted from the year 2014 and analysed. It was discovered that the failures of a locomotive alternator were the cause of such occurrences. Through this data a project was initiated to analyse the failures of locomotives alternator by use DMAIC methodology. Data collection was carried out though a visit to the company XYZ production plant.

The refurbishing process followed was analysed and consultations with Quality Assurance officers were conducted, wherein data of monthly recorded failures was sourced. This data was later used in data analysis phase. Therefore, Analyses was conducted and recommendation was made to improve the failure rate.

2. LITERATURE

This study was characterised by the analysis of the failures of locomotive alternators using the Six Sigma and DMAIC methodology. The author focused on Six Sigma, product quality, variation and defects when reviewing the relevant literature.

2.1. Definitions

Six Sigma is known as a methodology or a philosophy that rigorously focuses on quality improvement by reducing the variation and measurements of defects per million opportunities [12]. Any variation from customer specifications on either a product or a process is categorised as a primary problem to be solved using this methodology [14]. Six Sigma is also defined as a philosophy that is data driven to eradicate defects in the process of a product or service. In the early 1980’s the methodology was developed and recognised by the

Motorola company [3]. A product defect refers to the failure of a product in its purpose and the product is not fit for use and does not conform to specification [2]. Product quality refers to the ability of a product to satisfy the expectations of a customer [29]. Variation is the term that means a change in difference or a change in a form, position or condition [3].

2.2. Quality of a product

Over the years, quality has been viewed as one of the primary order winners of why customers choose a particular product or service [31]. Many companies have witnessed their corporate image being damaged by a reputation of poor quality where some organisations use quality as one of their marketing strategic initiatives to capture the clients. Many organisations view high quality as "more money", although literature reflects "doing things right the first time" as a definition of quality [2].It is therefore imperative for Company XYZ to produce good quality service to avoid reworking that will lead to high non-conformance costs, as well as increase the availability of locomotives to move the tonnages that will meet customer specifications.

2.3. Six Sigma and DMAIC methodology in manufacturing organisation

In manufacturing organisations, Six Sigma contributes to improving the processes and adds value to the product. It reduces the variation of problems that are complex to solve and could lead to high risks if left unresolved [14].The DMAIC methodology is not very different from other common process improvements methodologies. However it has always been known as a proven methodology that delivers results by using data and statistical analytics. The five step systematic approach of DMAIC (Define, Measure, Analyse, Improve, Control) constitutes the classic Six Sigma problem-solving process. Traditionally, the approach is to be applied to a problem within an existing, steady-state process or product and service offering [12]. The Six Sigma philosophy has been adopted worldwide in manufacturing companies to improve their financial status as well as to improve quality and process performance in order to ensure that the product conforms to specifications. This methodology increases the process performance and measures process capability by means of statistical measurement [11].

There are several studies in the literature regarding the application of Six Sigma to reduce the failure rate or defect of a product; for example, amongst others, a study undertaken to "reduce the failure rate of the Screwing process with Six Sigma approach" The aim of the research conducted by Nihal Erginel was to reduce the failure rate of the screwing process, where the failure rate was decreased from 30% to 14%. Nihal Erginel followed five sequential phases known as DMAIC to conclude the study [13].

A study on the "reduction of welding defects using Six Sigma techniques" was conducted. This study focused on identifying the root causes of failure in the welding process through the implementation of Six Sigma to eliminate the defect rate in the final product. This project aimed at improving customer satisfaction and product quality. It was also noted that in order for one to understand and follow Six Sigma disciplines, the SIPOC (Supplier, Input, Process, Output, and Control) identification needed to be carried out in order to document the welding process from beginning to end [15].

Another Indian company has successfully undergone a project to implement Six Sigma "to reduce defects of a grinding process". This project was instigated in an automotive company. The application of the methodology resulted in decreasing the defects from 16.6% to 9%. The project also yielded positive results in the reduction of scrap costs and the number of employee hours spent on rework and as well as an increment in production output. Savings of approximately $2.4million was reported as a result of this project. Common statistical tools such as a cause and effect diagram, process capability, ANOVA etcetera, were used in the study [18].

3. RESEARCH METHODOLOGY

3.1. Problem statement

Company XYZ had been experiencing a high failure rate of locomotive alternators. The quality assurance department saw a breach in service level agreements set at 6% rising to 18% and sudden spike in incurred maintenance costs. Data sourced from the non-conformance report system revealed that for each train set that could not operate, a loss of potential income of R7m was realised. Subsequent to this problem, a refurbished locomotive alternators would now needed to be re-serviced and thus the company incurs a maintenance cost of R65 000 per locomotive alternator. These problems affected the entity's profitability and customer service.

The problem statement was introduced through the investigation of non-conformance report system by tapping into the data that was used as feedback from the customer regarding quality issues of locomotive alternators. Through the analysis of 2014 data, it was noted that there are various root causes that explain why Company

XYZ was facing high failure rates of locomotives alternators. The project was therefore initiated to analyse the failures of the locomotive alternators by employing the Six Sigma and DMAIC methodology.

3.2. Objectives

The objectives of this study were to;

- Determine the root cause of failure in the locomotive alternators;
- Improve the failure rate from 18% to 6%;
- Improve the Sigma level from 3.8 to 4.2 sigma and
- Implement process control to ensure sustainability of the improvements.

3.3. Collection of data

To critically comprehend the problem statement, it was imperative to collect data regarding the failures of locomotive repairing process, and the locomotive alternator specifications as well as the non-conformance reports. The DMAIC methodology was followed to ensure a systematic problem solving approach.

3.4. Methods and dispersion of data

Six Sigma and DMAIC methodology was employed in command in order to better comprehend the failures experienced with the locomotive alternators. Six-Sigma comprises a rigorous, focused and highly effective implementation of proven quality principles and techniques [10]. The systematic methodology was employed in the following phases:

Define Phase: In this phase the project charter that comprises the project goals, scope, timeline and estimated benefits were defined together with the project leader, coach, sponsor and champion. The project team consisted of the engineering manager, quality controller, industrial engineer and a Six Sigma specialist (Black belt). A Pareto diagram was constructed in order to indicate the high contributors to failures. To establish a clear scope of the project or research, SIPOC (Supplier input Process Output Customer) aimed at summarising the inputs and outputs of a process of repairing and locomotive alternator AS IS process was defined in order to detail the high level mapping of the current process of repairing locomotive alternators.

Measure Phase: A data collection plan sheet was used to develop a sound data collection plan. To determine the baseline performance, graphical tools such as a control chart and histogram were used. Calculation of Sigma Performance (Defect per Million Opportunities) was performed to determine the Sigma level.

Analyse Phase: Once the sigma level was determined, the project team needed to identify the potential root causes of the locomotive alternator failures. The data were statistically analysed in order to obtain confirmation of the root causes and in turn to identify the contributors to the failure of the locomotive alternators. Tools such as fishbone diagram (cause and effect), FMEA (Failure Mode and Effects Analysis), and control charts, normality tests and correlation analysis were employed. Software such as Microsoft Office Excel, Six Sigma Excel and Mini-Tab were used as tools to graphically display the data.

Improve Phase: The main aim of this phase was to a identify solution that would prevent the failures of the locomotive alternators. During the brainstorming and generation of possible solutions, techniques such as using six thinking hats were employed by the project team. The proposed solutions were prioritised and selected by means of solution prioritization and selection matrix. In order to reduce the locomotive alternator failures, the To-be Process was defined by introducing more quality hold points and the FMEA (Failure Mode Effect Analysis) focused on the high priority items.

Control Phase: The purpose of the control phase was to implement the control mechanisms of process procedures to ensure that the improvements of the process are sustained. This includes the development of a process monitoring plan called the failure early detection system. Computation of the Sigma level was performed in order to compare the baseline Sigma level with the new Sigma level after the improvements has been implemented.

4. DISCUSSION OF RESULTS

4.1. Define Phase

4.1.1. Project charter

In order to provide a shared understanding from a bird's eye view for all the main stakeholders, a project charter was constructed with the main aim to outline and identify the scope, objectives, deliverables, constraints, expected benefits and main stakeholders of the project. Figure 1 comprises the project charter that detailed how the project was scoped with the estimated benefits, timelines and project goals.

Project Charter **Project Overview**

Business Case

Locomotive alternator contributes to the performance of Locomotive outputs significantly and consequently company XYZ objectives of hauling tonnages are imperative to ensure the economic growth of the country. The business has to meet the customer requirements of 675 electric motor alternator annually to be assembled without any defects. Currently the business has failure rate of 18% annually. The 124 locomotive alternator amount to R9m worth of revenue loss at an average cost of R72k per motor. As a result of the deficit, the business losses on average R744k per month.

Problem Statement

Failures on locomotive alternator impedes the achievement of company XYZ meeting customer expectation of 675 electric motors per annum . The current failure rate is 18% annually

Project Goals

Reduce failure rate from 18% to 6%

Estimated Benefits (R)

Non conformance cost reduced by R7.8m

Project Scope

Area of Focus: Locomotive alternator Repairing Process
Includes: Armature Inspection, Shaft repairing Section
Excludes: Commutator repair and End-shield Section
Start Point: Stripping Section
Stop Point: Assembly Section (Fitting armature into frame)

Project Timeline

Phase	Expected Completion Date
Define	End Jan 2016
Measure	End Feb 2016
Analyze	End Mar 2016
Improve	End May 2016
Control	End Jun 2016

Project Resources

Project Leader (s): Amos Mekwa
Project Coach: Tebogo Makhafola
Project Sponsor (s): Sondaha Maivha
Project Champion: Chris Fourie

Core Team Members: Bongani Nhlapo, Matome Makgoba, Mpho Tladi

Subject Matter Experts (SMEs): Andile Nqodi, Edgar Mothapo

Figure1: Project Charter

The project charter is a crucial part of any Six Sigma project to ensure that the project does not deviate from the expected outcomes and goals. The main aim of the initiated project was for the identified project team to reduce the failure rate from 18% to 6%.

4.1.2. Pareto

In order to focus on the highest occurring failures and graphically summarises the failures by categories, a Pareto diagram was initiated. This graphic assisted the project team in analysing which problems required immediate attention and illustrated which failures exerted the greatest effect on the locomotive alternator failures by applying the 80/20 principle. Diagram 2 indicates that insulation failure had the highest failure rate compared with other failure rates. Thus the focus was on the insulation failure that occurs during the armature repairing process.

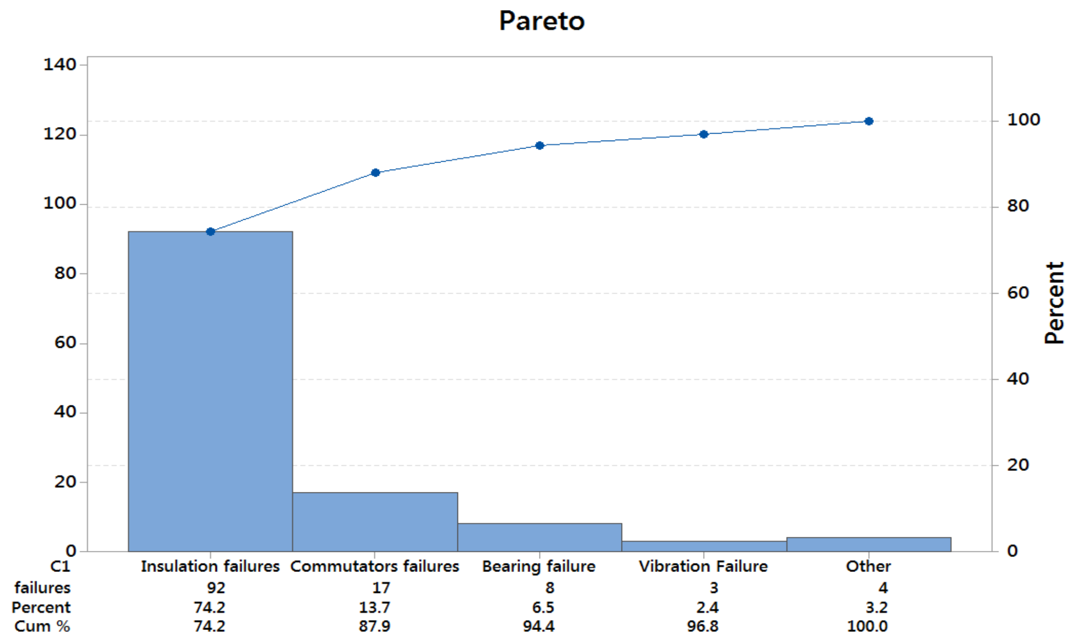

Diagram 2: Pareto graph

Diagram 3 depicts armature that has a failed insulation. The photograph was taken by a quality officer during the investigation period.

Diagram 3: Picture of Insulation failure

4.1.3. SIPOC

The SIPOC (Supplier Input Process Output Customer) identification process was conducted with a view to summarising the inputs and outputs of the process of repairing locomotive alternator (high level process map). The focus fell on the armature repairing process that failed insulation quality. Figure 2 depicts the SIPOC process in this regard.

SIPOC **Define Phase**

Process Start: Stripping Section

Process End: Assembly Section (Fitting Armature into a Frame)

Suppliers	Inputs	Process	Outputs	Customers
Stripping Section	Defective Armature	- Rewind - Pull Down & VPI - Balancing - Shaft Inspection & Repair	Good Armature	Assembly Section (Fitting Armature into a Frame)

Figure 2: Suppliers Input Process Output Customer identification

4.1.4. As-Is Process

Diagram 4 depicts the high level process of repairing a locomotive alternator. The first step of repairing the locomotive alternator is to receive the defective locomotive alternator. Thereafter, it is necessary to clean the component, inspect, strip, inspect the armarture, fix any defects, clean the frame, repair the coils, inspect the end-shield, repair any defects, fit the armature into the frame, test the locomotive alternator, paint it, and finally perform quality assurance.

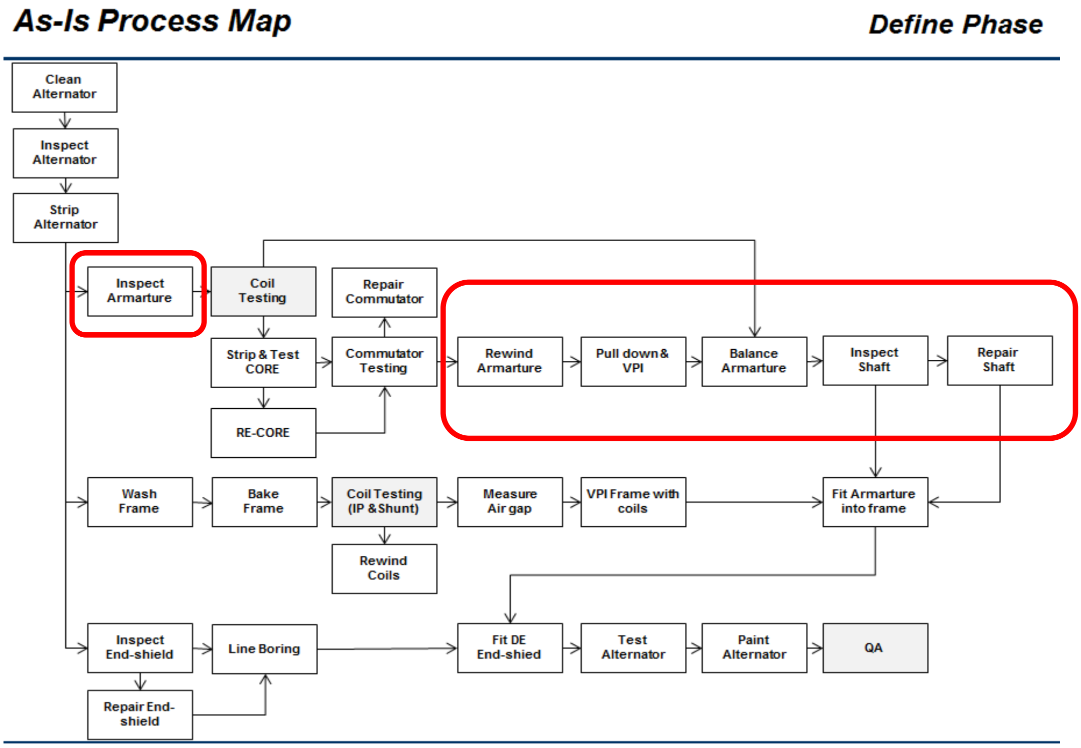

Diagram 4: As-Is Process

The main focus fell on the process of repairing the armature where the insulation failure occurs, as highlighted in red. A lean event was also conducted in the form of a Just-Do-It project in order to remove all the non-value adding activities that are not critical to customer specifications.

4.2. Measure Phase

4.2.1. DPMO

The DPMO is one of the significant Six Sigma metrics employed to determine how effective the process is. This process was significant to this study in order to establish a baseline level performance. After the process improvements had been initiated, the DPMO was recalculated to gauge performance gains. The current defect per million (DPMO) was determined at 11481 with 675 units annually as shown below at the Six Sigma level of 3.8 sigma. Out of average total of 675 refurbished locomotive alternators annually, a failure rate of approximately 18% was experienced.

$$DPMO = \frac{Number\ of\ defects}{\frac{Number\ of\ defect\ opportunities}{Units}\ x\ Number\ of\ Units}\ x\ 1{,}000\ 000 \ldots\ldots\ldots\ldots..(1)$$

Defects	124
Opportunities	675
Defect Opportunities per unit	16

DPMO	11481
Sigma Level	3.8

Six Sigma Table:

1	690,000
2	308,000
3	66,800
4	6,210
5	320
6	3.4

Calculation of DPMO

$$\boldsymbol{DPMO} = \frac{124}{675\ x\ 16}\ x\ 1{,}000\ 000 \ldots\ldots\ldots\ldots..(1)$$
$$\boldsymbol{DPMO} = 11481 \ldots\ldots\ldots\ldots..(1)$$

Therefore, the Sigma level was calculated by taking into consideration the calculated DPMO using Sigma Excel. The Sigma level of 3.8 indicates that about 6.7% of the time defects are transpired during the process of repairing locomotive alternators.

4.2.2. Histogram

To evaluate the current situation and to study the outcomes of the improvements, a histogram was used to display the numeric data. The histogram shape assisted in deciding how to improve the current situation of failures. Figure 3 indicates that most of the data falls on the left side and fewer on the right side. The mean in Figure 3 indicates that an average of 10.33 failures per month occurred over a 12 month period.

Sample Standard Deviation, s	5.5813542399238
Variance (Sample Standard), s^2	31.151515151515
Population Standard Deviation, σ	5.3437398472938
Variance (Population Standard), σ^2	28.555555555556
Total Numbers, N	12
Sum:	124
Mean (Average):	10.333333333333

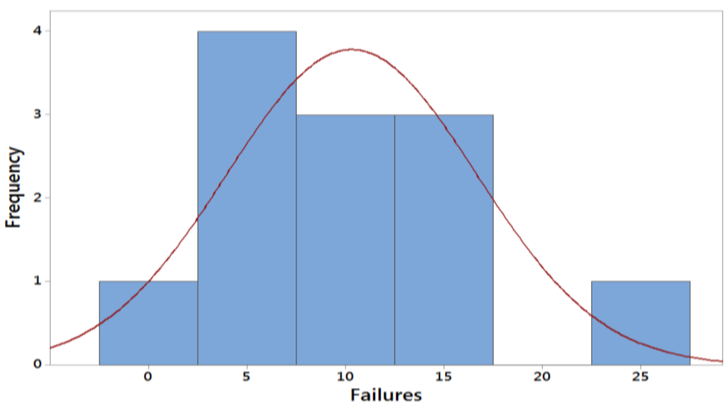

Figure 3: Histogram of the number of failures of locomotive alternators

The data in the histogram is relatively skewed to the right where it indicates that the mean failure is greater than median failure of 8.5.

4.2.3. Normality test

To avoid statistical errors and curb the assumption that the data would follow a normal distribution, a normality test was conducted by means of the Anderson-Darling Test. This test was recommended due to its precision and high power when testing whether the data followed a normal distribution or mean. The normality test was conducted to validate the data in order to determine whether it is normal or not (refer to Figure 4 which demonstrates that the data are normally distributed to the mean).

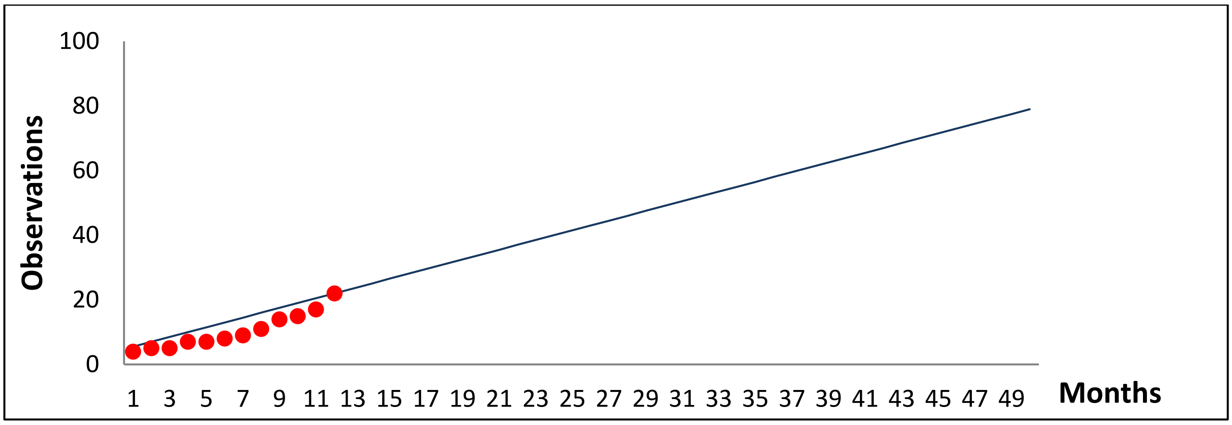

Figure 4: Normality test of locomotives alternator failures

The p-value was calculated at 0.0829, which is larger than 5%. Due to a lack of evidence that data in the graph is not normally distributed, the decision was to fail to reject the null hypothesis.

4.2.4. Control chart

A control chart was adopted to portray how the processes or failures change over time. The computed control chart depicts that there was a special cause variation in January where the point fell above the upper control limit. Further analysis and investigation were conducted regarding this special cause variation to ensure that it is permanently eliminated from the process. Figure 5 indicates the number of failures per month where there were more failures in January than other months.

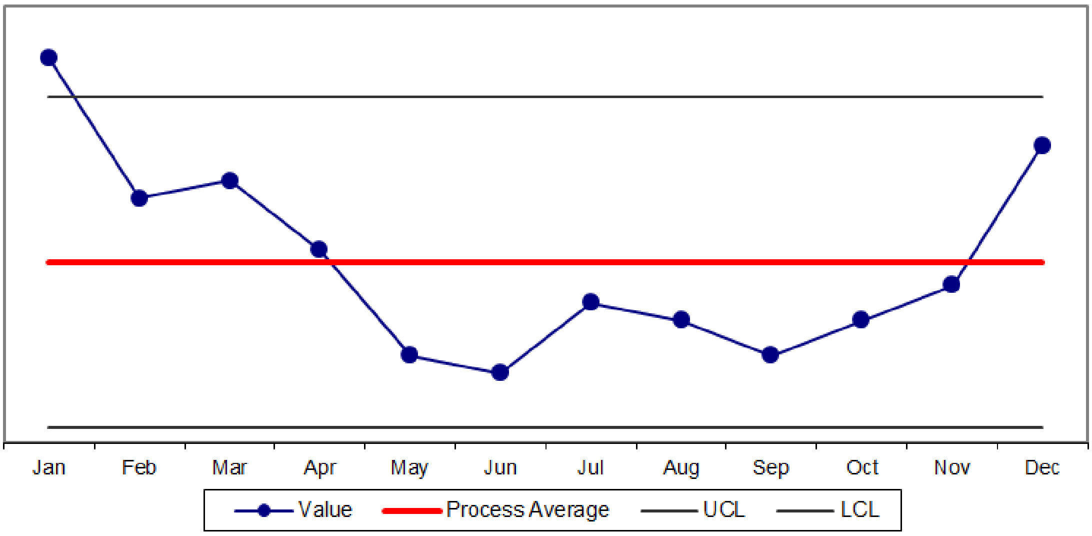

Figure 5: Control chart of the number of failures of locomotives alternator per month

It is commonly known that the failures occur mostly during the hot summer weather and the rainy season, meaning that the increase in number of failures is dependent on the weather conditions. The project team was gathered to craft a way forward on why a special cause occurred. A cause and effect diagram was used to further investigate the causes of the increase in failures of the locomotive alternators.

4.3. Analyse Phase

4.3.1. Fishbone

To analyse the root causes of the insulation failure, the team used the fishbone diagram below, which also indicates that an increase in the number of failures occurred during spring and summer. The results of the fishbone graphic in Diagram 5 indicate that both methods and mother-nature were the main root causes of why the locomotives alternators experience insulation failure. The two main root causes that contributed most to the increase in the locomotive alternator failures to being 18% were further evaluated using Failure Mode and Effect Analysis to prioritise the root cause that exerted such a major impact.

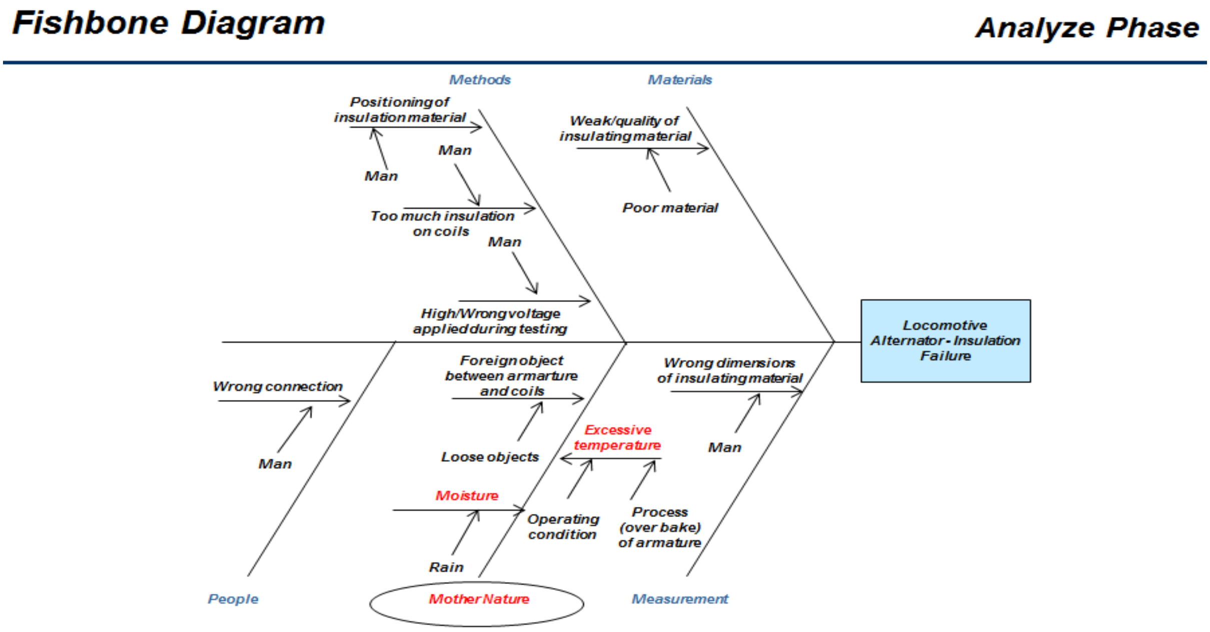

Diagram 5: Cause and effect of locomotives alternator failures

The transfer function Y=f(x) was used to identify all the possible causes (x) that impact Locomotive alternator insulation failure (Y) and to classify a relationship between the output and input, The table in Figure 6 displays all the x data that were evaluated as well as their relationship.

	X1	X2	X3	X4	X5	X6	X7	X8	X9
Possible causes	Weak insulation material	Positioning of insulation	Too much insulation	Wrong Voltage applied	Wrong connection	Foreign object between armature & coils	Moisture	excessive temperature	Wrong dimenstions on insulation
Relationship	M	L	M	M	M	M	H	H	M

L= Weak Relationship
M= Moderate Relationship
H=Strong Relationship

Figure 6: Y=f(x)

Through this transfer function, it was found that one variable has a weak relationship. The variable 6 has a moderate relationship and 2 has a strong relationship. Therefore, moisture and excessive temperature were the root causes to be addressed in a solution.

4.3.2. FMEA (Failure Mode and Effects Analysis)

Through an evaluation to prioritise which root cause has the main impact, it was observed that mother nature was the main cause of failure owing to excessive temperature and moisture, as highlighted in red in the Figure 7. The results of the FMEA depict that excessive temperature was a root-cause which ranked highly at 288.

Product Type	Possible Failure	Failure Mode	Causes of Failure	Ranking (1 – 10)			Risk Priority Number	Recommended Actions
				[O]Occurrence	[S]Severity	[D]Detection	OxSxD	
Locomotive Alternator	Insulation failure on armature	Positioning of insulation material	Man	3	7	5	105	Implement QA hold point
		Too much insulation on coils	Man	3	7	3	63	Implement QA hold point
		High/Wrong voltage applied during testing	Man	4	7	3	84	Follow Standard Operating Procedure
		Foreign object between armature and coils	Loose objects	2	8	2	32	Early Detection
		Moisture	Rain	5	8	6	240	Early Detection
		Excessive temperature	Operating Condition	6	8	6	288	Early Detection
			Process (over bake) of armature	5	8	6	240	Follow Standard Operating Procedure

Figure 7: Failure Mode and Effects Analysis

4.3.3. Correlation analysis

In the graph below, the increase in failures being dependent on weather conditions is validated. Since the evaluation in Figure 7 above indicated that moisture and excessive temperature are the main root causes of the increase in failure rates rising to 18%, indeed the excessive temperature cause an increase in the failures. Figure 8 indicates that in summer, when temperatures are high; there is an increase in the failures of the locomotive alternators.

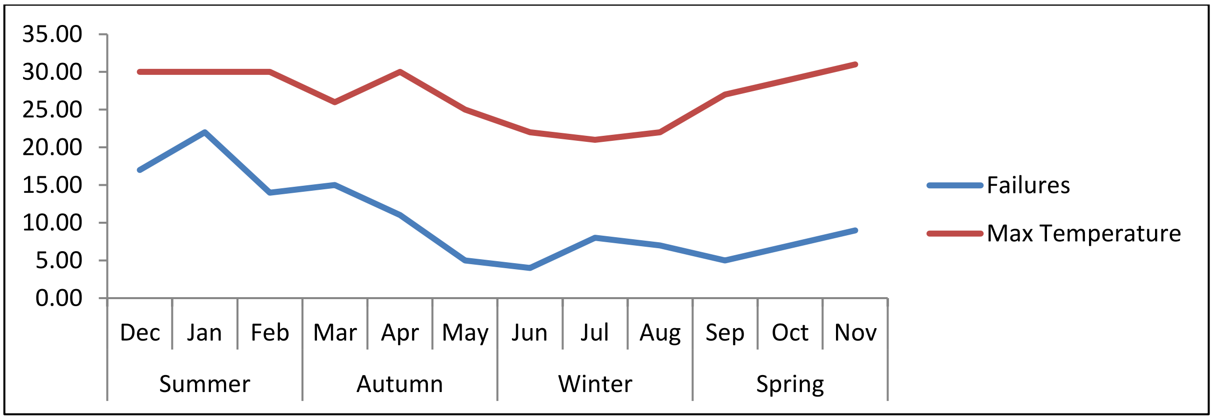

Figure 8: Relationship between failures and temperature

To establish whether there is a relationship between two variables, namely failures and temperature, correlation analysis was performed. The graph in Figure 9 portrays a straight line with a positive slope where the Pearson correlation coefficient (r) was used as a measurement to determine the significance between these two variables.

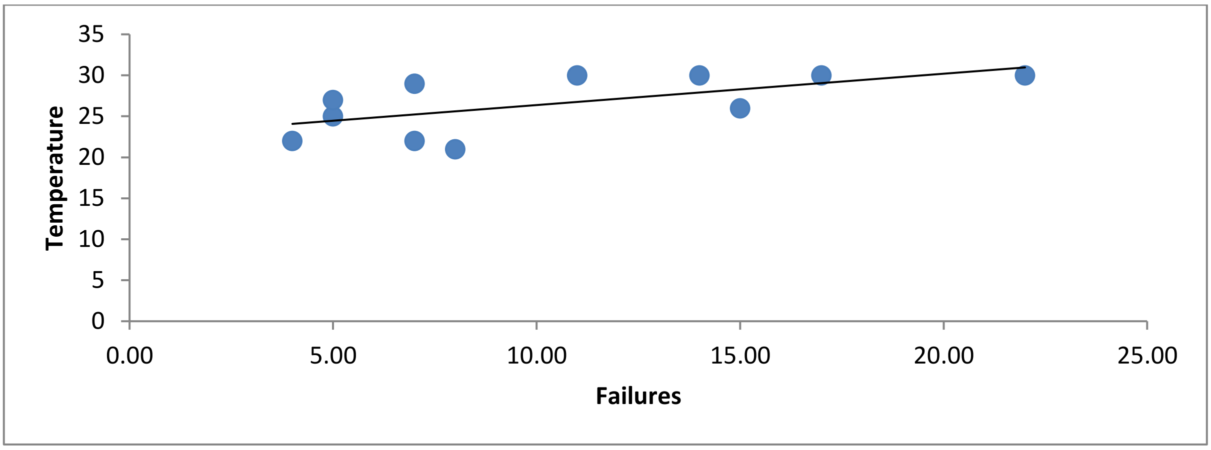

Figure 9: Correlation analysis of temperature and number of failures

Calculation of Pearson correlation coefficient (r)

$$\boldsymbol{r} = \frac{1}{n-1}\left\{\frac{\sum x \sum y\,(x-\bar{x})(y-\bar{y})}{s_x s_y}\right. \ldots\ldots(2)$$

where;

$n = 12$
$\bar{x} = 10.33$
$\bar{y} = 26.92$
$s_x \;=\; 5.58$
$s_{xy} \;=\; 3.65$

The r is calculated at 0.6, which indicates a strong positive correlation where r is close to +1.

4.4. Improve Phase

4.4.1. Solution prioritisation matrix

Three solutions were suggested by the project team, namely each locomotive alternator that has been in service more than 12 months must undergo complete re-insulation, increase number of quality check point and perform regular audits on a process to ensure adherence, change the current insulation type. All the solutions were ranked using solution prioritization matrix. It was therefore found out that solution that each locomotive alternator that has been in service more than 12 months must undergo complete re-insulation was recommended due to the fact that it addresses he problem at hand and it is a quick win that provides long-term solution. The quality hold points will also be added to prevent the armature from being over-baked during the repair process.

Solution Description	*Root Cause Addressed*	*CTQ Impact (H, M, L)*	*Implementation Effort (H, M, L)*	*Quick Win (Yes, No)*	*Technology Required (Yes, No)*
Re-insulate Alternators> 12 months in service	Excessive temperature-Operating condition	H	L	Yes	No
Change/Improve insulation material	Excessive temperature-Operating condition	L	H	No	Yes
Increase Quality Hold Points	Excessive temperature-Process Over bake armature	H	L	Yes	No

Figure 9: Solution prioritization matrix

To overcome the problem of insulation failure by performing re-insulation and adding quality check points, the project team proposed that each locomotive alternator that has been in service for more than 12 months must undergo complete insulation repair rather than only outer insulation. This process would serve as preventative maintenance to avoid unscheduled breakdown. Locomotive alternator change-out or replacement was also recommended to be included on scheduled service maintenance of the locomotive provided that the alternator had been in service for more than 12 months.

4.4.2. DPMO (Improved)

After implementing the solution, data were collected over months with data points in order to calculate an improved DPMO and Sigma level to gauge the success and check whether improvement solution addressed the problem at hand. A new Sigma level was calculated at 4.2 sigma level. This demonstrates an improvement of 12% of the number of failures experienced.

$$DPMO = \frac{Number\ of\ defects}{\frac{Number\ of\ defect\ opportunities}{Units}\ x\ Number\ of\ Units}\ x\ 1{,}000\ 000 \ldots\ldots\ldots\ldots\ldots(1)$$

Defects	42
Opportunities	675
Defect Opportunities per unit	18

DPMO	3457
Sigma Level	4.2

Six Sigma Table:

1	690,000
2	308,000
3	66,800
4	6,210
5	320
6	3.4

The Sigma level of 4.2 indicates that only defects are transpired about 0.62% of the time during the process of repairing the locomotive alternators.

Calculation for DPMO

$$\boldsymbol{DPMO} = \frac{42}{675\ x\ 18}\ x\ 1{,}000\ 000 \ldots\ldots\ldots\ldots\ldots(1)$$

$$\boldsymbol{DPMO} = 3457 \ldots\ldots\ldots\ldots\ldots(1)$$

Therefore, the Sigma level was calculated by taking into account DPMO using Sigma Excel. Through this solution, the failure rate was significantly reduced to 6% and the improved Sigma level was 4.2 Sigma level with DPMO of 3457 at 675 units.

4.5. Control Phase

The refurbishment process was required to include the re-insulation on the armatures whether it is for minor or major repair. Quality checks also needed to be performed on the process followed during refurbishment, and lastly, regular audits were required to check adherence to the refurbishment process and ensure that he corrective measures that were implemented are monitored and remain controlled. A regular trigger reminder needed to be implemented through a system that will enhance the tracking process of ensuring that each locomotive alternator undergoes intensive refurbishment service after it has been in service for more than 12 months.

The main aim of the system was to early detect and trace each and every alternator that was repaired and has been operating in a locomotive for more than 12 months. All those locomotive alternators mainly minor repaired ones were identified as stood a chance of the insulation failure if during the first repair process they did not undergo complete re-insulation.

The system utilised data from the ERP system, where the mathematical model was designed to check the last date of the repair of a production order completion date and date of delivery to the customer by matching the serial number of the alternator. As a result, the mathematical model enabled the system to produce a list of alternators for which insulation failure is a risk. The system user was informed by an early warning message trigger, to start repair process of such locomotive alternators.

The process of repairing the alternator was improved. An early detection system was implemented with the aim to prevent insulation failures of alternators before they occur. The new system enabled the organisation to prevent failure from occurring by determining the reliability rate which can be used as a filter for the preventative measure. This ensures that all the alternators are of high quality and are reliable before fitment.

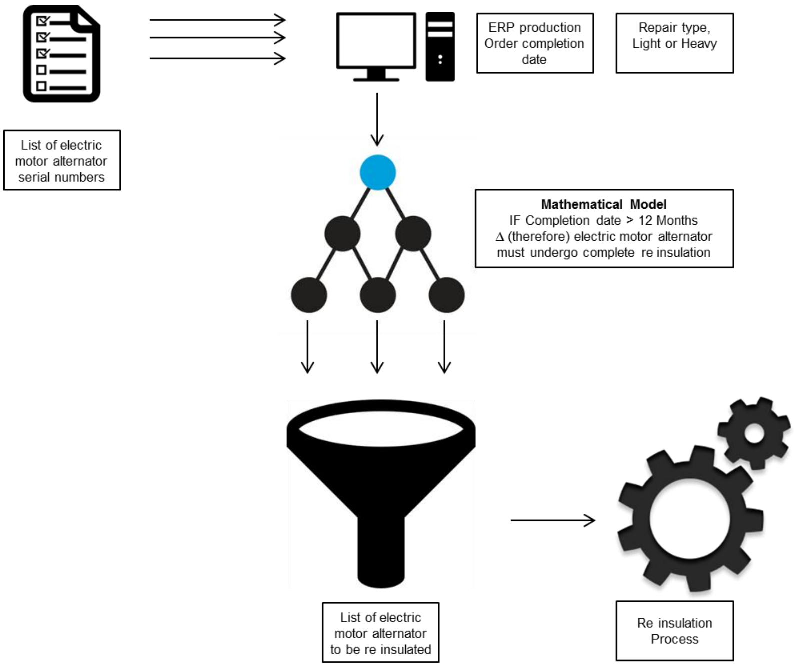

Diagram 5: Locomotive alternator failures early detection system

5. RECOMMENDATION

Company XYZ had experienced a high failure rate of locomotive alternators that led to potential income losses and re-incurred maintenance costs. Through the Six Sigma DMAIC methodology, it was experienced that during the refurbishment process, the insulation on the armarture was neglected.

Furthermore, the refurbishment process required to include insulation on the armatures whether it is for minor or major repair. Quality checks need to be performed on the process followed on refurbishment, and lastly, the regular audits were required to check adherence to the refurbishment process. A regular trigger reminder needed to be implemented through a system that will enhance the tracking process of ensuring that each locomotive alternator undergoes intensive refurbishment service after it has been in service for more than 12 months.

Implementation of the above recommendations had inherently improved the entity’s customer service by being able to provide the client with good quality locomotive alternators, thus ensuring income. The service level agreement was also improved and the failure rate was significantly reduced to 6 %. The maintenance cost incurred was greatly minimized as the process rejuvenation curbed the problem of failures of locomotive alternators.

6. CONCLUSION

Six Sigma aims to achieve virtually error free business performance. This project was aimed at improving customer service and product quality. It was critical to follow the DMAIC methodology step by step in order to arrive at a solution to resolve the failure rate of locomotive alternator. Furthermore, there was a need for Six Sigma DMAIC methodology because all the decisions that were made were data driven.

The following findings were observed after piloting this research on a failure analysis of locomotive alternator using the Six Sigma and DMAIC Methodology:

- The current Six Sigma level was determined at 3.8 sigma with a defect per million opportunities (DPMO) of 11481 at 675 units annually.
- It was recognised that insulation failure was the main contributor failure due to mainly moisture and excessive temperature.
- Excessive temperature was determined as the root causes for the problem.

- To overcome this problem, the project team proposed that each locomotive alternator that has been in service more for than 12 months must undergo complete insulation rather than outer insulation and two quality check holding points were added.
- Therefore, a quality assurer assigned to monitor the age of insulation using an early detection system was found to be an effective control measure for the problem in the control phase.
- The improved Sigma level was 4.2 sigma with a DPMO level of 3457 at 675 units
- Through this solution, the failure rate was reduced significantly from 18% to 6%. Although these results do not yield zero failures, other root causes of failure such as bearing failure, commutator failure, mechanical integrity failure, winding failure and vibration failure can be eradicated by means of the same methodology.

7. ACKNOWLEDGEMENT

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STRUCTURING DATA FOR A RSA SECTION 12L ENERGY EFFICIENCY TAX INCENTIVE APPLICATION

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ABSTRACT

South African industries are under pressure to remain internationally competitive. By investing in energy efficiency, companies can lower operating costs. Section 12L of the Income Tax Act, (Act No 58 of 1962) has been implemented to incentivise energy efficiency. To receive the benefit, an application must be compiled by an independent South African National Accreditation System (SANAS) accredited Measurement and Verification (M&V) team. M&V teams are not necessarily familiar with the details surrounding a sites initiative implementation, assistance from industry is required. This article investigates the M&V requirements to understand the complexities involved in analysing facility energy consumption. Different data management techniques are reviewed to identify approaches to handle the large volumes of data generated. The developed methodology is split into two parts. The first part assists in reducing facility complexity to enable the selection of a measurement boundary. The second part streamlines the collection, organising and processing of the measured data and supporting documents. The outcome of the methodology was validated by means of a single complex case study. In this case the methodology was applied to identify Section 12L compliant measurement boundaries. The transparent output of the collected data and supporting documentation illustrated the definitive auditability of the results.

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1 INTRODUCTION

1.1 Overview

South African energy intensive industries are under pressure to remain internationally competitive. The implementation of energy efficiency initiatives have the potential to reduce energy consumption while sustaining the same amount of production output. By investing in these initiatives, companies can lower costs and their carbon footprint [1].

Unfortunately, energy efficiency initiatives have been met with a number of barriers such as lack of upfront capital, ignorance regarding energy use and higher production priorities which have hindered energy efficiency investment [2]-[6]. This reluctance to invest is linked to the level of uncertainty involved with energy efficiency investment [7]. This phenomenon is known as the energy efficiency gap [8]. Research has indicated that consumer behaviour and decision-making processes can have an effect on the energy efficiency gap [5], [6]. To alter consumer behaviour and decision-making, government policy has to include financial incentives to promote energy efficiency initiatives and discourage energy inefficient practice [9].

South Africa is considering the implementation of a disincentive in the form of carbon tax [10]. This disincentive can increase energy intensive industry's priority to invest in energy efficiency initiatives. However, it still does not address the financial barriers surrounding energy efficiency investment. Consequently, the South African government will assist companies with a number of financial incentives [11].

Section 12L of the Income Tax Act, (Act No 58 of 1962) has been implemented to reward energy efficiency savings [9]. It allows companies a tax deduction of 95 c/kWh for quantified energy efficiency savings [12]. To receive the benefit, an application, which quantifies the initiative impact, must be submitted to the South African National Energy Development Institute (SANEDI). This application needs to comply with stringent requirements as set out in the Section 12L Act, Section 12L promulgated Regulations and the SANS 50010:2011 Standard. It is therefore mandatory that the application be compiled by an independent South African National Accreditation System (SANAS) accredited Measurement and Verification (M&V) team. Proof of compliancy in the form of supporting documents must be supplied with the application [9], [13].

Since the M&V team is not necessarily familiar with the technical details surrounding a site's initiative implementation, assistance from industry is required [9]. Effective collaboration between industry and the M&V team is therefore important to ensure that the Section 12L application can be effectively compiled [9]. In this paper, a methodology is presented to assist industry to compile the necessary data and documentation. The methodology followed should not taint the independency of the M&V team auditing process.

1.2 Calculating energy efficiency savings

Large-scale industrial energy intensive industries in South Africa mainly consume non-renewable commercially available energy sources generated mainly by fossil-fuels (such as coal, natural gas and petroleum products) [14]. These energy sources can be used to generate secondary energy sources for production related purposes for example compressed air and steam. Both primary and secondary energy sources will be referred to as "energy carriers". The consumption of energy carriers is driven by specific production outputs. These product outputs will henceforth be referred to as "energy drivers"[15].

The quantity of energy carriers consumed per energy driver output is defined as operational energy intensity. An energy efficiency initiative will reduce the consumption of the energy carriers while maintaining the same amount of energy driver output [16]. This indicates that the process has become more energy efficient, which results in an operational energy intensity reduction and energy efficiency savings. In addition, operational energy intensity shows that the energy savings is due to the reduction in energy usage and not the result of energy driver output reduction [9]. Figure 1 below demonstrates this principle:

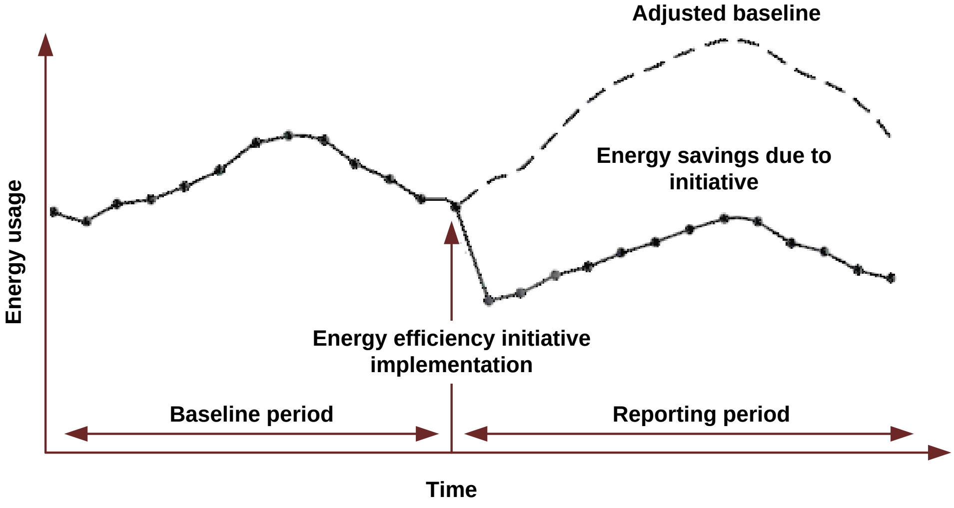


Figure 1: Determining energy savings (adapted from [9], [17])

The calculation of the energy efficiency savings must be conducted within the guidelines of the Section 12L Act, promulgated Regulations and the SANS 50010:2011 Standard [9].

The Regulations limit the type of energy efficiency savings eligible for the benefit. The following are claimable:

1. Energy awareness and conservation - The energy efficiency saving achieved by the implementation of energy management systems can be claimed. Energy awareness initiatives like training, switching off non-essential equipment, etc. which promote energy conversation savings are also eligible [9].
2. Modify equipment - Equipment, structures and/or process are replaced or modified to improve the energy efficiency of the equipment, structures and/or processes [9].
3. Combined heat and power - Waste heat recovery systems and/or co-generation systems [13].

There are four energy efficiency initiatives that are not claimable [13]:

1. Captive power plants with less than an 35% energy conversion efficiency
2. Renewable energies
3. Power purchase agreements
4. Projects that have been funded form any sphere of government or any public entity as listed in Schedule 2 or 3 of the Public Finance Management Act, (Act No. 1 of 1999)

Within the M&V SANS 50010:2011 methodology it is first necessary to identify a measurement boundary for the quantification of the energy efficiency initiative [9]. This is to determine which parameters and variables need to be measured for the calculations. However, the mandatory Section 12L requirements make it necessary to first identify measurement points that are compliant before selecting the measurement boundary.

According to the Standard there are four types of boundaries namely [9], [17]:

1. Retrofit isolation with key-parameter measurement: The energy efficiency initiative is isolated from the rest of the facility. The energy efficiency savings is calculated by identifying the key performance parameters that will influence the savings calculations.
2. Retrofit isolation with all-parameter measurement: same as 1, the savings calculation requires the measuring of all parameters which determines the energy usage of the equipment in the retrofitted isolation.
3. Whole facility: The measurement boundary is drawn around the entire facility or sub-facility level. The energy performance of the entire facility is assessed for the savings calculations. This option utilises the facilities existing utility and auxiliaries' meters. Energy invoices billed consumption amounts can be used with this option.
4. Calibrated simulation: When important data is missing or not available for extended periods, a calibration simulation approach can be used to predict the energy saving that would have been achieved. The calibrated simulation approach makes use of computer software to develop predictive simulation models.

After selecting the measurement boundary the selected measurement points' data and supporting documentation can be collected. Data accuracy plays a crucial role in the Standard's quantification process. Therefore the Standard requires that the energy carriers and energy drivers' data accuracy be verifiable by calibrated measurement equipment [15]. The calibration methodology used must however conform to national and international standards [15], [17]. This means that the calibration certificates should be supplied as proof of accuracy. Alternatively, supplier invoices are also an acceptable source of energy data. However, these supplier invoices are only acceptable if they are based on actual measured data [15].

1.3 Data organisation and structuring

Industry will have to make the data and supporting documentation available for the M&V team to conduct their inspection and calculate the energy efficiency initiative's impact. This data can have multiple sources and data formats. Poor data accuracy, quality and integrity can have a significant impact on the energy efficiency savings calculations [9]. Therefore, ensuring data traceability is important.

The data and documentation collected will be in a combination of hard copy and electronic data files. The hard copy files can be scanned to create electronic copies. The electronic files will need to be stored on a centralised server. However, an organisational structure will need to be developed to make the data and documentation easily accessible and traceable. A simple folder hierarchy can be used to organise the data [9].

Whittaker, S *et al*. identified two types of folder hierarchies namely broad and shallow or deep and narrow [18]. A broad and shallow hierarchy will allow the user faster access to the required files, however, the time to find the correct folder increases [9]. The deep and narrow option allows for a faster folder finding time, but the user will need to access more folders to find a file [9]. Whittaker, S *et al*. concludes that the researched group tended to use a wide and shallow approach to folder structuring [18].

All the collected data will need to be processed into the same unit for the energy efficiency savings calculations. A flat-file database table can be used for this purpose. A database is an organisational structure for a collection of information which can easily be accessed, updated and managed [9]. Figure 2 shows a simple database table.

		Field		
Label	Departure date	City	Car make	Name
	01-Jan-15	Bloemfontein	Nissan	Pieter
Record	02-Jan-15	Johannesburg	Toyota	Andries
	03-Jan-15	Pretoria	Fiat	Charl
	05-Feb-15	Durban	Nissan	Pieter

Figure 2: Example of a flat-file database (from [9])

As shown in Figure 2 a database table has three main properties, namely a field, a label and a record. A record will be related to a specific entity's information. The database table record entry will consist out of a number of fields. Each of these fields is related to an independent property of the specific entity information. The database table label identifies the different field's independent properties. A flat-file database is simply a single database table which can have an unlimited number of fields and records [19]. A good example is a Microsoft Excel spreadsheet [9].

2 METHODOLOGY

2.1 Overview

The objective of this section is to develop a methodology to assist industry to reduce system complexity, identify Section 12L compliant measurement points and select a measurement boundary. Thereafter the necessary data and supporting documents can be collected, organised and processed for the M&V team. This methodology will only focus on industries' responsibility to construct a traceable, transparent and compliant folder structure and processed flat-file database that can be used by the M&V team to calculate the energy efficiency initiative impact [9].

2.2 Measurement boundary selection

2.2.1 Overview

Janse van Rensburg, HM et.al. & Janse van Rensburg, HM developed measurement boundary selection methodologies specifically for selecting boundaries for holistic implemented energy efficiency initiatives for the mining industry [9], [15]. These methodologies will be reviewed in the following sections. However the methodologies will be optimised to be suitable for different large-scale industrial industries. Figure 3 illustrates the main steps which will be undertaken.

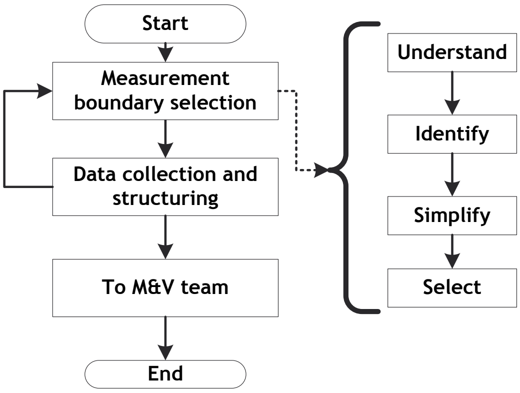


Figure 3: Key steps to identifying a measurement boundary [from [9]]

2.2.2 Understand

The first step is to understand the operations of the company [9]. A basic production flow can be used. This diagram must indicate all the facilities and/or components involved in production. The facilities can be based in the same premises or different regions. External companies operating on the same facility should also be indicated, especially if they share energy resources (for example electricity). The energy drivers for each stage of production should be indicated after each operational facility. Each production stage will have specific associated energy carriers. These energy carriers can also be collectively indicated on the production flow [9]. Figure 4 illustrates a simple example.

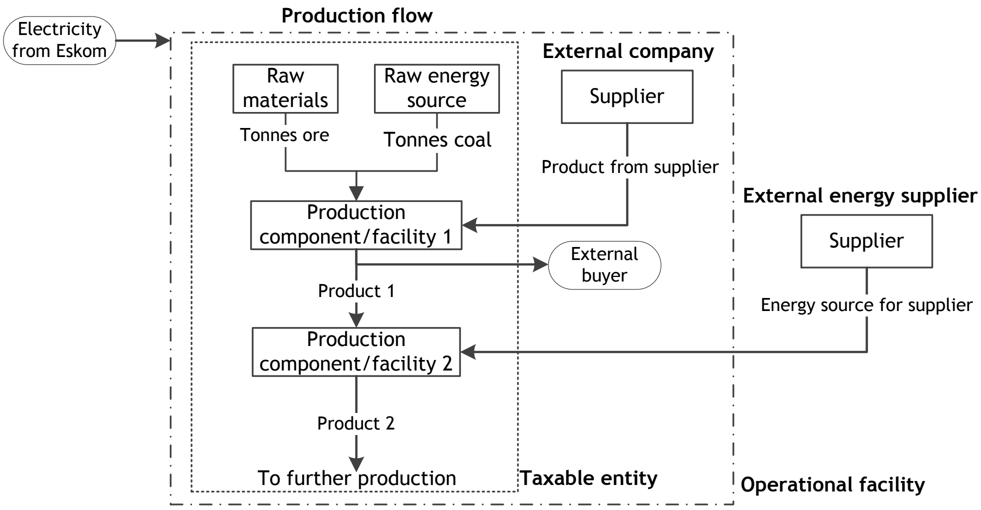


Figure 4: Understanding the operational facility

2.2.3 Identify

The methodology requires the identification of the incoming energy carriers and the outgoing energy drivers measurement points. Energy suppliers can supply multiple Points of Deliveries (PoDs). Therefore, it is necessary for the company to indicate all the facilities and/or components that are included in the supplier bill/invoice. Most of the energy consumption will be measured in weight or volume. If this is the case the specific energy or also known as calorific value (CV) sample point should also be indicated on the layout. These CVs are then used to calculate the energy (MJ) produced by the weight of energy carrier consumed. This CV data will also require proof of accuracy. Limitation projects should also be indicated [9]. Figure 5 illustrates how the invoice boundaries and measurement instruments need to be indicated.

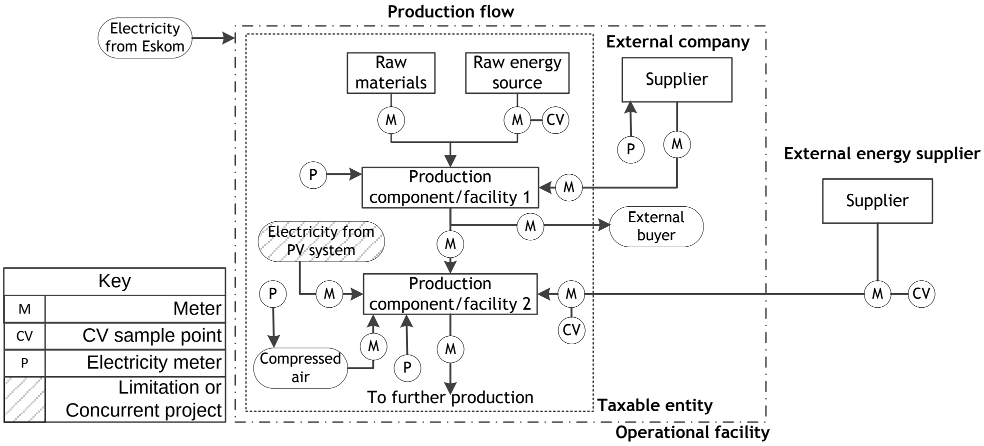


Figure 5: Identification of measurement points and limitations

2.2.4 *Simplify*

The key to this step is to simplify the complexity of the production flow, while not losing vital information. The Standard requires that the measurement of variables should be obtained from calibrated instrumentation or supplier invoices [9]. Compliance indication can be at three different levels namely;

- ***Not available*** – There is not sufficient information available for the measurement point
- ***Available*** – The measurement points indicate data available, but the data compliance is not known
- ***Compliant*** – The data available has sufficient supporting documentation to ensure the data compliance

Figure 6 shows below how compliance can be indicated on the production flow:

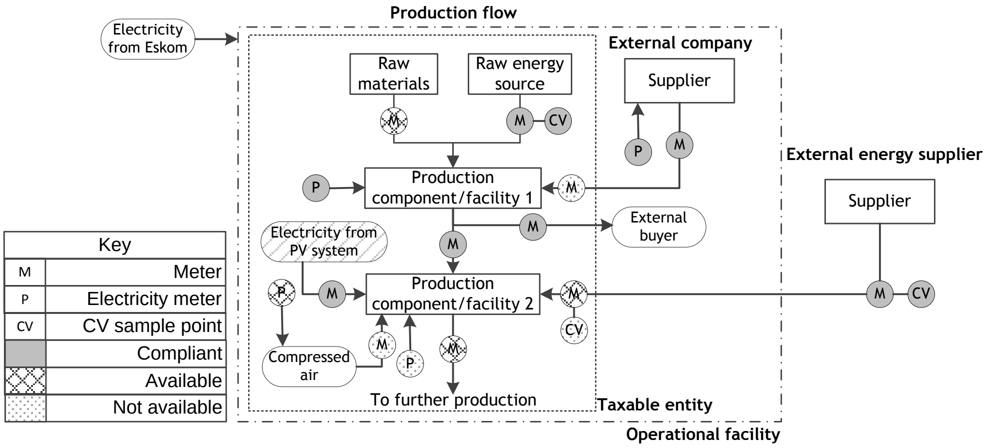


Figure 6: Measurement point compliance identification

2.2.5 *Select*

After the meter compliance is indicated, the user can start to identify possible measurement boundaries. Section 12L tax deductions can only be claimed for energy efficiency savings. It is therefore necessary to determine where energy efficiency initiatives were implemented. There are many types of initiatives that can be implemented on facilities. These interventions can range from major infrastructure projects to energy management programmes [9]. The interventions can then be indicated on the production flow, as in Figure 7. After all the necessary information has been shown on the production flow, the user can decide on the final measurement boundary.

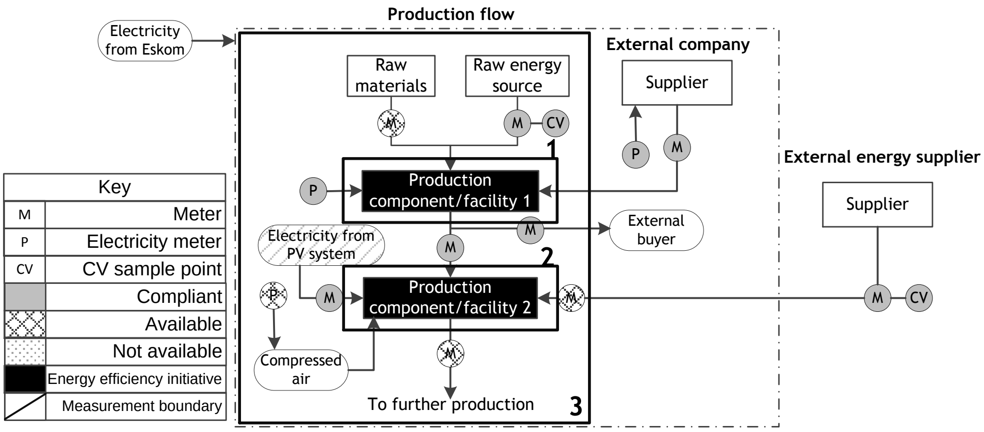


Figure 7: Measurement boundary selection

As shown in Figure 7, for this example there are three possible compliant measurement boundaries. However, each of the boundaries will have its advantages and disadvantages. There should be a balance between costs and time, for example, with option 1 there will be no further calibration costs for available meters. Yet, if a whole facility approach is used; both energy efficiency initiative savings are included which can increase the benefit. This approach will require a larger number of measurement points to be audited which can increase time and costs.

2.3 Data collection and structuring

2.3.1 Overview

When the measurement boundary is selected, each of the measurement points' relevant data and documentation must be collected, structured and processed [9]. Figure 8 illustrates the three steps to be developed to handle the large volumes of data generated.

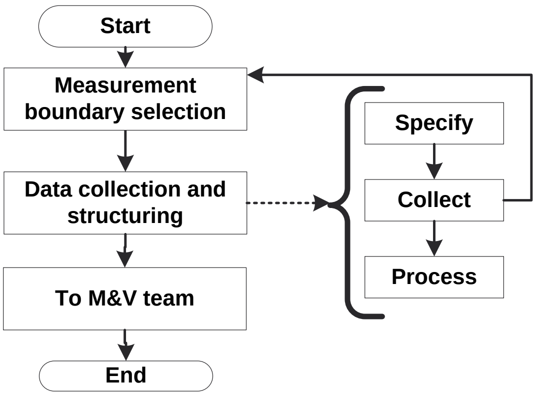


Figure 8: Data collection and structuring steps [from [9]]

2.3.2 Specify

Within the measurement boundary phase only high-level details regarding the measurement points and boundaries are indicated. A table summary should be constructed to specify these details. Figure 9 provides an illustration of a selected measurement boundary summary. The table should list the measurement point's energy group and necessary supporting documentation required. Energy supplier invoices which were relevant should also be specified. Only the energy driver measurement points chosen to represent the production process need to be summarised [9].

Energy carriers summary	
B1	Eskom electricity bills
P1	External company electricity usage data
P2	Electricity supply by the PV system
P1C	Meter calibration certificates for P1
P2C	Meter calibration certificates for P2
M1	Raw energy source supply data
M2	External energy supplier data*
M1C	Meter calibration certificates for M1
M2C	Meter calibration certificates for M2
CV1	Energy source calorific value data
CV2	Energy source calorific value data
CV1Acc	Testing laboratory SANAS accreditation
CV2Acc	Testing laboratory SANAS accreditation

Energy driver summary	
M3	Energy driver production data
M4	Product sold data
M3C	Meter calibration certificates for M3
M4C	Meter calibration certificates for M4

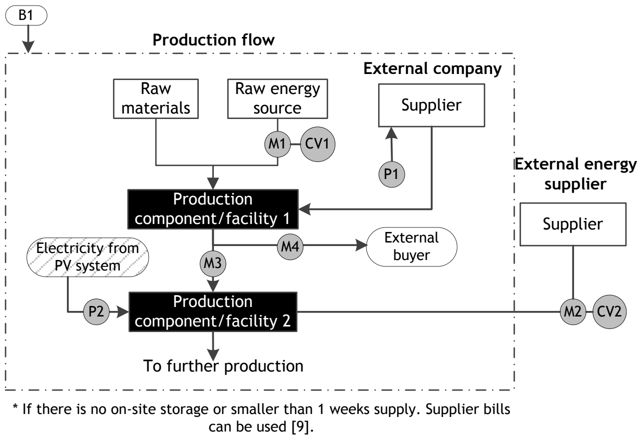


Figure 9: Data and supporting documentation summary

2.3.3 Collect

There may be numerous data sources where raw data and supporting documentation can be collected. The collection process will have to be done in systematically to ensure traceability. The relevant data and documentation is collected with the measurement boundary summary, before continuing to organise the information in a structure [9].

The data should first be tested for compliance. The compliance testing should ensure that all the supporting documentation was collected. However, if the data and documentation fails this test, a new measurement point will have to be identified. This may lead to the selection of a new boundary [9].

It is critical to have a dataset of acceptable quality[4]. After all the data and supporting documentation has been collected, data quality checks can be done. For the data, these checks should include error warnings identification, correct tag names, continuous period intervals, etc. The supporting documentation validity should be ensured by the quality checks. This will include checking the expiration date, the error percentages, meter numbers, account numbers etc.[9].

The SANS 50010:2011 Standard emphasises data accuracy within its requirements. Consequently, if the data is compliant with the Standard, the data accuracy is assured. Data integrity[5] however, will need to be verified within the context of the methodology. This can be done by comparing two independent data sources which contains the same relevant measurements. An example of this type of verification is comparing standard compliant utility electricity bills (e.g. Eskom) with the company's internal electricity metering system [9].

When data confidence is assured, the data and documentation can be structured. It is important that the structure displays the data and documentation in a transparent and straightforward manner. A folder hierarchy structure will be used to develop the storage location [9]. Figure 10 gives a breakdown of the structuring approach.

[4] Data quality refers to if the data is "fit for use". This will include ensuring that the data is relevant, complete, error-free and representative [20].
[5] Data integrity is the prevention of unauthorised alterations to data. These alterations can occur when data is retrieved and stored or when the data is transferred from one format to another [21], [22].

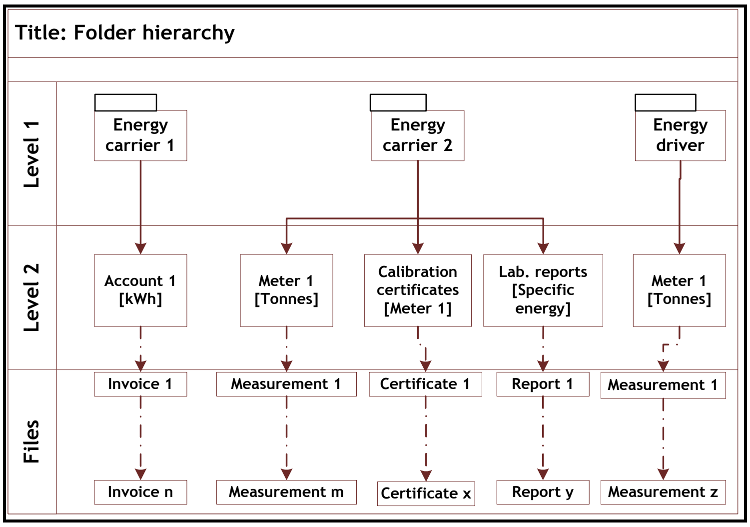


Figure 10: Folder hierarchy for collected data (adapted from [9])

2.3.4 Process

The information collected will not always be in a format which can be used to do calculations. It is therefore necessary to process the data to deliver useful information. For the energy efficiency savings, it is required that all the energy carriers have the same energy equivalent. This unit can either be in kWh or GJ. For energy carriers that are not in the required unit, a transformation formula will be required. An example of this is a multiplication formula with the meter data and the energy carrier's CV value [9]. Figure 11 shows the steps of this process.

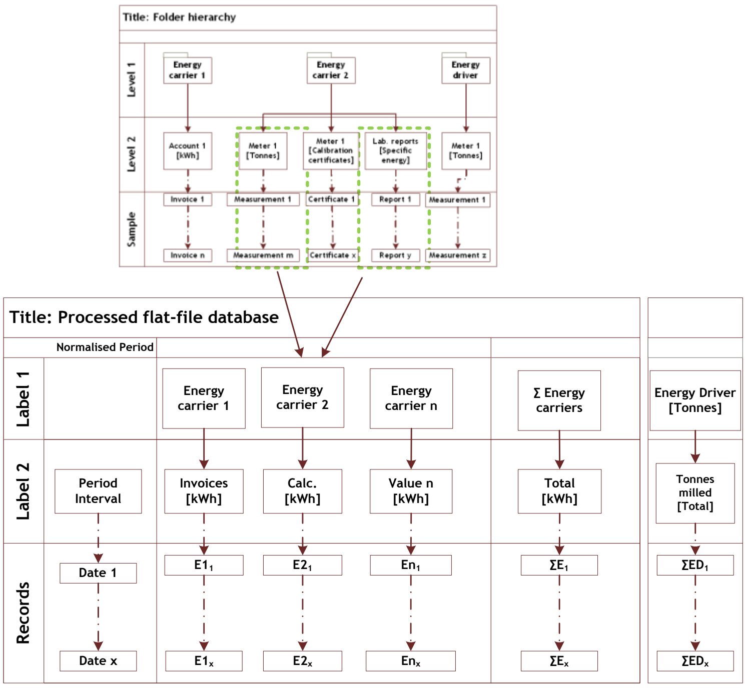


Figure 11: Processed flat-file database structure (adapted from [9])

Using a flat-file database, an energy equivalent table can be used to process all the energy carriers into the same unit. The sample data within this table should also be normalised to the same period interval. This can be in days, weeks, months or even years [9].

As seen in Figure 11 the first label should identify the energy category. The next label should identify if the data input was a calculation, or a direct input from the folder structure. For practical reasons the selected energy driver data should also be normalised to the same period interval and entered into the tables. The third level will be the normalised records [9].

2.3.5 Share with the M&V team

The final step of the methodology will be to share all the layouts, data and documentation with the M&V team. This will enable the team to audit the work and calculate the energy efficiency savings for the Section 12L application. There are three items to be shared with the team. These include the measurement boundary selection process, the folder hierarchy and the processed flat-file database. To assist the M&V team to understand the measurement boundary selection process, a report can be written [9].

3 CASE STUDY

The following section applies the methodology developed in a case study in industry. The case study presents operational production flow, measurement points, energy drivers and energy carriers which are based on actual operations [9]. This information was collected from interviews with personnel, operational layouts and the company's metered data. Due to strict confidentiality agreements, the company presented within this section will be referred as "the ferrochrome company".

3.1 Measurement boundary selection

3.1.1 Company operational overview

The ferrochrome company main production focus is the mining and smelting of chromite ore. The company has three main processing plants. The plant selected for this case study has three main energy sources which are electricity, coal and methane rich gas. The furnaces use electricity to generate extreme temperatures (exceeding 1500 °C) for smelting. Coal is mainly added to the chromite ore to not only generate heat but also carbon monoxide gas. This gas reduces the chromite ore to ferrochrome. Methane rich gas is used to dry the incoming raw materials and for other heating applications.

The main energy driver of the facility is the ferrochrome produced. The energy driver is weighed and sold to the market. The production flow consist of three separate smelting operations, namely the furnace section 1, furnace section 2 and furnace section 3. However, furnace section 3 was decommissioned in 2015, since the demand of the product decreased.

3.1.2 Measurement points compliance

Each furnace is supplied by a specific Eskom point of delivery, which are all invoiced individually. This means that the electricity consumption of each furnace type can be accurately determined.

Methane rich gas is supplied by an external supplier. There is no on-site storage facilities of the carrier and gas invoices are available. Although not fully compliant, additional metering is available for specific gas users. This means that these meters can be calibrated for the purpose of the application. The supplier invoices specify the CV (GJ/m^3) of the gas supplied.

The plant has a variety of coal suppliers from different mines. Coal is a natural energy source, therefore each coal mine will have a different coal composition. Due to this source variety, regular samples are taken and analysed to monitor coal quality and characteristics. Coal samples are analysed by a SANAS certified testing laboratory. The analysis results indicate the CV of the various coal types. Coal is weighed with a compliant device before it enters the furnace at the batching section of each furnace.

At each smelting section the ferrochrome production is measured in the weight of alloy produced. The alloy produced by the both the furnace section 1 and furnace section 2 is weighed using a calibrated weighbridge.

The pelletising and sintering plant (PSP) produces chromite ore agglomerations in the form of pellets. This plant however only provides pellets to the furnace section 2. When the PSP was not running, pellets were imported from one of the other plants. Since mid-2015, the plant started producing its own pellets again, and also exported to the other company sites. Pellets imported and exported will only be taken into consideration when assessing furnace section 2, or the whole facility.

Figure 12 demonstrates this in the final stage of the methodology. The company recently installed additional raw material drying equipment and improved furnaces section 1 raw material added ratios. This resulted in significant energy efficiency savings that are claimable. The company also participates in a Public Entity's funding programme, which is a possible concurrent project. The participation is only on furnace C & furnace D.

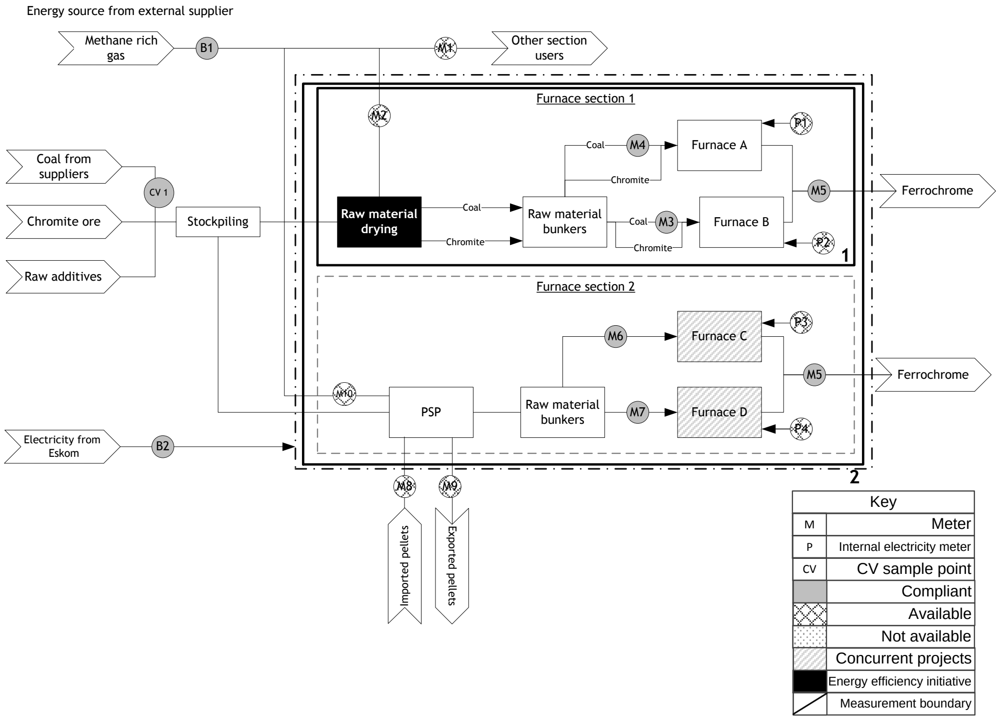


Figure 12: Case study measurement boundary selection

As is shown Figure 12 there are two measurement boundaries that can be selected. Because of the complexity involved with a whole facility approach, regarding the PSP usage, possible concurrent project and an increased number of variables. The best option will be to have a retrofitted isolation with all parameters measured around furnace section 1.

3.2 Data collection and structuring

The retrofitted isolation is drawn in more detail in Figure 13. Electricity, coal, methane rich gas and ferrochrome production measurements will have to be specified, collected and structured. Each dataset requirements is specified in the table summary, see Figure 13

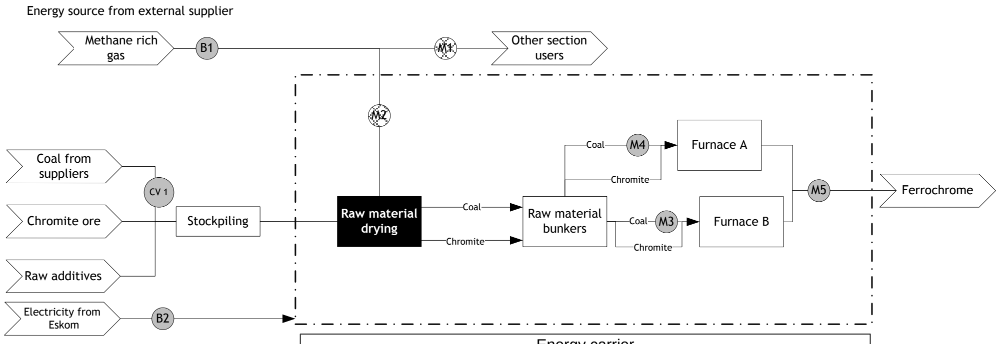
3.2.1 Compliance verification and data quality

The necessary data and supporting documentation quality checks were done on the information collected. These checks indicated that the all the required data and documents are of sufficient quality. The comparison of Eskom invoice values and internal electricity meter data resulted in an average aggregated deviation of 0.057% over a period of 24 consecutive months.

Certified test weights are used to calibrate the coal batching bins in regular intervals. This assures the data accuracy as required by the Standard. Unfortunately, the data integrity could not be tested due to the lack of extra data sources.

The methane rich gas only 12L compliant data source for measurement is the facility supply invoices. This is the result of the gas meters specifically to the furnace section 1 not being calibrated. However the total gas usage is a minor portion of facilities total energy usage, 1.99%. Although it is a minor portion, it will be important to account for the increase in gas usage due to the installation of additional equipment in the raw material drying facility. It was therefore concluded that the total usage of the supplier invoice can be used for the purpose of this application.

The ferrochrome weighbridges are calibrated by a SANAS certified verification laboratory. The calibration is carried out every two years in accordance with the relevant Standard.



Energy carrier			
B1	Methane rich gas supplier invoices	M3C	Furnace A coal weigh bin calibration certificates
B2	Eskom electricity invoices	M4C	Furnace B coal weigh bin calibration certificates
M1	Gas meter data to driers	CV1	Coal CV sample point data
M2	Gas meter data to other users	CVAcc	Testing laboratory SANAS accreditation
M3	Furnace A coal weigh bin meter data		
M4	Furnace B coal weigh bin meter data		Energy driver
M1& 2C	Arrange for calibration of M1&M2	M5	Ferrochrome weighbridge
		M5C	Ferrochrome weighbridge calibration certificates

Figure 13: Data collection table summary

3.2.2 Folder hierarchy

The verified datasets and supporting documentations was structured in a folder hierarchy. The structured framework is shown in Figure 14. Level 1 categorises the energy carriers and energy drivers. The preceding levels are a more detailed breakdown of the information collected. These levels should align with the specification for the table summary.

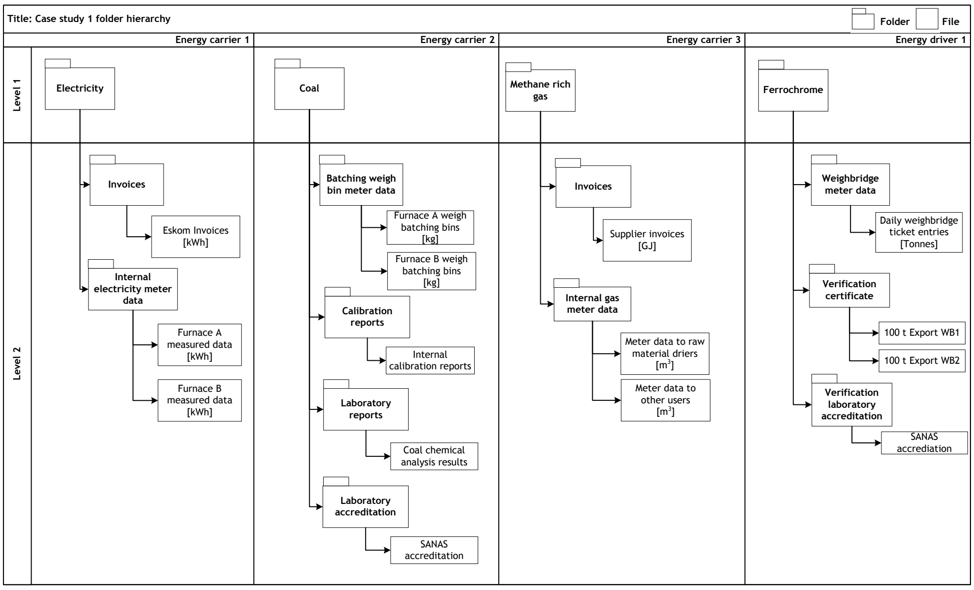


Figure 14: Case study 1 folder hierarchy

3.2.3 Processed data table

To calculate the operational energy intensity reduction a normalised dataset is required. This dataset should be in the same unit of measurement and all data points must be aligned with the period interval. The energy carriers' unit of measurement chosen for this case study is kWh. The period interval will be on a monthly basis. This means that all the energy consumed in a specific month must be normalised to a single monthly data entry. The energy driver should also be normalised to monthly values [9].

The Eskom invoices' dataset requires no processing and can be directly entered into the processed database table. The coal raw datasets are measured in kilograms. The average CV values for a month is multiple by the total coal usage for that same month. This multiplied value will be in a gigajoule (GJ) unit. Therefore to obtain a kWh value the GJ value should be divided by 0.0036. The methane rich gas supplier invoices the ferrochrome company in the energy content of the gas supplied (GJ). Therefore the monthly value can be also divided by 0.0036 to convert the value to kWh. Figure 15 shows the final processed database labels and fields.

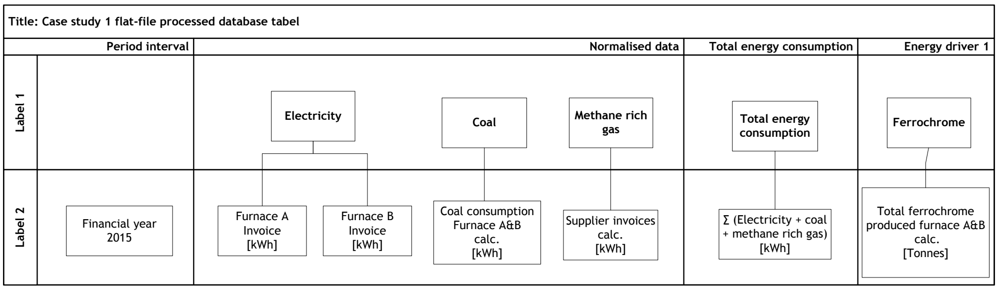


Figure 15: Case study 1 flat-file processed database table

4 CONCLUSION

The Section 12L tax incentive rewards companies for quantifiable energy efficiency savings. However, to claim the tax incentive a strict application process and requirements must be followed to ensure the quality, traceability and integrity of the quantified energy efficiency savings. These strict requirements together with system complexity require effective collaboration between the M&V team and industry. It will also be required by industry to assist in collecting, organising and processing the data and supporting documentation for the M&V team [9].

To facilitate this process a clear methodology was developed to reduce system complexity, identify Section 12L compliant measurement points and select an appropriate measurement boundary. Thereafter, the specified measuring point's data and supporting documentation was collected and organised in a folder hierarchy to ensure transparency. To further assist the M&V team, the energy carriers and energy driver's data was processed to the same measurement period and unit [9].

The outcome of the methodology was validated by means of a case study. In this case study the methodology was applied to identify Section 12L compliant measurement boundaries. The transparent and traceable output of the collected data and supporting documentation illustrated the ultimate auditability of results. The practical application and validation of the methodology confirmed that the original problem statement was sufficiently addressed [9].

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DESIGN OF A CONDITION-BASED ANALYTICAL DECISION SUPPORT TOOL

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ABSTRACT

As manufacturing companies thrive to achieve global competitiveness, effective plant monitoring and short decision making time has proven to be a big contribution for them to achieve their goal. To cut operational costs and offer a competitive edge, the companies need not only to capture equipment failure but to predict the failure occurrence. Relevant decisions also have to be made in the shortest possible time in the case of a failure. The paper discusses an analytical decision support tool for monitoring a generator thrust bearing of a hydro power station. The system consists of a distributed Multi-Agent System (MAS) comprising of diagnosis, decision alarm, database and distribution agents. The diagnosis agent is responsible for obtaining the parameter readings from the sensors using a Siemens S7-1200 PLC and Kepware OPC server. The decision alarm agent uses a Java Expert System Shell (JESS) rule base to monitor the parameters obtained from the diagnosis agent and make decisions on equipment availability using the Maintenance Free Operating Period (MFOP) concept. The desired action and equipment performance trends are then conveyed to the user by the distribution agent. The decision support tool is developed using the Java Agent Development framework (JADE). The proposed system showed an increase in machine availability and reduction in the maintenance scheduling time and parts inventory.

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1. INTRODUCTION

The information age has come with a change in focus of the manufacturing and service from being only product oriented to being customer oriented. The customers now have more variety of suppliers to choose from as the internet has made them to be no longer limited to the suppliers in their geographical area. The customer now demands more customized goods and more information on the state of their order. To meet the demands of the customer the decision makers in companies should be able to get more information from the state of their plant. The power sector industry in Zimbabwe still employs traditional methods of condition monitoring whereby the system is dependent on a centralized master computer for monitoring. However, the environment is now dynamic and technology can substitute the existing master-slave monitoring system with a more flexible intelligent system. This paper focuses on the development of a distributed approach to condition monitoring using a multi-agent system as a way of increasing plant flexibility. The structure of this paper is as follows, the AUML methodology for agent development is discussed, followed by the establishment of a knowledge base. We then move on to the design of a multi-agent system using the Java Development (JADE) toolkit and lastly the integration of the MAS with the control environment is shown as the result.

2. PROBLEM STATEMENT

During the year of 2013, a hydro-power station in Zimbabwe experienced several planned and unplanned outages. This was due to factors ranging from off-line maintenance, internal machine faults such as high bearing temperature, to external faults such as over-frequency. The number of failures for each month are shown on a graph in Figure 1.

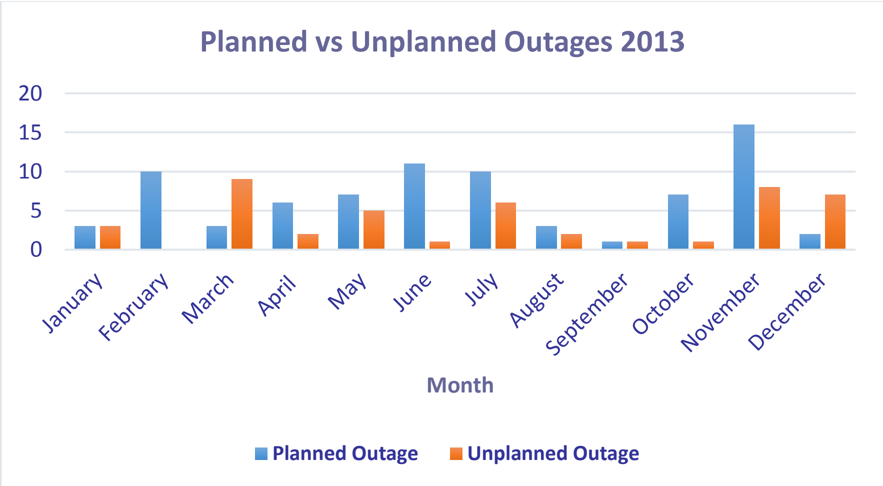

Figure 1: Planned and unplanned outages for the plant

With a proper decision support tool in place, fault predictions that are likely to occur on the machine based on its current condition can be computed in advance. This has the advantage of reducing scenarios where a forced outage due to high bearing temperature occurs. Traditional methods of decision support still exist for condition based maintenance and usually these influence how long maintenance will take. Mangina [1] carries out a case study for an agent monitoring the partial discharge of a Gas Insulated Substation. The parameters were measured online whilst analysis of the captured data was carried out using intelligent agents which base decisions on Artificial Neural Networks. The software tool mainly specialized in recognizing partial discharge sources and offered decision support based on Case Based Reasoning. This differs from the tool designed in this paper in that the designed tool uses a Rule-Based algorithm as an artificial way of manipulating data. The algorithm has two parts, the left hand side comprising of the condition and the right hand side comprising of the action Negnevitsky [2]. Furthermore, efficiency is increased by using JESS to develop the rule base and JESS implements the Rete Algorithm were only new facts are compared against any rule Friedman-Hill [3]. Another agent-based system that was designed for monitoring and control was discussed by Deshmukh et al [4]. The system was implemented on power systems with limited power availability so that the agents could determine the most suitable power from the source. The system, however differs from the tool discussed in this paper in that it comprises of a simulation agent which executes dual communication between the measurement and simulation where the data is used to customize the simulation hence the results from the simulation are used for decision support. The tool discussed in this paper however, has distributed multi-agents able to offer decision support based on the real time data from the sensor environment without simulating. Moubray [5], points out that it is important that condition based maintenance is applied where it is appropriate, not as an overall policy. This is because condition based maintenance techniques are expensive, hence it would not be cost effective as an overall policy.

3. METHODOLOGY

Dewa et al [6] mention in their survey that there are several methodologies that are available for building MAS and as a result methodology selection is a challenge for MAS developers. Hence a methodology used for MAS development should not only be suitable for the intended application, but should also show a distinction between the analysis and design stages. Out of the many agents-oriented design methodologies there exist one methodology which is suitable for application in a power generation setup. The Agent Unified Modeling Language (AUML) methodology approach was used in developing the agents of the system. An agent is defined by Russel & Norvig [7], as an entity that can be viewed as perceiving its environment through sensors and acting upon its environment through effectors. Rudowsky [8] points out that the most critical decision of an agent is to determine the most suitable action to perform in satisfaction to its design objectives. Agent UML is an extension of the Unified Modeling Language (UML) and it attempts to bring together research on agent-based software methodologies and emerging standards for object-oriented software development Bauer & Muller [9]. The methodology comprises of two phases, namely the analysis phase and the design phase.

3.1 THE ANALYSIS PHASE

The analysis phase as mentioned by Nikraz et al [10] describes the problem without necessarily developing the solution to the problem. The analysis phase comprises of the following seven steps;

- Requirements Analysis
- Requirements Modeling
- Initial Agent Types Identification
- Roles and Organisation Identification
- Acquaintances Identification
- Agent Refinement
- Agent Deployment Information

3.1.1 Step 1: Requirements Analysis

The requirements were captured based on the business requirements, maintenance feedback and plant performance from the mechanical, operations and electrical maintenance departments. Holt [11], pointed out that the requirements should be classified in a way that enables assessment of their status at any point in the project. Hence he suggests that requirements be classified in terms of defined features or attributes, generally an attribute represents the properties of a requirement. After sufficient requirements engineering, a summary of the attributes is compared against the requirements and the comparison is shown in Table 1.

Table 1: Requirements Analysis

	Attributes			
Requirement	**Source**	**Priority**	**V/V**	**Ownership**
Increase plant availability	KSPS plant objective	Essential	Internal/External Plant Trips Statistics	KSPS
Increase efficiency	KSPS plant objective	Essential	Key performance indicators	KSPS
Monitor System	Maintenance report	Essential	Operational Trends	Decision Support and Alarm Manager
Get readings	Maintenance report	Essential	Listing parameters to be monitored	Sensor Readings Provider
Decision and alarm status	Maintenance report	Essential	Established rule base	Decision Support and Alarm Manager
Send notification	Maintenance report	Essential	Email or SMS to the user	User Notification Provider
Maintain ISO 9001:2008	Quality report	Desirable	Quality Audits	Performance and Risk Officer
0% accident rate	Operations report	Desirable	Safety Inspections	Performance and Risk Officer
Store readings	Maintenance report	Desirable	Well established database	Readings Storage Provider

From the analysis, focus is shifted onto the user requirements and the constraints on them rather than with the high-level business requirements.

3.1.2 Step 2: Requirements Modeling

Siau & Lee [12] mention in their research that subjects perform better in model understanding when both the Use Case diagram and the Class diagrams are used together. Therefore, for the analysis phase a Use Case diagram was used whilst in the design phase discussed later, a Class diagram is used. Figure 2 shows the requirements encircled whilst the providers are represented by the actor symbol and the human user is shown on the external of the system boundary. Interaction between the use cases and providers is depicted by means of the association symbol.

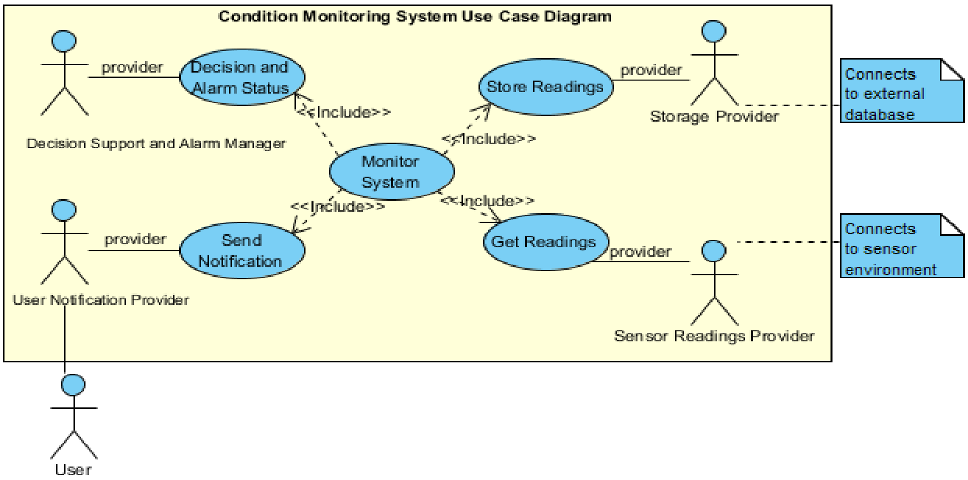

Figure 2: Use Case diagram for the system

The main requirement as shown is to monitor the system which includes sub-requirements fulfilled by the relevant providers.

3.1.3 Step 3: Initial Agent Types Identification

The third step dealt with identifying the main agent types and representing them on an agent diagram. Nikraz et al [10] suggests the following rules when identifying agents;

1. Add one type of agent per user/device.
2. Add one type of agent per resource.

3.1.4 Step 4: Roles and Organisation Identification

A role was identified for each agent type basing on the requirements noted on the Use Case diagram in Step 2. The artefact resulting from this process is the role table. For the condition monitoring system, the following rules were applied;

1. Deriving the initial set of roles from the Use Case diagram.
2. Considering the agents were these roles are clearer first and delay the identification of roles for other agents to later steps.

With the roles identified, they were then grouped together into an organisation. An organisation is a collection of roles that stand in certain relationships to one another, and that take part in systematic, institutionalised patterns of interactions with other roles.

3.1.5 Step 5: Acquaintances Identification

Interactions between agent types were identified in this step, hence adding the agent types to the role table. With the condition monitoring system the Diagnosis Agent interacts with the Decision Alarm Agent which in turn interacts with the Database Agent and the Distribution Agent. The Distribution Agent interacts with the Database Agent and the Human User. The role table is then reviewed to cater for the added agent types and is shown in Table 2.

Table 2: Reviewed role table

Agent Type	Roles	Organization
Diagnosis Agent	• Monitoring variations of hydro bearing parameters • Ensure operation of sensors • Estimating values in case of sensor failure	• Input
Decision Alarm Agent	• Triggering alarms • Offering decision support	• Administration
Distribution Agent	• Pushes alarms raised to the user • Pushes decision support to the user	• Dispatch
Database Agent	• Communicating with the external database for storage of measurement readings	• Administration

3.1.6 Step 6: Agent Refinement

Modification of the agent types identified in Step 3 was done using the following considerations;

1. **Support:** what supporting information agents needs to accomplish their roles, and how, when and where is this information generated/stored.
2. **Discovery:** how agents linked by an acquaintance relation discover each other.
3. **Management and Monitoring**: is the system required to keep track of existing agents, or the starting and stopping of agents on demand.

The given considerations were applied to the condition monitoring system and it was noted that the agent types in the main domain required, the services of the Yellow Pages Agent in helping to discover the Diagnosis Agent. As for the management and monitoring, no new agent types were required to manage or monitor the condition monitoring system.

3.1.7 Step 7: Agent Deployment Information

Agents in their respective domains were represented on an agent deployment diagram. Poggi et al [13] mentions that the deployment diagram is useful in systems that require visualization of the current topology and distribution of components and agents. The methodology adopts an AUML approach by representing the system artefact as nodes which are connected through communication paths to create network systems of arbitrary complexity.

3.1.8 Overall System Architecture after Analysis Phase

The condition monitoring system after the analysis phase comprised of the agent types, users, organisations, the environment, external resources and also it showed the interactions between the mentioned artifacts. Figure 3 shows a clear diagrammatic view of the system architecture for the MAS.

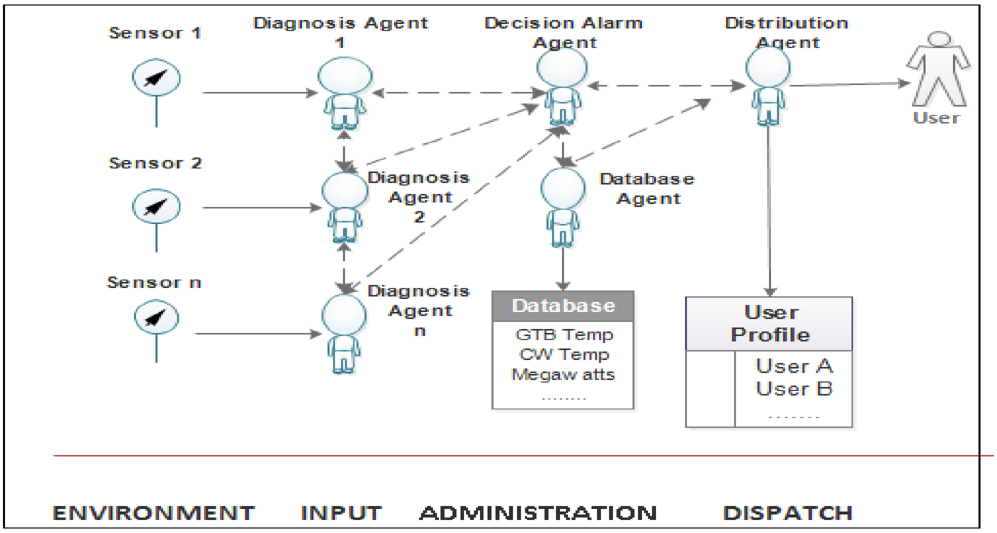

Figure 3: Architecture of the multi-agent system

The parameters that were monitored by the condition monitoring system included;

- Generator Thrust Bearing Oil Film Thickness
- Generator Thrust Bearing Temperature
- Generator Thrust Bearing Vibration
- Cooling Water Temperature
- Guide Vane Opening
- Generated Power

3.2 THE DESIGN PHASE

Nikraz et al [10] point out that the design phase is concerned with specifying a solution to be implemented by JADE. The approach used in the design phase was based on the AUML language which represents agents as they are, not as objects, while employing state chart diagrams to model their behavior and extended interaction diagrams to model their communicative acts. Basically the steps involved in the design phase are;

1. Static View Representation of Agents
2. Internal Agent States
3. Agent Interaction Specifications
4. Control Flow Overview of Agents

3.2.1 Step 1: Static View Representation of Agents

An Agent UML class diagram is used to describe the static views of the agents. An agent class according to Huget [14] is denoted by the stereotype <agent> and a unique agent name. The agent classes are then combined together with the behavior class diagrams and other class diagrams in relation with the agents. This gives an overall class diagram shown on Figure 4.

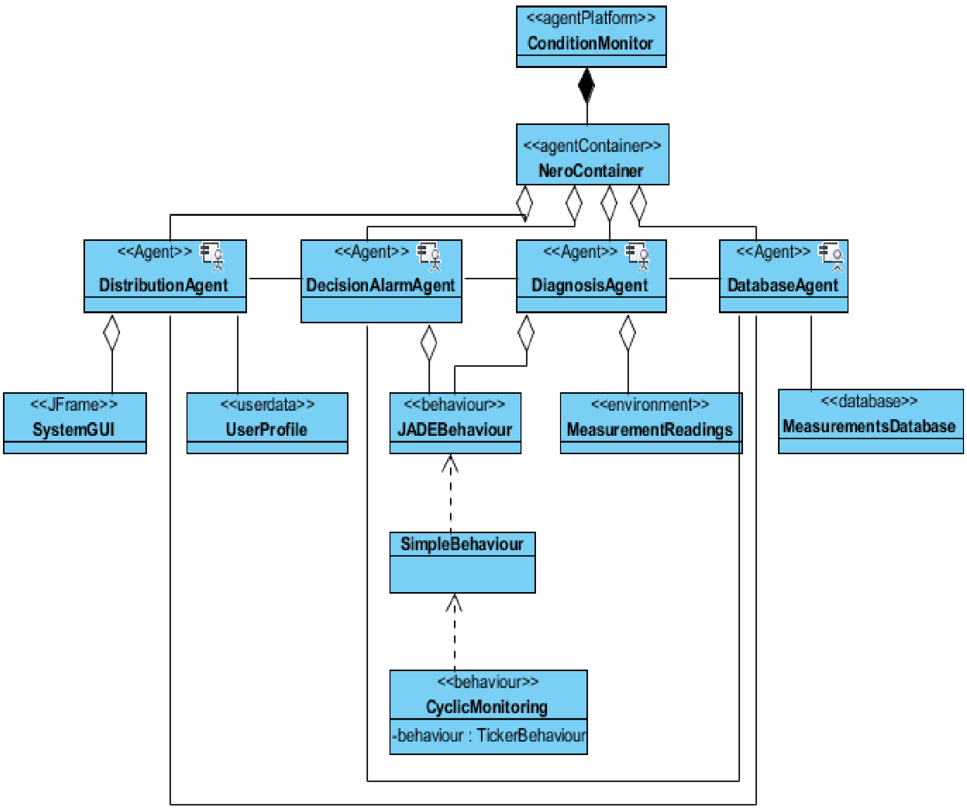

Figure 4: Overall agent class diagram

The various relationships are clearly shown and these include associations, dependencies, and aggregation and composition relationships. It can also be seen that there is an existing relationship between the Diagnosis Agent and the environment. Malaal & Addou [15] emphasize the importance of the environment in a class diagram as it influences the way information is perceived by the agents and also the appropriate action in response to the information supplied.

3.2.2 Step 2: Internal Agent States

An agent has different states that it occupies during its execution lifetime. Hence these states have to be identified so as to see how an agent reacts to events, together with its responses and actions. A State Diagram was used to represent the internal state of an agent and it also provides a graphical way of representing discrete behavior through finite state transition systems.

3.2.3 Step 3: Agent Interaction Specifications

Gomez-Sanz & Pavon [16] note that the UML sequence diagram is extended so as to specify FIPA interaction protocols. The agent interaction diagram used observes the FIPA interaction protocols as shown on Figure 5.

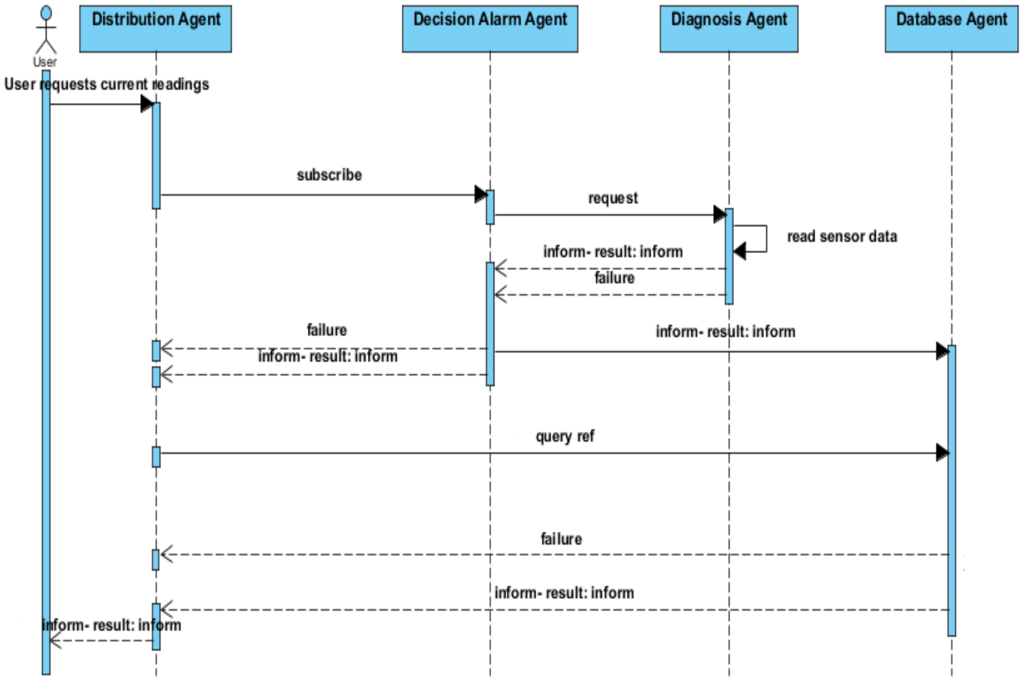

Figure 5: Agent interaction diagram

There are two parts that can be considered in sequence diagrams: a frame, which delimits the sequence diagram and the message flow between roles through a set of lifelines and messages as suggested by FIPA [17]. According to the diagram, the user can request for the current readings at any time and these requests are processed the Distribution Agent. In this kind of flow the Distribution Agent will carry out a FIPA Query Protocol for the measurement readings that can be obtained by the Database Agent. The Database Agent will in turn query the external database so as to obtain the current trends or measurement readings. The Database Agent will inform the Distribution Agent which in turn informs the user of the current measurement. The Distribution Agent subscribes to the Decision Alarm Agent using the FIPA Subscribe Interaction Protocol so that it is notified whenever an alarm or decision support advice is available. The Decision Alarm Agent executes a FIPA Request Protocol to the Diagnosis Agent to get the measurement values and execute the rule base required to inform the Distribution Agent of any alarms or decision support. The Diagnosis Agent will reply with an "INFORM-RESULT" which includes the sensor readings in its message.

3.2.4 Step 4: Control Flow Overview of Agents

The control flow overview of the agents is shown by means of an Activity Diagram that shows the internal activities executed by each agent in its lifecycle. These activities prove that an agent is autonomous and show that data is decentralized Sycara [18].

4. SYSTEM DEVELOPMENT

System development covered areas such as the JADE system development, development of the sensor environment and the JESS rule-base development. Singh et al [19] carried out a comparison between various agent developments toolkits and it can be noted that JADE used in this paper was more advantageous as compared to other toolkits. Nicolae et al [20] also did a comparison on expert system development toolkits which favoured Jess.

4.1 Sensor Environment Development

The development of the sensor environment was carried out using the Siemens S7 as a controller and the KEPServerEX 5.16 as the server. The S7-1200 models and the Windows-based programming tool gives you the flexibility you need to solve your automation problems as pointed out by Siemens [21]. The main aim was to create an environment where the agents can access and monitor the station parameters by obtaining values from the sensors in the environment. Five analog inputs and 10 digital outputs were used to create a tag table. The server and the PLC were placed on the same subnet and an S7 connection was established between the server and the PLC. This connection will allow any client to manipulate data from or to the sensors without any challenges being faced. The client in this project is JEasyOpc which consists of Java code that is able to connect and register to the OPC Group hence making it possible to read/write tag values. Diaconescu & Spirleanu [22] strongly believe that JEasyOpc can be used in control structures comprising of the JADE multi-agent platform and the software to connect to a PLC.

4.2 JADE Multi-Agent System Development

Wooldridge & Jennings [23] review the first agent programming languages such as TELESCRIPT and PLACA that were used to manipulate agents. However, technology has advanced greatly and there exist user-friendly software programs like JADE. JADE is a Java written agent-oriented middleware system that supports add-on modules Bellifemine et al [24].
Four agents were developed and these are;

1. Diagnosis Agent
2. Decision Alarm Agent
3. Database Agent
4. Distribution Agent

Each agent comprises of a behaviour that determines how it executes its functions. A behaviour represents a task that an agent can carry out and is implemented as an object of a class that extends the jade.core.behaviours.Behaviour class. Caire [25] pointed out that an agent can execute several behaviours concurrently. It is important to notice that the scheduling of behaviours in an agent is not pre-emptive but cooperative.

4.3 JESS Rule Base Development

Using Jess, you can build Java software that has the capacity to "reason" using the knowledge you supply in the form of declarative rules. Jess is small, light, and one of the fastest rule engines available. Jess was originally conceived as a tool for building expert systems. Cardoso [26] elaborates that in the multi-agent systems world, Jess can be used as a decision component of an agent, which is implemented in a declarative way. The rule base for this tool was dependent upon two factors namely;

1. The defined allowed maximum and minimum operating parameters of the station units. 2. The MFOP period.

The MFOP period helps in predicting availability of the power station unit, Nyanga et al [27] developed a resource agent that was capable of predicting machinery availability however in a manufacturing setup. Shaalane & Vlok [28] also voiced the improvement and enhancement of equipment if the MFOP concept is applied. The rule base is integrated together with JADE, so that the message content used in the ACL message format of JADE is manipulated by JESS. The JESS reply meant for the agent will be sent via the same path after asserting the facts and comparing the left-hand-side to the right-hand-side of the facts and rules.

5. RESULTS

The results of the system were mainly those from the Multi-Agent System. Analog inputs were used for the sensors so as to obtain a respective engineering value after normalizing and scaling the analog value.

5.1 Results from the Multi-Agent System

Once a connection had been established with the server, the agents obtained the tag values via the JEasyOpc toolkit. Hence the multi-agent system consisted of autonomous agents communicating via ACL messages.

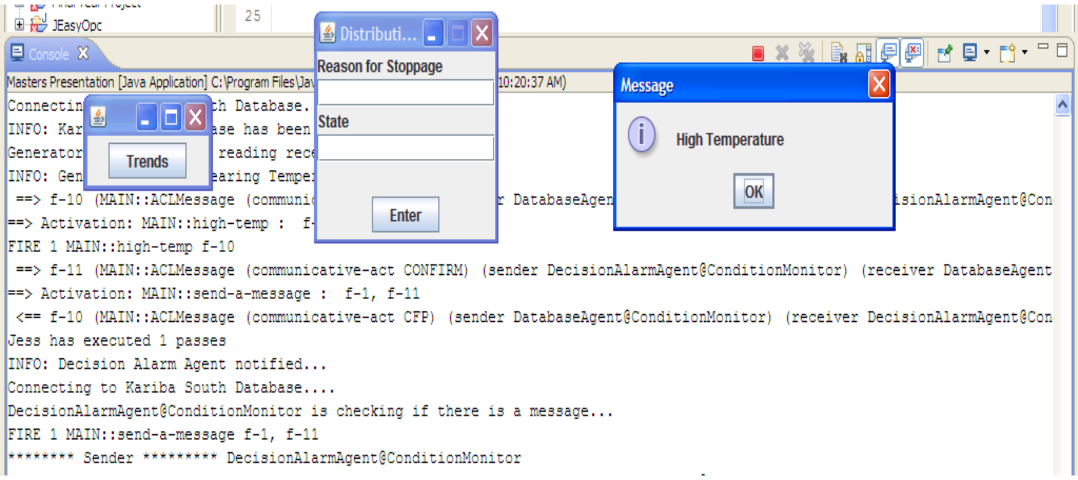

Figure 6: Diagnosis Agent retrieving an item value

Figure 6 shows the Diagnosis Agent is displaying the generator bearing temperature reading of the sensor and also an interface used to enter the reason for stoppages when the unit is down.

5.1.1 Communication between the Condition Monitoring Multi-Agents

The sniffer agent in JADE has sniffing features that allow us to track every message directed to or from an agent in a group of agents. The communicative acts are shown in Figure 7 for each agent and this is a sign of communication between the several agents.

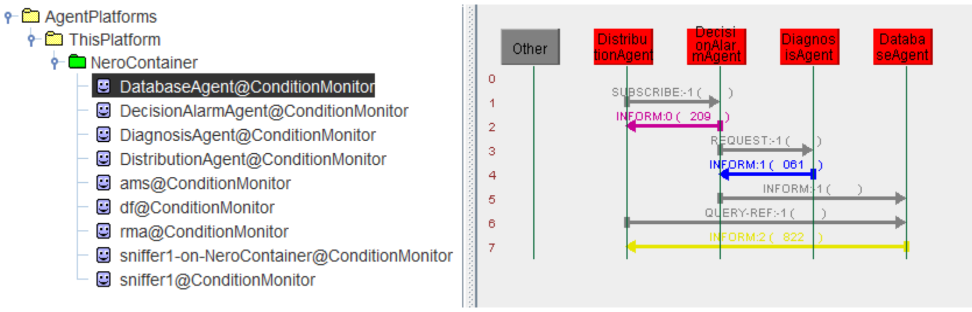

Figure 7: Sniffer agent showing agent communication

It can be seen from the diagram that the agents adhered to the FIPA Interaction Protocol diagram that was discussed earlier. Basically it discussed about how agents communicate using the standard communicative acts.

5.1.2 User Interface

A user interface based on the Distribution Agent was created so as to communicate with the user. The user interface shows the current status of the plant as well as any other condition-based advice that the user might require. The user is able to select the option to view the unit trends of the selected unit. Figure 8 shows the designed user interface.

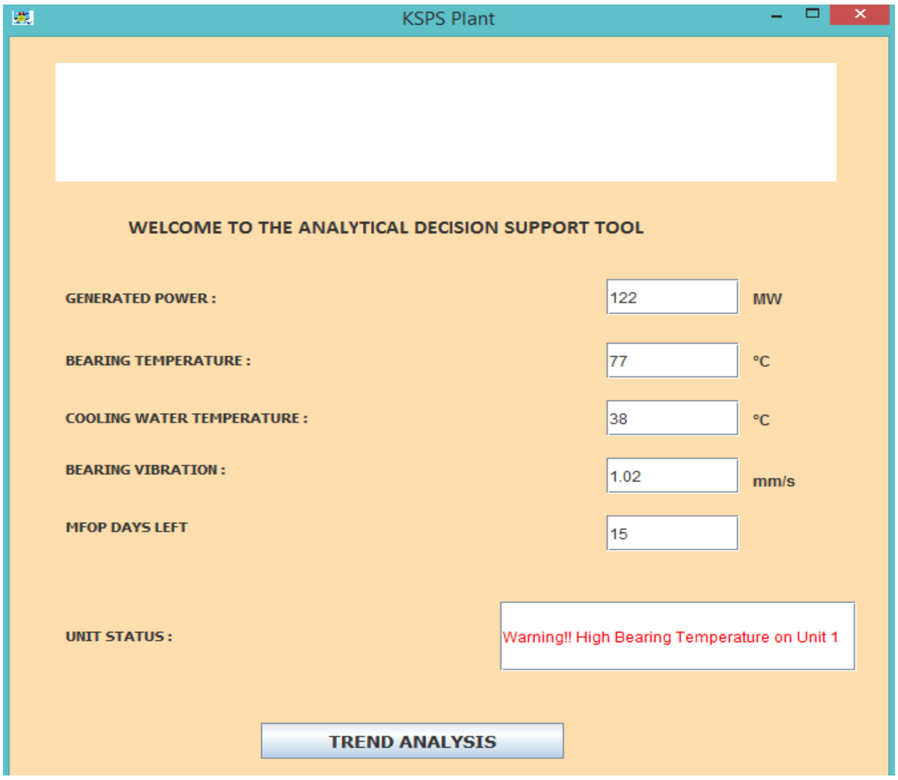

Figure 8: User interface

The space for unit status shown on the diagram indicates any alarms that the user has to be notified of.

5.1.3 Parameter Trends

The tool was able to trend the system parameters such as generator bearing temperature upon request from the user. Figure 9 clearly shows a snapshot of the online trends produced by the Distribution Agent.

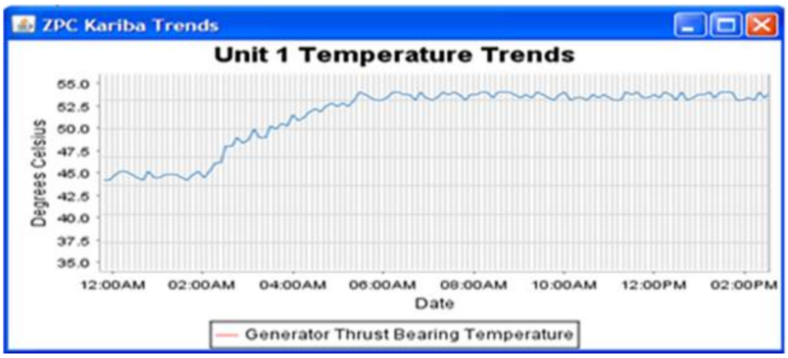

Figure 9: Temperature trends

After requesting for system trends, the tool is also capable of storing an image file of the system trends, which can be used for offline analysis.

5.1.4 Database Storage and Retrieval of Parameter Readings

An added feature of the tool is that it has a database where it can store and query data upon request. Two databases were created using MySQL, the first database was for storing parameter readings whilst the second database was for storing MFOP data that were to be used for MFOP calculations and analysis. Figure 10 shows the database created for MFOP decisions.

```
mysql> select * from mfop1;
+----+------------+----------+--------------------+------------+------+
| id | date       | time     | stoppage_reason    | state      | unit |
+----+------------+----------+--------------------+------------+------+
|  1 | 2015-04-24 | 10:05:10 | High Temperature   | Failure    |    3 |
|  2 | 2015-04-24 | 10:16:41 | High Temperature   | Failure    |    2 |
|  3 | 2015-04-24 | 10:21:43 | High Pressure      | Suspension |    2 |
```

Figure 10: Database created for MFOP decision making

The database is accessible both online and offline depending on what the user wants. The database for MFOP logging was created in such a way that the user enters the data manually on an available GUI.

6. FUTURE WORK

The future work of this tool is to integrate the self-predicting maintenance free operating period function into the multi-agent system so as to increase the efficiency of the tool. This will imply creating an agent that is responsible for calculating the MFOP predictions automatically as soon as plant fault data is entered into the database. Agent communication is greatly improved as agents will now be in the same agent platform, meaning messages are sent and responded to in the shortest possible time. The applicability of the tool can also be implemented in areas such as the tertiary institutions, manufacturing industries and health sector. So much time is taken in analyzing data for students, manufactured products and patients yet there are agents who can manipulate large amounts of data in the shortest possible time.

7. CONCLUSION

The condition-based analytical decision support tool was designed so as to have a positive impact on the decision making process of the company under study. The positive impact mentioned here is that the tool has the ability to save unnecessary breakdown costs for the company. Engineers at the company under study supported the design and assured that the implementation of the tool in a real industrial setup will help cut the time taken in decision making. Therefore the tool can be regarded as an emerging technology that supports condition-based maintenance in that it reduces maintenance costs as it tends to detect failure before it occurs.

Several benefits that are realized upon implementation and some of these benefits include improved generating capacity. The tool comprises of user-friendly functions that can help the shift charge engineer to monitor the plant with relative ease and understanding since it eliminates the manual compilation of large quantities of data. Hydro-power plant equipment is delicate and requires continuous monitoring so as to reduce catastrophic failure and this paper introduced a tool capable of monitoring plant equipment.

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DEVELOPMENT OF A MULTI AGENT SYSTEM FOR PART TYPE ALLOCATION TO MACHINES

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ABSTRACT

Multi Agent Based system (MAS) is a technology that has become more popular in E-manufacturing and is being used in a wide range of control applications including scheduling and planning. It enables a manufacturing company to be highly flexible, agile, and versatile. In the paper a MAS is used to allocate parts to machines in a company with high excessive stock in which work in progress is accumulating in between work stations with an aim of improving scheduling of jobs, utilisation of machines and production throughput. The MAS was developed using Multi Agent System Engineering (MASE) methodology with Analytical Hierarchy Process (AHP) used to develop the decision making model for best machine selection. Each machine was assigned priority value according to time, cost and quality as the decision criteria for determining the best machine to perform the intended operation. Java Agent Development Environment (JADE) was used for the deployment of agents. Simulation of the existing production set up shows that the proposed MAS model will reduce the lead time of developing work order by 83%, machine utilisation is increased from 73% to 84% and prioritization of machines is increased from 0.193 using a human expert to 0.197 using the MAS.

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1. INTRODUCTION

Today's manufacturing businesses are facing immense pressures to react rapidly and robustly to dynamic fluctuations in demand distributions across products and changing product mix. Efficient and practical methods for scheduling and optimization technology are the key to improve the productivity and efficiency of a manufacturing plant as stated by Ayton and Lawley[1].According to Shen[2] the manufacturers' success is no longer measured by their ability to cost-effectively produce a single product butits now measured in terms of flexibility, agility, and versatility.

Local manufacturing companies are aiming at investing in new technologies to produce high quality products more economical than competitors so as to increase market share. Multi Agent Based system (MAS) is the new technology that has become more popular in E-manufacturing and is being used in a wide range of control applications including scheduling and planning as indicated by Colombo[3] andZhang[4].A MAS automates decision making normally done by human beings hence enabling a total integration of thefactory to the supply chain. An E-manufacturing framework for the South African industry has been proposed in Nyanga and Van der Merwe[5].The main aim of the E-manufacturing framework is to increase machine utilisation and factory productivity by sharing resources using an E-manufacturing platform. In this paper, MAS for allocating parts to machines in different sections of a single factory is proposed. A transformer manufacturing plant is used as a case study. The paper is structured as the following: section 2 reviews related literature, sections 3contains the Multi Agent System Engineering (MASE) methodology that was used in modelling thesystem and section 4 is the deployment phase. The paper finally ends with the conclusion.

2. RELATED LITERATURE

Russel and Norvig [6] define an agent as an entity that can be viewed as perceiving its environment through sensors and acting upon its environment through effectors. Wooldridge and Jennings [7] specifies that software agents are programs that engage in software based computer system displaying the properties of autonomy, social adeptness, reactivity and pro-activity. Agent's actions are based completely on both its own experience and the built-in knowledge used in constructing that agent for the particular environment in which it operates.Wooldridge [8] extends the definition of an agent to an intelligent agent by extending the definition of autonomy to flexible autonomy. A multiagent based system consists of many agents interacting together with the aim to achieve a negotiated common goal.

In agent-based manufacturing process planning and scheduling systems, bidding-based negotiations or market-like approaches are commonly used. In systems of this kind, the applied agent negotiation protocols require individual agents to reply to the incoming offers, to compete, and to negotiate or to bargain with other agents. As a result, rich knowledge bases and powerful learning and reasoning mechanisms are very important. Each agent should have at least knowledge of the *capability, availability, and cost of the physical resource* (e.g, a machine) represented by it. Some sophisticated agents need to have knowledge of other agents in the system, the products to be manufactured, and the know-how (historical experience, successful cases)as indicated by Gordillo and Giret [9].

2.1 Methodologies for Multi Agent System (MAS)

With the rapid growth and promise of the agent technology, a number of methodologies for developing MAS (denoted as "MAS methodologies") have been proposed in recent years as discussed by Quynh-Nhu and Low [10]. So far no standardized design methodology has been recognized for Multi Agent System as stated by Omiciniand Molesini[11].There are many methodologies for analysis and design of multi-agent systems and some examples of the common existing methodologies are Multi-agent systems Software Engineering (MaSE), Gaia, Jade/Gaia, JADE, SODA (Societies in Open and Distributed Agent spaces) and MESSAGE.

Multi-agent systems Software Engineering (MaSE) is a start-to-end methodology that covers from the analysis to the implementation of a MAS as stated by DeLoach [12]. The main goal of MaSE is to guide a designer through the software life-cycle from a documented specification to an implemented agent system, with no dependency of a particular MAS architecture, agent architecture, programming language, or message-passing system.

The Gaia methodology views the system as a society or organization, with the elements of that society defined by roles. In Gaia, roles are initially captured in a prototypical role model, which are incrementally expanded and fully elaborated by the end of the analysis phase. These roles have direct correspondence to roles and role model defined in MaSE developed by Deloach [13].This methodology gives the possibility to design MAS using an organizational paradigm and to traverse systematically the path that begins by setting out the demands of the problem and to lead to a fairly detailed and immediate implementation as shown by Florea et al[14]. Gaia permits to design a hierarchical non-overlapping structure of agents with a limited depth. From the organizational point of view, agents form teams as they belong to a unique organization, they can explicitly communicate with other agents within the same organization by means of collaborations, and organizations can communicate between them by means of interactions. If inter-organization communication is omitted, coalitions and congregations may also be modelled as stated by Isern et al [15].

However, Isern et al [15] goes on to state that the GAIA methodology is somewhat limited since we can describe MAS with different architectures of agents. The strength of MaSE compared to Gaia is completeness of the methodology; all the stages of extracting the goals from functional requirements of the system, to definition of roles up until the agents are created are so clearly described in MaSE. It has a strong software and methodology support, unlike Gaia. The architecture that describes the internal behaviour of the agent is included in MaSE but in Gaia it's not well adopted.

Gaia methodology can be used in the development of MAS combined with JADE. Gaia methodology and the JADE develop an environment that enables implementation of a real multi-agent system as shown by Moraitis, and Petraki[16].JADE is a software development framework fully implemented in JAVA language aiming at the development of multi-agent systems and applications that comply with FIPA standards for intelligent agents. JADE provides standard agent technologies and offers to the developer a number of features in order to simplify the development process. Gaia methodology is an easy to use agent-orient software development methodology that however presently, covers only the phases of *analysis* and *design*.

The Societies in Open and Distributed Agent spaces (SODA) methodology developed by Omicini and Molesini [17]is an agent-oriented methodology for the analysis and design of agent-based systems. SODA focuses on inter-agent issues, like the engineering of societies and environment for MAS. It adopts Agents and Artifacts (A&A meta-model) as building blocks for MAS development. SODA introduces a simple layering principle in order to manage the complexity of the system description and adopts a tabular representation. MESSAGE developed by Caire and Leal[18] tries to integrate different methodologies. It is built on five viewpoints that are described with meta-models as UML extensions: organization, agents, goals/tasks, interactions and domain. Itadopted the Unified Process and centred on analysis and design phases of development.

2.2 Multiple Criteria Decision-Making (MCDM)

Multiple Criteria Decision-Making (MCDM) refers to making decisions in the presence of multiple and usually conflicting objectives. It is divided into Multi-Objective Decision-Making (MODM) and Multi-Attribute Decision-Making (MADM) as discussed by Wang, and Chin[[19]. MODM consists of a set of conflicting goals that cannot be satisfied simultaneously whilst MADM deals with the problem of choosing an alternative from a set of candidate alternatives which are characterized in terms of some attributes.

There are different Multiple Criteria Decision-Making models, among these are Linear Goal Programming (LGP), Multi Attribute Utility Theory (MAUT), Merit Point System (MPS) and Analytical Hierarchy Process (AHP). The Analytical Hierarchy Process (AHP) is perhaps the commonly used method for prioritisation of decision alternatives as proposed by Ababutain[20]. In this researchpaper, AHP is the method that was used in prioritisation of machines in the production system.

2.2.1 Analytic Hierarchy Process (AHP)

Analytic Hierarchy Process (AHP) developed by Saaty [21] is a multi-criteria decision-making approach which is used to solve complex decision problems. It uses a multi-level hierarchical structure of objectives, criteria, sub-criteria and alternatives.The top level of the hierarchy reflects the overall goal objective of the decision problem. The factors influencing the decision are represented in the intermediate levels. The lowest level comprises the decision alternatives. Nyanga et al [22] implemented AHP in the development of a multi agent system for machine selection.

3. SYSTEM MODELLING USING MULTI AGENT SYSTEM ENGINEERING (MASE)

MaSE was used in modelling of the system. The analysis phase consists of three steps which are capturing goals, applying use cases, and refining roles. The Design phase has four steps which include creating agent classes, constructing conversations, assembling agent classes, and system design. Unified Modelling Language (UML) was used to support the modelling of the system. The development of the designed Multi Agent System (*system design*) is considered in section four and it was implemented using Java Agent Development Environment (JADE) software.

3.1 System Analysis

At the analysis phase, a set of roles whose tasks describe what the system has to do to meet its overall goal were identified from various departmental functions which work hand in hand in manufacturing of the transformer as highlighted in the next paragraph. Each role played by every personal from coordinated sub systems of the enterprises were analysed on how they are directed and focused in meeting the overall goal. A role describes an entity (sub system) that performs some function within the system.

"The Sales Department captures the requirements of the customer and transfers them to the Production Engineering where the needs of the customer are translated into technical characteristics and specifications. The Production Engineering function develops initial plan of how the customers' requirements are going to be met (scheduling of jobs). It interacts with the Stores Department for provision of raw materials required in producing the product."

3.1.1 Capturing Goals

In capturing of goals, the following two sub-steps were considered; identifying goals and structuring goals. Primary and secondary data was gathered straight from the manufacturing source through questionnaires, meetings with the relevant people and from company records during the industrial visits. Industrial expects and the management were asked about the overall goal of the company in the transformer manufacturing business, the importance of Competitive Performance Objectives (time cost and quality) in the production. These Competitive Performance Objectives (CPOs) were compared to each other and ranked according to the fundamental 1-9 standard scale by Saaty [21] using a pair wise principle. A checklist was used as a guide to confirm if all aspects relating to area of study were looked at through structured interviews and observations.

The goals were identified from the functional requirements of the system obtained from the gathered data are listed as follows:

- Capture customers' requirements
- Translate requirements to specifications
- Plan for processing of the customers' requirements
- Supply of materials to the production system.
- Execute planned work (manufacture the product)

The identified goals are then structured into a Goal Hierarchy Diagram as shown inFigure 1.The highest-level goals (design, plan and supply of materials) are summarized to create an overall system goal which is to manufacturea transformer and the high level goals became sub-goals of the system goal. The sub goals were further decomposed into new sub goals supporting the parent goals.

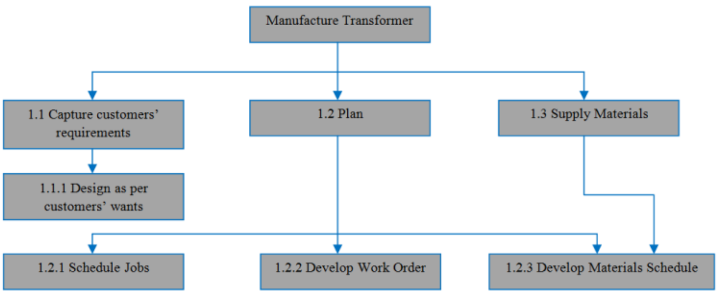

Figure 1 Goal Hierarchy Diagram

3.1.2 Applying use case diagrams

The system works cooperatively with respect to other departmental functions having different roles in order to satisfy the demand or order placed. To represent how the system interacts with the environment as it captures the requirements of the system, use case diagrams were used. The use case showing the overall transformer manufacturing system (all involved departments) is represented in Figure 2.

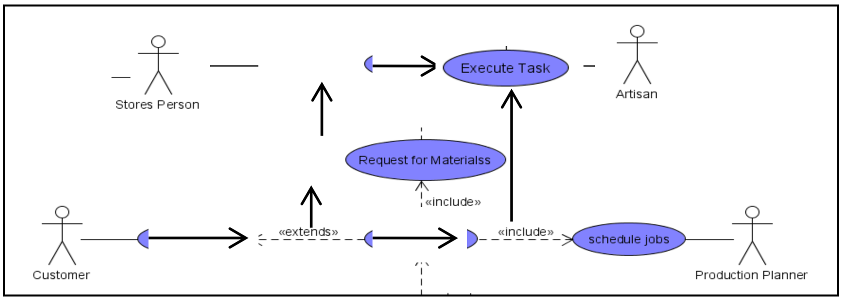

Figure 2 Use case showing the overall transformer manufacturing system

The customer places an order at Sales Department which then captures requirements of the customer and *extends* them to the Production Engineering where planning is done. Planning *includes* requesting of materials from the Stores Department and scheduling of job. The Stores Person supplies materials upon receipt of a request from the Planning Department. After planning, the process *extends* to task execution and this is done by the Artisan.

3.1.2 Sequence Diagrams

The sequence of events that are transmitted between roles identified from use cases were represented (from the moment a customer places an order to loading of machine) as shown in the sequence diagram Figure 3. The roles or classes are laid across at the top and time is assumed to flow from the top of the diagram to the bottom represented by the lifelines in the diagram.

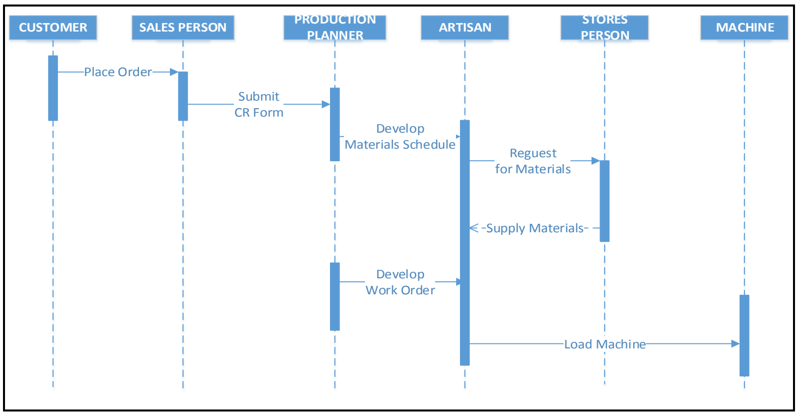

Figure 3Sequence Diagram showing flow of events between different roles

3.1.3 Refining Roles

The structured goals and roles represented in the sequence diagram were further refined by combining some roles into a single role and decomposing other roles in the case that it has been noted that there are tasks that cannot be carried out by the same role. Roles are the building blocks used to define agent's classes and capture system goals during the design phase. *Database* class have been added in this role refining stage and intend to add *user interface* as well at design phase.

Customer and sales roles were not considered during the refinement stage, more focus was put on the actual production of the product. These roles were not taken into account in the detailed design phase of agents and the role modelling. The developed MaSE role modelling is shown inFigure 4

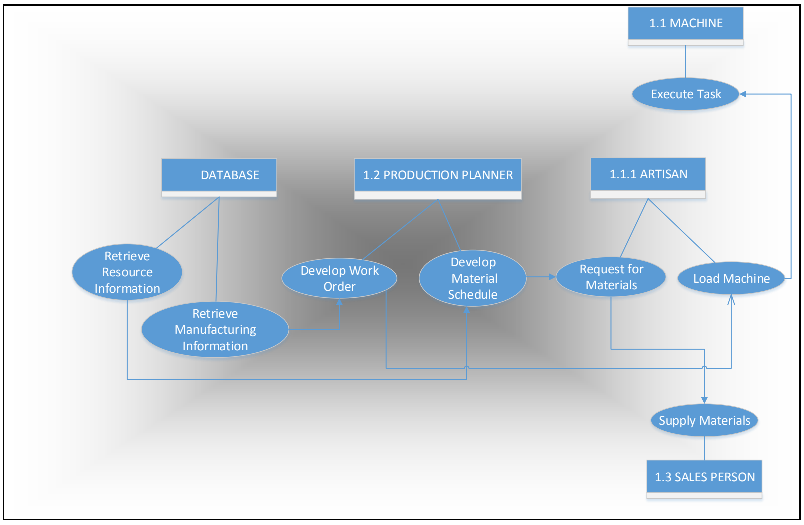

Figure 4 MaSE Role Model

When an order is placed, the production planner access the resource and manufacturing information from the database about the product that needs to be manufactured and develops materials schedule and work order. The materials schedule is used to request for materials from the stores and the work order guides the artisan in executing the planned work.

It can be noted that the MaSE role model is not really showing how the jobs are being allocated or scheduled to machines, which is the overall objective in this context. To show that, Figure 5 is a further refinement of roles and tasks to represent how the researchers intend to cost effectively assign planned jobs to machines. English auction where the bidder with the highest bid is the winner is used in bidding and allocating jobs as illustrated in Nyanga et al.[22]Once a customer has placed an order the production planner will propose bidding for jobs to the machines using contract net, a JADE default standard interaction protocol compliant of FIPA-ACL language for communication between agents, the initiator and responder. The machines will request the database to search for details of the job so that they will be able to prepare bids and submit to the production planner. The production planner will now compute bids using the English Auction protocol in order to determine the winner who will undertake the proposed job. This is going to be explained in detail at the design stage when these roles are being mapped to agents.

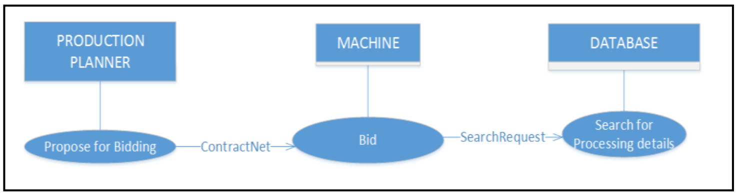

Figure 5 Refined roles showing how jobs are going to be allocated to machines

3.2 System Design

In the systems design stage roles were assigned to specific class of agent types by creating agent classes. The conversations between agents were developed showing how they interact, coordinate and negotiate to achieve the desired goal of effectively assigning part type components to machines in the production environment. A winner determination criteria (AHP) was developed to select the best machine to process the part type component by comparing the required machine specifications and the specifications of the machines in the factory as shown in Nyanga et al [23]. The agent's classes were then assembled with the internal architecture, reasoning processes and behaviour of the agent classes also designed. Finally, in the last step of System Design, the designer defines the actual number and location of agents in the deployed system and in this paper it is addressed in the next section (section four).

3.2.1 Creating Agent Classes

Roles are the foundation upon which agent classes are designed. Since roles correspond to the set of system goals defined in the Analysis phase, they form a bridge from what the system is looking forward to achieve to how that is going to be achieved in the design phase. The agent class diagram is shown in Figure 6.

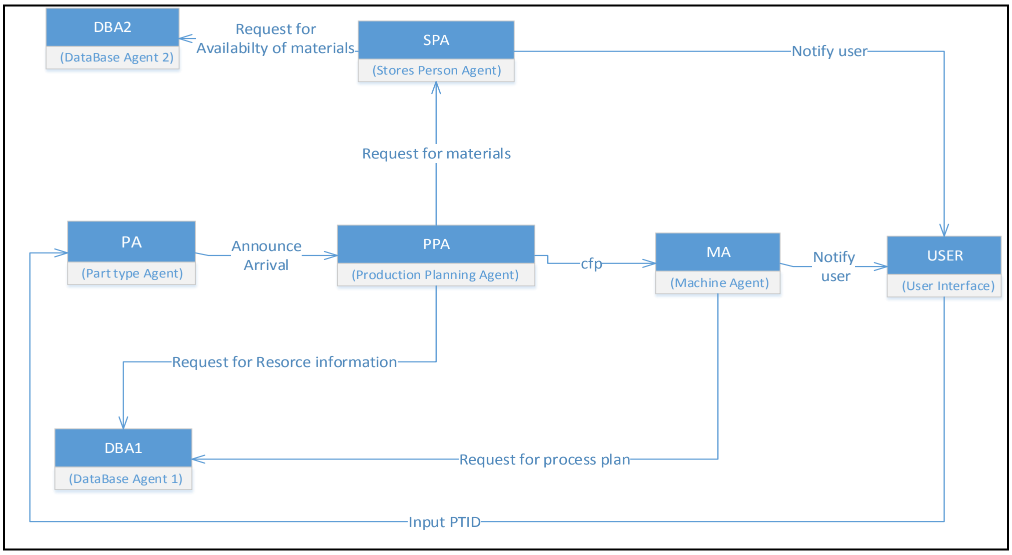

Figure 6 Agent Class diagram

Two Database Agents were included since the Engineering departmental function has got its own server different from that of stores department. There are other agents considered as system resources, such as databases and user interface in order to have complete interactive classes that associate to achieve a common goal. Conversations in which different agent classes must participate were identified and are shown in Table 1.

Table 1 Agents' roles and conversations

STEPS	AGENTS CONVERSATION PROTOCOL/ROLES
1.	▪ The USER triggers the PA to initiate a conversation by announcing a part type arrival to the PPA the moment an order is placed.
2.	▪ PPA identifies the part type ID and request for resource and manufacturing information from DBA1 for the particular part type component. ▪ DBA provides the requested information to the PPA.
3.	▪ Based on the resource information retrieved by DBA1, PPA request for raw materials from the SPA. ▪ SPA request for availability of raw materials from DBA2. ▪ The DBA2 retrieves the requested raw materials details to the SPA and the SPA returns required materials information details to the PPA and notifies the USER about availability of the materials. ▪ If the raw materials are unavailable, the PPA informs the PA and PA announces a new part type to the PPA is in *step 1*. ▪ The USER acknowledges the receipt of the message about the availability/unavailability of the raw materials and waits for part to machine allocation.
4.	▪ PPA asks for submission of bids from MA for processing the part type component. ▪ The Machines request for the process plan of the part type to be processed from DBA1, develop bids and submit the bids to the PPA. ▪ PPA computes submitted bids using the embedded *AHP algorithm* to select the best machine (refer to Nyanga et al [23] and Nyanga et al [22]).
5.	▪ PPA notifies the MA about the winner/successful bidder. ▪ The MA notifies the USER about the selected Machine to process part type.

3.2.2 Constructing Conversations

At this stage of the design phase, conversations that take place between agents, the initiator and the responder are now described in detail. The initiator always begins the conversation by sending the first message.When an agent receives a message, it compares it to its active conversations. If it finds a match, the agent transitions the appropriate conversation to a new state and performs any required actions or activities from either the transition or the new state. Otherwise, the agent assumes the message is a request to start a new conversation and compares it to all the possible conversations the agent can participate in with the agent that sent the message.

The detailed designs of conversations were derived from the concurrent tasks associated with roles. Agents' communication diagrams showing stages of communication from the point a Part type Agent (PA) is created up until the overall goal of allocating that part type component to the selected machine were developed. Figure 7 Communication class diagram (PPA - MA)shows the communication class diagram between the Production Planning

Agent (PPA) and the Machine Agent (MA). The same communication diagrams were developed for all other agents in the system.

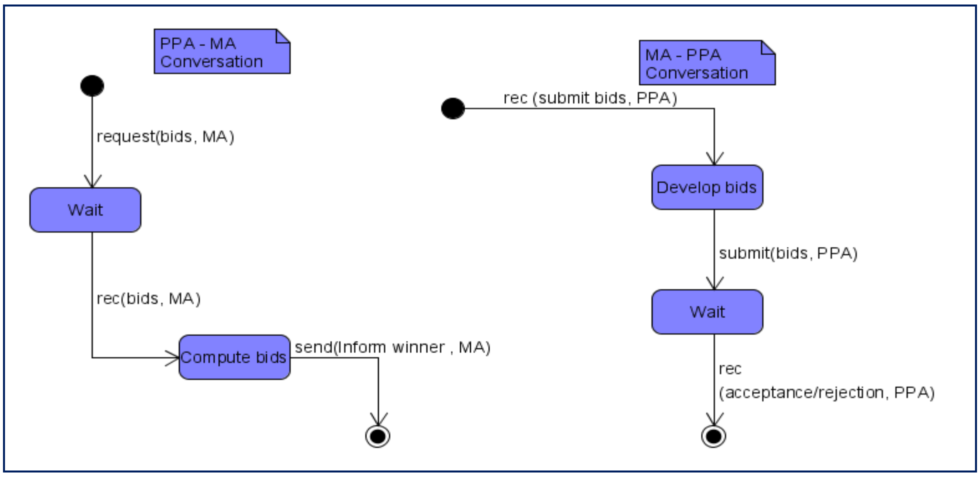

Figure 7 Communication class diagram (PPA - MA)

PPA – MA: The Production Planning Agent (PPA) invites the Machine Agent(MA) for submitting of bids to process part type with the requested PTID, waits to receive the bids and compute the bids after receiving the submitted bids. PPA computes bids using a predetermined and embedded AHP algorithmin the system to select the best machine with highest priority bid value and send the message of the winning bidder to the Machine Agent (MA).

MA – PPA: The Machine Agent (MA) first request for the processing part type details using the PTID from DBA1 and develop bids based on the provided process plan. It then submits the bids (available machines) and waits to receive response of acceptance/rejection.

3.2.3 Winner Determination criteria, Analytic Hierarchy Process (AHP)

Analytic Hierarchy Process (AHP) algorithm was formulated for multi-criteria decision-making in selection of the right machine to process a part type component in the manufacturing of a transformer tank. It uses a multi-level hierarchical structure of objectives, criteria, sub-criteria and alternatives. The methodology of selectingthe best machine to perform the intended task is based on the priority ranking of each and every machine in the plant developed by Nyanga et al[23]. The machine priority ranking values will Production Planning Agent (PPA) requests the DataBase Agent (DBA) for retrieval of the best suitable machine according to the AHP machine ranking stored in the MAS database.be stored in the MAS database and during auctioning of jobs to machines; the Production Planning Agent (PPA) interacts with Machine Agent (MA) to submit available machines as bids and in order to determine the winner by computing the submitted bids, the winner by computing the submitted bids, the Production Planning Agent (PPA) requests the DataBase Agent (DBA) for retrieval of the best suitable machine according to the AHP machine ranking stored in the MAS database.

3.2.4 The AHP hierarchy structure of machine selection

The machine selection when a job is introduced in the manufacturing system, it is based on time, cost and quality as shown in Figure 8 Machine selection top hierarchy. The best machine selection being the overall objective of the MAS system is decomposed from top level hierarchy to second level (sub criteria). Time, cost and quality are the three selection criteria factors considered.

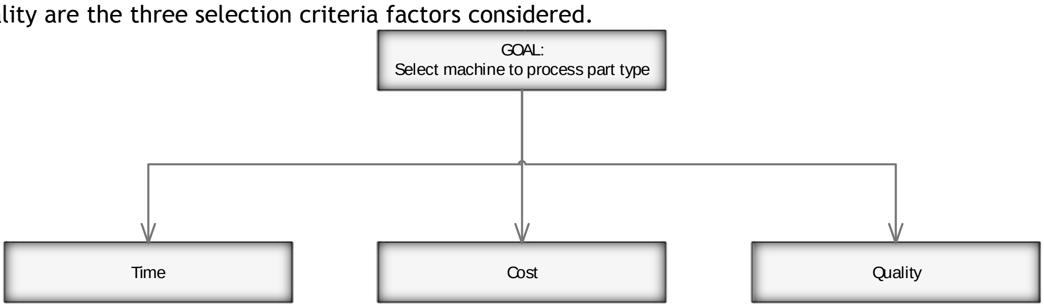

Figure 8 Machine selection top hierarchy

3.2.5 Sub criteria (Time, Cost and Quality)

The factors (set up time, processing time and machine availability) are considered in determining the time priority.In order to increase throughput of the production process, the machine with the minimum set up time, loading time and processing time are given high priority values. If the machine with the highest priority value is busy, the next available machine is considered according to its priority value. The same is being done in terms of cost and quality/capability.

For the cost analysis, operational/processing cost of machine, machine maintenance cost and material handling cost were considered to come up with an annual cost of a machine. The objective was to select the machine that process part type component at a minimum cost meanwhile greatly benefiting from that operation.The annual worth of machine was calculated using the formula developed by Cimren and Budak[24].

$$AW_K = \frac{1}{P_K}\left(\frac{(1+r)^n - 1}{i(1+r)^n}\right) \quad (1)$$

$$P_K = A_{K0}(1+r)^0 + A_{K1}(1+r)^{-1} + A_{K2}(1+r)^{-2} +,,,, + A_{Kn}(1+r)^{-n} \quad (2)$$

$$A_{kt} = PC_{kt} + MMC_{kt} \quad (3)$$

Where Ak_t is the annual cost of the machine *k* in year *t*, *r* is the annual interest rate, P_k is the net present value of the machine *k*, AW_k being the annual worth of machine $_k$, PC_{kt} is the processing cost of the machine *k* in year *t*, MMC_{kt} is the machine maintenance cost of machine *k* in year *t*, and *nk* is the economic life of machine *k* in year *t*. *(t = 0,,,,, nk).*

In coming up with quality (or capability) priority, productivity and flexibility sub criterion were considered as illustrated in Nyanga et al[23], Nyanga et al [25] and Nyanga et al [26]. Productivity sub-criterion is being determined by the following machine attributes; machine power, machine speed, machine precision and dependability. Flexibility sub-criterion considers the ability of the machine to perform different operations; number of tool slots, operation flexibility and mobility (fixed/mobile) are the machine attribute being considered in prioritising the selection of the best machine to process a part type component

3.2.6 Assembling Agents

The internals of the agents were created at this stage. Architectures of each of the agents were developed from the logic based aspect of how the agent should behave. The behaviour of the each agent is explained in detail and the conversations that take place between agents. When developing agents, each task from each role played by an agent defines a component in that agent class. The components for each of the agent are represented in the table showing the conversation ID of each as shown in Table 2.

Table 2 Components of agents and the associated conv ID

Agent No.	Agents	Components	Conversation ID
1	PA	Announce arrival	1.1
2	PPA	Request for materials	2.1
		Inform PA about materials availability	2.2
		Request PT operations from DBA1	2.3
		cfp from MA	2.4
		Compute bids	2.5
		Inform winner	2.6
3	MA	Request for PP and compatible machines	3.1
		Submit bids	3.2
		Inform USER	3.3
4	SPA	Check for materials availability	4.1
		Inform PPA	4.2
		Inform USER	4.3
5	DBA1	Retrieves PT Operations	5.1
		Retrieves compatible machines	5.2
6	DBA2	Retrieves materials available	6.1
7	USER	Input PTID	7.1
		Acknowledge availability of materials	7.2
		Acknowledge unavailability of materials	7.3

3.2.7 Production Planning Agent Architecture

Out of all the agents, Production Planning Agent (PPA) is the agent which plays many roles because it acts as the intermediator between the Machine Agent (MA) and Part Agent (PA). It frequently communicates with Database Agent (DBA) as well. It is made of different components as in Figure 9. The request resource information will be connected to DBA1, request for materials from SPA and request for bids from MA. How the components interact is represented by the thin arrows connecting them together. The architecture of other agents were developed showing their different roles and how they interact with each other.

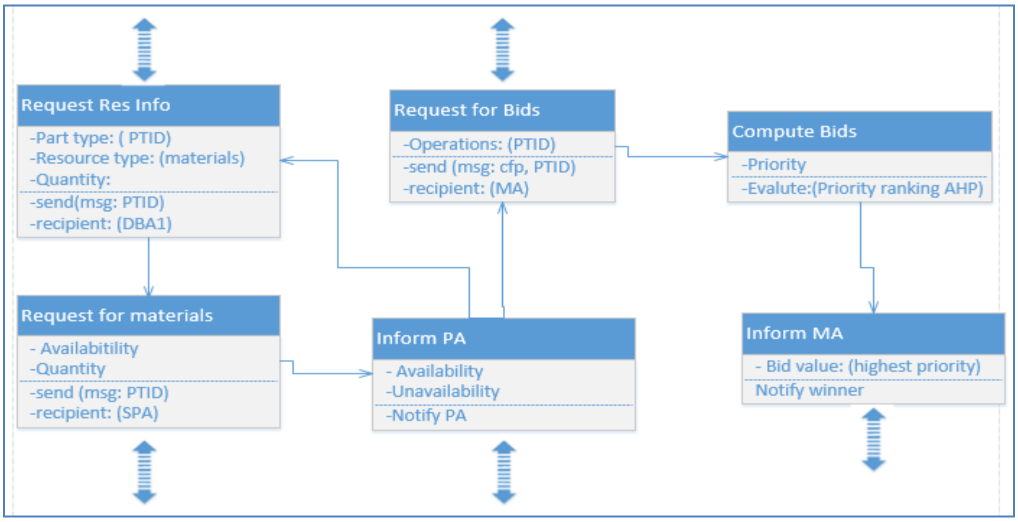

Figure 9 Production Planning Agent Architecture

3.2.8 *Message Templates*

The message template shown in Table 3 shows the interactions that takes place between agents, the interaction protocol (IP) that is used in the conversation, the *role* of initiating and responding *with* other agents *when* triggered by a certain event occurs. The template column describes the conversation IDs for each interaction that takes place on how the conversations IDs were determined.

Table 3 Message Template

Interaction	IP	Role	With	When	Template
Announce arrival (PA)	Query if	I	PPA	Order is placed	Conv 1.1
Request for materials (PPA)	Request protocol	I	SPA	PTID is announced into the system	Conv 2.1
Access stores DataBase (SPA)	Request	I	DBA	PPA makes a request	Conv 4.1
Retrieves materials info (DBA2)	Query if	R	SPA	SPA makes a request	Conv 6.1
Informs USER about materials status (SPA)	Query if	R	USER	DBA retrieves info	Conv 4.3
Informs PPA about materials status (SPA)	Query if	R	PPA	DBA retrieves info	Conv 4.2
Informs PA about materials status (PPA)	Query if	R	PA	SPA informs PPA about materials	Conv 2.2
Call for proposal (PPA)	Contract.net protocol	I	MA	SPA informs availability of	Conv 2.4
Submit bids (machine availability), (MA)	Contract.net protocol	R	PPA	It receives a call for proposal	Conv 3.2
Compute bids (PPA)	Request protocol	I	DBA	It receives bids	Conv 2.5
Retrieves highest priority machines among the submitted machines and inform MA. (PPA)	Request protocol	R	PPA &USER	Request for priority by PPA	Conv 2.6
Inform User (MA)	Query	I	USER	Informed about the winner	Conv 3.3

3.2.9 *Agent Behaviours*

For each agent to perform a particular role, it should have behaviour in order to execute the intended role. An agent can have different behaviours depending with the roles that it is supposes to play. The behaviours of the agent are executed concurrently depending with flow of interactions between agents. The behaviours of the two main agents; Production Planning Agent (PPA) (Figure 10) and Machine Agent (MA)(Figure 11)were considered in this paper. However other agents' behaviours were developed as well for easy implementation of the whole MAS system.

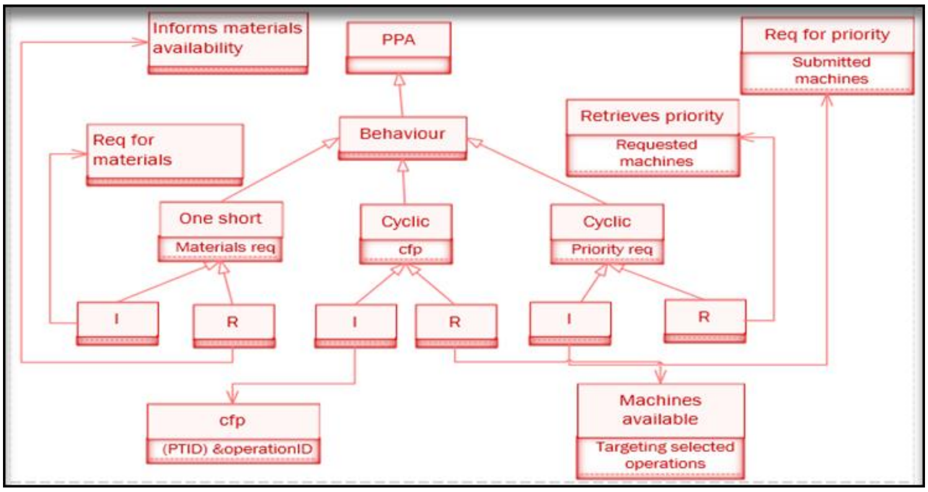

Figure 10 Dynamic behavior pattern for Production Planning Agent (PPA)

When the PA announces arrival to the PPA, the Production Planning Agent (PPA) starts to execute its behaviours which are *one shot* and *cyclic behaviour* concurrently. The ticker behaviour is also nested in the cyclic behaviour to periodically execute the set operation. The one shot behaviour is being applied when it is requesting for materials from the Stores Person Agent, this is done only once. The moment the one shot behaviour is terminated, the cyclic behaviour is initialised as the PPA interacts with the Machine Agent (MA) when calling for proposals (cfp). This is done repeatedly since there should always be something in the PPA catalogue (PT) ready for processing and this is when the ticker behaviour is being applied as well. The cyclic behaviour is executed at two scenarios including when the PPA is computing bids to determine the winner using the Analytical Hierarchy Process (AHP) priority algorithm. Every moment, the Machine Agent (MA) submits available machines as bids, the Production Planning Agent periodically computes them and informs winner.

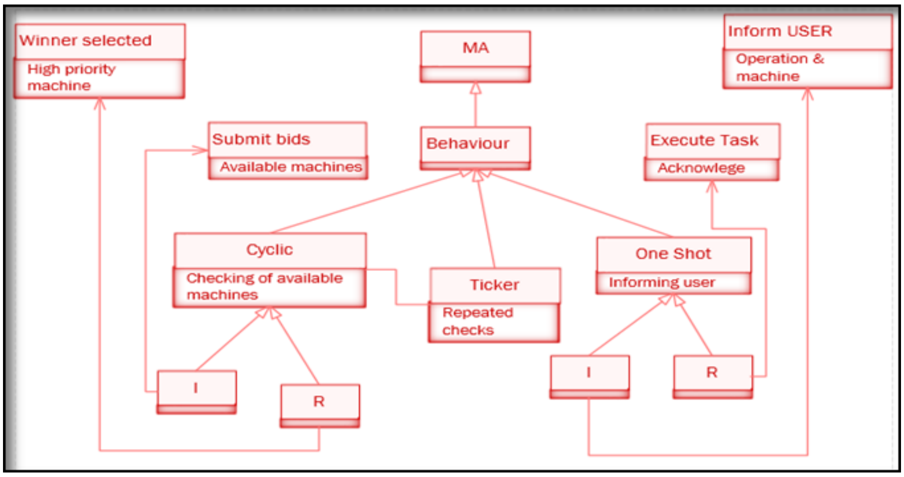

Figure 11 Dynamic behaviour pattern for Machine Agent (MA)

How the Machine Agent (MA) responds to the request of the jobs that would have been placed in the catalogues is determined by its behaviour. The Machine Agent (MA) should always check for jobs placed in catalogue repeatedly so that it can submit bids. This behaviour is executed by the ticker behaviour of the machine agent as it always checks for availability of machines. The other behaviour being executed by the Machines Agent (MA) is one shot behaviour as it informs the USER about which machine is suppose do perform the auctioned job, Figure 11shows the all the behaviours of MA.

4. IMPLEMENTATION OF MAS (DEPLOYMENT)

The Production Planner user interface was developed using Active Server Pages (ASP.NET). The (ASP.NET) is an objected oriented language that is not limited to script languages; it allows the developer to make use of .NET languages like C#, J#, VB. However, ASP does not support agent based system in the JADE environment; therefore JADE LEAP was used to interconnect the ASP.NET developed interface with JADE as shown Figure 12.

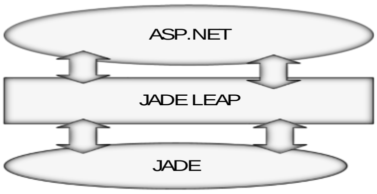

Figure 12 ASP.NET connected to JADE using JADE LEAP

The interface has a provision where the user first request for availability of the materials from the Stores Department by entering the Part ID and quantity required as shown in Figure 13. At the background the Production Planning agent request for materials from the Stores Person agent and informs the user about the materials status.

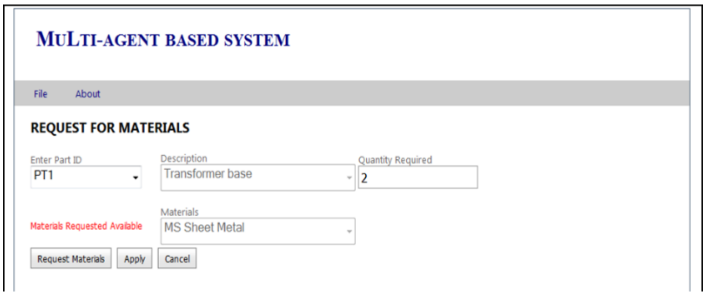

Figure 13Production planning user interface

The Multi Agent System (MAS) is implemented using Java Agent Development Environment (JADE). JADE is a software platform that provides basic middleware-layer functionalities which are independent of the specific application and which simplify the realization of distributed applications that exploit the software agent abstraction. The developed Multi Agent System (MAS) model supports integration of departments (Stores department, Production planning department and the Mechanical department). It also allows running of distributed application across a network in different working environments. The developed model allows the production planner to schedule jobs in real time. Figure 14 shows how the production planner plans for a placed order obtained in running of the MAS developed model during testing.

```
Agent container Main-Container@localhost is ready.
--------------------------------------------
Production Planning Agent PPA@localhost:1099/JADE is ready.
Request for processing for Part: PT1
PT1 exists.
Proceeding to request for machines to process...
Database Agent DBA@localhost:1099/JADE is ready.
Machine Agent MA@localhost:1099/JADE is ready.
Waiting for machines to process Parttype PT1
Found the following Machine Agents:
MA@localhost:1099/JADE
PartID process request received by Machine-Agent from PPA: PT1
The following processes will be applied on:PT1
PT1 | Cutting
PT1 | Marking
PT1 | Punching
PT1 | Bending
Machine-Agent responds to PPA with Machine Catalogue.
Attempt failed: PT1 cannot be processed/ Machines busy.
The following machine Gillotine Machine and priority 980 is available for:PT1
The following machine Marking 1 (scribers/m.rules) and priority 6825 is available for:PT1
The following machine Marking 2 (scribers/m.rules) and priority 6811 is available for:PT1
The following machine Punching Machine 1 and priority 1374 is available for:PT1
The following machine Punching Maching 2 and priority 1179 is available for:PT1
The following machine Cropping Machine 1 and priority 1247 is available for:PT1
The following machine Cropping Machine 2 and priority 1193 is available for:PT1
The following machine Cropping Machine 3 and priority 1197 is available for:PT1
The following machine Cropping Machine 4 and priority 1162 is available for:PT1
The following machine Bending Machine and priority 1040 is available for:PT1
Waiting for machines to process Parttype PT1
Found the following Machine Agents:
MA@localhost:1099/JADE
PartID process request received by Machine-Agent from PPA: PT1
Machine-Agent responds to PPA with Machine Catalogue.
Bids received by PPA from MA: ((ConversationId: Parttype-trade) AND ( InReplyTo: cfp1433279925128 ))
PPA computing Bids from MA
Confirmation of machine allocation to PPA from DBA
```

Figure 14 Results of the developed Multi Agent System

5. RESULTS

Order processing of 100kva transformers shown in Table 4 is used to assess the effect of the MAS by comparing the decisions made by a human expert and the MAS.

Table 4 Number of orders per for 100kva

Time (Days)	Number of orders/day
1	1
2	0
3	3
4	4
5	2
6	3
7	4
8	0
9	1
10	6

The current existing scenario of developing a work order for a raised job at the company takes an average of 2.5 minutes as time is being spent in interacting with relevant departments to enquire manufacturing and resource information. Implementation of a real time Multi Agent System (MAS) will reduce the lead time in processing of work order by 83% as shown in Figure 15, thus increased overall throughput is achieved.

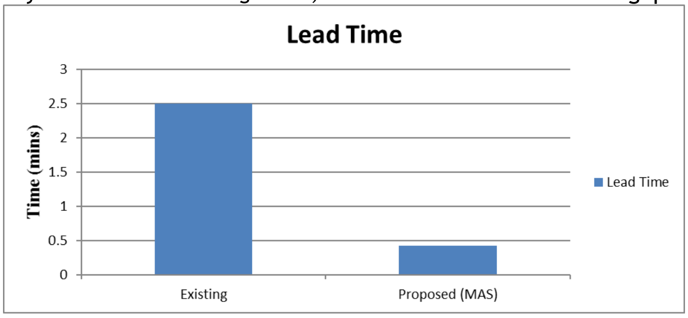

Figure 15 Lead times of processing work order

A sample of frequency orders per for a 100kva that was used in creating arrival rates in the simulation of the existing production system at the company as shown in Figure 15. The average machine utilization at the workstations when a human expert is used to plan for production and when a MAS is used are shown in Figure 16. The results show that machine utilisation is increased from 73% to 84%. Prioritization of machines is increased from 0.193 using a human expert to 0.197 using the MAS.

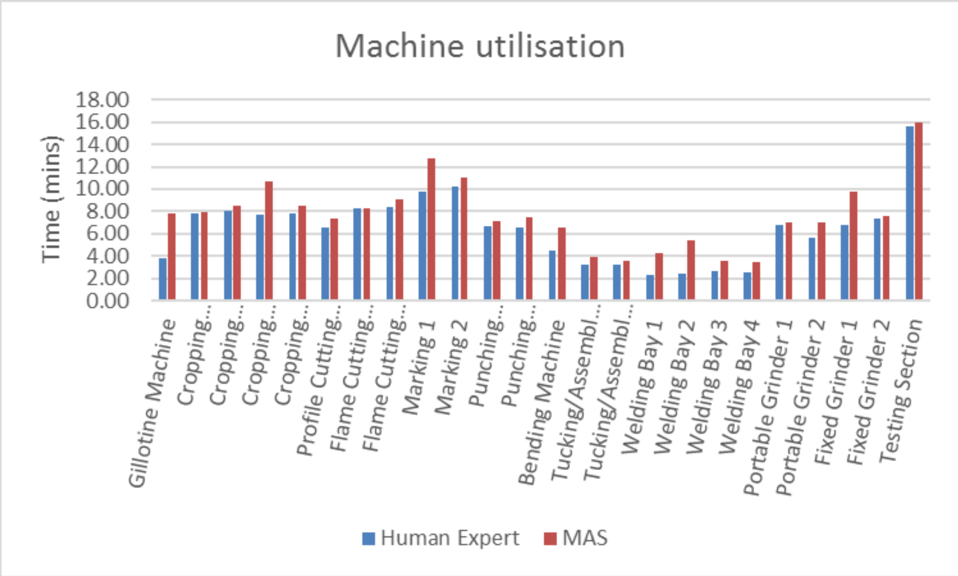

Figure 16 Machine utilization

6. CONCLUSION

The application of Analytical Hierarchy Process (AHP) in conjunction with a Multi Agent System (MAS) ensures high machine utilization and increased throughput. The process of machine selection is automated by developing a multi-agent system that handles the interactions and negotiation in order to achieve an optimised solution. Different departments of a single factory are used to access the performance of the system. The departments can be extended to different companies in an Industrial cluster. This enables the creation of anE-manufacturing system in which resources are shared using a network. Multi Agent System (MAS) enhances efficiencies in management of system files through integration of departmental functions. The proposed Multi Agent System will outperform the current existing system in execution of operations during production planning and control.

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DESIGN OPTIMIZATION OF A SCHEDULING SYSTEM FOR A MULTI-PRODUCT FLOW LINE ENTERPRISE IN ZIMBABWE

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ABSTRACT

This paper presents a simulation-based scheduling tool which assists production planners in Zimbabwe to generate optimal production schedules, quickly react to unexpected events and give customers more accurate delivery promises. It was noticed that a cable manufacturing company suffered a lot by failing to meet customer due dates as a result of using manual static scheduling techniques which are inadequate to use in such a dynamic environment. The proposed system employed discrete-event simulation modeling as a means to evaluate the sequencing rules and then use tardiness and flow times as performance measurement parameters in order to select one optimum rule. The objectives pursued include developing the description of processes document, designing a simulation model for the plant operations, designing an information system and performing experimental designs of the simulation model. A user friendly excel interface was designed so as to retrieve data from Arena and present it in a more comprehensive manner. 2 sets of experiments were done under different conditions and the Simulation based Scheduling system was developed. The system is recommended for use by small to medium cable manufacturers in Zimbabwe.

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1. INTRODUCTION:

1.1 Background to the Study

A cable manufacturing company that manufactures and supplies an extensive range of cables and allied products for the transmission and distribution of information and energy for the Southern and Central African markets, has a wide range of products. The policy used is a make to order policy. For some stock the cost of cable manufacturing is high therefore each product has a minimum order quantity and when this quantity has been satisfied, the order is accepted for manufacture.

Currently the scheduling system being used is a static manual scheduling system whereby the schedule is generated manually by the production planner and is unaltered until the next scheduling period. However, besides being complex and time consuming, this production scheduling technique is ineffective in a dynamic environment since it does not manipulate occurrences of unexpected events such as cancellation of jobs, changes in job priority and much more. If an unexpected event should occur, the available schedule might then be far from optimal, or will be invalidated. This has resulted in many instances where there would be bottlenecks, more idle times, and low machine utilization. Consequently this has seen the company constantly failing to meet targeted customer due dates.

The focus of the paper was to address the problem of customer due dates not being met due to inadequate scheduling techniques therefore a simulation based production scheduling system was developed. Objectives pursued included design of an information system and the determination of optimal and effective methods for schedule reconfiguration to accommodate the dynamic changes.

2. RELATED LITERATURE

2.1 Dynamic Scheduling and Real Time Events

De Jong [1] pointed out that a scheduling problem is dynamic if changes in the problem properties or in the problem environment cause a previously produced schedule to be invalidated. Cowling and Johnson [2] highlighted that a dynamic scheduling system is one that uses real time information as it arrive. One frequent assumption of scheduling theory, which rarely holds in practise, is that the scheduling environment is static. Petrovic et al. [3], stated that manufacturing environments are dynamic in nature and are subject to various disruptions, referred to as real-time events, which can change system status and affect its performance. Vieira et al. [4], highlighted that these real time events can be categorized into resource-related and job-related. Resource-related include machine breakdown, unavailability or tool failure. Job related include rush jobs, job cancellation, due date changes, change in job priority etc.

2.2 Dispatching Rules and Simulation

Vieira et al. [4], noted that no single dispatching rule excels well in all criteria. They highlighted that in order to assess the performance of various dispatching rules dynamically under different dynamic and stochastic conditions of the shop floor, simulation can be used. Simulation has a long and strong track record in the analysis of manufacturing systems whose complexity and interaction of components defy closed-form methods according to Clark [5]. Tamaki et.al [6] also stated that one of the most promising manufacturing activities to employ simulation techniques and tools is production scheduling. Further, recent advances in techniques of analysis and computer software enable simulation to provide excellent support to real-time, hence dynamic and adaptable scheduling, and this was purported by Harmonosky [7]. Simulation allows the execution of several dispatching rules, and the rule that yields the best performance is selected.

2.3 Heuristics

According to Vieira et al. [4] heuristics are problem specific schedule repair methods, which do not guarantee to find an optimal schedule, but have the ability to find reasonably good solutions in a short time. Heuristics may therefore be used to increase the chances of obtaining solutions of acceptable quality. A heuristic can be defined as an inexact algorithm that is based on non-rational and credible arguments which may lead to reasonable solutions n a short time for a given problem, but are not guaranteed to do so according to De Jong [1]. Michelle [8] suggests that the use of heuristics will help decrease the number of variables and unknowns, resulting in a more efficient scheduling process. As a result, the use of heuristics may decrease the time it requires to solve a problem, but the trade-off is optimality in the solution. Heuristics as applied to dynamic scheduling problem may be defined as non-exact problem solvers involving both heuristic functions and algorithms De Jong [1]. Heuristic algorithm applied may or may not accept the new schedule as a replacement of the current schedule. This only goes to show that heuristic optimization involves much fine tuning on the side of the algorithm, the neighbourhood function, and objective function Coy et. al [9].

2.4 Approaches to Dynamic Scheduling

Leus et al. [10], classified dynamic scheduling into four classes which are: complete reactive scheduling, predictive-reactive scheduling, robust predictive-reactive scheduling and robust pro-active scheduling.

2.4.1 Complete Reactive Scheduling

In a completely reactive scheduling no firm schedule is generated in advance and decisions are made locally in real-time. Priority dispatching rules are frequently used. A dispatching rule is used to select the next job with highest priority to be processed from a set of jobs awaiting service at a machine that becomes free.

2.4.2 Predictive Reactive Scheduling

Predictive-reactive scheduling is a scheduling/rescheduling process in which schedules are revised in response to real-time events. Predictive-reactive scheduling is a two-step process. First, a predictive schedule is generated in advance with the objective of optimizing shop performance without considering possible disruptions on the shop floor. This schedule is then modified during execution in response to real-time events.

2.4.3 Robust Predictive-reactive scheduling

Most of the predictive-reactive scheduling strategies are based on simple schedule adjustments which consider only shop efficiency. The new schedule may deviate significantly from the original schedule, which can seriously affect other planning activities that are based on the original schedule and may lead to poor performance of the schedule. It is therefore desirable to generate predictive-reactive schedules that are robust. Robust predictive-reactive scheduling focuses on building predictive-reactive schedules to minimize the effects of disruption on the performance measure value of the realized schedule.

2.4.4 Robust Pro-active Scheduling.

Vieira et al. [4], highlighted that a robust pro-active scheduling approach focuses on building predictive schedules which satisfy performance requirements predictably in a dynamic environment.

2.5 When to Reschedule in Real time Events

There are three policies that have been proposed in the literature, which are: Periodic, Event driven, and hybrid.

2.5.1 Periodic Policy

Under this policy, schedules are generated at regular intervals, which gather all available information from the shop floor. The dynamic scheduling problem is decomposed into a series of static problems that can be solved by using classical scheduling algorithms. The schedule is then executed and not revised until the next period begins, where the planning horizon is renewed by taking into account new information gathered from the current shop floor status. The periodic policy yields more schedule stability and less schedule nervousness. Unfortunately, following an established schedule in the face of significant changes in the shop floor status may compromise performance since unwanted products or intermediates may be produced. Determining the rescheduling period is also a difficult task.

2.5.2 Event Driven Policy

In this policy, rescheduling is triggered in response to an unexpected event that alters the current system status.

2.5.3 Hybrid

A hybrid policy reschedules the system periodically and also when an exception occurs. Events usually considered are machine breakdowns, arrival of urgent jobs, cancellation of jobs, or job priority changes.

It has been reviewed that although the use of heuristics in dynamic scheduling is simple, the drawback with them is their possibility of becoming stuck in poor local optima and it requires much fine tuning on the side of the algorithm, the neighbourhood function, and objective function. The use of simulation provides a very promising method to solve dynamic scheduling problems. Furthermore, recent advances in techniques of analysis and computer software enable simulation to provide excellent support to real-time, hence dynamic and adaptable, scheduling.

3. RESEARCH METHODS

The procedures adopted by the researchers was an experimental design research, and used a combination of quantitative and qualitative techniques. Focus was on the following product lines:

- PVC 35×4C RS (UA) (Poly Vinyl Chloride insulated, 35mm diameter, 4 Cored, Red Striped, Unarmoured cable).
- PVC 150×4C RS (SWA) (Poly Vinyl Chloride insulated, 150mm diameter, 4 Cored, Red Striped, Steel Wire Armoured cable).
- LHC 70×4C BS (UA) (Low Halogen Compound insulated, 70mm diameter, 4 Cored, Blue Striped, Unarmoured cable).

3.1 Interviews

Informal interviews with two production personnel at the cable manufacturing company were carried out. From the interview it was revealed that the company suffers a lot by not meeting customer due dates. It was also highlighted that there are a lot of bottlenecks in the system which usually results in low machine utilization. A root cause analysis and several brainstorming sessions were carried out and it was then noted that the scheduling system being used is not only manual and time consuming, but it is inadequate to use in a dynamic environment.

3.2 System Design

After obtaining the processing times from a time study, Microsoft Visio was used to generate the conceptual model of the system through flow process diagrams and workflow diagrams prior to the development of the simulation model. The Simulation model was then designed using Rockwell ARENA. Microsoft Excel was used to design the user friendly interface of the scheduling system. The user interface allows the user to enter data such as the orders for the day, rush orders and system capacity for a particular scheduling period, and allows the retrieval of simplified information of the statistics of scheduling rules that may be adopted.

The Arena Simulation Model was designed using the steps summarized in Fig. 1.

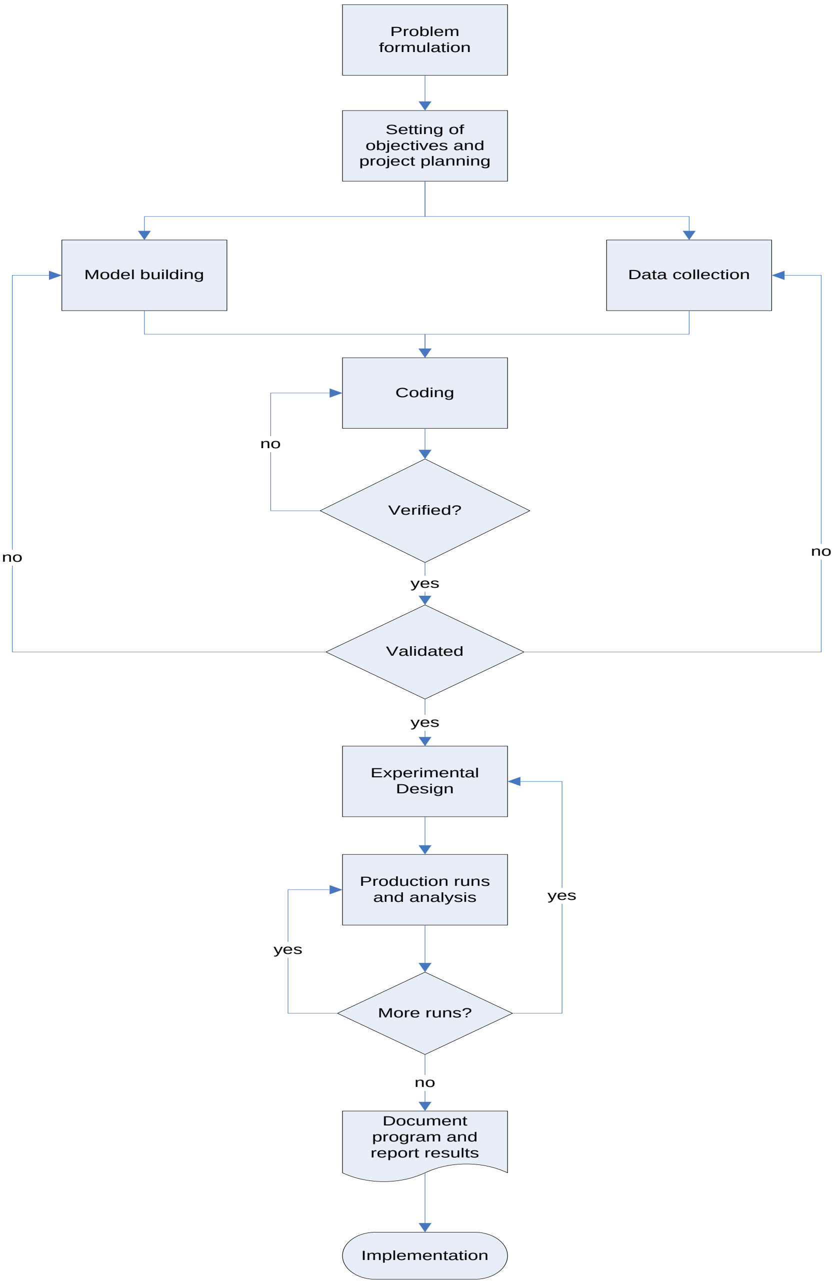

Fig 1: Steps Taken in developing a Simulation Model

4. SYSTEM DEVELOPMENT

Operations at the cable manufacturing company are summarized in the workflow and process flow diagrams given Fig. 2 and Fig. 3.

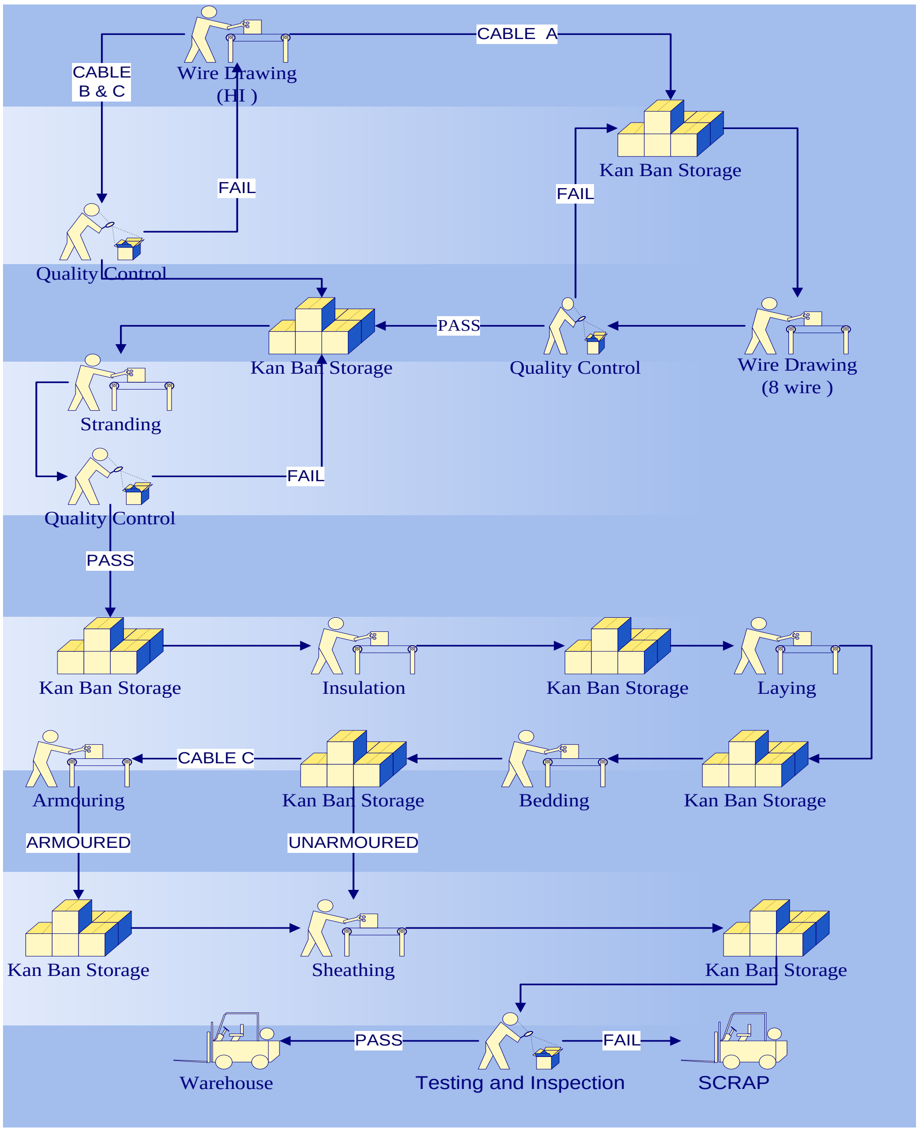

Fig 2: Workflow diagram

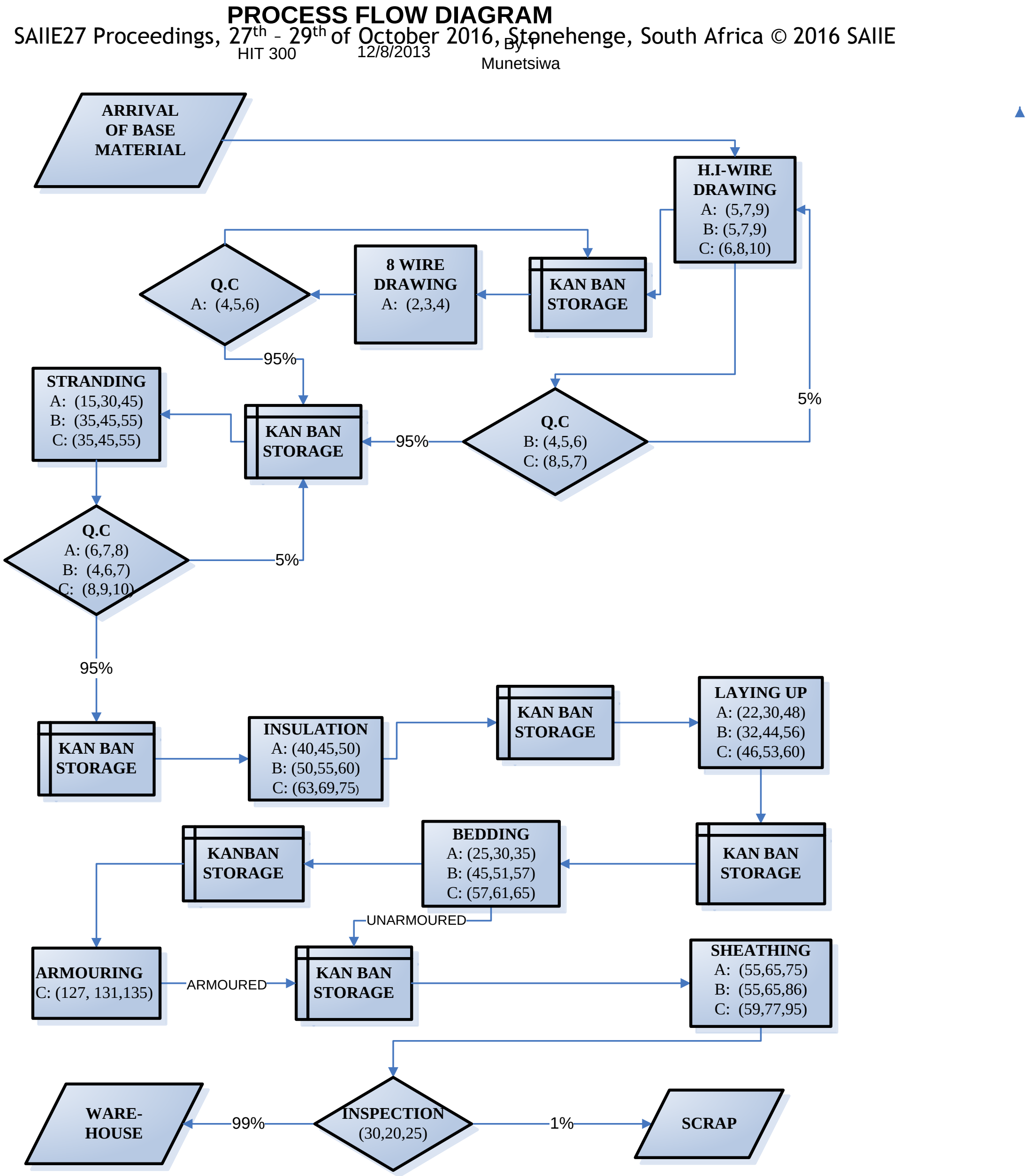

Fig 3: Process flow diagram

Key:

- Product A represent the PVC 35×4C RS (UA)
- Product B represent the LHC 75×4C BS (UA)
- Product C represent the PVC 150×4C RS (SWA)

Fig. 2 and 3 show that all the products go through almost the same processing routes. This makes scheduling of these products difficult since there are many products to be processed with limited resources.

4.1 Information System

The information system provided a user-friendly interface to write the orders to be scheduled. It automatically retrieved the simulated results from Arena and presented them in a more comprehensive manner where it is analysed. The database was designed using Microsoft Excel. The interfaces are as shown in Fig. 4 and Fig. 5:

DATA ENTRY USER INTERFACE

PRODUCT DESCRIPTON	PRODUCT TYPE	Order Number	QUANTITY (km)	ARRIVAL DATE	Est. ORDER PROCESSING TIMES (days)	EXPECTED FINISHING DATE	DUE DATES	COVERT
PVC 35X4C RS (UA)	A	5	2.5	10/08/2016	4.0	16/08/2016	18/08/2016	0.5
LHC 70X4C BS (UA)	B	3	3	09/08/2016	5.0	17/08/2016	18/08/2016	0.2
LHC 70X4C BS (UA)	B	6	0.8	08/08/2016	1.0	13/08/2016	14/08/2016	1
PVC I50X4C RS (SWA)	C	1	1.2	11/08/2016	2.0	14/08/2016	14/08/2016	0
					0	0		0
					0	0		0

FISFS EDD SEE RESULTS CLEAR DATA

COVERT SPT

Fig 4: Order data entry interface

RESULTS ANALYSIS

PRODUCT DESCRIPTION	ENTITY TYPE	Order Number	START DATE	FLOW TIME (Days)	ACTUAL FINISH DATE	DUE DATE	TARDINESS (Days)
PVC 35X4C RS (UA)	A	5	12/08/2016	4.38	16/08/2016	18/08/2016	-1.62
LHC 70X4C BS (UA)	B	3	12/08/2016	6.57	18/08/2016	18/08/2016	0.57
LHC 70X4C BS (UA)	B	6	12/08/2016	0.97	12/08/2016	14/08/2016	-1.03
PVC I50X4C RS (SWA)	C	1	12/08/2016	2.63	14/08/2016	14/08/2016	0.63
				0.00			0
				0.00			0

AVERAGE FLOW TIME	3.64
MAXIMUM FLOW TIME	6.57

TARDINES ANALYSIS

AVERAGE TADINESS (Days)	0.30
MAXIMUM TARDINES (Days)	0.63
TOTAL TARDINESS (Days)	1.20
NUMBER OF TARDY ORDERS	2

BACK TO DATA ENTRY

Fig 5: Simulated results interface

4.2 Simulation Model Design

The simulation model was designed using a discrete event simulation software called ARENA. The role of simulation is to mimic the real plant operations under some given conditions and evaluate the system performance, then automatically feed the results to the Microsoft Excel Database. The Arena model logic is shown in Fig. 6.

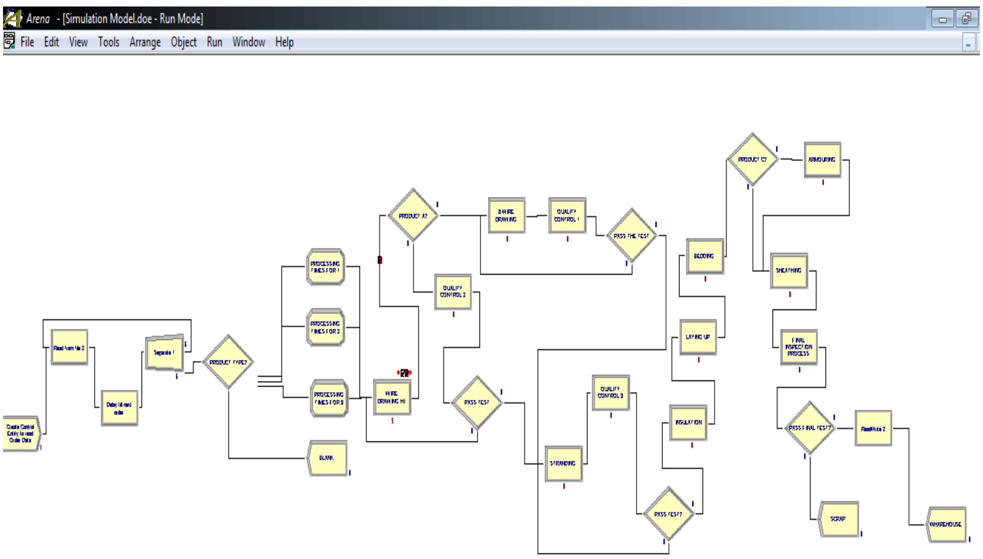

Fig 6: The Model Logic

5. RESULTS AND DISCUSSIONS

5.1 Experimentation

Typical scenarios were replicated to represent a manufacturing system. Table 1 shows four orders used to test the model.

Table 1: Orders Table

ORDER	*QUANTITY (Km)*	*ARRIVAL DATE*	*DUE DATE*
C1	7	24/11/2015	25/12/2015
A5	7	25/11/2015	20/12/2015
B3	12	05/12/2015	25/12/2015
A6	15	20/11/2015	22/12/2015

Table 2 shows simulation results obtained using the Earliest Due Date dispatching rule.

Table 2: Experimental Results Table

EARLIEST DUE DATE (EDD)		
ORDER	TARDINESS (hrs.)	FLOW TIME (hrs.)
C1	6.42	21.42
A5	-0.78	9.21
B3	1.73	16.73
A6	0.88	12.88
Average (hrs.)	2.26	15.06
Maximum (hrs.)	6.42	21.42
Total Tardiness (hrs.)	9.03	
Number Of Tardy	3	
SHORTEST PROCESSING TIME (SPT)		
ORDER	TARDINESS (hrs.)	FLOW TIME (hrs.)
C1	0.47	15.47
A5	-0.34	9.66
B3	2.39	17.39
A6	7.55	19.55
Average (hrs.)	2.60	15.51
Maximum (hrs.)	7.55	19.55
Total Tardiness (hrs.)	10.41	
Number Of Tardy	3	
FIRST IN SYSTEM FIRST SERVED (FISFS)		
ORDER	TARDINESS (hrs.)	FLOW TIME (hrs.)
C1	-0.39	14.61
A5	6.93	16.93
B3	4.09	19.09
A6	-3.80	8.20
Average (hrs.)	2.75	14.71
Maximum (hrs.)	6.93	19.09
Total Tardiness (hrs.)	11.02	
Number Of Tardy	2	
COST OVER TIME (COVERT)		
ORDER	TARDINESS (hrs.)	FLOW TIME (hrs.)
C1	4.55	19.55
A5	7.39	17.39
B3	10.23	25.23
A6	15.95	27.95
Average (hrs.)	9.53	22.53
Maximum (hrs.)	15.95	27.95
Total Tardiness (hrs.)	38.12	
Number Of Tardy	4	

Comment
From the simulation results it can be deduced that in order to reduce the number of tardy jobs and to reduce flow time, the FISFS dispatching rule can be used.

Continuing with the experiments by including two more orders that have just arrived into the current schedule. Table 3 and Table 4 give the results obtained when using the different dispatching rules.

Table 3: Orders Table

ORDER	*QUANTITY*	*ARRIVAL DATE*	*DUE DATE*
A6	15	20/11/2015	22/12/2015
C1	7	24/11/2015	25/12/2015
A5	7	25/11/2015	20/12/2015
B3	12	05/12/2015	25/12/2015
C4	9	10/12/2015	29/12/2015
B2	8	10/12/2015	30/12/2015

Table 4: Experimental results Table

EARLIEST DUE DATE (EDD)		
ORDER	**TARDINESS (hrs.)**	**FLOW TIME (hrs.)**
C1	6.54	21.54
A5	1.83	11.83
B3	8.86	21.54
A6	3.71	23.86
C4	7.10	26.10
B2	8.46	28.46
Average (hrs.)	6.0	21.25
Maximum (hrs.)	8.86	28.46
Total Tardiness (hrs.)	36.50	
Number Of Tardy	6	
SHORTEST PROCESSING TIME (SPT)		
ORDER	**TARDINESS (hrs.)**	**FLOW TIME (hrs.)**
C1	5.14	20.14
A5	-1.74	8.26
B3	6.92	21.92
A6	12.13	24.14
C4	7.74	26.74
B2	-3.72	16.28
Average (hrs.)	5.32	19.58
Maximum (hrs.)	12.14	26.74
Total Tardiness (hrs.)	31.95	
Number Of Tardy	4	
FIRST IN SYSTEM FIRST SERVED (FISFS)		
ORDER	**TARDINESS (hrs.)**	**FLOW TIME (hrs.)**
C1	2.87	17.88
A5	12.17	22.17
B3	9.29	24.29
A6	2.26	14.29
C4	7.53	26.53
B2	8.88	28.88
Average (hrs.)	7.17	22.34
Maximum (hrs.)	12.17	28.88
Total Tardiness (hrs.)	43.04	
Number Of Tardy	6	
COST OVER TIME (COVERT)		
ORDER	**TARDINESS (hrs.)**	**FLOW TIME (hrs.)**
C1	6.20	21.20
A5	5.58	15.58

B3	10.23	25.23
A6	15.95	27.95
C4	23.37	4.37
B2	10.33	-9.67
Average (hrs.)	7.06	20.61
Maximum (hrs.)	15.95	27.95
Total Tardiness (hrs.)	42.34	
Number Of Tardy	5	

Comment

It was observed that continued use of FISFS resulted in having all jobs tardy. Using EDD also resulted in all jobs being tardy although it reduced maximum tardiness. Adopting COVERT rule resulted in one of the jobs being delivered in time; however it further increased the maximum tardiness. Using SPT in this scenario gave the best option which resulted in both jobs being delivered in time and also reduced the average and maximum tardiness of the jobs. SPT in this scenario again resulted in a significant reduction in flow time.

It can be concluded from these results that no one dispatching rule excels in all criterion, hence the need for a Simulation based Scheduling System to quickly evaluate the system performance under the different criterion and help decision makers to take action in the shortest possible time.

5.2 Conclusion

In this paper, we have developed a simulation based scheduling tool which is aimed to assist production planners to quickly generate optimal production schedules and to quickly react to real time events. Several experiments were carried out and it was concluded that no one scheduling rule excels in all real-time events, hence the need for the simulation-based scheduling tool to help production planners to quickly react to unexpected changes and generate optimal schedules.

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THE IMPACT OF OBESITY ON MUSCULOSKELETAL DISORDER IN SOUTH AFRICAN AUTOMOTIVE INDUSTRY

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ABSTRACT

In Automotive industries a number of repetitive tasks (RT) are performed frequently leading to musculoskeletal disorder (MSD). Due to prevalence of obesity and MSD in South Africa, this paper deals with the impact of obesity on MSD in SA automotive industry. Workers were classified into ten subgroups, each of which obesity status (measured in Kg/m^2) fell within same Body Mass Index . All workers were within active working age group of 25-28 years. Five workers from each subgroup were chosen and subjected to RT. The average RT was considered as the subgroup value. Regression analysis was used to test the relationship between workers' weights and RT.

It was observed that as workers' weights increased, RT increased reaching a maximum, which then starts decreasing with continuous increase in weights of workers. It was concluded that obesity and underweight have negative impacts on RT or productivity.

Keyword: Automotive industry, Repetitive tasks, Musculoskeletal disorders

Introduction
In today's fast pace and highly competitive world, production processes are rapid (i.e. aimed at reducing cycle time) and Musculoskeletal Disorders (MSDs) are common as a result of repetitive works that are prominent in automotive industry [1].
Vehicle manufacturing is a major industry worldwide, accounting for at least 7 per cent of the manufacturing workforce in countries as diverse as the U.S.A., Canada, Mexico, Brazil, Sweden, Spain, Japan, India, and Australia [2]. In general, this sector is characterized by high capital investment in manufacturing facilities and an organized workforce [2]. As in many other industries, musculoskeletal disorders are the largest type of "injury" in the automotive industry. A number of studies have found that MSDs are associated with the physical demands of jobs in automobile assembly and the manufacturing stages (e.g. for engines, upholstery, and so forth) that precede final vehicle assembly [3].
Lacks of attentions to workplace design and work-method design have unfavourable consequences to workers' health and safety, including musculoskeletal disorders, psychological distress, just to name a few [4]. In addition to the resulting human pain and suffering, which cannot be quantified monetarily, there are also increased costs to employers through workers' compensation claims, lost productivity, scrap and decreased production quality, medical insurance premiums, and ultimately the sustainability of a company or even of an entire sector. It has been estimated that the direct and indirect economic burden of musculoskeletal disease in the United States, including arthritis and repetitive trauma disorders, totalled $149 billion in 1992 [4]. However, within individual firms, typically large proportions of these costs often are not specifically identified by traditional accounting methods as they are due to ergonomic problems in the work process. There is evidence that the frequency of work-related musculoskeletal disorders (MSDs) is severely underestimated when relying on traditional administrative data sources such as workers' compensation records and OSHA logs of recordable injury and illness [5].
The current paper investigates on the Impact of obesity on MSDs in automotive industry in S.A. The work was carried out at a local car maintenance or repair workshop. The study involved observing operators while they lift and fit the gearbox. The back and shoulder disorders were recorded by counting the number of lift-and-fit processes that were performed before the operators complained of tiredness or could be seen stressing themselves. The observation lasted for a period of three months.

Method
Body Mass Index (BMI)
Body mass (kg) (measured with an electronic scale [5]) and the body height (m) (measured with metric rule [5]) were used to calculate BMI (BMI (kg/m^2) given by body mass (kg) divided by the squared of body height (m^2).

Participants
Workers from automotive manufacturing based in Pretoria participated in this study and were divided into ten groups. The participants were workers whose jobs required manual force and awkward posture as repetitive operations. All the workers were within an active working age group of 25-28 years. They were divided into the subgroup according to their BMI values and were subjected to repetitive tasks (i.e. assembly of gear boxes). The BMI Values ranged from 17-to-33 Kg/m^2 with an interval of 1.5Kg/m^2.

Data collection and analysis
MSD is understood as a sign of abnormal condition (abnormality) experienced by employees, typically expressed in the form of body pain or other related illnesses. MSD, which is a form of physiological disorders typically causes change in efficiency of the workers. Since time is used by Industrial Engineers as one of the parameters of measuring efficiency, cycle time was used to quantify efficiency in this report. As such the measure of MSD was cycle time which was quantified using stop watches. The onset of MSD was identified by the fact that a task cycle time started becoming longer than (i.e. changing from) those of the previous ones that were constant.

While onsite data collection process was performed, others sources of information were consulted such as worker's medical records. Data was collected from a database on the medical records of the company's clinic for acute and chronic musculoskeletal disorders. Information about symptoms and respective working environments were obtained by employing work-study techniques. The two work-study techniques (method study and work measurement) were used to systematically record and examine the manner in which the work was done necessary improvements [6]. Before any recording was made, according to these techniques, a series of observations were conducted to satisfy the choice of job selection for study and application of techniques. The workers (or patient) were then referred to the medical practitioner for medical examination.

Regression analysis technique
Regression analysis was used to establish the relationship between the two variables, which are the workers' weights and the number of repetitive tasks that a worker could bear before the MSD was noticed per shift (to avoid influence of resting) for workers from each BMI subgroup. Two sets of data were obtained, which can be likened to the use of normal working shift and over time. The first set of data (that can be used to establish a normal shift workload for workers of the specific weight group) was when the workers could easily recover

from MSD through simple resting after shift. The second set (see Fig.1), which could be used to study the impact of over-times, was when the workers were asked to do further jobs after they started experiencing the MSD, and the maximum number of repetitive tasks that they could perform with no further ability to perform more tasks were recorded. *Since most of the workers were around the same average height, the weights of the workers were used* during analysis of results as depicted in Figure 1. Subsequently, the cost implication of MSD to the company was investigated and is presented in Figure 2. The cost implication was obtained by getting unit product done cost multiplied by the number of repetitive tasks and the cost incurred due to MSD or over-time.

Results and Discussion
It can be observed from Figure 1 that as the weights or the workers were increasing the number of repetitive tasks that they could perform before MSD were increasing. The maximum number of repetitive tasks was measured for workers whose weights were around 70Kg. The number of repetitive tasks started decreasing with increasing weights (obese) workers (see Fig.1).

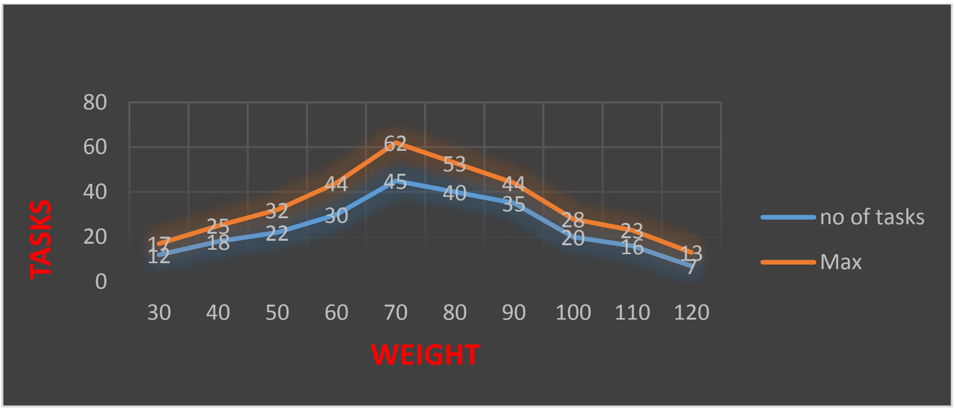

Figure 1: The relationship between tasks and weight

The cost implication, as depicted in Fig.2, indicates that as the number of repetitive tasks increases the cost of job also increases linearly until the onset of MSD were the cost start increasing exponential with additional repetitive tasks. It can then be seen from this Fig .2 that underweight and overweight (obese) workers will cost the company more as the plots of their costs are above those of normal weight workers who have weights of 70Kg.

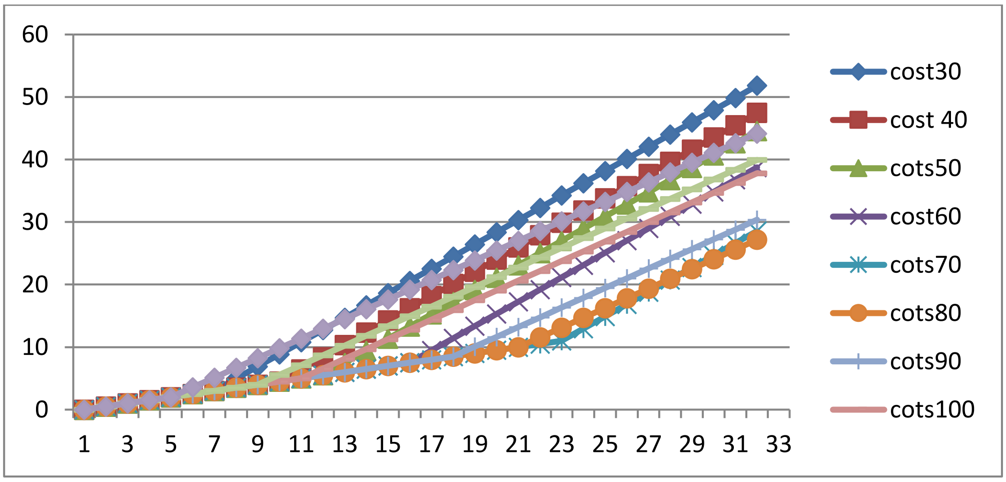

Figure 2: The cost implications of MSD and repetitive tasks

The prevalence of repetitive tasks in automotive industries escalates the risk of musculoskeletal disorders on employees and would increase in the long run due to cumulative exposure [7]. The results of this study (Fig. 1) indicates that those employees with a normal weight can perform tasks assigned to them for a standard shift until excess overtime tasks with minimal amount of fatigue, and those with low or high BMI level experienced deteriorating level of operations leading to more MSDs, ultimately increases the costs to employers.
In performing tasks, generally there is a standard time set for an operation, and repetitive tasks are no exclusion to this. Workers must follow a predetermined pace [8]. With a higher work pace, the levels of muscle activities

are also higher, which contribute to muscle fatigue and MSD risks [6]. Muscle fatigue is a stage, which the muscle is not able to sustain the required force or work output level [3]. Accordingly, figure 1 indicates that a general increase in the number of repetitive tasks was associated with the decrease or reduction of employee performance for those with weights between 30kg – 45kg and 95kg-120kg; and sustaining the active working weight of between 50kg and 90kg should be the better option.
Most industries prefer over-time as opposed to hiring more staff member because the cost-to-company when a company employs more employees is higher due to financial reasons [9]. The impact of overtime has been observed to be problematic to all employees particularly to those underweight and overweight persons/employees as classified by BMI [10]. A person whose weight is between 30kg – 45kg and 95kg - 120kg, when subjected to more repetitive tasks, would require longer resting break to return to their initial state of muscle function. This would cost the company as the productivity rate would reduce.

Conclusion
The results of this study showed that both overweight (i.e. obesity) and underweight have negative impacts on number of repetitive tasks or productivity [11]. It was observed that as workers' weights increased, RT increased reaching a maximum, which then starts decreasing with continuous increase in weights of workers. It was concluded that obesity and underweight have negative impacts on RT or productivity.

Therefore, the employee's health and safety were affected and that reduced their performances and subsequently affected the company productivity. This research ignites the desire to know how lack of performance resulting from MSD affects the employer with regards to employee's productivity

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PHYSICAL ASSET MANAGEMENT MATURITY IN MINING: A CASE STUDY

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ABSTRACT

Successful implementation and execution of asset management strategy is found to be a critical element in driving value, which depends on physical assets' performance. This paper shows that strategic asset management targets measured as AM Maturity are often not attained. This study identifies key issues that prevent mining organisations from attaining the desired level of Asset Management Maturity. A qualitative methodology was utilised on a single case study design in order to investigate a particular phenomenon which is Asset Management Maturity at "A-Coal" site. The study revealed the following key issues: lack of strong Asset Management leadership; lack of a favourable organisational structure which will provide Asset Managers with credibility and the authority to make decisions in support of organisational objectives; no leadership support; and a lack of training limits the benefits that can be realised from improvement initiatives which motivated, committed and enthusiastic employees will be delivering. In addition to these challenges are organisational culture and a certain level of employees' competitiveness in the field of asset management.

Key words: Asset Management (AM), AM Maturity

1 INTRODUCTION

Asset Management is defined as the coordinated activity of an organisation to realise value from assets, where an asset is defined as an item, thing or entity that has potential or actual value to an organisation [14]. Societies are faced with massive challenges of managing assets in their endeavour to identify the lowest cost or high return on investments; understanding the lifecycle costs, as well as extending the life of these assets. If these assets are not managed effectively it will be a wasteful exercise. AM is important especially for asset intensive organisations, like mining, because it can assist to improve financial performance; to make informed asset investment decisions; to improve services and outputs; where some benefits can be directly quantified such as reducing capital and maintenance costs [14]. Additional benefits [6] are the potential reduction of the health impacts and the safety risks as well as minimising the environmental impact of operating assets. Managing assets assists mining organisations to reduce legal risks; improving the regulatory performance; thus maintaining and improving the reputation of the organisation.

Asset Management Maturity is a measure of how well an organisation is capable of optimising and sustaining the performance, risk, investment and costs related to their assets [11]. The global forum on maintenance and asset management GFMAM [8] defines AM maturity as the extent to which the capabilities, performance and ongoing assurance of an organisation are fit for purpose to meet the current and future needs of its stakeholders, including the ability of an organisation to foresee and respond to its operating context.

The purpose of this study is to identify key challenges experienced in a mining organisation in South Africa inhibiting it from achieving the desired level of Asset Management Maturity. A qualitative case study method was chosen. Three data sources of evidence were used to obtain information, these included; archived documents, semi-structured interviews and participant observation. Data was analysed using content analysis.

2 LITERATURE REVIEW

The purpose of this chapter is to, outline the fundamental concepts in asset management including issues associated with implementation and execution; and to, uncover the key challenges experienced in mining in relation to physical asset management maturity. A typical AM framework to measure Asset Management maturity will be presented and compared with other AM Maturity frameworks. This chapter is correspondingly used as a foundation for the development of the questionnaire in the next chapter.

2.1 Asset

An asset is an item, thing or entity that has potential or actual value to an organization. The value will vary between different organizations and their stakeholders, and can be tangible or intangible, financial or non-financial [14]. Any item of economic value owned by an individual or corporation is defined as an asset [6]. PAS55 [22] defines an asset as a plant, machinery, property, buildings, vehicles, and other items that have a distinct value to the organisation.

2.2 Asset Management

The activities of asset management start when there is an existing tangible asset and it is being operated [12]. There are four key areas to be developed to improve AM practise namely [5]:

Effective decision making - Improving decision making across the organisation, through better use of longer term financial, and non-financial, metrics to deliver value for all involved in managing assets;
Organisational changes – The organisation must evolve to enable better decision making and share knowledge and skills, breaking down silos and boundaries resulting from functional specialism and multiple cost centres;
Data capture, sharing and standards - Improving the quality and availability of the information available for decision making and
Predictive Analytics - New information technologies are available to improve AM, but several barriers prevent their effective use.

AM is best seen as an integration framework that uses any combination of tools and techniques to achieve these aims, provided that they are appropriately applied and deliver added value [11]. AM embodies the important principle of proportionality or fitness-for-purpose, so any objective definitions of capability and Maturity must recognise context and are appropriate, possible and worthwhile in such an environment [29]. The purpose of the Physical Asset Management function is to provide resources and expertise to support the acquisition, in-service support and disposal of the physical assets required by the organisation. More precisely, the asset management function, when present at Company level, should provide inputs to asset planning, take a role in major acquisitions and developments and provide the systems and facilities needed to support assets throughout their life [9]. An asset management system provides a structured approach for the development, coordination and control of activities undertaken on assets by the organisation over the different life cycle stages, and for aligning these activities with its organisational objectives [14].

2.3 Asset Management and Maintenance Management

Maintenance management focuses more on the short-term activities, where the primary purpose is to determine which activities are performed on which asset, including the cost of maintenance. Asset management, however, is intended as a proactive approach to managing organisational investments over the longer term. Maintenance management should be imagined as a subset of asset management [25] Asset Management achieves the realisation of AM which has evolved from maintenance management to provide a holistic approach to managing the life of physical assets [20]. The terms "maintenance management" and "asset management" are frequently used interchangeably in mining industry when, in fact, they should be viewed separately [25].

2.4 Asset Management (AM) Maturity

AM maturity can also be defined as an extent to which the capabilities, performance and ongoing assurance of an organisation are fit for purpose to meet the current and future needs of its stakeholders, including the ability of an organisation to foresee and respond to its operating context [8]. It refers to the organisation level of Asset Management practice [25]. AM Maturity is also defined as a measure of how well an organisation is capable of optimising and sustaining the performance, risk, investment and costs related to their assets [11]. The importance of measuring, knowing and understanding Asset Management Maturity practices aids organisations to optimise their business performance, through reduction of risks, higher returns on assets (ROA) invested in and reduced costs [11].

Asset Management Maturity knowledge helps asset owners to understand if they are really getting value from the asset management systems put in place in ensuring assets perform as expected, reliably and safely [12]. Increasing asset management maturity may deliver the following benefits [8]: Aligning individual activities and behaviours that achieve the organisation's objective; improve both financial and non-financial results; provide clarity about the goals and direction of the organisation; optimise lifecycle cost; aligning risk with stakeholders' risk appetite; and enables benchmarking, even between organisations managing different assets in different operating environments. There are three important questions that a company should be asking with regards to AM Maturity [21]:

1. Where are they? – Mining organisations should establish a baseline level that indicates their current assets, how well they are being taken care of and how these assets contribute to supporting service delivery.
2. Where do they want to be? – What are the mine's plans for the future and what assets are required in order to support current and future service needs? Having this in mind the organisation will set targets for improving the condition and performance of assets so that they match future requirements or needs.
3. How do they get there? – How will the organisation move from the current to desired level of AM Maturity? The prioritisation of future investments in assets will be important to match their future service needs.

2.5 AM Maturity Models

An Asset Management Maturity model can be viewed as a set of structured levels that describe how well different processes of an organisation are able to produce the required outcomes in a reliable and sustainable way [25]. There exist similarities between AM maturity frameworks because most of them were developed based on PAS 55, the first Institute of Asset Management (IAM) maturity scale to be published. The AM framework used for this research has level 1 to level 5, starting from Fire-Fighting, Stabilising, Preventing, Optimising and Excellence [3]. An overview of AM Maturity levels definition is described below [25]:

Level 1 - an organisation has a clear Asset Management vision. This includes a policy statement that provides top-down direction regarding Asset Management expectations, a strategy that summarises the methodology for completing the policy, and a plan that details the people, activities, and resources needed for addressing the policy and strategy.

Level 2 – an organisation has one or more asset inventories with condition data that support multiple business processes. There is a well-defined owner and processes for all this data to maintain its reliability.

Level 3 – The organisation can conduct a risk analysis or a performance assessment to evaluate the assets' current performance and to assess how well the organisation is doing against the policy and strategy objectives.

Level 4 – At this level, an organisation can set priorities amongst and throughout all asset classes based on risk and performance data available. This is important in the development of the capital program, operations and maintenance budget.

Level 5 – Herein an organisation can apply performance modelling and other analytical tools to optimise how funding is allocated to all the organisation's asset classes.

2.6 Key AM Implementation Steps

Implementing the changes suggested to become a mature asset management organisation requires a well thought out planning and execution strategy. Organisations that are highly productive, they typically place more emphasis on executing strategy than formulating it [16]. These are the principles for implementing AM [25]:

- Understand the organisations asset management drivers – Organisations undertake an AM improvement program for various reasons. The organisation should develop an implementation approach that maintains a focus; however, the approach should be flexible enough that it can shift focus as priorities change.
- Build upon existing strengths and practices – The organisation should leverage its departments' existing asset management activities, identifying best practices and lessons learned with one asset class and applying these practices and lessons to others.
- Provide value immediately – Through incremental implementation activities, an organisation can quickly achieve results that demonstrate the value of implementing improvements to asset management practice and provide momentum for future activities.
- Recognise that asset management is a process – Identify the core processes that provide a starting point for developing an asset management process that will pay dividends in improved service delivery and asset sustainability.
- Prioritise people, tools, and information – Asset management is, at its core, about data-driven management, so your managers should identify the people who can understand and lead this change initiative and establish the data and develop tools that best support the organisation's decision-making processes.
- Invest smartly – Managers should identify the investments that will provide the best "bang for the buck" and only if these investments support the organisational strategy.
- Develop your human resources – Managers should identify the appropriate skillsets needed to implement the asset management strategy and invest in those people with recognition, incentives, and training.
- Provide top-down leadership and assign clear ownership for asset management activities – Strong leadership will set expectations and accountability for implementation, while your asset owners should "own" and drive implementation by developing and implementing lifecycle management plans.

2.7 AM Challenges and Associated Risk

Some of the institutional and technical challenges faced within organisations are: to secure senior management support and leadership throughout the period of asset management implementation, which may extend over several years and to improve the life cycle analysis methods and incorporate them fully into planning and programme development [19]. Repenning & Sterman [18] suggests that the inability of most organisations to gain the full benefits of the implementation of an innovation lie in the manner in which this improvement programme has been introduced to the Company and how the process reflects the whole system. One of the main practical challenges to the improvement of AM practices in organisations is the disconnect between tactical and implementation groups [33]. Management Involvement and commitment are the most essential fundamentals in adding any of the desired productivity improvement initiatives [1], [4], [10]. Since strong leadership permeates a vision and strategy for generating, while permitting a flexible organisational structure. Good leadership ultimately encourages effective skills and knowledge enhancement amongst its workforce [27]. Maintenance is technically considered as a "necessary evil" and not pertinent at the strategic level as a business issue [7].

High performing organisations are those with a culture of sustainable and proactive improvement [27]. The Asset Management Council of Australia (AMC) defines Asset Management Culture as: "the extent to which all levels of the organization have the knowledge, skills and commitment to achieve the documented asset management goals of the organization". Organisational capabilities are critical for addressing the cultural challenges within the organisation [26]. Most people think that organisational culture is the biggest single obstacle to improving the asset performance [21]. This requires the training of people to utilise the programme, financial resources that organisations are often not willing to invest. Risk management is the identification, assessment, and prioritisation of risks followed by coordinated and economical application of resources to minimise, monitor, and control the probability and/or impact of unfortunate events or to maximise the realisation of opportunities [13]. There are other risks involved which if not addressed properly will inhibit AM growth, these risks contribute to an organisation's failure to manage its assets optimally. These risks are overly exposed for example [17]:

1. If asset owners don't know what assets they have;
2. If they are under or over maintaining their assets;
3. If operators are not properly operating their assets;
4. The asset risk at hand with regards to assets is not managed properly
5. And Sub-optimised asset management systems are in place.

3 RESEARCH METHODOLOGY

The primary approach utilises a Case Study design as the research investigates a particular phenomenon, Asset Management Maturity, in a particular context, the case company, "A-Coal". The essence of a case study is the tendency among all types of case study as it tries to illuminate a decision or set of decisions: why they were taken, how they were implemented and with what result [30]. "A-Coal" is a coal washing plant situated around Ogies in Mpumalanga a small town outside eMalahleni. It is a 50/50 percentile joint venture of "Client A" and "Client B". The plant is designed to beneficiate 16 million tons of ROM coal per annum at 2400 tons/hour. This study sought to establish the key challenges inhibiting the achievement of the desired levels of AM Maturity in A-Coal by:

- establishing the importance of stakeholder's involvement when it comes to executing asset management activities and the improvement of AM Maturity.
- assessing employees' attitudes, culture, perceptions and understanding of AM and its associated benefits for properly executing Asset Management Processes.
- analysing A-Coal employees' understanding of Change Management, Asset Management and Business Risk Management.

A qualitative approach was chosen because of direct and personal contact with the employees at the A-Coal site in the natural setting of the phenomenon (AM implementation and execution). A summary of data source used is detailed below:

- Documentary evidence in the form of information from A-Coal when the initial Maturity assessment was conducted, implementation took place, and all the other annual assessments were captured with findings. The initial strategy, policy, and master plan were also captured.
- Semi-structured interviews with thirteen interviewees were conducted at the case site (excluding the pre-test interviews). The interview sessions duration ranged from 15 to 45 minutes. A set of interview guides with a list of questions were crafted in such a way that they are mostly the same for all interviewees; however, some were restructured differently as follow-up questions emerged during the sessions. The profile of the interview participants was from senior, middle, and lower management, as well as engineers and planners. A set of interview guides that summarised a list of questions following Wengraf's Pyramid Model [28].
- Participant Observations: The researcher worked for over three years at case site as an Asset Care Centre Manager offering asset management services, and has been involved in meetings, when certain initiatives were implemented, but only observed and documented some of the things that he was exposed to but also of interest to the study. The data collected through this method also contributed as a trigger to this study.

Content analysis was used to analyse the data. This method relies on the subjective interpretation of the content of text data through the systematic classification process of coding and identifying themes or patterns" [23]. The process is designed to reduce collected data into categories or themes based on valid inference and interpretation [24]. Analysing data from three exclusive sources ensured data quality, integrity, reliability and validity of the research.

4 RESULTS AND DISCUSSION

This chapter presents the processed data from the documents, interviews and participant observations. The current state of AM and AM maturity is first outlined leading to the initiation of this study. This largely relies on documentary data sources. Subsequently, the data from the interviews and participant observations is analysed with the objective of answering the research question for this study. The strategy data received is qualitative by its very nature, and was examined by the researcher and any change in the organisational strategy, mission and goals, which can be triggered by internal or external influences mainly from the shareholders (Client A and B as referred to in the interviews transcribed works). Data extracted from the transcribed works contained both but mostly qualitative than quantitative data. As for Asset Management Maturity, this is represented as a figure or can be expressed by describing the level of Maturity (such "fire-fighting, or excellence").

4.1 Current State-Analysis

The following describes the state of AM in A-Coal prior to the start of this study. In this phase of analysis, the focus was on analysing data received from archived documentation of the implemented AM systems at A-Coal site. This data provided a holistic understanding of the implemented system detailing the financials, methodology, framework used, assessment results conducted, developed AM Strategies, AM Policy, setting up AM Objectives and the AM Master-plan, with AM activities that were set to be actioned during the initial year of implementation, based on the AM gaps identified. The establishment of technical and steering committees to drive AM activities occurred during this period. The objective of this analysis was to provide a brief background of A-Coal site's context, AM capabilities and a description of the AM implementation leading to this research study.

Company B, the AM consulting company which was employed to assist Company A (asset service providers) who operate and maintain the plant and the implementation and execution of AM. Company B has developed AM Maturity framework which is aligned with the newly adopted ISO55000 and with GFMAM 39 Subjects. The model used is called Asset Management Improvement Planning (AMIP) and has grouped the Key Performance Areas into 17KPAs. Company B assessed A-Coal AM maturity in relation to best practices and the associated Key Performance Indicators (KPIs). Table 1 below illustrates the initial AMIP assessment results that were obtained against the target set for the organization to be achieved within a 12 months' period.

Table 1: A-Coal initial AMIP assessment results and set target [3]

	BP Scores		KPI Scores	
	BP Target	BP Maturity	KPI Target	KPI Maturity
Strategy Management	4	1,6	4	4
Information Management	4	2,5	4	2,8
Technical Information	3	2	3	2
Organisation and Development	3	2	3	3,8
Contractor Management	3	2,4	3	2
Financial Management	3	3,1	3	3
Risk Management	3	2,3	3	3
Environment, Health and Safety	3	3,3	3	2,5
Asset Care Plans	3	1,5	3	2,7
Work Planning and Control	3	1,9	3	2
Operator Asset Care	3	2,4	3	2,5
Materials Management	3	2,2	3	2,4
Support Facilities and Tools	3	2,9	3	3,3
Life Cycle Management	4	2,7	4	4
Project and Shutdown Management	3	2	3	3
Performance Measurement	3	2	3	1
Focused Improvement	3	1,9	3	3
Average	3,18	2,28	3,18	2,76
	BP Target Average	BP Maturity Average	KPI Target Average	KPI Maturity Average

The average Best Practice (BP) obtained was at 2.28 of a possible 5 but the worrying thing was that the key maintenance areas of asset management were scoring the lowest (such as Strategy Management, Asset Care Plans). The desired average AM Maturity BP level was set at 3.17, with only three KPA targets set at level 4 and the rest of the BP KPAs targeted for level 3 for the next 12 months. Some of the supporting maintenance processes (finance, safety,) were well established and working well. However, a lot of asset history was lost in the initial phase, although a basic Enterprise Asset Management System (EAMS) was in place with standards and business processes documented. There were basic asset care plans "asset maintenance strategies" which also needed to be improved. There was also a basic material manager function under control [3]. On the other hand, Company A did not have a consolidated AM Policy or Strategy and a platform to discuss AM issues and goals as part of the shareholders' operations review. The EAMS systems implemented was not configured as per documented standards resulting in under performance or sub-utilising the system. With the shortage of staff complement it was a challenge for the operation to escape the fire-fighting mode of operation. The planning department needed to be enhanced from a one-man operation in capacity and capability [3].

There were limited asset management KPIs available compared to production related KPIs which were readily available. These KPIs were not broadly communicated amongst all the employees on site. Some optimisation that needed to occur, was at the stores department where stock levels and critical spares needed to be identified. Only a very limited structured improvements process was in place. This included the use of routine failure analysis on all breakdowns experienced. There was very little control in the process of updating asset manuals and drawings [3].

At the start of the implementation phase the AM Steering Committee and AM Technical Committee were established to drive and coordinate all asset management activities. The stakeholders of the meetings also took responsibility for change management during the implementation of the ACC [3]. The members of both the technical and steering committees were trained in the overview of asset management to create a knowledgeable forum where all major decisions regarding asset management can be made. Company A employees were trained in generic ACC principles and practices in preparation for the execution phase [3].

4.2 Semi-Structured Interviews

The semi-structured interviews were used to explore any problems and successes related to the implementation and execution of asset management. They were also used to gain understanding of some of the data obtained from the documentation with regards to the current execution of AM. The most predominant themes which emerged during the analysis of the interviews are:

1. Reactive mode of operation;
2. Asset Management Understanding;
3. Stakeholders' involvement;
4. People's training and development;
5. Organisational Culture;
6. Skills Retention and Skills Transfer.

4.2.1 Reactive mode of operation

The Asset Management programme was not implemented during the commissioning phase of the A-Coal [3]. It was discovered that a call for AM implementation was made because investors realised that the plant was operating in a fire-fighting mode. They commissioned A-Coal without a developed AM strategy, without adequate documented proper maintenance strategies. This, in turn, indicates a reactive mode of operation because such documentation should have been implemented before the plant was operated considering that it is a new plant. It is considered a reactive mode of operation for a plant to be commissioned without an appointed Engineering manager. The asset management department consisted of one person who was not capable to execute the AM activities as set by Brown and Humphrey [3].

4.2.2 People's training and development

Leadership and management play a vital role in driving change in an organisation. For successful execution of AM activities Company B required strong support from Company A and both the shareholders Client A & Client B. Senior management must play their role in ensuring that all affected by the implementation of AM, are sensitised and well trained for the success of the implementation, execution and sustainability of AM. Company A's employees were trained in generic ACC principles and practices in preparation for the execution phase [3]. However, this will not bring about a total understanding of what AM is to these employees, simply because employees were going through the change process and having to deal with the pressure of being in a fire-fighting mode and the new changes brought in. In addition to that was a mental shift on the way they used to execute their AM activities.

A few noteworthy points can be highlighted as follows; Client A and Client B made a call to have AM implemented two years later after commissioning and this could have been done right at the start of the project. The operations and maintenance staff focused on equipment breakdown rather than on preventative maintenance. The responsible engineering manager was appointed in 2011 which should have been right at the beginning or commissioning phase of A-Coal. A feasibility study should have been conducted at the beginning of the project to understand the skillset required and capacity for driving asset management for an organisation of A-Coal size and nature than to appoint only one resource to drive AM.

AM management should not be driven by a one-man-band show; an organisation should not find itself in a state whereby AM is driven by an individual. Generally, interest is created through exposure. It was found that the majority of the participants interviewed had never received formal AM training. Training must be used as a platform to create interest in the subject in question and as such employees will understand better why they have to do what they opt to do. Training also stimulates people's minds to be more proactive than reactive as it creates an inquisitive mind. Another subliminal finding is the loss of skill, including tacit knowledge. It is a fact that people change position for various reasons. And tacit knowledge is not easy to transfer. These findings can be considered to augment and agree with other challenges mentioned in the literature review [7], [1], [34], [25].

4.2.3 Asset Management Understanding

An important phenomenon occurred when different views and understanding of what asset management from the participants was observed. Majority of the interviewees' understanding of asset management is that an asset needs to be fully utilised, or maximising value from that asset, whereas some of the participants explained asset management as maintenance, tracking and measuring performance. One out of the thirteen participants explained asset management as coordinating activities to optimise asset life cycle cost. Having different views on what asset management is, is not a good start where AM Maturity is concerned and where team work is essential to improve asset management capability. Senior, Middle and lower management must align in working towards improving AM capabilities. This can be seen as a concern where management needs to have a clear vision of why they are driving asset management.

4.2.4 Stakeholder's Involvement

About 75 per cent of the respondents indicated that they are aware of the Steering Committee Meetings (SCM), and 16 per cent of the 13 are attending the SCM. This can be seen as a concern, which hampers the success and improvement of asset management's capabilities when there is no leadership or a lack of leadership's involvement in steering committee meetings. Between 60 per cent and 80 per cent of all companies fall short of the strategic targets that they have set [15]. It is highly desirable to have a certain degree of leadership engagement throughout the Company, long-term focus of management and the strategic team while executing AM activities. In many organisations, focusing the business practices around improved asset management can require a change in the way the Company does business. This means leadership needs to provide a clear direction regarding people's responsibilities. They must also provide suitable accountability mechanisms, develop and follow a structured communications strategy. The steering committee (SCM) and technical committee meetings (TCM) are the platforms that enable such activities to take place

If lower and Middle Management believes that Senior Management is not leading them in the right direction of AM excellence, they will lose trust and commitment to where matters of Asset Management are concerned. And most importantly lose confidence of Senior Management to leading them in AM. A very strong AM leadership is required to drive AM capabilities or Maturity to excellence. An organisation with low Maturity increases the organisation's business risk, because when a Company is matured it will have a strong competitive advantage over its rivals. If Asset Management is not executed properly, the three functions; cost, risk and performance which AM aims to balance will be compromised as such exposing the business risk to be higher.

Changing AM leadership exposes an organisation to high risks for not accomplishing AM activities set to improve AM Maturity. A-Coal experienced this challenge as key asset management position were affected due to staff turnover from the three parties involved. The four key positions that were affected are the following:

- **The Plant manager (Company A)**
- **The Engineering manager (Client A)**
- **The Plant Engineer (Company A)**
- **Asset Care Engineer (Company B)**

Looking at the above staff turnover picture of asset management the leaders within A-Coal fail to present a favourable picture for AM capability improvement. It helps to have a minimal staff turnover within an organisation in order to maintain the level of commitment and execution to AM activities. Woodhouse [29], mentioned that managers often rotate or move every 2-3 years and it can be as worse as 6 months. This leads to employees getting changing messages as AM leaders are changing. It was found that at A-Coal most of the senior managers who were initially responsible to drive asset management and were involved during the implementation of AM were no longer working for A-Coal for various reasons during the period when this research was conducted. It is without doubt that such experience will result in plummeting the enthusiasm of driving AM activities which will hinder AM maturity growth.

None of the senior management and middle management had received formal AM training, such as an overview of asset management, ISO 55000, GFMAM 39 Subjects. It is rather surprising that an organisation can strive to attain a certain level of AM maturity with a leadership that is not fully abreast on current matters of AM. To understand Asset Management one needs to have the love for it and must understand the benefits that can be reaped if AM is executed properly. But having the passion only, will not bring about changes and improvement in the AM Maturity of an organisation. Passion combined with AM understanding and knowing the benefits associated if AM is executed properly are the ingredients to AM Maturity improvements and success and of course implementing the required actions.

Prior to AM implementation Company A had standards developed for the use of EAMS, without an AM Strategy, AM Policy or AM Objectives. During implementation these documents were developed and then became static documents rather than dynamic. These documents had never been updated from the time they were developed. The documents are supposed to be dynamic to align with organisational objectives, which supposedly gets updated at least on a yearly basis [3]. Strong AM leadership which understands how AM contributes to an organizations competitive strategy and how to translate an organization's objectives to AM activities is a must for the success of AM activities' execution and the improvement of AM Maturity thereof [8].

4.2.5 Organisational Culture

When establishing an organisation's asset management system, consideration should be taken on internal and external context. As ISO 55000 states that the internal context includes the organisational cultures and the environment as well as the mission, vision and values of the organisation. Stakeholders' inputs, concerns and expectations are also part of the context of the organisation [14]. Stakeholders' influence is key to setting rules for consistent decision making and also to contribute in the formulation of organisational objectives.

Organisational structure plays an important role in the execution of AM activities and success thereof. Structures shape the way in which assets are managed across the business and for the whole life cycle of the assets. A silo mentality obstructs the efficiency and effectiveness of AM as compared to team work. Key to asset management success is gaining the commitment from top management to drive change in organisational culture.

Leadership needs to improve their understanding of how good asset management contributes to achieving organisational objectives. Once leadership understand this, they need to encourage it throughout the life of the plant and across the organisation by encouraging system thinking and working towards eliminating organisational limitations to improve AM practices. An improvement in AM Maturity requires an organisational culture shift from reactive to a proactive mode with a culture of proactive improvements efforts. Employees must also have pride in what they do, especially if they understand the benefits of AM. It is important that all employees understand the importance of AM and their relation with business risk. There is no distinct link between AM maturity growth and business risk. However, an improvement of how well organisation is able to carry out AM activities indirectly influences the risk that the business is exposed

The results obtained from the study indicate that there is some alignment with what was found in the literature as Markow & Rackosy [19] stated that some of the technical and institutional challenges faced within organisation is securing senior management support and leadership throughout AM implementation. Management needs to supports change and execution of AM to realise improvement in AM maturity. A culture where all the levels in the organisation have the knowledge, skills and commitment will help achieve asset management goals. If the organisational culture is not supportive and personnel don't have pride in taking care of the asset they are looking after AM execution will fail. Without senior management support and commitment attempts of implementing AM with not succeed. Lack of senior management buy-in can also mean that AM training will not be allocated any budgets or minimal at best. It was found that at A-Coal most of the senior managers who were initially responsible for driving asset management and were involved during the implementation of AM were no longer working for A-Coal. In essence, these inconsistencies and lack of AM continuity with new management will hinder AM maturity growth.

4.3 Summary of Findings

The study aimed to identify challenges faced by mining organisations for not attaining their desired level of Maturity, herein is a list of findings compiled after an analysis was made from the various sources used.

1. The current AM Organisational structure has limitations to the improvement of AM maturity growth. Asset managers are currently reporting to Asset service providers instead of asset service providers to repot to asset managers [2].
2. Lack of alignment between organisational objectives and operational activities. (AM strategy has never been updated since it was developed to align with business objectives. Therefore, poor communication of the Company objectives to translate into AM activities) [3].
3. Company A management supports Technical Committee meetings. Through lack of management backing they don't fully support Steering Committee meetings.
4. There is a general lack of knowledge and understanding of Asset Management principles from management.
5. Lack of systems which resulted in key man/woman dependencies syndrome. (AM initiatives are driven by individuals and skills retention).
6. Poor management support to drive AM capabilities of employees. Employees have training matrices which focus on technical skills development.
7. Resistance from people to do the same things in a different way, as AM was introduced.

5 CONCLUSION

The identified key challenges have been noted not only to have surfaced from the execution stage, but also what happens during the implementation of Asset Management plays a massive role. It has been cited in this study that there are many challenges and issues faced with the implementation of Asset Management, little has been written with regards to challenges faced during the execution phase of AM. This study maintains that the key issues identified prevent mining organisations from attaining the desired level of Asset Management Maturity which is; lack of a strong Asset Management leadership; A favourable organisational structure which will provide Asset Managers with credibility and the authority to make decisions in support of organisational objectives; No leadership support; and a lack of training limits the benefits that can be realised from improvement initiatives which motivated, committed and enthusiastic employees will be delivering.

In addition to these challenges are organisational culture and a certain level of employees' competitiveness in the field of asset management. It is noted that there is an indirect correlation between Asset Management Maturity and Business Risk. An organisation with low level of Maturity it would mean they are operating in a reactive mode. Organisations that execute reactive activities are doing a minimum of planning or planned work (pro-active). Organisations that operate in a proactive mode are most likely to survive rather than those in reactive mode, thus, exposing the organisation to a high risk of failure.

Continuous improvement is the core of Asset Management. Challenges identified during the study at A-Coal are not unique to the case site, and are surely similar to challenges experienced in some other organisations.

Future work in some other organisations or industries on different sectors could lead to a wider spectrum of challenges identified at A-Coal in order to develop a more solid base of the key challenges that hinder organisations from attaining their desired level of asset management Maturity.

5.1 Limitations of Research Findings

One of the limitations of this study is that it was based on a single case study. There is always a possibility of the researcher making errors when dealing with qualitative data due to the imprecision of the data, interpretation, presentation or analysis. Given the methods used to collect data, especially from interviews, errors such as the possibility of poor recording, cannot completely be eradicated. It could happen that one single data could be interpreted twice or misinterpreted completely. Apart from the fact that this is a single case study and the sample was not well represented, especially where only one position participated, such as Finance Manager, there can only be one Finance Manager in an organisation. With these limitations in mind, the findings can still be compared to similar studies. The analysis depended on a single point of view of the researcher, which could be a weak point or distort the results or misinterpret participants' opinions and expressions.

The findings or results of this study could be improved and validated by future studies, which could take place in larger samples or multiple case studies. The aim is to generalise whatever could be generalized in mining, as key challenges that impede the AM Maturity improvement as desired. And this study could still be expanded not only within mining, but to other sectors, such as manufacturing or public sectors.

5.2 Industry Significance

To mature an AM process costs money and time, and AM benefits are not realised immediately, thus Senior Management might not give it priority of implementation or spend the monies required in relation to the AM initiatives. This is probably one of the reasons why senior management does not really commit, as they do not clearly see how their investment in improving the AM system/process will benefit their organization financially. Therefore, it is extremely important to pick a few KPAs which are in line with organisational objectives, ensure availability of resources and focus on those, once the desired Maturity has been attained, then one can pick the next set of KPAs or aiming for higher target on current KPAs driven or of focus. It is also important to ensure that a proper balance is attained since the KPAs are not in isolation and some could be linked. Following a structured and focused approach to improving AM Maturity could move the organisation to a more competitive position in the mining industry, and will provide results in the organisation which will have the following advantages:

1. A more focused and effective approach in executing AM activities;
2. An easy to follow translation of organisational objectives to AM activities;
3. Employees at 'coal-face' level will have a clear understanding of why they do what they are doing and how it contributes to the bigger picture for the organisation and what that means to them;
4. A proactive organisational culture can be developed.

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THE EFFECTIVENESS OF THE INTERNAL QUALITY AUDITING AT A CABLE MANUFACTURING COMPANY IN SOUTH AFRICA

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ABSTRACT

This is a case study that investigates the effectiveness of internal quality auditing at a South African cable manufacturing company, hereafter referred as Cable Manufacturer. Cable Manufacturer is a supplier of a wide range of electrical cables for household and industrial applications. It receives raw material in the form of copper rod, 7.9mm diameter, and draws it to various conductors ranging from 0.205mm to 2.59mm in diameter. The conductors are then bunched into strands varying in cross-sectional area from 0.5mm^2 to 70mm^2. Cable Manufacturer is ISO 9001 certified. Data for this study was collected by a University of Johannesburg Industrial Engineering Student through interviews with employees, observation of processes and review of company documents. The research revealed that Cable Manufacturer's internal audit team does not adhere to set audit schedules. Moreover it does not have control on the system thereby resulting in line managers not adhering to plans. It focuses on compliance as well as continuous improvement audits. These findings have an impact on the company's growth and its ability to eliminate waste. Lastly, the study contributes by suggesting the internal quality auditing approach that Cable Manufacturer should adopt.

Key Words: Cable Manufacturer, ISO 9001 quality system, Internal quality Auditing, competitiveness, Customer specifications

1 INTRODUCTION

Cable Manufacturer is one of the leading cable manufacturers in South Africa. It manufactures an extensive range of electrical cables for application in power transmission, power distribution, rail, petrochemical, mining, ports, airports, wholesale, construction and domestic building environments. The company receives raw material in the form of copper rod, 7.9mm diameter, and takes it through a cable making pipeline that involves drawing, annealing, bunching, insulation, layup, bedding, armouring and sheathing. Figure 1 shows the schematic diagram of the cable making process flow in the company.

The company is one of the first organisations in South Africa to be awarded the South African bureau of standards (SABS) quality assurance certification, and has been ISO 9001 certified since 1991. Cable Manufacturer takes pride in its ability to identify and satisfy customer needs. The company serves on a number of South African bureau of standards (SABS) working groups. It produces an unarmoured cable designed to reduce the propagation of fire. Cable Manufacturer is listed with underwriters laboratories of United Kingdom.

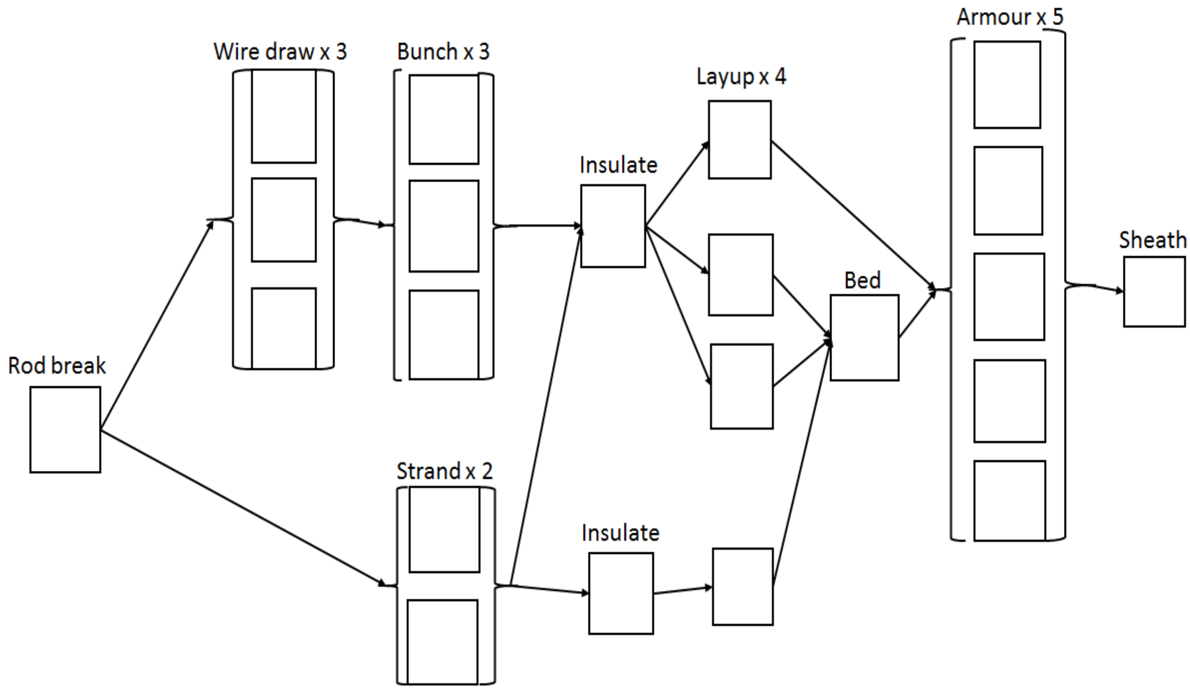

Figure 1: Cable Manufacturer process flow diagram

This case study investigates the effectiveness of an internal quality auditing at Cable Manufacturer. The focus is on:

- interactions that the internal auditing team does with suppliers, factory management, workers and customers;
- internal quality auditing schedules;
- the role of internal quality auditing as a management tool in the company; and
- the contribution of the internal quality auditing in improving quality across the plant.

Internal audit is one of the techniques required by ISO 9000 standard [1]. It is conducted by a company on itself to check for compliance with requirements of the ISO 9000 standard and to report any identified non-conformities as a basis for corrective actions [2]. By eliminating non-conformities the company formally meets requirements for attaining or maintaining ISO 9000 certificate [2]. As the quality management system becomes more mature, the management's expectation of the internal quality audit changes. The purpose and orientation of the internal audit is changed from a compliance assessment to an assessment of continuous improvement and management system [3]. It becomes imperative that organisations concentrate on continuous improvement – in fact, it becomes a survival issue [4]. Continuous improvement is required in product or service quality, timeliness and in costs [4]. Figure 2 illustrates the focus of first party, second party and third party auditing. Second party and third party audits are beyond the scope of this study.

Kapapetrovic and Willborn [5], argue that first party (internal) auditing is a set of interdependent processes or activities using human, material, infrastructural, financial, information and technical resources to achieve objectives related to the continuous improvement of performance. It is an approach used by top management to follow up on the status of a management system and to provide input to improve processes and change attitudes. When the quality system conforms to ISO 9000, it becomes necessary that:

- all areas including the management review and the audit activities are audited;
- internal audits are documented;
- a documented audit plan is prepared for a particular period;
- people carrying out the audits are sufficiently competent;
- results of the audit are documented; and
- audit findings are used as a basis for improvement.

Measuring internal quality audit effectiveness involves the evaluation of the whole audit system, including its objectives, processes and resources. According to Beckmerhagen et al [6], an effective audit is defined as a joint probability that the audit will be:

- suitable to achieve set objectives under a defined scope;
- reliable;
- valuable; and
- maintainable.

In order for an audit to achieve its objectives, Beckmerhagen et al [6] suggest that the following principles should be adhered to:

- any audit should be conceived according to the guidelines specified in the applicable audit standard;
- the auditor should plan the audits; identify the goal, purpose, available resources and possible problems;
- general criteria or standards for proper audit performance should be clarified, such as auditor qualification and competence;
- the evaluation of audit effectiveness must be based on facts;
- the auditor must assess his/her own competence before accepting an auditing assignment;
- the auditor should assess and measure his/her own performance in order to identify improvements;

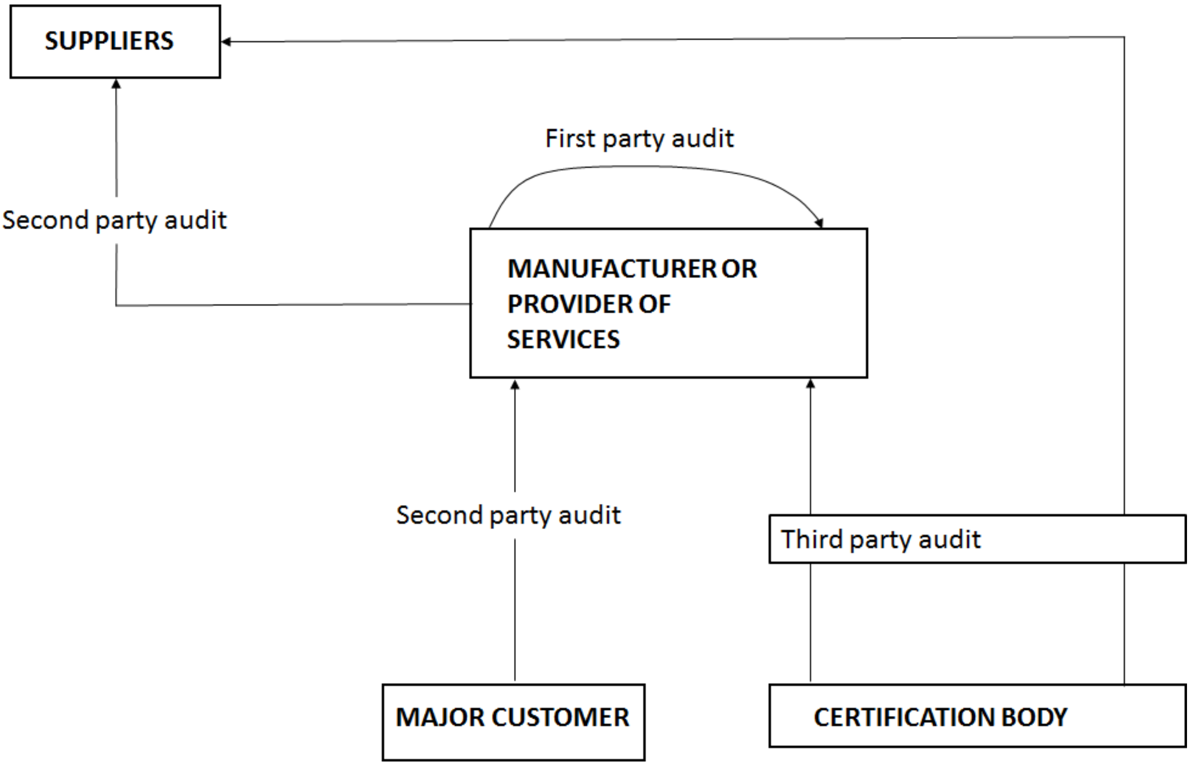

Figure 2: Types of Quality Audits (Orr, [7] Lecture Material- The Queen's University of Belfast)

- reviews of audit effectiveness should be conducted periodically as a matter of procedure or when requested by the auditor. The best time is shortly after a regular audit has been conducted and completed;
- linkages to preceding and subsequent audits should be considered. Individual audits are interconnected in such a way that the output of a preceding audit must be considered as one of the inputs into the subsequent audit;
- the auditor must be able to discontinue an audit when risks become unacceptable;

- an effective audit is aimed at continuous improvement;
- all parties interested in the successful audit performance, including the client, auditee, and the audit management, should be involved in the process of determining audit effectiveness.

Moreover Beckmerhagen et al [6] suggest that the criteria for effective audits are:

- defining adequate and feasible audit objectives, which are approved by all interested parties;
- preparing a suitable audit plan, which is accepted by all interested parties;
- providing adequate resources and time to complete the audit;
- planning and executing the audit by a properly appointed and competent auditor;
- conducting the audit in accordance with recognised audit standards and procedures;
- finding valid non-conformances;
- audit results that lead to corrections and improvements;
- satisfying the client completely in terms of achievement of stated objectives; and
- providing objective evidence to all interested parties that the audit resulted in an improvement of the quality management system.

The purpose and outcome of internal quality auditing depend on the purpose or motivation for introducing the quality management system [2]. A company that has an external motive, only implements a compliance audit, which just checks formal conformity with the quality standard. This enables the company to maintain the certificate [2]. Since the business environment demands not the status quo, but continuous improvement, then an effective audit must be adaptable to the changes in both the quality management system and the overall business [6]. By virtue of being a goal-oriented activity, the audit process and its achieved outcomes (audit performance) are always compared with the planned objectives [6].

The success of internal auditing depends on the co-operation of both auditors and auditees within the audit process. They need to have an open conversation without hiding the facts [2]. Managers should show some understanding in the case of detected non-conformities and regard them as a chance for improvement [2]. Moreover internal quality Auditors can detect cases of good practices and spread these good practices and ideas to other environments within the company.

According to Alic and Rusjan [2], other benefits derived from internal audits are:

- they give an in-depth understanding of the company's quality system and its requirements;
- they help employees become familiar with the other organisational units. This gives better knowledge of the internal "customers" and "suppliers";
- they encourage cross-organisational learning and experience sharing;
- they influence workers' attitudes to the quality of their work;
- when preparing for an audit both auditors and workers review work processes, documentation and records. So they renew their knowledge and possibly find something in the documentation that should be corrected;
- they are a means to stimulate business improvements; and
- they help managers attain the business objectives of the company.

Once an internal audit and review process has been done, a challenge that one faces is prioritisation of the findings. As the number of deficiencies or opportunities for improvement increases, the probability of implementing effective solutions decreases [4]. In this regard one would find refuge in focusing on the vital few areas than to take on too many changes and implement none [4].

2 METHODOLOGY

Data for this study was collected by a University of Johannesburg industrial engineering student. The student had interviews with the quality assurance manager, quality auditors, production manager, procurement manager, and calibration officers. She had attained her Bachelor of Technology in industrial engineering and had just started her studies for an M-tech in industrial engineering. The student undertook the following:

- arranged appointments with departmental heads;
- delivered and explained the contents of the questionnaire;
- collected the completed questionnaire and verified the answers by taking tours of the production floors and offices of the facility.

Moreover, the student collected secondary data from the company working documents and reports that satisfied the research objectives. Lastly a reviewed of journal articles was done to gain knowledge on the current direction of internal quality auditing.

3 FINDINGS

3.1 Principles upon which audits are based

Cable Manufacturer believes that ethical conduct is the foundation of professionalism. All internal quality auditors at Cable Manufacturer are obliged to observe this requirement.

The auditors are bound to report truthfully and accurately the audit findings. The company requires them to report correctly, significant obstacles encountered during the audit as well as unresolved or diverging opinions between the audit team and the auditee.

They are bound to be independent of the activity or process being audited and be free from bias and conflict of interest. This ensures that the findings and conclusions are based purely of evidence found.

There is a drive that encourages that audit evidence generated at Cable Manufacturer must be verifiable.

3.2 Internal audit

Cable Manufacturers does the audits to:

- to verify the effectiveness of the quality management system; and
- meet the objectives of Cable Manufacturer ISO 9000:2008.

To facilitate effective execution of the audits, the company develops audit plans every calendar year. The plan is then uploaded onto the SAP system for easy access by the respective line manager. The plan identifies:

- what is to be audited;
- when audits will be done; and
- who does the audits. Figure 3 does not show the auditor concerned. This is to protect the identity of Cable Manufacturer.

3.3 Audit scope

Internal audits at Cable Manufacturer focus largely on ensuring compliance of products and processes with; the ISO 9000 standard, legal requirements, regulations as well as specific customer requirements. The audits cover marketing, sales, technical department, operation, warehouse, and engineering. The task of improving products and processes is delegated to the continuous improvement department. This is a shortcoming in the effectiveness of the internal quality auditing department. There is however a strong working relationship between the auditing department and the continuous improvement department. Improvement opportunities and updates are communicated across the departments.

Figure 3 shows a representative sample of the audit plan at Cable Manufacturer. The plans are for the 2014 and 2015 calendar years. The figure shows that 2014 was a smooth year and did not have disruptions to the audit plan. However in 2015 things did not go well. There were eighteen planned internal audit activities that were cancelled. Two were not executed as initially planned.

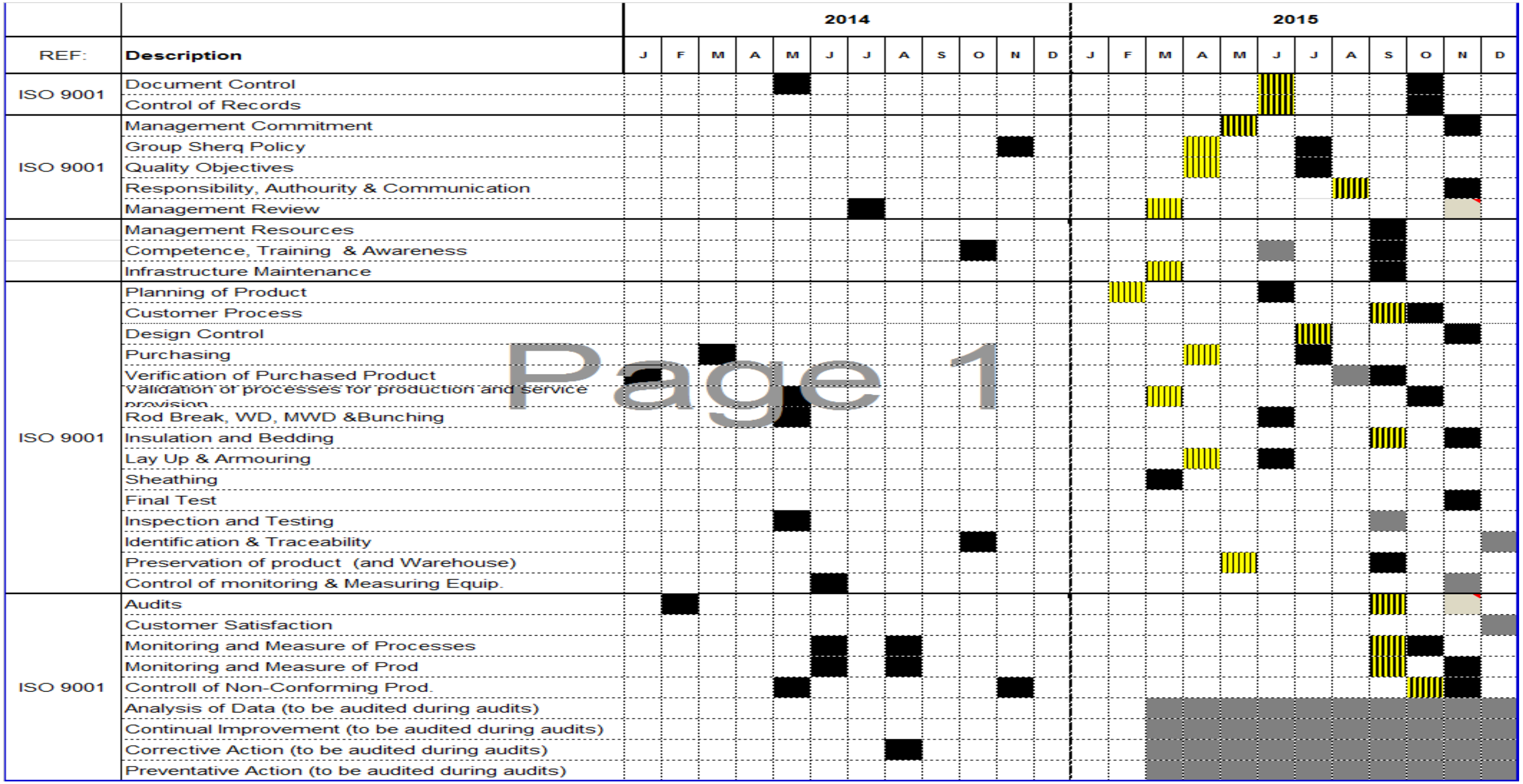

Figure 3: Disruptions to 2014 and 2015 internal quality audits at Cable Manufacturer

Key:
Dark black – means the planned internal audits activity was successfully completed. Note this does not mean it was done on time.
Yellow with black stripes – means that the planned audit activity was cancelled.
Medium black – planned audit activity
Light black - the initially cancelled activity was rescheduled

The disruption in the 2015 plan (Figure 3) were partly due to:

- the resignation of one of the internal auditors in December 2014. A suitable replacement was only recruited in August of 2015;
- lack of cooperation from some line managers. They did not avail themselves on the planned dates. This resulted in the non-fulfilment of the audits.

These disruptions had a negative impact on customer complaints. The period January 2015 to July 2015 saw a major increase in customer complaints. These complaints were associated short lengths, wrong labelling, damage, rough sheathing, tight stripping, wrong cable supplied and oversize outside diameter. These complaints point to the worsening of processes and management system in Cable manufacturer. During that time the performance of the company was getting worse. Table 1 shows the extent to which 2015 customer complaints compare with those of 2014.

The situation started improving from August 2015, when a new auditor arrived. This drop in customer complaint, starting August 2015, shows significance of internal quality auditors in the company.

Table 1: 2014-2015 Cable Manufacturer customer complaints

	Number of Complaints	
Month	**2014**	**2015**
January	7	15
February	4	19
March	7	31
April	9	5
May	14	18
June	18	20
July	12	25
August	43	6
September	17	15
October	20	1
November	18	12
December	11	2

3.4 Corrective Action

Audit findings are presented to respective line managers as feedback for continual improvement and verification of conformance to the quality. Table 2 shows a typical internal quality audit report for the sheathing department. The company classifies the findings into three categories; comment, minor and major.

Table 2: Typical Internal Quality Audit Report (Sheathing department)

Ref No.	Standard and clause number	Finding (classification	Description of Findings
FH230315-001	ISO9001:2008 8.2.3	Minor	Incorrect product loaded onto the Machine Execution System (MES) – 2.5mm^2 x 4 cores instead of 2.5mm^2 x 2 cores as per job shop order (work instruction) number 7621378
FH230315-002	ISO9001:2008 7.5.3	Minor	The label used for identification and traceability at machine PR0352 could not be traced to the previous shop order number and the product size was not recorded on the ticket.
FH230315-003	ISO9001:2008 8.2.4	Minor	The label used for identification and traceability found at machine PR0352 did not have an inspection and test criteria as required on the identification ticket. (QC approval)
FH230315-004	ISO9001:2008 4.2.3	Minor	Extrusion pointer and die selection chart found on machine PR0995, Doc No. MWD 7510 issued by Hamilton Ndlovu, was not controlled in the Aberdare Integrated System, i.e. it was not a controlled document.
FH230315-005	ISO9001:2008 6.4 and OHSAS 1800:4.4.6	Minor	Two electrical switch boxes were open (cover broken) at the machine payoff at PR0995.
FH230315-006	ISO9001:2008 8.2.4 and SANS 1507 part 2	Minor	When running 2.5mm^2 x 2 suffix wiring cable black, the Clinton spark tester model Hf-15AC was set incorrectly at 6 KV instead of 8KV.

A comment is a token of appreciation of the adherence to quality standards. A minor finding is a moderate non-conformance. The standard practice in the company is that all minor non-conformances should have been rectified by the time the next audit is done. Lastly, a major non-conformance is a serious finding and it calls for an immediate corrective action. The affected department is given a maximum of seven working days, from the day an audit report is presented, to rectify the non-conformance.

The categorisation of findings has an added advantage of helping in prioritization of findings. As a rule of the thumb, major findings are prioritized ahead of minor findings. This emanates from the benefits associated with attending to major findings.

Irrespective of the category of the finding, Cable Manufacturer follows a standard approach in effecting a corrective action. Figure 4 shows the steps that were taken in attending to a minor non-conformance number FH230315-002 in Table 2.

Description of finding:
The label on machine PR0352 used for identification and traceability could not be traced to the previous phase. The previous shop order number and the product size were not recorded on the ticket.

Root cause of finding:

Operator at previous phase had not filled in the ticket correctly.

Immediate action taken: (Correction)

The ticket was filled in correctly and then the quality assurance department verified the test status.

Corrective action taken: (Man/Machine/Method)

The significance of the identification and traceability ticket was explained to the machine operator. Moreover the operator was shown how to adequately and correctly fill in the ticket.

Figure 4: Corrective action taken to finding FH230315-002 in Table 2.

To encourage respective departments to take corrective action on findings reported, the internal auditors make follow up at set dates. They close all non-conformances for which corrective action has been taken. This way the internal quality auditing team influences continuous improvement.

3.5 Analysis of performance of Stock Items

Cable manufacturer has specifications for all its stock items. These specifications are only reviewed and changed when there is a change in product design. What is lacking is a trend analysis in stock item performance. If done, this could be one source of information for continuous improvement initiatives.

3.6 Benefits derived from internal quality audits.

Benefits that comes with internal audits at Cable Manufacturer are:

- that processes that are not performing in accordance to the set standards are highlighted and are resolved and/or controlled as soon as they are identified;
- the internal quality audits have helped decrease quality costs as well as the number of customer complaints received;
- there is sustainable production of quality products;
- the internal quality audits have shortened the gap between the workforce and management. They have induced a unifying effect on driving workers and management in working towards attaining the company objectives.

3.7 Audit of an audit

In addition to internal audits conducted at Cable Manufacturer, the company has engaged South African Bureau of Standards (SABS) to conduct third party audits for ISO 9001 quality standard certification. Eskom being a major customer also conducts second party audits. To help market its products in United Kingdom Cable Manufacturer has engaged British Approval Service for Cables (BASEC) to conduct third party audits. This assures European customers of quality products. All these external audits help the internal audit team in Cable Manufacturer improve.

4 CONCLUSIONS

From the study done on Cable Manufacturer the following conclusions were arrived at:

- Cable Manufacturer has both internal and external motives. The audits on one hand check formal conformity with ISO 9000 quality standards. On the other hand they are used as a basis for quality improvements.
- As shown in Figure 3, there are no adequate controls put in place to avoid disruptions to internal audit plans. These disruptions compromise the effectiveness of the audits.
- Cable Manufacturer has a system to capture non-conformities (Table 1). This is the basis for effecting corrective actions and improvements.
- The company also has a standard procedure of effective corrective action.
- Lastly Cable Manufacturer internal audit team work with three external auditors, SABS, Eskom and BASEC. These collaborations help improve the operations of the auditing team.

5 RECOMMENDATIONS

- The internal auditing system at Cable Manufacturer has not done much to involve workers. Quality circles are one way the company could involve workers. When workers are involved they feel motivated and this way they make significant contribution towards improving the quality system.
- Cable Manufacturer has a rigorous quality control system for all stock items. On purchase, each item is subjected to compliance tests. However, the company does not have a supplier selection system. Having a supplier selection system in place helps decision makers monitor the performance of existing supplier portfolio [8]. This, in turn can be used to negotiate further contracts in different segments with the existing vendors, given their current capabilities [8].
- Cable Manufacturer developed skills matrix in all production departments. The matrix determines the adequacy of workers in addressing the challenges of the company. There is also a need to develop such a matrix in the internal auditing department.

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PRACTICAL IMPLEMENTATION OF THE ISO 50 001 STANDARD FOR LARGE INDUSTRIES

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ABSTRACT

Energy management is becoming a necessity when competing in large industries in South Africa. An effective energy management system will improve a company's competitiveness by decreasing energy inputs while increasing production outputs. Therefore, one of the main challenges in energy management is to implement an effective energy management system to best benefit the company's needs.

The stipulated requirements and practical guidelines for a recognised energy management system are available in the ISO 50 001:2011 (Energy Management System) International Standard. However, due to the complexity of the standard, most companies defer their energy management strategies to outside contractors or cease implementation altogether.

There is therefore a need to simplify the process of implementing the ISO 50 001 standard for large industry. This study describes a simplified implementation model for the industry. The aim of this model is to keep the implementation time to a minimum. To ensure minimum effort for the implementing company, an industrial template was also developed.

Sectional checklists and practical examples form the basis of the model and the template can be adjusted as specified in the different industrial requirements. A practical execution of the model also showed promising results.

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1. ENERGY MANAGEMENT IN THE INDUSTRY

South Africa is in a stressed situation involving electricity usage. Constraints in Eskom's electricty supply places users in a difficult situation in terms of increases in electricity tarrifs and this has a negative economic impact on users.

The annual electricity tariff increase has been higher than the consumer price index (CPI) for a significant number of years. This results in an increase on production costs within local industries. With these price increases, the need to obtain cost savings in various ways has become crucial [1].

The consumption of energy within large industries is manageable to a certain extent. Therefore, the need to develop and implement an Energy Management System (EnMS) arises. Companies with the focus on continuous improvements for their energy management processes and waste reduction, have increased their profitability and operating quality. This has resulted in improved productivity, global respect and significant profit increases [2].

Organisations strive to implement effective energy management strategies in order to reduce costs and energy consumption. They also strive to improve their corporate image in the relevant market by reducing their environmental impact. In order to realise these advantages, organisations should aim to reduce their total energy waste by following specific programs. [3]

The most effective programs are being developed according to the set requirements and guidelines from the ISO 50 001 standard [4]. However, before a successful energy management strategy can be developed, the international standard should be understood completely. This is one of the most challenging tasks a company faces in terms of the ISO 50 001 standard.

It is not necessary for an organisation to be certified in order to be successful in managing their energy. Thus, some organisations comply with the standard but never complete the step of registering for certification [5]. The key to implementing the ISO 50 001 standard in an organisation is to develop a sustainable system within the shortest time possible. This study will thus detail the ISO 50 001 standard and provide a framework for its effective implementation.

2. OVERVIEW OF ISO 50 001

ISO 50 001 is a published standard that describes how to develop an EnMS. The ISO 9 001 (Quality Management System) and ISO 14 001 (Environmental Management System) standards assisted in the development of this standard. Thereafter the ISO 50 001 standard was published and released by ISO in 2011 [6].

The ISO 50 001 standard provides specific requirements and guidelines to develop, implement, manage and improve an EnMS [7]. The main intention of the standard is to control and minimise the total energy consumption for companies. Employee behaviour and process changes, within feasible boundaries, can outline the activities that will ensure the achievement of this purpose [8].

Unlike the ISO 9 000 series, ISO 50 001 does not have a series of standards. The ISO 50 001: 2011 is a single standard that describes energy management using an EnMS. Compliance to the standard can also be certified by external certification bodies. An integrated certification from some of the other ISO standards can also be achieved and accepted by ISO 50 001 [7].

The main focus of the standard is for an organisation to develop a strategic model to successfully manage energy consumptions and performance. It is expected that the ISO 50 001 standard could influence about 60% of the energy used internationally [2].

The ISO 50 001 standard follows the continual Plan-Do-Check-Act (PDCA) cycle. Organisations need to implement this cycle into their EnMS and daily energy management strategies [9]. Figure 1 indicates the corresponding PDCA steps outlined in the ISO 50 001 standard. Every aspect in the development and implementation of an EnMS using the ISO 50 001 standard is based on a continuous improvement cycle.

The energy policy and corresponding energy plan should be investigated and developed during the planning phase. The developed energy plan should then be implemented during the second phase and the performance thereof verified during the checking phase. During the act phase, an organisation's energy performance and effectiveness of the EnMS should be analysed and the necessary amendments should be modified on the EnMS. The management's decisions will be based on the performance results. These managerial alterations should be integrated in the energy policy and energy plan to continually improve the EnMS.

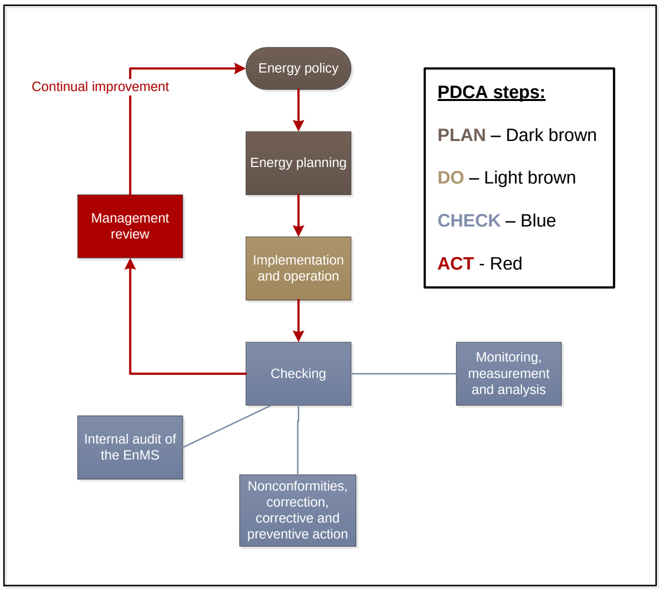

Figure 1: The corresponding PDCA steps in ISO 50 001

The ISO 50 001 standard guides an organisation in order to achieve the following [9]:

- Develop a system to manage energy more efficiently,
- Establish unique requirements and goals to achieve within the system,
- Process data to explain and control energy usage more effective,
- Compare and provide intelligent feedback on the processed data,
- Monitor the system, and
- Improve the EnMS continually.

General recommendations and frameworks can be established within each uniquely developed EnMS. This will serve as the benchmark by which energy performances can be measured. By implementing a strategy with benchmarking targets unique to a specific organisation, more realistic financial benefits could be seen.

3. IMPLEMENTATION STRATEGY

3.1 Introduction

An EnMS serves as a centralised strategy for companies to manage their energy performance. This paper will identify several shortcomings in the implementation of previously developed energy management systems.

The model developed will also be discussed according to three levels of implementation. These levels are defined to assist companies in choosing the level of detail required in which they want to manage their energy needs.

3.2 Shortcomings of implementation

Every organisation develops or uses their own specialised EnMS in order to best benefit their operations and objectives. As there is no set strategy for implementing the ISO 50 001 standard, shortcomings could exist in every system.

It should thus be a critical step for any organisation to identify and investigate the possible shortcomings from similar systems before developing their own. The implementation time for an EnMS should also be kept to a minimum. This can be done by eliminating all identified shortcomings before implementation.

Some inefficient EnMS could be due to organisations not planning properly. An EnMS should be developed according to the specific industry or service provided. Problems may occur when organisations do not address certain challenges correctly. These challenges may include reductions in resources for the same production targets. These resources may involve energy as well as materials [10].

The ISO 50 001 standard does not provide information about the most productive procedures when implementing the standard according to specific industry. Companies might have insufficient infrastructure available to implement an EnMS. A lack of measuring devices or knowledgeable resources can be a big concern [10].

Issues such as the availability of data should be addressed as soon as possible. These issues should be identified in the plan phase of the PDCA cycle. The collection of historical energy data should also be considered. This process of data collection could be inaccurate and may delay the process, which will influence the implementation time [11].

A successful energy management model should thus be developed by using the PDCA cycle approach. This will ensure proper planning as well as continual improvements [12]. The basic ISO 50 001 standard represents good practices. However, this does not always ensure that the model will be sufficient to achieve ideal energy performances [13].

3.3 Levels of implementation

3.3.1 Introduction

Developing an EnMS for an organization can take months or even years to complete. There is however several action steps that will form the main part of the system. Every fundamental step helps develop a more detailed model and ultimately an effective EnMS for an organization.

Three standard levels of implementation were identified in this article. They include the following:

- Basic model,
- Intermediate checklist, and
- Advanced EnMS.

3.3.2 Basic model

After investigating the requirements stipulated in the ISO 50 001 standard, a high-level framework was developed. This framework indicates a simplified division of the various criteria involved in developing an EnMS. These criteria were grouped according to the PDCA cycle steps for a more understandable approach. Figure 2 indicates this simplified framework.

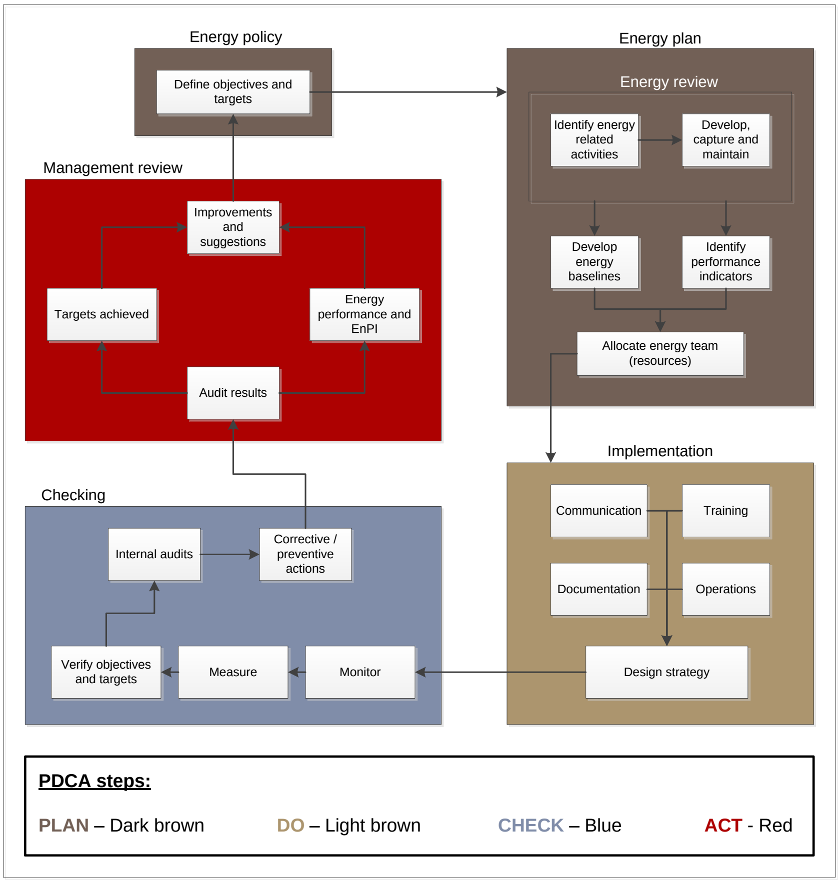

Figure 2: ISO 50 001 requirements simplified according to PDCA cycle steps (Basic model)

The basic model is indicated in Figure 2 above. This represents the high level investigation of an ISO 50 001 system for any organization.

As soon as an organization considers developing an EnMS, they could use this model to identify the steps that need to be followed according to the PDCA cycle. They can then identify all the basic requirements that should be included in the final EnMS.

However, organisations will not be able to register for an ISO 50 001 EnMS certification audit after completing this model. This can only be seen as a blueprint of an organisation's proposed EnMS and does not provide any detailed information regarding the energy performances of the company.

3.3.3 Intermediate checklist

After a basic proposal for an EnMS is created, the detailed investigation should proceed. At this level, data will be captured and collected from various sources. Data will then be compared to baselines and thereafter compared to targets. An EnMS checklist should be created in order to identify the detailed areas to be investigated next. The checklist allows the user to identify missing criteria in the EnMS. This should be used to create an auditable system for accreditation in the future.

The developed checklist consists of the same five steps as mentioned in the basic model above. Under every step extended criteria are mentioned to ensure that those elements are included in the organisation's EnMS. The level of detail for each element in the checklist is dependent on the type of organisation, the size of the company and the need for certification. An example of this checklist is illustrated in Figure 3 below.

Intermediate checklist for EnMS

Company name:
Company type:
Date checked:

Step 1: Energy Policy	**Yes/No**
Management commitment	
Defining scope of system	
State resources and information to achieve targets	
Define significant energy users	
Legal requirements	
12 month comparison for EnPI	

Step 2: Energy Plan	**Yes/No**
Analyse and compare baselines	
Prioritise energy savings opportunities	
Realistic objectives and targets	
Predictions on energy savings	
Verification procedures	
Energy performance tracking	

Step 3: Implementation	**Yes/No**
Design specifications for SEUs	
Hardware and software	
Training	
Internal and external communication	
Document templates and latest versions	

Step 4: Checking	**Yes/No**
Monitor the energy performance	
Calibration of measuring devices	
Identify and investigate outliers in the performances	
Corrective actions for non-conformaties	
Preventative actions in place	

Step 5: Management review	**Yes/No**
Internal audit results	
Continual improvement strategies	
External audit	
Send EnMS to accredited certification body	

Figure 3: Developed EnMS checklist for organisations (Intermediate checklist)

A descriptive energy policy should be compiled during the first step. This policy should primarily include the commitment from management to comply with the set targets. The energy performance targets should be stipulated in accordance with the identified Significant Energy Users (SEU) of the company. The legal requirements identified for the type of company should also be stated in the policy.

The energy plan is created in the second step in accordance with the energy policy defined previously. The main part of the energy plan is the continuous improvement of the identified SEUs. Performance data should be compared with the developed baselines. This could determine whether the set targets are realistic. Energy performance tracking should be conducted in order to revise the set targets and objectives.

Step 3 forms the body of the EnMS. The specific energy related projects, as identified through the SEUs, should be designed to ensure the most effective energy management on the site. The required instrumentation and applications should be obtained to best fit the organization and its projects. Continuous training should be provided on new initiatives and projects. This will ensure awareness and help minimise the implementation time of the EnMS before results are available.

Overall system monitoring should be done during the fourth step. This is also a continuous process and should be analysed and improved as regularly as possible. The energy performances should be monitored in order to verify the accuracy of the targets at all times. Calibrations should be done where required to ensure energy savings are measured accurately. This allows action to be taken on the actual performance of energy saving initiatives.

The last step of the process is the management review which must ensure that the EnMS is performing as required and decide on how it can be improved. In this step audits should be done internally and externally in order to determine the success of the EnMS. External audit results will influence the certification process. Therefore the intermediate checklist should be completed as far as possible before completing the advanced EnMS as mentioned in the next section.

The responsibilities of all the internal and external stakeholders which may include the energy management team members should be clearly stated. Document control should be followed for all the relevant instructions, procedures, specifications and reports. All documents should be reviewed and approved before being filed.

3.3.4 Advanced EnMS

The ISO develops standards, but does not provide certification. External certification bodies are responsible for the certification process [14]. This means that a company can be ISO (standard requirements) compliant, but not certified as such.

For companies to be ISO 50 001 certified, they need to adapt to the standard requirements and prove their improved energy performance. The management strategy and results should then be certified by an external party [15].

During this level of implementation, organisations should focus on completing the missing elements in detail after completing the intermediate checklist. This will ensure an ISO 50 001 compliant EnMS to be audited.

4. PRACTICAL IMPLEMENTATION ON A GOLD MINING COMPANY

The developed method was implemented at a selected mining group in order to develop their EnMS. Various system phases were investigated to evaluate the efficiency of the EnMS.

All the steps involved in the PDCA cycle were conducted individually to achieve sustainable results. The plan and do phases focused mainly on developing the EnMS and its functionalities. The defined energy objectives and targets were set forth in the energy policies of the mining group as well as for the individual mines. The SEUs were defined for every mine and can be seen in Table 1.

Table 1: Identifying the SEUs in projects

Mine	Projects	SEU	Savings target (%)
Mine A	Initiative A	Pumping	19%
Mine A	Initiative B	Air network	11%
Mine B	Initiative C	Cooling Air	20%
Mine B	Initiative D	Water network	9%
Mine C	Initiative E	Air network	12%
Mine C	Initiative F	Pumping	15%
Mine D	Initiative G	Air network	26%
Mine E	Initiative H	Air network	28%

From the energy policy, the energy action plan was developed. The actual implementation of the activities for data collection, system setups and report generations were delivered according to the energy action plan. Energy savings initiatives were also implemented as per this plan.

The energy performance results of the initiatives were analysed during the check and act phases. The performance impacts were compared to the targets set during the planning stage. These targets were confirmed after the initiatives were implemented and enhanced where necessary.

Through the process of developing their own EnMS the mining group achieved significant savings on their electricity cost. All eight identified initiatives achieved their specified target savings during the course of assessment. A summary of the project performances after 8 months since implementation is given in Table 2.

Table 2: Energy management projects performance summary

Mine	Project	Savings target (%)	Actual savings (%)	Total cost savings
Mine A	Initiative A	19%	21%	R 1 513 482.00
	Initiative B	11%	26%	R 11 297 061.00
Mine B	Initiative C	20%	32%	R 5 272 794.00
	Initiative D	9%	21%	R 6 661 934.00
Mine C	Initiative E	12%	13%	R 5 170 715.00
	Initiative F	15%	17%	R 2 444 439.00
Mine D	Initiative G	26%	45%	R 12 261 942.00
Mine E	Initiative H	28%	33%	R 7 472 724.00
TOTAL				**R 52 095 091.00**

5. CONCLUSION

Many different models have been developed in order to manage the energy usage in large industries. Organisations also often develop their own EnMS strategies to improve their energy performance. This can however result in overly long and complicated implementations. This study therefore describes a model which divides the implementation strategy of an EnMS into three main levels.

The first level (basic model) is defined to ensure that the company has the basic elements required according to the ISO 50 001 standard. These elements include a basic description of an energy policy, energy teams and management targets. The next level (intermediate level) is used with the basic model to ensure compliance with the standard. Relevant data, processes and actions are compared to a developed checklist to determine the status of the company's EnMS.

The third and final level of implementation (advanced EnMS) would be where the implementing organisation gathers and develops all the missing detailed elements from the second level. This is the level of implementation where companies ensure continual improvements and is the point at which the EnMS can be certified as compliant to the ISO 50 001 standard.

After implementing the first two levels of this model, a selected gold mining company already saved over R 52 million in electricity costs during 2014. This combined saving was recorded after eight months of implementation of eight separate energy savings initiatives.

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THE IMPACT OF MAJOR ENVIROMENTAL, SOCIAL AND ECONOMIC FORCES ON THE FIELD OF INDUSTRIAL ENIGINEERING

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ABSTRACT

Every profession is bound to adapt in response to changes in the macro environments. Industrial Engineering is especially affected due to its broad application across various fields, i.e. manufacturing, customer service design, consulting and more. This article argues that the need for change is envisaged to be radical due the deep-rootedness of Industrial Engineering in specific areas where environmental, social and economic (ESE) forces are prompting fundamental transformation. This transformation often manifests itself in an evolving technology. The argument of this article is that 1) Means of production are changing due to 3D printing and additive manufacturing 2) Employees work arrangements and corporate structures are changing 3) Customer behaviour is changing due to sharing and knowledge economy 4) Supply chains are changing (supply/demand) due to drones and radically different supply/demand relationships 5) Human concerns/values (such as education, health and other concerns) are changing. Therefore, Industrial Engineering must adapt to these changes due to its connection with these fields. This article further addresses the major forces impacting Industrial Engineering from 3 starting points: top down (macro-landscape challenge view), bottom-up (technology impact view) and middle ground (IE sub-discipline point of view).

Keywords: Industrial Engineering, Economic Forces, Social Forces, Environmental Forces, Impact Analysis

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1. INTRODUCTION

The world is changing and so is Industrial Engineering. A Coldwell Banker Richard Ellis (CBRE) report finds that "50% of occupations in corporations today will no longer exist by 2025" [1, pp.6]. Yet, this does not mean the other 50% are safe. Although they will not become obsolete, their occupations are most likely to change dramatically. The simple fact of the matter is, in the knowledge era, the inability to pick up on relevant forces shaping the context or work of a field of study can result in misalignment, outmodedness and deterioration of that field or its tools and techniques. "The next 15 years will see a revolution in how we work, and a corresponding revolution will necessarily take place on how we plan and think about workplaces" - Peter Andrew [2]. Technology is perhaps the greatest force that requires consideration. A failure to adjust and integrate technology into practice results in ineffective, minimally applicable and obsolete practices. It is important to remember, though, that technology development is often instigated by economic, social or environmental factors.

The topic of interest for this article is the occupation of Industrial Engineering. After rising to a high standard and developing capabilities that are seen as immensely valuable by industry, it would be disappointing to see that some of methodologies, tools and skills are no longer seen as useful (especially since it is possible to adapt them). The concern here is that creating something of value without the perception that it is valuable often results in similar effects as something not being valuable at all. Much like the companies that Industrial Engineers work in have contingency, human capability and risk plans; the Industrial academic and work departments have to be structured in a way that integrates and caters for all potential changes to macro environments. After all, the tools for change management and integration are being taught in those same departments; it would be unwise not to use them to do a self-analysis. In summary, in the words of Sperotto [3, pp. 8]:

> *Rapid changes in the social and industrial environment continue unabated, driven by accelerating technological developments, availability of information, networking, and globalization. Developments in polymers and new materials from nanotechnology, for example; the variety of energy sources; new manufacturing processes and paradigms, such as additive manufacturing and distributed manufacturing; aerial and robotic networking; neuromorphic technology and predictive intelligence; the Internet of Things (IoT); the spread of integrating techniques, technologies and systems throughout the whole supply chain and its parallel, waste flow management; the increasing value-adding applications in the service industries; and the blossoming world of virtual reality; will extend the complexity of integrated systems and change the focus of industrial engineering, the needs of industry, the nature of work, the human-machine relationship, and the culture and lifestyle of people. Inevitably, the industrial engineering profession and its institutions will need to embrace these changes in order to remain relevant and to contribute meaningfully to industry and society.*

1.1 Background and Summary of Argument

The Industrial Engineering profession faces many challenges in the 21st century. Yet, one can still argue that these forces are unlikely to completely change Industrial Engineering and the need for Industrial Engineers. Especially since, in many countries, it is considered a scarce skill (8th in South Africa) [4]. However, this does not change the fact that IE can remain ahead by conducting self-assessment and improvement studies. Additionally, doing so would be keeping true to the vision and core values of Industrial Engineering. There are, however, challenges arising from specific economic, social and environmental forces. Perhaps the most pressing issue is that the 21st century is experiencing the evolution of a new macro-economic system that is better suited for the needs of society and the environment. Many have labelled this new economic system as the "knowledge economy" and the "sharing economy" [5-6].

Although one cannot neglect the immense impact of the latter 2 macro-systems on the economy, it would seem that the economy is the one where humans have the most direct control. Therefore, it makes them the preferred option to influence change and actually 'do' something. This is mainly because participating in the economy is almost fully mandatory and virtually everything seems to be linked to it in some way or another [6]. Simple day to day reference to global warming, income inequality and employment wellbeing all have deep social and environmental instigators [6]. However, they seem to attract much more attention when one finds a way to display them on a balance sheet and show their link to the economy (carbon taxes, knowledge accounting, intangible accounting, talent capital…etc).

The problem of dealing with massive technological, social and economic changes is not unique to Industrial departments. "Rapid changes inevitably destabilise established institutions, and cause misunderstandings and stresses between conservative and progressive groups and individuals" [3, pp. 8]. The beauty of the field of Industrial Engineering is that it understands "that adapting to the new economic regime would require philosophies and methods tailored to the forms of work that defined the new mode of production" [7, pp. 737]. However, technological forces of the 21st century (reinforced by social and environmental forces of awareness) have completely changed the meaning of key words like 'supply chain', 'work', 'production', 'system' and even 'value'. Arguably, though, it is a key responsibility of Industrial departments to provide the frameworks, connections and strategies to deal with such rapid changes (since there is an implicit claim to understand this complexity best and since Industrial Engineers are often in management positions and are well known for designing the systems that deal with these changes). This is also partially due the broadness of IE sub-disciplines. These sub-disciplines can be defined as: "Management Information Systems; Systems Engineering; Modelling and Simulation; Mechatronics and Automation; Robotics and Artificial Intelligence; Operations Research and Operations Management; Facilities Management and Maintenance Systems; Quality Management Systems; Project Management; Logistics and Supply Chain Management" [3, pp. 6].

The solution, however, must not simply focus on future graduates (most likely from generation Y and Z). The Industrial Engineering department has to embrace a transformative role which develops existing graduates already in industry, similar minded professions in other disciplines and interested individuals willing to progresses their holistic abilities (both privately and at universities). Yet, the most valuable network to an Industrial Engineer might be fellow Industrial Engineers (and their networks within other industries) who have mastery over some skills and can further one's own connections. The common understanding between Industrial Engineers allows for ease of communication, while the clear distinction in specialty allows for a wide influence. This also requires understanding the perception of Industrial Engineers, both in academia and in industry, on the forces changing the environmental, economic and social landscape. The overall aim of this article is to suggest developmental areas for Industrial Engineering knowledge. This will help adapt, reform, integrate and promote sustainable and healthy changes, whilst opposing, eliminating and transforming obsolete theories and technology. In short the focus of the argument in this article is as follows:

1) Means of production are changing due to 3D printing & additive manufacturing
2) Employees and corporate structures are changing, and customer behaviour is changing due to sharing and knowledge economy
3) Supply chains are changing (supply/demand) due to drones and radically different supply/demand Relationships
4) Human concerns/values (such as education, health and other concerns) are changing
5) Industrial Engineering is deep-rooted in above systems

∴ **Industrial Engineering must develop to adapt to these changes**

Section 2 review the impact of major forces in the economic, social and environmental spheres. Section 3 further explores a specific technology (additive manufacturing) as a case study to show how specific research projects can contribute to adapting to these changes. Lastly, section 4 aims to classify the challenges into relevant IE disciplines.

2. MACRO CHALLENGES ON THE INDUSTRIAL ENGINEERING DISCIPLINE

2.1 Economic Specific Challenges

The rise of drone delivery, 3D printing, EBay, Airbnb, Fiverr and even Uber will challenge every conceivable industry. This is not only because they add complexity to the network, but also because they change the rules of the game with regards to supply and demand. This has led to the rise of supply networks (example shown in Fig. 1) which "should visually depict all the linkages between buyers and suppliers throughout the world" [8]. For example, large organizations offering services and products have very high overheads with shareholder expectations as well as big boss bonuses built into their pricing might be replaced by decentralized producers. The local 3D printer/Uber driver/Airbnb room simply have their capital repayment of their hardware, living costs and some savings built in. Additionally, there might be an interpersonal relationship between the producer and supplier of goods and services. Yet, they are producing the same product or offering virtually the same core service. In fact, these applications are going a step further in truly answering the customers need because they are offering only what the customer is willing to pay for. This in itself is an excellent display of value offering design, minimum viable product thinking and system thinking. The sharing economy is a result of complex socio-economic forces with some very positive environmental effects (due to less resources being used and more being shared). Part of the forces shaping this new idea are a disillusionment with consumption, need to connect, requirement for more specialized/customized service and a lack of opportunity in the mainstream economy [1]. Additionally, a CBRE report notes that "a growing proportion of jobs in the future will require creative intelligence, social and emotional intelligence and the ability to leverage artificial intelligence. And for most people that will be a route to happiness and fulfilment." [1, pp.33].

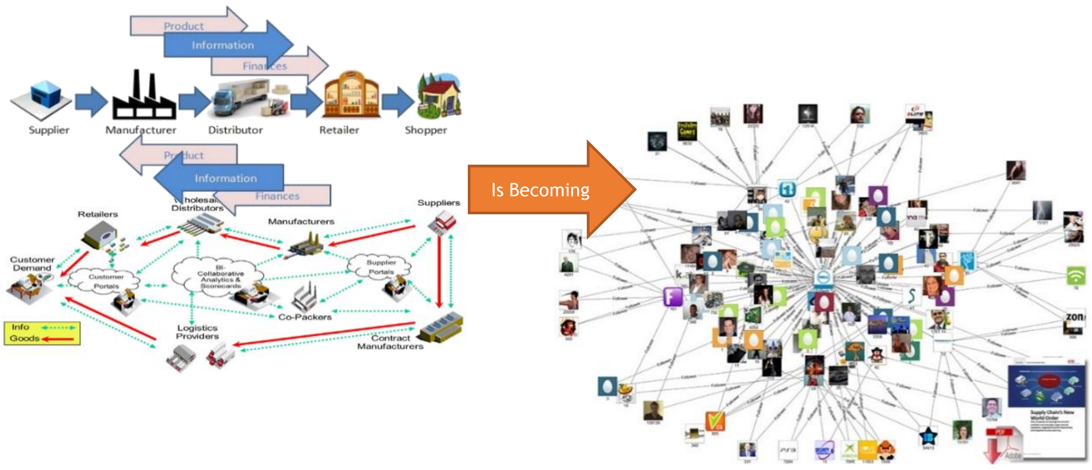


Figure 1: Supply Chain to Supply Network [8-10]

Additionally, the sharing economy seems determined to eliminate traditional hierarchical structures. It is also commonly referred to as 'collaborative consumption', "which is a trending business concept that highlights the ability (and perhaps the preference) for individuals to rent or borrow goods rather than buy and own them" [11]. Part of the reasons this shift is occurring are that traditional capitalistic and consumption models (idea that 'more' consumption holds the solution) did not create value for the overwhelming majority of agents participating in them [12]. For some, it showed a shift towards an inhumane way of living, especially since a large part of the assumptions of the previous model depend on less knowledgeable consumers who do not question as much. Additionally, the previous model resulted in more than half of the world's wealth being owned by 1% of the population [13]. Even though one might debate whether humanity has reached the sharing economy stage, it is commonly agreed that the knowledge economy is in play. The sharing economy is a natural progression stemming from the sharing of knowledge, experience and ideas. More often than not, this content has been freely available on the internet. The knowledge economy recognizes 'intellectual capital' and with that change "a significant part of a company's value may consist of intangible assets, such as the value of its workers' knowledge (intellectual capital)" [14]. The fact that more knowledge is freely available and attainable will naturally lead to more wealth distribution since wealth is no longer viewed merely as capital assets.

2.2 Social Specific Challenges

The concern for human well-being, health, ethics and culture is not just a passing concern in Industrial Engineering. It is a fundamental pillar of the engineering profession [15-16]. In the words of Nelson Mandela "like the gardener, a leader must take responsibility for what he cultivates" [17]. Engineers, in general, face a similar responsibility especially since the products, services, technologies and processes they design affect virtually every human being on earth [16]. Industrial Engineering are especially responsible since most of the time they are specifically responsible for the designs of the interfaces with society at large of engineering products (or at the very least, they are responsible for coordinating efforts with those who do). This is what makes humanity/society the second anchor of IE focus [15-16].

Industrial Engineering is not only capable of providing relevant approaches to managing the facilities, infrastructure and systems governing urban life; it can setup the collaborative approaches, adoption strategies and decentralization necessary to avert unhealthy effects. One of the key specialties in Industrial Engineering is the ability to adapt to scaling up and scaling down. This is why Industrials should naturally work with city planners to "modify the design and use of our cities [and] develop approaches to allow us to live in high-density ''urban villages'' separated by parklands, recreation facilities and garden plots, and connected by light-rail transport" [18, pp.1123]. In addition to traditional IE tasks, several vigilant IE postgraduates and professionals have noticed the immense benefits that IE can have in developing the systems necessary for governance and providing services (especially health and education). Uzosoy in Christensen discusses that "like industrial supply chains, the health care 'supply chain' consists of multiple independent agents, such as insurance companies, hospitals, doctors, employers and regulatory agencies" [19, pp.143] and "the task is complicated because demand for service is determined by both available technology and financial considerations (such as whether or not certain treatments are covered)" [19, pp.143].

Government services (education, health and voting) face similar challenges and have had some benefit from Industrial Engineering intervention [20]. Although IE is still in very early stages of intervention in the public sector, one can only wonder how much benefit can arise from IE using systems principles to restructure government services to be more transparent, effective and consistent [20]. The most relevant point here is that humans naturally interact with systems. There is no doubt these systems are complex, but IE tools can extract relevant factors. Additionally, they can participate in designing systems which best reflect the virtues of its agents. Whether this system is education, healthcare or something else is not the issue. Industrial Engineers will naturally work with the available professionals and specialists in that field to develop a system which answers a principle need [15]. Part of answering a need requires Industrial Engineers to review some theory from industrial psychology and organizational behaviour. The increasing connectedness of the world has resulted in people's voice being better heard [8]. Social media is a great example of how each person can create an online presence which represents them as an agent [8]. The communication between these agents, their exchange of culture and mail has created an effect that converted this once disperse world into a small village. Another effect of this is rapid urbanization as more people try to find more opportunity, interact with similar minded people and experience new things as they setup their lives [1].

The most pressing issue, however, remains that modern human psyche is different and the impact of perception greater. Part of this lies in the fact that "evolutionary emergence of advanced symbolizing capacity enabled humans to transcend the dictates of their immediate environment and made them unique in their power to shape their life circumstances and the courses their lives take. In this conception, people are contributors to their life circumstances, not just products of them" [21, pp.164]. The prime role of an Industrial Engineer, with regards to the above, is aligning perception with reality. An additional focus can be on finding a way to "balance between the individual and collective aspirations" [15, pp.6]. Lastly, perhaps the Industrial Engineer should adopt a clear focus on application. There is no shortage of people creating knowledge/technologies, so Industrials would be perceived better if they focused on applying it for the benefit of society.

A good place to start benefiting society is radically changing the idea of work. When asked about work, the perception of an 8-5 workday comes to mind (with 1-2 hours each side for traffic) [1-2]. This is unfortunate and perhaps the reason flexible hours and deliverable based pay work systems came to be. The idea of work was largely developed to suit the needs of a previous century where it was believed that the 8-5 model provided the best productivity and health. When this pre-21st century idea is applied in the 21st century, family relations are strained (since working parents have less time to interact), time is actually wasted at work (due to an imbalance between pay and expectation) and so on [1]. Thus, overall productivity is lower and the perception is self-defeating. However, work, in the broadest sense, is a physical or mental effort directed towards the production or accomplishment of something. Due to the fact that this creates value, one can naturally expect a share of the value in the form of a salary, benefits…etc. Ironically, even in the definition, physics arguably reaches better results than the perception of fixed hours. The definition in physics is the transfer of energy from one system to another. If IE works on converting this definition to accurately account for work/energy coming from individuals and collectives, then Industrial Engineers will have something better to base a "work" theory on (which will determine remuneration).

2.3 Environmental Specific Challenges

The 21st century has seen a rise in environmental regulation. Interestingly, this is only partially due to government efforts. The devastating cycle of consumption has lead scientists, sociologists, engineers and others to seek alternative technologies. Customers all around the world are becoming more aware of the effects of their actions and consumer choices [15]. Additionally, a larger focus is being placed on sustainability, preservation and conversation of the resources that allow us to live our lifestyles. Although some of these technologies have existed for a long time, the reason they fall under the environmental section is because the rising interest in them as a true alternative only grew in response to environmental problems [15]. The technologies that will be discussed share a common idea in that they aim to be wasteless (in doing so, they are also sustainable and environmentally friendly). For Industrials, a wasteless process is an ideal process. Theoretically it is impossible to produce no waste at all; yet, when one studies nature, one finds that the idea is more about creating waste which is usable by another system as a resource.

Environmentally-driven technologies are striving to provide the closest thing to wastelessness and symbiotic relationships humanity has known. They might hold the key to a healthier environment with less polluting chemicals and better sustainability [12]. If an Industrial Engineer is asked what an ideal manufacturing process would look like, there is no doubt that the definition will include eliminating the waste. Additive manufacturing and 3D printing not only do this, but they also simplify a production process which used to take 12 machines in a 100m line into a 3 by 3m build area. These developments are constantly brought to light in the media world. However, there is a need to understand how additive manufacturing affects the entire world around us. Beyond reviewing what techniques are available and what design processes are used today, a deeper understanding must be developed on how these developments affect our supply chains, facilities, customizability, quality of and even the way companies will design our products. The rapid destruction of our natural resources prompted a revision of our energy production [12]. Some countries were fast to convert fully to alternative energy while others remain sceptic. Whether there is direct links to global warming and natural catastrophes, it is no secret that the chemicals involved and created by non-renewables are harmful to the environment and everything living in it, both directly and indirectly. It also simplifies the energy conversion process immensely (from raw potential energy into usable energy). Alternative energy technologies include geothermal, solar, wind and various others. Yet, the problem does not seem to be with the technology, but rather it seems to be an inability to see the true financial benefit of alternative energy. Industrial Engineers naturally need to take a proactive part in resolving this problem by utilizing skills learnt in management accounting, engineering economics and other courses to accurately reflect the financial and non-financial benefits of alternative energy to companies and decision makers [15]. Accounting for the right things might lead to very different decisions and will facilitate a swifter transition to more sustainable energies.

Energy and products are definitely important but they are not nearly as important and vital as food to human survival. Food security is a growing concern across the globe. "Eating is the most important act of human existence" – Bob Cat [22]. The ability of the planet to produce food sustainably for 7 billion people has decreased due to environmental decay [12]. What adds more complexity to the issue of the food supply chain is the nature of its variability in the supply demand relationship. Different cultures have different diets and different people demand different types of food daily (which is perhaps one of the most unpredictable sources of demand). The question here is how does one provide demand locally (to ensure high quality), whilst ensuring rapid response times to demand (keeping low stock which also increases quality), and ensuring that minimal resources are used in the process?

Hydroponic and aeroponic faming might provide the answer since they utilize a water or air based medium to give plants the exact nutrients the need [22-23]. This is often done in a controlled environment, requires virtually no soil and produces high quality good consistently due to the lack of severe environmental changes typically encountered in normal farming [23]. The idea itself was largely conceived by recognizing that soil is merely a transfer agent. The actual nutrients are what is really required by the plants (differentiating perceived need from true need). Additionally, business cases can be made for both small scale decentralized production and large scale centralized production.

Sustainable food cycles recognise and utilize the waste of one organism to feed another until a complete cycle is achieved (forming symbiotic relationships) [24]. This naturally occurs in nature, but restaurants and businesses are starting to notice its positive impacts. A great example of this is a symbiotic relationship between beer, fish and plants which several restaurants have taken advantage of on [24]. The fish produce waste used to grow the beer, the fish eat some of the vegetation to grow and both of them are served at a restaurant which provides the funds to run the entire operation [24]. This shows that these methods can be applied to the business environment as well to create more sustainable and healthy competition less focused on the 'dog eat dog' metaphor. Drawing parallels between the natural world and business world can create for some very interesting answers.

3. TECHNOLOGY IMPACT REVIEW: ADDITIVE MANUFACTURING AS A CASE STUDY

During the past decade humanity saw the rise of consumer electronics due to the rise of the micro-processor. Moore's law predicted that processing power will double every 1-2 years with components becoming more affordable, reliable, usable and widespread; and he was correct. However, a new buzzword has hit the technology world: Additive Manufacturing. Additive manufacturing is a process by which components are built, altered or repaired using a variety of processes [25-27]. This concept mainly focusses on the addition of material rather than subtraction; thus creating less waste whilst saving time, money and ensuring top quality. Processes vary from laser manufacturing to cold spraying. Some processes (mainly known as 3D printing) only require heating and placing certain polymers into the preferred form. However, one thing is clear from the scientific literature and technology markets: Additive Manufacturing is here to stay [25, 26]. Additive manufacturing by nature is a superior process capable of very advanced designs. In the past 3-4 years there has been a trend developing within this technology and it is expected that the next decade will see the same effect as the processor (shown in Fig. 2).

Printing a pizza at your local shop or having an old piston rebuilt like new with metal powder were topics mentioned solely in science fiction only a couple of years ago. However, developments in the additive manufacturing world have led to a new production method which is not restricted by tolerances, geometries or complexities [25, 26]. Although somewhat expensive at this point in time, it is argued that additive manufacturing will be the way we produce any product in the future [26]. Whether it be our food, metallic service parts or even our organs; scientists have found a way to use additive manufacturing techniques to use raw powders to create an endless possibility of products [26]. These developments are constantly brought to light in the media world, however, there is a need to understand how additive manufacturing affects the entire world around us. Beyond reviewing what techniques are available and what design processes are used today, a deeper understanding must be developed on how these developments affect our supply chains, quality of our products and even the way companies will design our products [26].

With any growth of this kind it is natural to see problem areas such as: inefficiency, quality, process and other multidimensional problems. Since this technology deals with aspects of man, money and machine; it is vital that an Industrial Engineering perspective is developed to help save millions in future and assist in advancing this fantastic technology. Additionally, the simplified supply chain and facilities can be a research area on their own within IE. Perhaps due to the smaller facility sizes and improved power efficiency, alternative energy can be used.

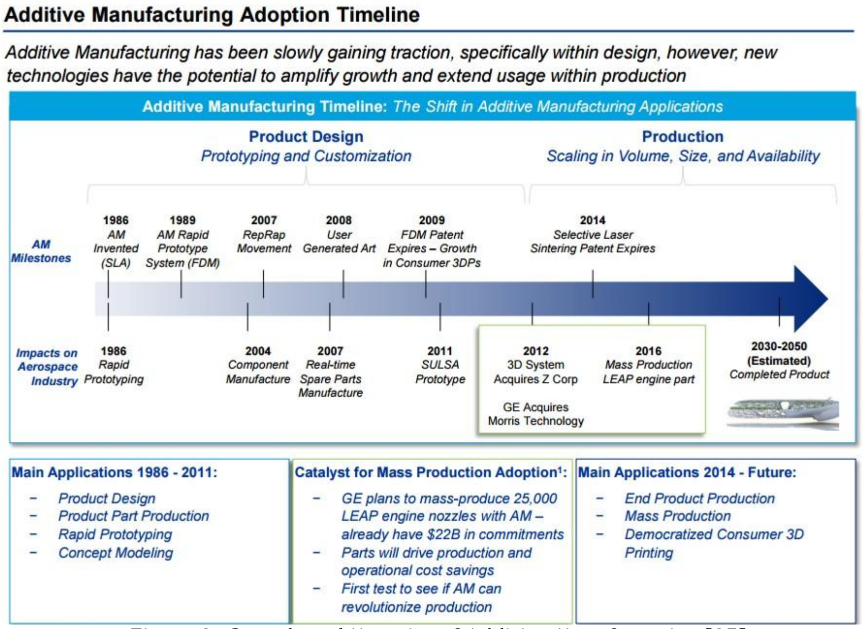


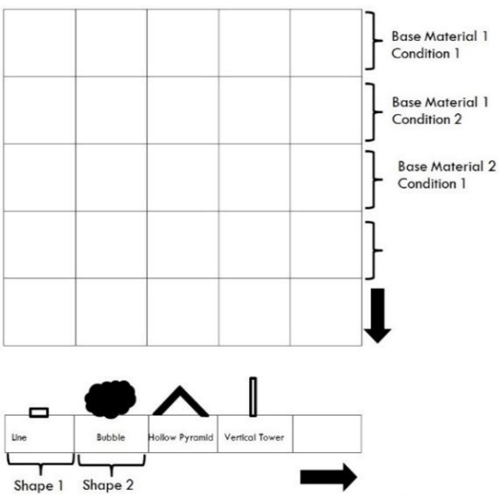
Figure 2: Growth and Maturity of Additive Manufacturing [25]

3.1 Potential IE Research Topics in Response to Additive Manufacturing Technology

3.1.1 Quality Standards & Decision Support Data for Additive Manufacturing

A potential idea is to create a universal test jig/board, using quality management and design of experiment tools, to be able compare different additive manufacturing technologies to each other and thus be able to understand to what industry they can be used in. The aim is to test one powder material at a time on the base given below with different scenarios such as different base materials and conditions to create a variety of shapes and figures designed to test the full capabilities of the technology.

Each technology will be compared on the basis of 3 aspects: Cost, Quality and Time. Each of these aspects has sub qualities indicated in the table below to show the exact area where technologies surpass each other. Such a deliverable will provide a very good platform for analysing the different technologies. Different "boards" can be developed by experts for different test fields and material however the concept must test a variety of operating conditions, materials and builds while ensuring that accurate data is recorded about the time, cost and quality. This can help create a way to compare apples with apples. Overall this would provide an excellent platform for companies to test machines, technologies, materials or suppliers. This will give them an excellent test before commencing production with that specific supplier and will ensure that their criteria are met. A visual representation is shown in Fig. 3.



Quality	Cost	Time
Strength Properties	Cost of Material	Experiment Time
Curvatures	Cost of Operator	Post Analysis Time
Angles	Cost of Overhead	Preparation Time
Tolerances	Power Costs	Downtime
Micro-Analysis	Idle Costs	Idle Time
Other	Machine Costs	Other

Figure 3: Universal Additive Technology Test Jig/Boards [Own Work]

3.1.2 *Production and Manufacturing Requirements & Specifications*

From this above it can easily be seen how specific requirements can arise for different industries. Industries will most likely be grouped by product size and complexity; changing the way in which production and manufacturing requirements are classified and communicated (shown in Fig. 4 below).

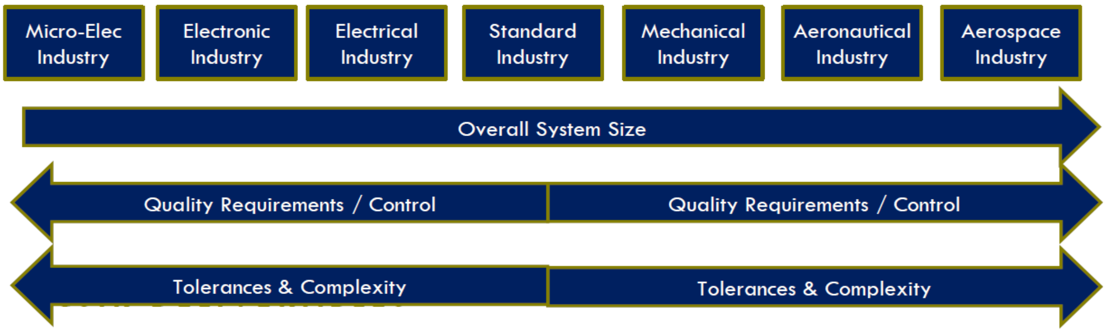


Figure 4: Production and Manufacturing Industry Classification [Own Work]

3.1.3 *Wasteless Design Methodology*

The development of this new hardware will naturally require a new industrial design methodology. The design processes available today are somewhat lacking if we try to apply them to additive manufacturing. The main problem is that they do not take the full spectrum of possibility when it comes to additive manufacturing. There are modern techniques on how to define and design a product which allow rapid prototyping and testing. In addition to this most design processes do not consider the ability to refine designs in real time. Additive manufacturing allows easy additions to designs as well as reconstructions. There is much less waste involved and designs are modified relatively quickly. Even manufacturing errors can be corrected easily without creating unnecessary waste. If the product has already reached the customer, a simply process can allow them to get their product fixed on site without scrapping or returning the product. Products can be upgraded in this manner as well. This is why a define-design-refine and manufacture technique should be considered when designing products for the 21st century.

Figure 5: Design Process [Own Work]

3.1.4 *Supply Chains, Facilities Planning and other Considerations*

In addition to having immense impact on our products, the additive manufacturing technique has major impacts on the way we source our products, produce and store raw material (powder in this case) and even on the facilities that will produce products. Some argue this might be decentralized but some products will have to be proceed in centralized facilities (for intellectual property, legal and health reasons). Designing a future manufacturing facility, as well as the considerations that need to be taken, can form the basis of many studies. These facilities can be decentralized or centralized, multi-product group focused or single product group focused, produced on order or customized from stock. More importantly, traditional location models, production scheduling, inventory management (which has to adapt to powder based inventory) would have to adapt massively to these changes.

4. IMPACT ON SPECIFIC INDUSTRIAL ENGINEERING SUB DISCIPLINES

Without context on where the literature and case study (from sections 2 and 3) fit within the broader structure of the Industrial Engineering body of knowledge; several vital questions and connections can be missed or overlooked. This section explores the impact of some of the developments and arguments discussed above on specific sub disciplines of Industrial Engineering in dialogue format.

System Engineering/ Project Management: It would seem the forces above will definitely result in more and more projects becoming available to Industrial Engineers. Although some of them will be large scale, it is likely that a large proportion will be small scale development and management projects. However, traditional project management and system engineering tools and methodologies simply do not cater for these types of projects. Industrial Engineering must be proactive in finding ways to distil the core of the theories and tools and develop appropriate module based models to assist in implementing successful project management and system engineering regardless of scale. The focus, then, will be on adapting theory to the specific scopes and requirements of each respective project.

Logistics and Supply Chain: The fact that most additive technologies are powder/particle /nutrient based will most likely radically change the technology, vehicles and methods of warehousing and delivery of products. The biggest question with regards to the above is: will supply chains be reduced to a simple 5 step process that: 1) converts ores/raw materials into powers 2) transfers them to appropriate warehousing facilities for storage 3) delivers them to relevant AM technologies for conversion to parts 4) assembles them into final products and 5) ships them to clients? Will returns management be a corrective process where a 3D printer is taken to client site to correct product? Is the carbon footprint for this activity significantly less than existing supply chains? The interesting thing here is hydroponic farming is very similar to additive technologies in that it simply adds what is required by the plant (natural machine in this case) in order to produce the final product. Does this make the future of everything we eat and use (accounting for most products) additive based?

Information System Design: Advances in payment, booking and tracking technologies is forcing traditional information systems out of their comfort zones due to a significant difference in user interaction available (arising due to new supply-demand relationships). Additionally, the sheer amount of data required to understand this complexity is engulfing. Yet, the widespread use of smartphones as a data collecting tool is becoming a reality. The concerning questions are: how will the data be collected? How can it be stored effectively? How does one best make use of this data for competitiveness? And, most importantly, how does this data transition to information and then knowledge and perhaps artificial intelligence in the near future? The customer is most likely going to want answers to these questions especially because of rising concerns on privacy.

Simulation/Automation: The ability to simulate this uncertainty and adapt automation technologies to react appropriately is most definitely a challenge. With so many factors to test for sensitivity, is it even practical to conduct simulations? Or is there a way to simplify the chaos into specific agent based characteristics? Can this be done proactively or is it destined to be reactive? Additionally, simulations models will most likely have to develop a way of simulating generational human culture and ethics, especially if this sub-field hopes to create convincing models/arguments for government services.

Business Engineering: With the rise of the sharing economy comes the reality that many business engineering tools will have to be restructured to cater for the individual instead of the corporate structure. The biggest impact of the forces above is that money that is used to flow to traditional business hierarchies will now go directly to individuals. Thus, traditional strategy development, process modelling and business models need to adapt. The question is: does each individual then become his own business or do they follow the business model of the app which brings them customers? If they are unique and are not app reliant, how will these individual ‘businesses’ differentiate their processes/value offering? Will the sharing economy find symbiotic relationships with the traditional economy or remain competitive?

Operations Research: The algorithms in the code of every application are constantly determining the most effective ‘route’, ‘producer’ and more broadly ‘connection’. These optimization algorithms are essentially the decision makers. Yet, with this continuously changing environment, a static decision maker will result in tremendous waste. Dynamic decision making and optimization is the most likely the future of operations research. Whether it is a que, production or infrastructure problem: optimality is based on dynamic factors and thus will have a dynamic answer. The question remains, however: is it possible to truly get the optimal answer in these scenarios or will optimization radically change to accept certain confined area as ‘optimal’? What if this confined area radically changes in the solution space? Does that mean the introduction of sensitivity as a core element in operations research problems?

Operations/ Facilities Management: The sharing economy will perhaps more accurately reveal the meaning of the word ‘facility’ and ‘operation’. In a nutshell, the facility will become the encompassing structure that facilitates business operations to take place. People are most likely to convert their garages, gardens and bedrooms to facilities (production, servicing and other). However, with this comes massive facilities designs and safety regulation problems. Are there realistic methods to properly oversee such operations?

Quality Management: Perhaps the biggest question for quality management going forward into the knowledge economy is how one assesses the quality of intangible assets (mainly knowledge, human capability and talent). As for the sharing economy, will new standards for decentralized producers come to existence? Will perception play a bigger role in quality? Or will technology facilitate a way to create more accurate quantitative measures for perception?

General IE: The sharing economy and knowledge economy are most definitely challenging legal and business regulations both nationally and internationally. The simple fact of the matter is they create interactions and assets that governments and lawmakers are not traditionally accustom to deal with or account for. More worryingly though, some sharing economy transactions are not even trackable by most governments and some knowledge assets require a whole set of new depreciation and taxation laws.

5. CONCLUSION

It would seem, at some level, that adopting and adapting to even a few macro ESE trends will naturally lead to the others. Maybe this is because once a new ideology of wastelessness, equality and humanity comes into operation they indicate and make us realize (individuals and collectives) how bad the previous ideology was; which can naturally result in a continuous cycle of reconsideration and improvement. There is no doubt in the Industrial Engineers ability to deal with economic changes. However, environmental and social changes are unfortunately more difficult to adapt to and require an authentic focus. This paper recommends, for example, that Industrial Engineers naturally need to take a proactive stance in resolving environmental problem by utilizing skills learnt in management accounting, engineering economics and other sub-disciplines to accurately reflect the financial and non-financial benefits of alternative energy to companies and decision makers. Accounting for the right things might lead to very different decisions and will facilitate a swifter transition to more sustainable energies. Additionally, although there is no doubt that humanitarian engineering projects exist, yet, they represent a minority of projects. This is not to say that projects don't take human concerns into consideration, but, it does show that most projects have a different central focus: money, enormity or competition. Over time this can lead to human factors being disregarded and left to satisfy the minimum. Industrial Engineering should be the champion of the humanitarian engineering movement. After all, the roots of IE are so intertwined with workers, their rights, their health and balancing or superseding it over financial considerations.

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BENCHMARK INDICATORS FOR COMPETITIVENESS ANALYSIS OF TIER 2 AUTOMOTIVE INDUSTRY

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ABSTRACT

The importance of micro economic drivers is well established globally, and leading economies are largely driven by small and medium scale enterprises. The paper seeks to determine major internal benchmarks for determining competitiveness of tier 2 manufacturers who in turn supply automotive components to tier 1 enterprises, who are the only approved suppliers recognized by Original Equipment Manufacturers (OEM). This is against the backdrop that the automotive industry contributes largely to South Africa's GDP and as such, its lower tier need to be strengthened. The study sampled tier 2 automotive component suppliers and initial competitiveness assessments were conducted. The relevance and suitability of different competitiveness benchmarking parameters were revealed based on tested Key Performance Indicators (KPI). To achieve higher competitiveness, lower tier automotive component manufacturers are advised to promote workplace cooperation, improve employee working conditions and apply productivity improvement systems that will boost efficiency and improve product quality.

KEYWORDS:
Benchmark, Indicators, Competitiveness, Automotive, South Africa

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1. INTRODUCTION

From a retrospective standpoint, some large international firms currently notable as industrial giants in the context of competitiveness, all started out as Small, Medium and Micro Enterprises (SMMEs), and these were able to survive massive technological changes during the industrial revolution. The technological changes pruned volumes of enterprises off the radar, thereby creating opportunities for new entrants. However, the manufacturing space is fast changing as the world is not only contending with disruptive manufacturing innovation according to Campbell et al. [1], but also, it is faced with the unfavourable outcomes of globalization, resulting in product divergence and market convergence [2]. Imports are major bane to growth of local enterprises in some countries with unfavourable policies affecting SMMEs [3] [4] as witnessed in most developing nations. Nevertheless, quality of products and service delivery by local manufacturers has been found wanting, within the lower tier automotive component value chain. Accordingly, larger enterprises that depend on local suppliers alternately resolve in sourcing components from suppliers that guarantee quality, less rejects and better lead times, even when products cost more to acquire than local substitutes. Furthermore, some large manufacturers prefer sourcing components from affiliate enterprises abroad. The effect this has on a nation's economic growth cannot be overlooked, which calls for proactive measures that can effectively boost competitiveness of home grown industries. Enterprise Improvement (EI) is essential at this point in time because for the SMMEs in the automotive industry to be in existence and be entities to reckon with in future, they must become competitive locally and progressively work towards global relevance.

The study focuses on internal benchmarking indicators which tend to rank the competitiveness level of enterprises using multiple indicative matrix. It aims at identifying areas which need attention, in order to build a competitive industry. Institutions and agencies charged with the responsible of improving local production will therefore have empirical data to base decisions upon, when focusing on productivity improvement initiatives within this industry segment.

Numerous studies have been carried out at higher levels involving tier 1 enterprises and Original Equipment Manufacturers (OEMs); however, little information exists at the tier 2 enterprise level which are more often smaller in terms of product volumes, structures and workforce, and the industry conformance standard (according to ISO demands), are less demanding in comparison to higher level enterprises. Indicators adopted in other countries or other industries could have easily been copied and adopted directly for competitiveness evaluation; however, the results might then be skewed because of a lack of relevance in the context of the industry where it has to be tested based on employment act differentials and economic variances.

This is the pilot phase of a larger Enterprise Improvement (EI) project and as such, this paper focuses specifically on the identification of relevant benchmarking indicators which can be adopted on a larger scale for Enterprise Improvement (EI) projects within this industry segment.

2. REVIEW OF LITERATURE

Competitiveness of an industry can be viewed from various perspectives depending on the aims and objectives of the evaluation. Industry competitiveness is also attributed to economical competitiveness of nations based on further classification matrix. According to Saranga [5], the indicative elements worth considering for classification of competitiveness grouped by Durand and Giorno [6] are: (1) financial indicators such as price, exchange rate, Return on Investment (ROI) and Return on Assets (ROA) (2) Non-financial indicators such as customer satisfaction, market share, inventory, market share growth, sales volume, sales growth, quality measures, productivity, lead time, performance to schedule and preventive maintenance measures.

Enterprise improvement is believed to yield higher productivity and in turn, competitiveness. Competitiveness Key Performance Indicators (KPIs) as explained by the World Economic Forum (WEF), are the set of institutions, policies, and factors which determine productivity level of a country. Equally, success and economic prosperity of a nation is attributed to the level of productivity of enterprises, generating wealth from internal production within, and not from its externally generated revenue from branch outlets abroad [7].

Productivity is a major factor considered when measuring competitiveness as identified from literature. Major components identified in literature are: (1) Current state of manufacturing and complementing infrastructures (2) ability to innovate (3) macro-economic environment (4) training structure especially at the higher education level (5) institutional performance (6) efficiency of Labour market (7) market efficiency (8) financial market inclusion (9) size of market (10) technological readiness (11) level of sophistication of businesses (12) accessibility to health care (13) accessibility to primary education [8][9][10][11]. These factors all complement productivity but they are not always used in a single evaluation due to factors peculiar to various industries. Furthermore, some of these factors are influenced by other external measures. For instance, automotive component manufacturers compulsorily require to operate in global value chains to remain competitive in Korea and Malaysia [12], which is not the case in South Africa's tier 2 automotive industry. According to bargaining agreements unique to each industry in every country, labour cost varies across countries which can be linked to the level of prevailing economic dynamics. Just as oil prices are regulated at international levels, so also pricing is habitually determined at international levels for homogenous standardized components, produced across continents. Lack of comprehensive bilateral price data however, affects the pricing policy which leads to uncertainties and subjective claims, according to [13]. As such, it is important to consider export prices, logistics cost and labour cost [13] when determining competitiveness. The level of Research and Development (R&D) also determines growth of an industry. Based on a two-way fixed effect model for estimation of a firm's growth [14], industry growth level was linked to percentage of sales revenue channeled into Research and Development (R&D) and existing technology utilized, as against foreign equity participation and import of capital goods. Another important factor worth considering is service delivery time. On time service delivery is generally seen as higher lead times, which is attributed to time based competitiveness [15] [16]. The ability of a manufacturing system to respond to customer demand promptly shows the effectiveness of internal systems and processes so long quality of products is maintained. The lead time is critical to business success as amplified in international levels [17].

3. METHODOLOGY

The use of appropriate feedback mechanisms greatly contributes to information harnessing in industry competitiveness assessment. To adequately identify the views of various levels of the workforce within the enterprises, instruments for employees were different from those of employers/management. The study was approached with this understanding and as such, primary data was harnessed using observation sheets, employee evaluation forms and standard questionnaires with KPIs for a benchmarking enterprise baseline. The questions were designed to sufficiently provide information that will guide in taking informed decisions regarding strategy adoption, for improving the automotive industries competitiveness level. The questionnaire identified gaps relating to enterprise productivity, workstation environment, production systems, Health Safety & Environment (HSE) practices, resource allocation, resource planning, quality management system, supply chain, visual management, suggestion schemes, problem solving techniques, research & development, workplace cooperation amongst others. It was also designed to identify existing practices, which make some of the enterprises competitive in a bid to learn from them and promote same among others. The tools adopted were developed for consistency of result analysis and this guaranteed effective communication of KPIs during the project. The project was in 3 phases as presented in figure 1.

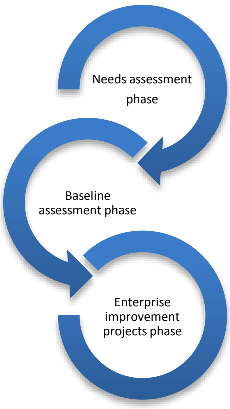

Figure 1: Project implementation plan

For the pilot phase of the study, the 3 tools were tested in 15 enterprises while they were applied in 5 enterprises during the baseline study. Feedback was received from shop floor employees, shop stewards, supervisors, middle managers and some management staff of the evaluated enterprises, according to accessibility of stakeholders. The evaluation instruments (observation sheet) and employee feedback form were designed using the Likert scale of measurement. Relative weight was important due to the large population of respondents. Data collected at the baseline assessment phase was mainly to correlate accuracy of initial data during the needs assessment. Due to multiple instruments utilized, the collected data were carefully matched for balanced result. The observation sheet results obtained from the interviewers were normalized and analyzed for accuracy and consistency, and were further averaged. The initial assessment had 73 structured questions which covered all internal competitiveness areas articulated from literature. Some critical competitiveness indicators that are externally influenced were not included in the study, such as Research & Development (R&D), which is hypothetically measured through the level of research outputs and R&D infrastructures existing within a country and around the region.

Effort was made to link literature findings pertaining competitiveness benchmarking indicators at this level with determining factors considered globally. The focus was on developing internal productivity enhancers, through improvement of soft skills and to some extent, hard skills needed for day to day functions. This article is structured not only for academics and high level professionals, but in a format that can be easily understood by enterprise improvement teams responsible for competitiveness improvement within the tier 2 automotive component manufacturing segment. The information harnessed from the survey, informed the proposed KPIs herein referred to as benchmark indicators. During the EI project phase, a table of KPIs was issued to the

Enterprise Improvement Teams (EIT) within the enterprises and each were at liberty to select 5 indicators from the list of 20 generic KPIs provided. The selections were weighed relative to data captured in the observation sheets and the corresponding outcomes supported the shortlisted benchmarked indicators presented in the results. Furthermore, Enterprise Improvement Plans (EIPs) were developed by each of the enterprises at the commencement of EI projects, and the resonating indicators across all enterprises validated choice of benchmark indicators.

Due to very large data obtained from the various phases of the project, a multi level criteria approach for indicator selection was utilized. Based on time constraint, averages of the various feedback averages were taken for employee assessment while average of the modal evaluation scores obtained from all interviewers using observation sheets were used and further normalized for standardization. Figure 2 shows the implementation model adopted for the study.

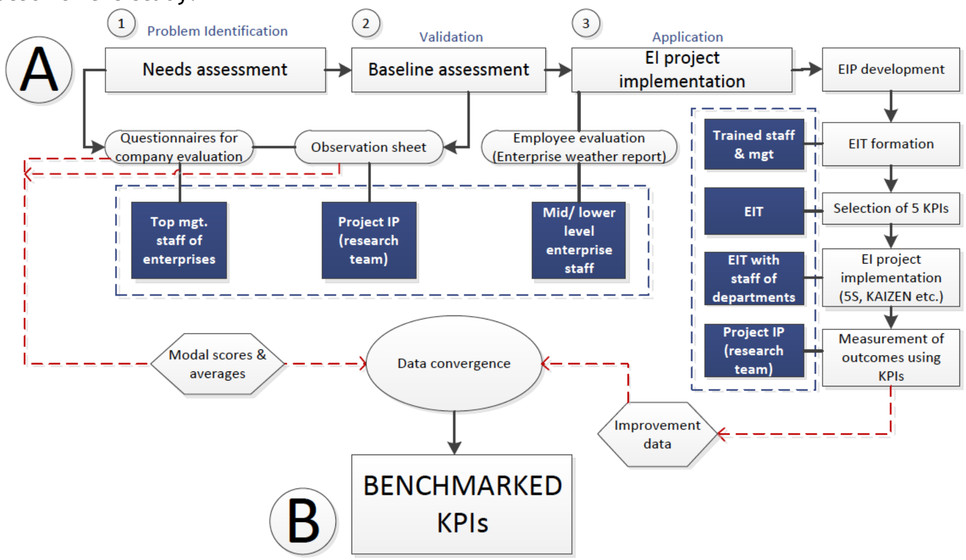

Figure 2: Implementation model

4. DATA ANALYSIS

The data collected was normalized using Range Equalization Method (REM) to improve its interpretation.

$$\text{Normalization} = \left[\frac{\text{Actual Value} - \text{Minimum Value}}{\text{Maximum Value} - \text{Minimum Value}}\right] \times 100\% \qquad \text{(i)}$$

To evaluate the collective importance of response received from each indicator, Relative Importance Value (RIV) was used for analyzing collected data. RIV describes level of importance of respondent's views, thus an index value was adopted based on the 5-point rating scale for questions and answers within the questionnaire [18]. The measure RIV for each individual competitiveness indicator was obtained from the weighted average using the survey data through the following formula:

$$\text{RIV} = 100 \times \frac{\sum ax}{5N} \qquad \text{(ii)}$$

X: frequency of the responses for a specific indicator; N: total number of responses; a: the weighting value corresponding to a specific question (ranging from 1 to 5 as suggested in the questionnaire) where 1 is least acceptable (most unacceptable) or insignificant and 5 is extremely important (most acceptable) or critical.
The aggregate index for each of the indicators was derived first using relevant variables (sub-indicators).

$$V_i = \frac{1}{n}\sum_{i=1}^{n} x_i \qquad \text{(iii)}$$

where, V_i is i_{th} indicator, xi is the i_{th} sub-indicator; n: number of sub indicators within the indicators. The aggregating of all the indicators into competitiveness index for a firm in the automobile industry.

$$C_j = \frac{\sum_{i=1}^{n} W_i V_i}{\sum_{i=1}^{n} W_i} \qquad \text{(iv)}$$

where, C_j is the competitiveness index of j_{th} firm, W_i is weight of the i_{th} indicator, V_i is i_{th} indicator and n is the number of indicators.
The Likert scale of measurement is usually utilized in an attempt to weigh respondent's opinions in a survey [19]. It was applied by coding the results on a cumulative basis according to scale of 1 to 5 with the following representations: strongly agree-5, agree-4, Indifferent (Neither agree nor disagree)-3, partially disagree-2, Strongly disagree-1. To effectively analyze the Likert data, the results were arranged in an ordinal measurement scale using the descriptive statistical approach for ordinal measurement scale.
For the Centre of Tendency measurements, the median and mode was utilized while the frequencies were observed for the variability measurements and this was achieved by analyzing the variables at intervals. The

Likert scale items were tested for reliability at the onset and also tested for outliers and missing data. Since most of the harnessed data were normally distributed, one tailed Grubb's test was used to analyze the data to eliminate outliers as recommended by Marino and Gladyshev [20]. This was achieved using a software add-on to Microsoft Excel called "real statistics".

Table 1: Analyzed KPIs

	Summarized evaluated parameters (measured elements)
K1	Team work
K2	Suggestion Scheme & Grievance Mechanism (policies, grievance procedures, suggestion box)
K3	Adherence to Standard Operating Procedures (SOP) and effectiveness of Process Failure Mode Effects Analysis (PFMEA)
K4	Ergonomics (working position, temperature, weight of objects hand lifted, condition of air)
K5	Error proofing utilization
K6	Calibration/ validation of measurement devices as required
k7	HSE (Health Safety and Environment), HIV/AIDs awareness)
k8	Legal Compliance and workforce wellness (workers safety, welfare, minimum wage, sexual harassment prohibition, role understanding, demography mix, performance linked payment)
k9	Workforce Management (Policy related to gender equality,
k10	HSE (handling of sharp objects, exposed electrical cabling, hazardous wastes; complete use of PPE, fire prevention, building inspection; availability of potent first aid items)
k11	Planning (SWOT, order driven production planning, contingency plan, continuous improvement plan, skill development plan)
k12	Cleaner Production (TIMWOODS status, monitoring of consumption, reference to consumption norms, leakages and waste elimination)
k13	Visual Management (use of display boards during production & green area meetings, clearly defined and understood goals &targets)
k14	Communication (Daily meetings, news letters, display boards)
k15	5S (toilet hygiene, organized inventory, environmental hygiene, availability of drinking water)
k16	Customer Need & Expectation Assessment (list of customer internal & external needs and expectations)
k17	Data availability (display of trends & analysis & understanding of same by workforce)
k18	Statistical Process Control (display of analysed components on X-bar, R chart etc.; Understanding of Stability, variation, capability, over adjustment etc.)
k19	Use of Quality Tools (Pareto chart, why why analysis, fishbone diagram, histogram, analytics tools)
k20	Product development status, OEE, Inventory Turnover Ratio (ITR), Downtime/Uptime, On Time Delivery (OTD), Turn Around Time (TAT), scrap rate, rework, defects, costs savings, absenteeism, injury, near misses
k21	Level of implementation of productivity improvement tools utilized by employees (VSM, line balancing , KANBAN, KAIZEN, continuous production flow, QC tools, time-motion study)

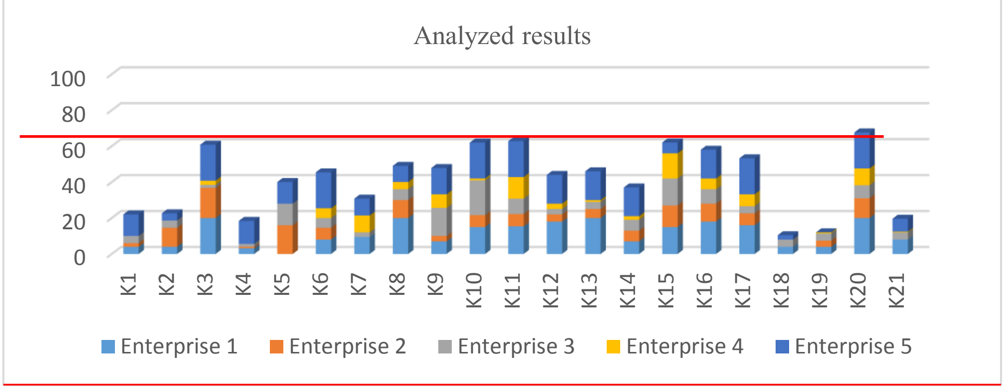

Figure 3: Analyzed results ranked according to KPI Scores, showing need for intervention

4.1 Discussion of results and recommendations

The study explored preselected automotive component SMMEs and exposed internal competitiveness gaps existing within the firms during the pilot phase of the study. 60% level of conformance was set as minimum ranking upon which the indicators were considered sufficient, and any results below this mark are clear pointer for comprehensive intervention. Above 80% is the desired level according to the study matrix employed. From the results, only K20 was sufficiently above the minimum bar which shows that most elements within the selected indicators are not adequately addressed across the analyzed enterprises. From closer analysis of K20, despite being above the minimum bar, it did not meet the 80% mark which is the desired conformance level for which the indicator will not be considered. K3, K10, K11 and K12 were close to the 60% mark, and from analysis of these indicators, they were all critical conditions which must be addressed for the enterprises to meet regulatory standards (k10) and others were essential for productivity improvement. From the results, team work (k1) was rather weak and the formation of Enterprise Improvement Teams (EIT) as shown in the implementation model in Figure 2 was a right step in addressing this issue, common to most enterprises surveyed. From the study, there is need for improved communication policies through effective visual management boards and displays. Walkways also need to be clearly demarcated using approved safety colour codes. Employees should be trained and must adopt problem solving techniques especially in the shop floor. Regular green area meetings using defined meeting agenda is equally required because effective communication guarantees higher productivity from employees. Taking a closer look at the results, enterprise 5 contributed largely to the high scores, neutralizing some of the scores from lower performing firms. An in depth study of the companies showed that company 5 had to some extent, effective communication procedures which encouraged workplace cooperation even though communication policies were not documented. Team work is equally emphasized in company 5 which is lacking in the other companies studied. Furthermore, productivity is given utmost priority in this company with emphasis on TIMWOODS (Transport, Inventory, Motion, Waiting time, Overproduction, Over processing, Defects and Skills). Identified waste is constantly being investigated and soft measures are in place for reduction of such. However, emphasis on total waste elimination was not seen in some instances which was linked to cost-benefit considerations. Company 5 is found lagging in terms of legal compliance and work force wellness. Equally, the results reflect very little use of quality tools for the enterprise day to day operations. Formation of Enterprise Improvement Teams (EITs) is highly recommended because the team will serve as "change agents" for promoting required changes.

Since the project is in its pilot phase, to take the work further, a Decision Support Systems (DSS) may be considered for further analysis of the data, which is an alternative selection criteria mechanism. Additionally, the use of quality tools should be emphasized and statistical process control for line area meetings should be considered because of the potential they have in effectively communicating critical production elements. The results obtained should be compared in detail with the method adopted in this phase of the project.

5. CONCLUSION

Competitiveness of any industry requires holistic improvement of processes, management systems and all elements that promote productivity. Internal factors have to be addressed at the enterprise level while external factors have fiscal economic bearings which are controlled by government policies and global market forces. Tier 2 automotive component producers within South Africa need to address competitiveness gaps which make their products less competitive, by improving internal systems in order to meet international industry standards, thereby entering global markets since there is continual convergence of market as it is currently. The industry should equally take advantage of favorable policies already in place, which will guarantee sustainability, so long their product offerings meet internationally acceptable quality standards with zero defects. Based on the results obtained, there are evidences to show that all the hypothetical Key Performance Indicators (KPIs) assumed at the onset of the study have to be considered.

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A DYNAMIC OPTIMAL CONTROL SYSTEM FOR COMPLEX COMPRESSED AIR NETWORKS

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ABSTRACT

Mines use large compressed air networks to supply shafts and processing plants with compressed air. These networks can however be very complex as multiple compressors are located at different locations. Each end user of compressed air is also often a separate business entity – each following its own schedule and usage requirements. Despite this complexity, most mines still use static compressor control, which is based on typical usage patterns, on these networks. However, the static control strategy is only effective when all the end users use compressed air matching the typical usage pattern, since if one end user deviates from this pattern, the strategy becomes outdated. This typically happens on a daily basis. The article describes a dynamic compressor controller that offers an optimised solution for controlling the network. This optimised solution will specify the running compressors as well as the minimum pressure set point for these compressors. This ensures that the compressed air network is controlled optimally. The system was tested repeatedly and has shown that the system has the potential to reduce the running costs of a typical mine by up to R17 million per annum.

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1. INTRODUCTION

South Africa has a large mining sector which forms an essential part of the economy [1]. However, mining is an energy intensive industry, especially from an electricity consumption point of view [2]. In 2011, mining consumed 16% of South Africa's total electricity [3]. Gold and platinum mines further accounted for 80% of the total energy use [4],[5].

According to Fraser, compressed air generation on mines consumes approximately 25% of the total electrical energy use for gold mines and 40% for platinum mines [6]. This is approximately 9% of the total electricity consumption of South Africa's industrial sector [7]. Further, when examining the total cost of a compressor over 10 years, the electricity usage represents approximately 75% of the total cost [8]. With this in mind, it is clear that the energy usage of compressed air generation is an obvious target for electricity consumption reduction.

Most South African gold- and platinum mines supply compressed air to the shafts and processing plants through large compressed air networks called compressed air rings. Compressed air is supplied to these rings from either a single or multiple locations. However, each shaft or processing plant does not usually have its own compressed air source. These compressed air rings are also usually massive, consisting of up to 75 km of piping [9]. By using these compressed air rings, the reliability of compressed air is improved by providing backup compressors.

In order to ensure the optimal operation of the compressed air ring, a supply pressure profile can be generated depending on the combination of equipment, the number of the compressed air requiring equipment and the usage times of said equipment. These pressure profiles show the necessary supply pressure throughout the day. Each mine has a unique pressure profile with a noted maximum and a minimum pressure. If the pressure is too high, it could damage equipment; if the pressure is too low, the equipment ceases to work.

Each end user on a compressed air ring has its own compressed air requirements, thus if all end users on the compressed air ring are combined, a total pressure profile can be generated. However, if one end user changes its requirements, the pressure profile of the ring will change. Mines routinely deviate from their normal schedules, causing the schedules to become obsolete [10]. This makes the pressure profile generation of a compressed air ring a complicated problem.

As a solution to this, Van Heerden developed the Dynamic Compressor Selector (DCS) system [11] based on the work done by Venter [12]. The DCS system can observe the real-time requirement of compressed air networks and dynamically control the compressors to satisfy that need. This system was successfully implemented on a platinum mine [13].

2. SHORTCOMINGS OF PREVIOUS WORK

The DCS was not without its problems. Van Heerden mentioned that the DCS suffered from poor stability and non-optimal compressor selection [11]. Van Heerden thus further developed the dynamic compressor controller system and created the Dynamic Compressor Controller (DCC) [14]. However, during the development of the DCC system Van Heerden identified even more shortcomings in the DCS system.

The DCS system calculated a pressure set-point dynamically for each compressor house. However, ideally each compressor requires its own individual set-point. This is required because the compressors on a compressed air ring are located at different locations. The distance between the supply and demand can therefore be so extensive that the pressure drop becomes significant.

Further, when controlling compressors it is often assumed that compressors are most efficient when running at full power or that the largest compressor available is the most efficient. The DCS system also operated on this assumption. However, when looking at compressor efficiency curves it can be noted that the most efficient control point for a compressor is not always at full power, neither is the largest compressor always the most power efficient. When selecting the trimming compressor this assumption is also made, and in turn will cause the smallest running compressor to always be selected as the trimming compressor. However, advance larger compressors will sometimes be able to control their flow delivery more effectively and energy efficiently.

From a maintenance perspective reducing cycling, which is the continuous on and off switching of equipment, is a key objective. Therefore, in order to control the compressor optimally and prevent cycling, the future state of the network needs to be estimated. In order to be able to estimate the future state of the network the future flow requirement of the network needs to be estimated. This enables the control system to start the optimal sized compressor for the required present flow rate as well as the future flow rate.

Figure 1 One-dimensional network [14]

The DCS system worked on a one-dimensional level by only having a total supply and total demand. An example of such a one-dimensional network can be viewed in Figure 1. The controller then attempts to do flow matching. However, to ensure that the dynamic compressor controller is able to work on most networks the controller needs to be location attentive and work on a two-dimensional level [14]. This means that more than one supply point as well as demand point is present. An example of this can be viewed in Figure 2. Tying in with this is the fact that the controller needs to be able to identify when a compressed air pipe is closed in real-time and adapt its control philosophy accordingly.

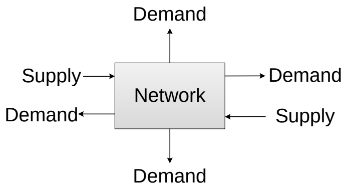

Figure 2 Two-dimensional network [14]

3. THE DYNAMIC COMPRESSOR CONTROLLER

3.1 Simulation

The method of simulation used by the DCC system [14] was based on how the DCS system completed simulations [10].This simulation model was developed by Venter [12]. He made the assumption that using the compressor exit temperature is satisfactory for isothermal flow calculations [12]. This assumption was used made Sun [15] as well as Ke and Ti [16].

The DCS requires the user to determine the pressure drop over a pipe empirically and incorporates this into the surface friction of the pipe. This ensures that any pressure drop attributed to temperature changes is automatically accounted for. For this reason empirical simulations utilise an average temperature throughout the system.

Simulating transient temperature changes on a pipe network that spans hundreds of kilometres is not practical, as there are simply too many variables influencing the temperature. This would require a magnitude of temperature measurements on a system that changes continuously.

Van Heerden proved that the simulation method could successfully calculate large compressed air networks [11] and Van Niekerk successfully used the system in a project [13].The system of nodes and pipes are used to build up a complete network and by using Bernoulli's theorem [17], equation (1), the network can be simulated. However, one of the reasons the DCS system [11] was having stability issues was in its inherent design which made recovering from erroneous output almost impossible. This can be viewed in Figure 3.

$$\frac{\rho v^2}{2} + pgz + P = constant \tag{1}$$

ρ : Fluid density [kg/m^3].
v : Fluid velocity [m/s].
g : Gravitational acceleration [m/s^2].
z : Measured height [m].
P : Pressure [Pa].

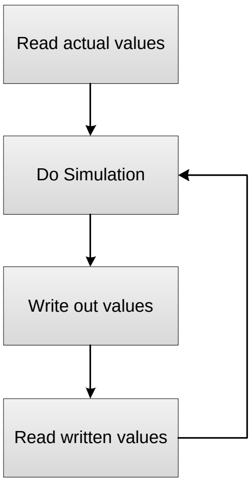

Figure 3 The DCS simulation process

All the calculations of the DCS system were also based on the idea of having a supply pressure to calculate the demand pressure. This is then used to simulate the current state of the network. To calculate the supply set-point pressure, the supply pressure is increased or decreased until all the demand pressures are equal to or greater than their respective set-point pressures. However, by following this approach only one supply pressure set-point per compressed air ring can be calculated.

Furthermore the DCC system's calculations are based on the idea of calculating the ideal state of the network and not the current state [14]. It will then attempt to assign inputs in order to create this ideal network state. The DCC simulation process can be viewed in Figure 4. The "viable inputs" is data captured from the compressors in order to estimate their ability to deliver compressed air.

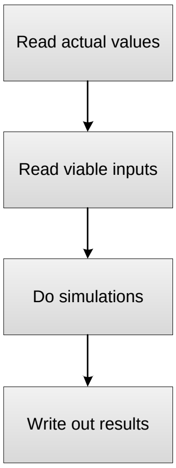

Figure 4 The DCC simulation process

The simulation process that Van Heerden [11] used is based on nodes, an example of which can be viewed in Figure 5. By using this structure and having nodes represent end users, supply points and junctions, a complete network can be built. An example of this can be viewed in Figure 6.

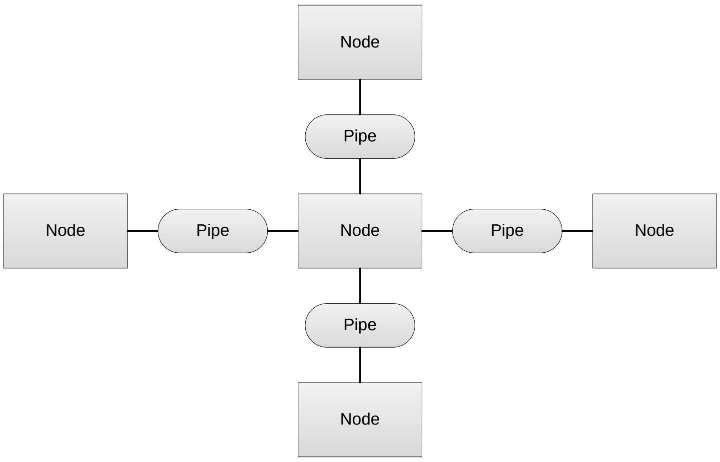

Figure 5 Example Node[14]

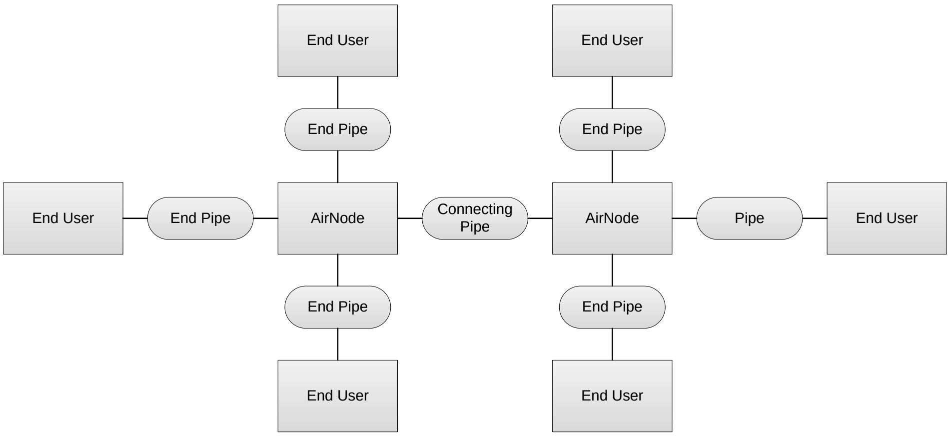

Figure 6 Example network [14]

For calculating the pressure, it is assumed that the end point pressure is known. The center node pressure is thus iterated and with each iteration the flow rate through the pipes are calculated. The center pressure is then iterated until equation (2) is valid. This whole process is repeated for all nodes until the rate of change of the flow through the pipes converge to 0.

$$\sum m_{flow\ into\ node} = \sum m_{flow\ out\ of\ node} \tag{2}$$

m : Mass flow [kg/s].

For the End User nodes the pressure must be calculated based on the flow as only the flow is measured upstream of the control valve. For this calculation equation (3) is used. The DCC also makes use of a "driven node" when simulating. This node is the demand node which drives the supply set-point up. Practically it means that the driven node will have its pressure be equal to the set-point pressure whereas all other nodes will have their pressure exceed the set-point pressure. This is done in order for the input pressure to be calculated at the lowest possible value while still supply enough pressure.

$$P = P_n - \left[\left(\frac{v^2}{2}\right) \bullet \rho \left(f\frac{L}{D} + k\right)\right] \quad (3)$$

P : Pressure [Pa].
P_n: Pressure of other node [Pa].
v : Fluid velocity [m/s].
ρ : Fluid density [kg/m^3].
f : Darcy friction factor.
L : Measured length of pipe [m].
D : Pipe diameter [m].
k : K-loss factor.

Like the calculations of the DCS, the DCC systems read the flow values from the demand in order to use them in the calculations. However, because compressed air systems usually have leaks, this read value must be adjusted. The formula used to adjust the flow can be viewed below in equation (4). Finally, if all of the measured demand flow is adjusted, flow matching of the supply and demand can be done.

$$m_{adjusted} = m_{measured} \bullet \left(1 + \frac{\sum m_{total\ supply}}{\sum m_{total\ demand}}\right) \quad (4)$$

m : Mass flow [kg/s]

3.2 Future flow

The future flow estimation for the DCC [14] is based on historical averages with a resolution of 30 minutes which can then be used to generate a profile for each day. The current flow rate is logged every 2 minutes and in order to keep the values current the amount of loggings are limited to 650. The data is logged as a count and a total, this is then adjusted with each log. When the maximum logs of 650 is reached the formula in equation (5) is used to calculate a new average.

$$Total\ flow_{new} = \left(\frac{Total\ flow_{old}}{650}\right) \bullet 200 \quad (5)$$

This new total flow is updated with a fake logged count of 200. This will allow the future flow estimation to keep estimating the flow historically while adjusting the historical value with time. For the simulations, the highest flow value between the current flow, 30 minute predicted flow and 60 minute predicted flow is used. This is to ensure that the compressed air supply will always be able to supply the required flow of the network within the hour period.

3.3 Compressor performance estimation

Compressor performance will change over time, since there are many factors influencing compressor performance such as inlet filters and seasonal temperature changes. The DCC system will thus actively log the pressure and the flow that the compressor can deliver. The power usage is also logged with this data, which is routinely updated to insure that the logged data is as relevant as possible.

This data is stored in a lookup table, which allows the DCC to seek the historic energy usage as well as the historic supply pressure and flow ranges. By combining these, the DCC can estimate how much power a compressor will use to deliver the specified flow. This estimated power usage is used as a cost metric.

3.4 Integrated solution

3.4.1 Overview

The DCC system works within a structure of solutions, worker, network, pipe and node structures. The relationship of these can be viewed in Figure 7. Each solution contains a number of individual workers, each worker contains one network, which in turn contains many pipes and nodes. The pipes and nodes are used to create the network.

3.4.2 Solution object

The solution represents a running combination of compressors. When the DCC simulates a network it will create multiple solutions in order to test different compressor combinations. By taking inspiration from genetic algorithms the DCC creates different combinations of running compressors for simulation. In order to reduce cycling and improve simulation speed a solution tree is built, this can be viewed in Figure 8. The starting solution is always taken as being the current running combination of compressors.

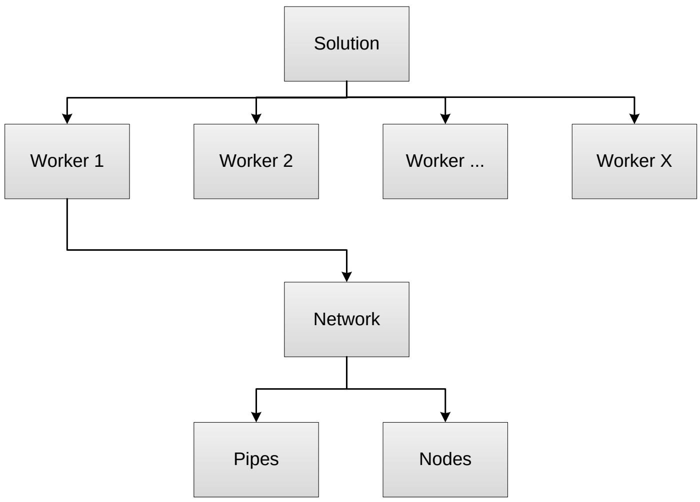

Figure 7 The DCC simulation structure [14]

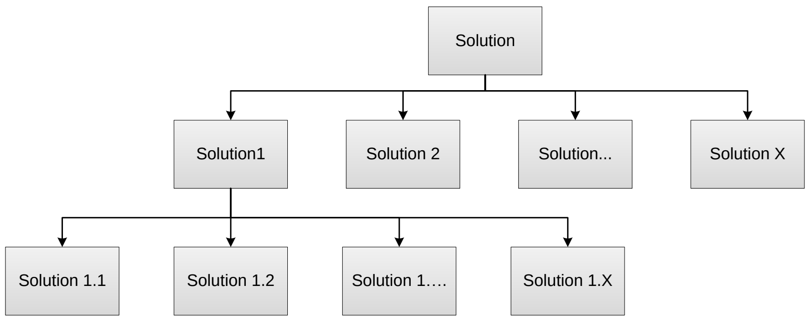

Figure 8 The DCC solution tree [14]

Solutions are created by representing compressor states as either 0 or 1. These combinations then form a binary string. A degree of evolution is made as one solution is evolved to all possible states by only changing one bit. A second degree of evolution is when all the children of the first solution are evolved. Figure 9 is an example of one degree of evolution. These solutions are evolved using modifications on genetic algorithms as they require a cost to find the best solutions to modify. As the cost metric is only available after simulation, the solution must be evolved to multiple possible solutions. To reduce cycling the amount of evolutions are limited as each evolution is a change of a compressor state.

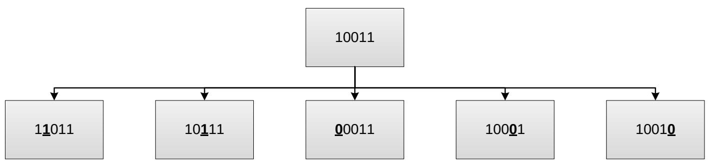

Figure 9 The solution evolution [14]

Before simulation the solutions are filtered for unfeasible solutions. These are considered as solutions which don't supply enough compressed air, supply too much compressed air or are a duplicate child solution. This reduces the amount of simulations that require computing.

3.4.3 Worker

The purpose of the worker is to simulate its own network and calculate the energy usage of its network. Each worker runs on a different CPU thread (multithreading) in order to improve simulation efficiency. The solution assigns different running set-points to all the compressors supplying compressed air in the simulation. These flow set-points are calculated using a shotgun hill climbing algorithm. This can be viewed in Figure 10. The same problem as with the solutions exists here in that the cost metric is energy usage and this is only available after simulation. However, by having multiple workers, different possible solutions are made which allows the DCC to find the optimal running point of the current compressors.

3.4.4 Energy estimation

After all the workers of all the solutions have finished with the simulations, the DCC can calculate an estimation as to the energy requirement of the simulations done. The DCC will then choose the most energy efficient completed simulation as the ideal state of the compressed air network. Further, in order to promote energy savings by stopping the DCC system cycling compressors, a scaling value can be selected to artificially reduce the energy consumption of the current running solution. This will ensure that a new solution is only chosen if the new solutions reduces the energy consumption by the scaling value or the current solution is rendered invalid by either supplying too much compressed air or not enough compressed air.

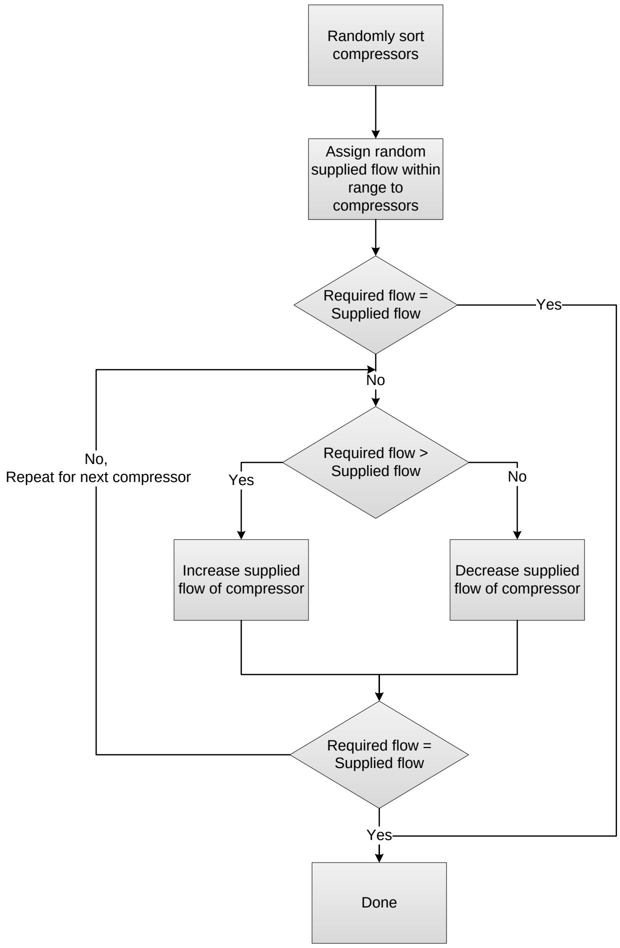

Figure 10 Hill climbing search flow diagram [14]

4. RESULTS

4.1 Node balance simulation testing

In order to test the DCC's network simulation, the network in Figure 11 was simulated in the DCC. The x represents the supply node and its pressure must be calculated. All the pipes in the network are 1 000 m in length, have an internal friction of 45 µm and have a diameter of 0.6 m. The results can be seen in Figure 12.

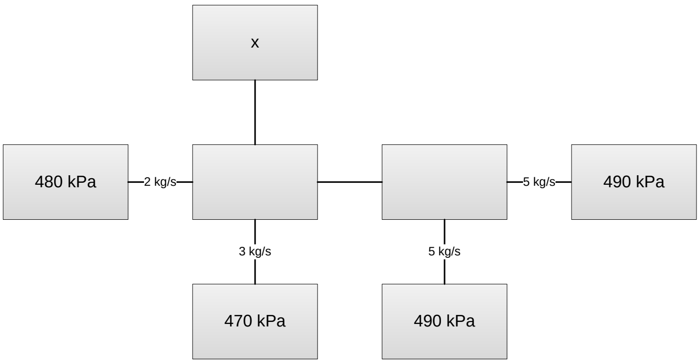

Figure 11 Sample small network

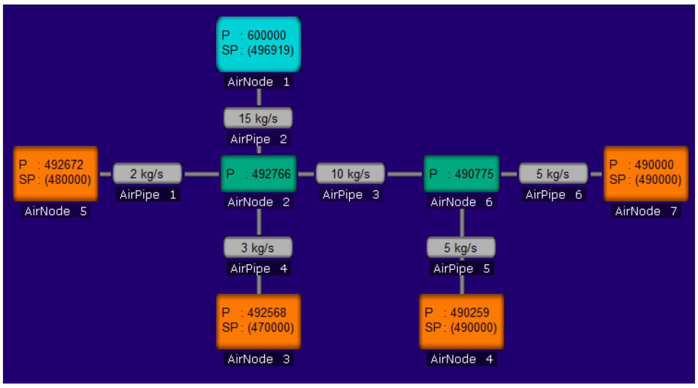

Figure 12 Sample small network result

Figure 13 and Figure 14 shows how the pressure and flow differences change during the simulation process of AirNode 2. In Figure 14 it can clearly be seen how the pressure of AirNode 2 is iterated twice. This is because the pressure of AirNode 6 has changed and the flow in AirPipe 3 has changed as well requiring the pressure of AirNode 2 to be recalculated.

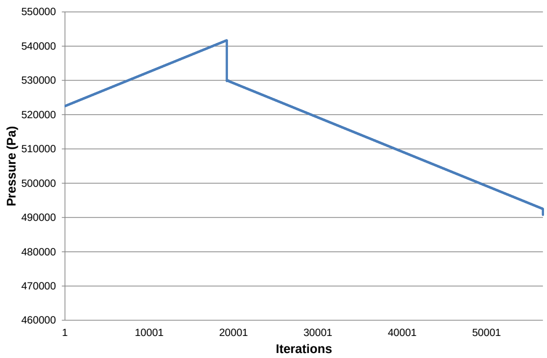

Figure 13 Pressure convergence of AirNode 2

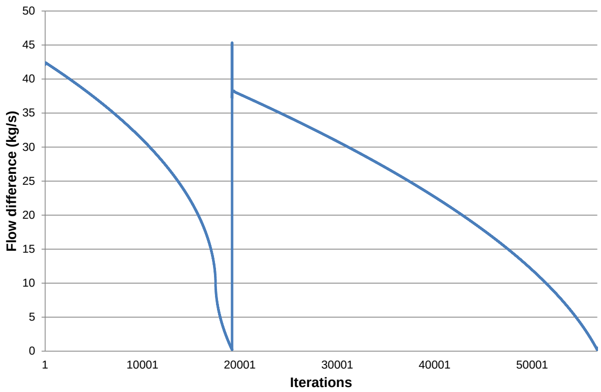

Figure 14 flow difference convergence of AirNode 2

From the above mentioned figures it can be seen how the DCC system successfully simulates the future state of a compressed air network. The DCC also assigned a supply set-point pressure that will ensure that every end user on the compressed air ring will receive their respective minimum air pressure.

4.2 Network testing

In order to verify if the DCC system can simulate a network accurately, it was compared to the DCS and KYPIPE by simulating the network in Figure 15. KYPIPE is a commercial compressed air simulation program. The simulated network can be seen in Figure 16.

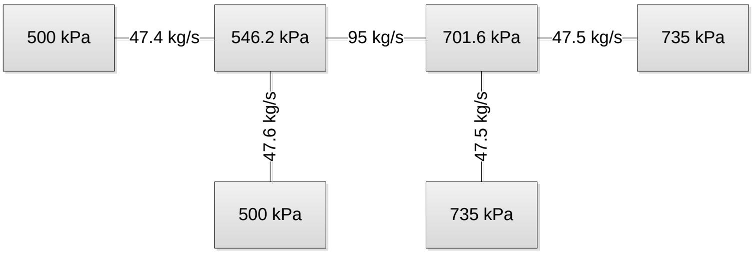

Figure 15 Test network

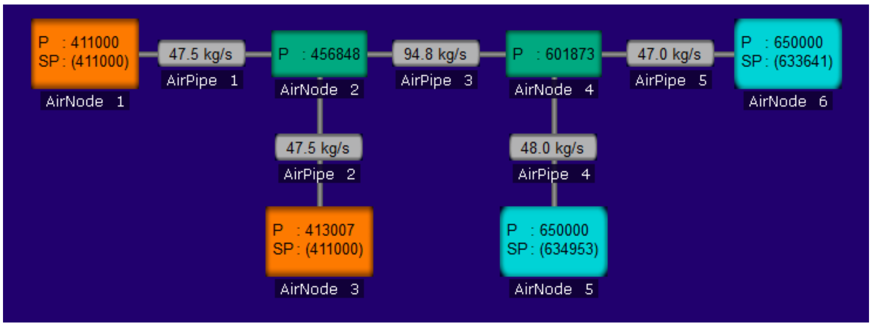

Figure 16 Simulated test network

The results of these comparative simulations can be viewed in Table 1 and Table 2. It should however be noted that the DCS and the DCC works on gauge pressure while KYPIPE works on absolute pressure. Gauge pressure is defined in equation (6). For these tests the atmospheric pressure was 89 kPa.

$$P_{gauge} = P_{absolote} - P_{Atmospheric} \quad (6)$$

P : Pressure [Pa].

From the below mentioned tables, it can be seen how the DCC favourably compares to the DCS and KYPipe in terms of simulation accuracy. The standard deviation of the results was less than 1%. From this it can be said that the DCC simulations are accurate.

In order to show the effect of the CPU threads on the calculations, a screenshot was taken of Windows® Task Manager after a simulation was completed. This can be viewed in Figure 17. As stated, the load is spread out on the different threads of the CPU, taking full advantage of modern CPU design.

Table 1 Pressure comparison [14]

KYPipe value (kPa)	DCS value (kPa)	DCC value (kPa)	Difference: K-pipe vs DCC (kPa)	Similarity: K-pipe vs DCC	Difference: DCS vs DCC (kPa)	Similarity: DCS vs DCC
500.0	508.8	500.0	0.0	100.00%	8.8	98.27%
500.0	508.4	500.0	0.0	100.00%	8.4	98.35%
546.2	553.4	545.8	0.4	99.93%	7.6	98.63%
701.6	701.8	690.9	10.7	98.47%	10.9	98.45%

735.0	735.0	724.0	11.0	98.50%	11.0	98.50%
735.0	735.0	722.6	12.4	98.31%	12.4	98.31%
Average difference			5.75	99.20%	5.75	99.20%
Standard deviation			5.64	0.78%	5.64	0.78%

Table 2 Flow comparison [14]

KYPipe value (kg/s)	DCS value (kg/s)	DCC value (kg/s)	Difference: K-pipe vs DCC (kg/s)	Similarity: K-pipe vs DCC	Difference: DCS vs DCC (kg/s)	Similarity: DCS vs DCC
47.5	47.4	47.5	0.0	100.00%	0.1	99.79%
47.5	47.6	47.5	0.5	98.95%	0.6	98.74%
95.0	94.8	94.8	0.2	99.79%	0.0	100.00%
47.5	47.5	48.0	0.5	98.95%	0.0	98.95%
47.5	47.5	47.0	0.5	98.95%	0.5	98.95%
Average difference			0.34	99.33%	0.34	99.33%
Standard deviation			0.2	0.47%	0.2	0.47%

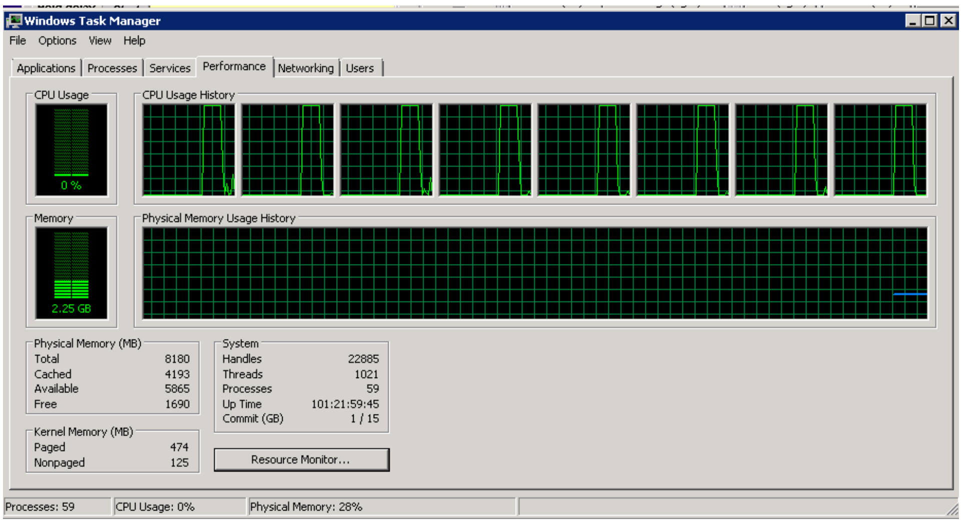

Figure 17 Simulation CPU usage

4.3 Simulated energy reduction

According to Van Heerden the DCC can reduce the energy consumption of a compressed air system by up to 86MWh which, by using 2014-2015 Eskom tarrifs, extrapolates to R17 800 000 per annum [14]. By following a worst case scenario of compressed air energy use and using the energy usage data metioned in the introduction, the DCC could potentially reduce the energy usage of South Africa by 1%.

5. CONCLUSION

The DCS system designed by Van Heerden was the first dynamic compressor controller for compressed air rings on mines [11]. Van Niekerk *et al* proved that the concept worked and that it could succesfully reduce the energy usuage of a compressed air ring [18]. Van Heerden's results also showed a reduction in the flow fluctuations of the delivered compressed air, which is a byproduct of proper demand-supply matching [11].

However, the DCS system cannot function on all compressed air networks, the DCC systems addresses this and improves on the energy usage according to Van Heerden [14]. The DCC system was however only tested in parralel to current working systems and in simulations.

By continsously trying to optimise the compressed air network and doing supply-demand flow matching, the DCC system provides a way to efficiently control compressors in such a way as to reduce the energy usage. As an additional benifit the DCC will also reduce flow fluctiations during control as the supply flow will be better matched to the demand flow. The DCC system also succsessfully addressed all the shortcomings of the DCS system.

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AN INVESTIGATION INTO THE CONTRIBUTION OF VARIOUS HUMAN FACTORS TOWARDS THE SUCCESSFUL OUTCOME OF A COMPLEX WEAPON SYSTEM ACQUISITION PROCESS

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ABSTRACT

This research investigates the effect of a specific set of human factors on the successful outcome of an acquisition project in a complex design to order environment. This study addresses the following overall research question:

- **What are the significant human related factors contributing towards the success of a project or enterprise during the acquisition phase of a complex system when interacting with a customer?**

The study is limited to the supply of a complex (engineered to order) system through a structured acquisition process. The example used is the supply of a military vehicle system as produced by one specific company.

[1] The author was enrolled for a PhD (Industrial Engineering) degree in the Department of Industrial Engineering, Stellenbosch University.

1 INTRODUCTION

This paper presents the study of a selection of projects in an enterprise in the military vehicle supply business domain. The acquisition process spans a number of years and follows a predetermined (prescribed) process. The acquisition process involves the successful passing of specific technical milestones in order to lower the technical risk profile as the design matures. In order to pass these milestones successfully, a significant interaction between the supplier and the customer is required.

The study therefore addresses the following problem statement:

- **What are the significant human related factors contributing towards the success of a project or enterprise during the acquisition phase of a complex system when interacting with a customer?**

In figure 1 below the success events, factors influencing the outcome, as well as their inter-relationships are presented. As depicted, the study is about the central focus in the diagram, which is to investigate the process and influences on the interactive and consequential events that occur between the supplier and the customer throughout the life cycle of the product's development, production and support.

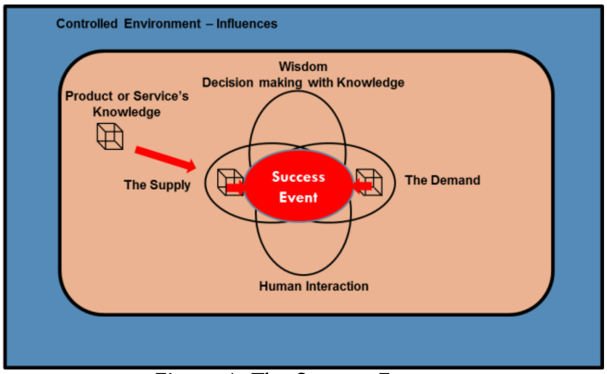

Figure 1: The Success Event

The evaluation and categorisation of these interactions, defined as success events, are done utilising a specific a case study (Yin) [1]. The case study under review comprises of six sub cases involving three different vehicle projects spanning over three phase of the enterprise lifecycle (Ward) [2] as well as four phases of the product life cycle (DOD) [3].

A framework was developed in order to define and contextualise the effect of specific human interaction factors on the successful outcome of a project. A comprehensive structured questionnaire was also developed to investigate the contribution of these human factors in relation to the process defined above. This questionnaire was distributed to 144 respondents of which 120 replied. One response was incomplete and was discarded resulting in a response rate of 83%. The results were analysed and are presented in this paper.

The author was actively involved in these projects in the company at executive level, for at least ten years. Triangulation of the results is obtained through the summary of the questionnaire results, comparing it to the current executive opinion of the outcome and also adding the author's interpretation of the outcome.

2 THE ACQUISITION PROCESS

2.1 The Defence Acquisition Processes

The acquisition of a complex military vehicle system is well documented in the western world with the USA's Department of Defence (DOD) [4] and the UK's Ministry of Defence (MOD)'s [5] acquisition system guidance explaining in detail the process required to ensure a successful acquisition of these military systems. The generic phases and decision points in this process are depicted in figure 2 below.

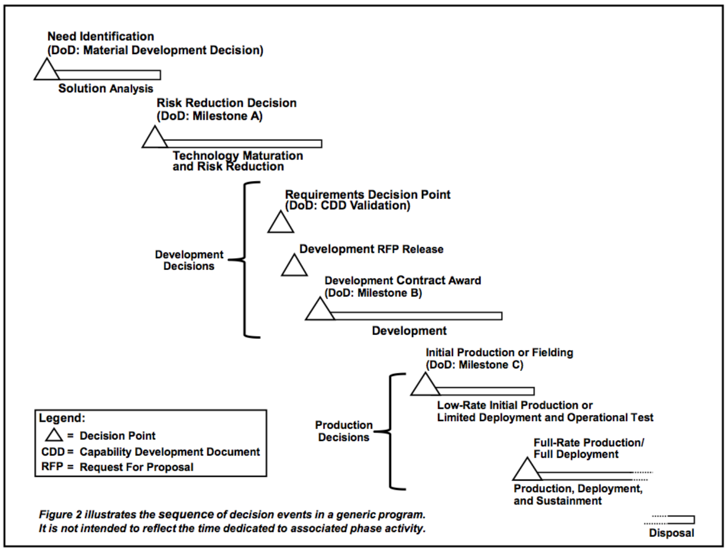

Figure 2: DOD Acquisition Policy 5000.02: Generic Acquisition Phases and Decision Points [5]

The UK, European, North American, Australian and South African acquisition supply processes were used to derive BAE System's Engineering Life Cycle Handbook [6] to be applied in all their global businesses.

2.2 BAE Systems Life Cycle Handbook

The supply of a weapon system has to be aligned in co-ordination with the customer's acquisition processes. To this end BAE Systems [6] defined the generic process in their Engineering Life Cycle Handbook System as having five major phases as follows:

- Concept Creation Phase
- Development and Qualification Phase
- Manufacture Phase
- Support during Deployment Phase
- Disposal Phase

Figure 3: The Engineering Life Cycle of a Product or System, BAE Systems.[6]

Thirteen design review gates (0 to 8 in figure 3 above) have been identified to manage the success of the knowledge migration throughout the life cycle.

2.3 The Engineer to Order Product Life Cycle

The acquisition phase for a military vehicle system typically covers between two and five years in time. We investigate this process in more detail by considering the specific engineer to order product process defined by Land Systems South Africa [7] as depicted in figure 4.
The engineer to order product life cycle consist out of three distinct phases' namely:

- The development of a generic or base vehicle. This can also be the previous model produced. The knowledge attributes of the base product must reach a minimum level of maturity to obtain an **acceptable risk level** to continue with potential contracting.
- The customisation phase where the design is completed against the stated commitments. This phase's main aim is to mature the product's **knowledge attributes**. If the customisation is extensive, it will increase the technical risk level and lower the current design maturity level as measured against the required performance.
- The industrialisation as well as the successful production of the customised product – this phase is primarily orientated to mature the knowledge attributes of the **processes** used during the production phase.

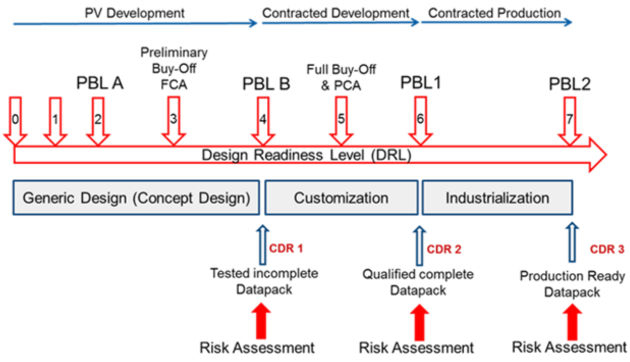

Figure 4: The Engineer to Order Product Life Cycle, Land Systems South Africa. [7]

The sequential phases of the engineering life cycle define an increasing maturity level of knowledge of the item under development. This is defined as a set of technical states or baselines indicating the growth in Design Maturity Levels of the product. It is important to note that as the design maturity levels increase the technical risk levels decrease.

3 SUCCESS REDEFINED

According to Porter [8], a successful acquisition project can be described with the following two results:

- A successful value outcome for the business owner.
- A successful product value realised as experienced by the customer.

3.1 Business Owner Value

The value for the business owner is a measure of the increase in the monetary value of the business for which there are many published financial models. Although the business owner value is of paramount importance to the investor, it will only be sustainable with continued delivery of true customer value.

3.2 Customer Value

The customer normally defines mandatory attributes as well as a weighted scale for the required functional performance for a specific project. In an engineer-to-order project [8], the customer also contracts a future commitment of the product performance. This is normally defined in a performance matrix, against stated requirements and timeline. Alignment of the offered product's attributes is based on subjective and objective elements combined in the three-dimensional space against the customer requirement set. Competitive product analysis is also done within this framework.

The three domains of presenting a knowledge item are defined as a structural or hierarchical view, a functional view as well as a logic or timeline view one can superimpose the required vs. the achieved attributes of the knowledge item during its application, we can define the following values and expectation gaps in the various views as defined in figure 5:

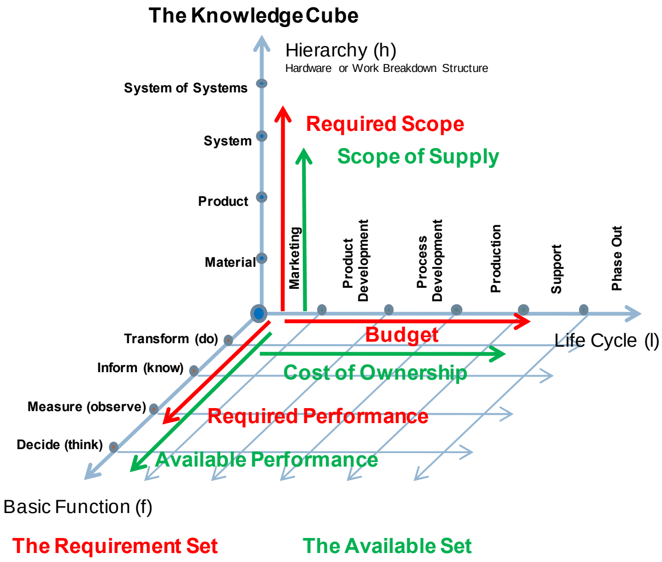

Figure 5: The Customer Value Realised - Pretorius et al. [9]

As can be seen from the above it is always critical to meet, but not exceed, the customer expectations in all the areas. We need to involve the customer through continuous engagement in order to understand his real needs and value system as this may differ from the explicit knowledge available during the process. The continuous interaction is defined as events where the supplier can demonstrate success and, in themselves, can also contribute towards the satisfaction of the customer as this is the only way in a complex product environment to obtain and react to the real (and perceived) value system of the customer.

3.3 Critical Success Factors

Kerzner [10] defines *"The goal of any project is to achieve technical objectives within the allotted time period and within the allocated budget."* Davis [11] stipulates that the project is only as successful as the added business value to the organization. The US Government Accountability Office (GAO) [12] stipulates that military acquisition management systems can only be successful at the macro level (DOD) if the correct strategies and tactics are implemented at the micro (program) level. Rockart [13] defined Critical Success Factors as *"the areas of operation where results must be positive for the organization to achieve goals and attain satisfactory performance"*. Bjorn [14] in his study of the USA Department of Defence acquisition process, employed multiple methods to assess the impact of system engineering reviews in order to define the correct approach to knowledge and risk in line with the funding of the program.

Dobbins and Donnelly [15] developed a standardised process for the formulation of Critical Success Factors specifically for defence program execution. This process is based on risk management when it considers the probability to achieve each Critical Success Factor. The DoD Risk Management Guide [16], *"risk is a measure of future uncertainties in achieving program performance goals and objectives within defined cost, schedule and performance constraints."* Risks are often divided into three categories based on the program performance measurement that is impacted upon realization of the risk. These are cost, schedule and performance risks. The significant amount of risk prevalent to the acquisition of advanced systems must be managed by a knowledge-based approach to system acquisition and development (GAO, 2008) [17]. *"Knowledge-based approaches are characterized by early management and technical reviews coupled with technology development activities to replace risk with knowledge and reduce first-time events and program uncertainty."* According to the Defence Acquisition Guidebook [18] the knowledge-based approaches also require systematic re-assessments as knowledge becomes available thereby reducing uncertainty as the program progresses. New Knowledge provides decision authorities with greater degrees of certainty (wisdom), increasing the propensity for success that the system will provide the required capabilities and be delivered on cost and schedule.
We can now focus on the events surrounding the technical reviews where, as indicated above, the potential for the influence on the outcome resides.

3.4 Success Events

A success event is defined as a series of premeditated, tacit and explicit knowledge exchanges that contributes towards the ultimate success of a technical baseline, the project and thus also that of the business. Examples of success events are:

- A communication interaction like a meeting, a letter, an e-mail, during work or social sessions with the customer.

- A formal presentation of a bid, a product description or contract negotiations as part of the acquisition life cycle.
- A formal design, program and contract reviews with the customer, i.e. milestones in the acquisition life cycle.
- A sincere, honest and speedy reaction towards mitigation of a problem or a perceived problem.
- An informal and formal presentation of in-process (stage buy-off) and the final product presentation.
- The interactions during the delivery of a service.
- The actual performance of the deployed product against the expected performance.

In summary success (or failure) events occur before, during and after each technical review gate in the acquisition process [5], is cumulative in nature [12], is mostly based on the perception of the customer [14] and requires consistent human interaction between the supplier and the customer.

3.5 Factors contributing to Success

Bob Seelert identifies leadership as a critical factor contributing towards successful client interaction [19]: *"Leadership is intangible. The first step is earning the trust of people you work with. Everything else follows from that."*

Soupios et al. [20] defines the need to investigate relationships with their statement *"We are convinced that enduring success is ultimately traceable to those rare men and women who, by virtue of their personal insights and integrity, are able to command the loyalties and commitments of their subordinates. To our way of thinking, failure to see matters in these terms constitutes the real naïveté as well as the greatest impediment to building a meaningful enterprise."*

Courtney et al. [21] studied the social learning at the Australian Defense Organization (ADO) in order to identify factors that will enable the generation and transfer of knowledge to contribute to creation of organizational culture in support of continuous learning. These factors are described as *"common identity, morale, problem solving, team building, performance management, workplace design, organizational culture, records keeping, information exchange, IT infrastructure, professional training, and induction and enculturation."* It will be important to understand the contribution of corporate culture on the success of the project.

3.6 Human Intervention

According to Briskin et al. [22] *"change happens on a macro systems level but also on a micro level—one conversation at a time, one group at a time, one new idea spawned among a group of committed people, setting off a chain reaction of new possibilities"*. They conclude that collective wisdom is the human ability in finding alternatives ways in pursuing "*wise action*". Wise action is defined as the capability to exercise good judgment, and to reflect real understanding of the issue at hand. Collective wisdom result in unexpected and positive results that holds more value than any single individual can contribute.

The human's interaction within an organisation is very complex and cannot be segregated into specific functions. For example, a leader needs relationships, communication, teamwork, knowledge, sound judgement etc. to affect his leadership within an organisation. Similarly, communication cannot be isolated as it requires at least two parties to be successful which implies some sort of relationship at play.

During the preceding years of working in a complex organisation the writer identified that the effect of leadership, relationships, collective wisdom and company culture did have some role to play in the success of a project. We now investigate these specific human related factors as follows:

3.6.1 Leadership

Ward [3], through the study of companies at different stages of the organization's lifecycle, concluded that there are unique challenges facing organizations and their leadership at each transition between the different stages, as the demand for a specific leadership style between phases differ significantly. Consequently, it requires significant changes in managerial and leadership skills to lead an organisation at these different transitional periods. Hence, the Leadership Lifecycle with the leadership styles of the Creator, Accelerator, Sustainer, Transformer and Terminator are required for success in each phase of the life of the organisation.

3.6.2 Relationships

The human interaction is depicted by a relationship model as defined by Stiglingh [23] where he combined the ABC model (Activity, Belief and Consequence) of both the customer and the supplier as depicted in figure 6 below:

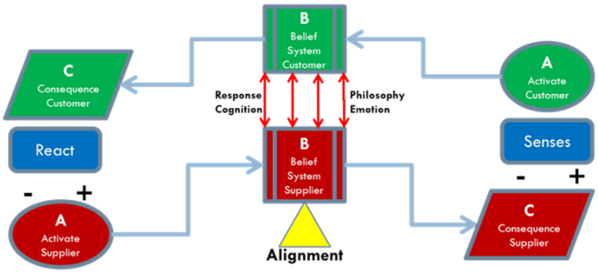

Figure 6: The Influencing Framework adapted from Stiglingh [23]

To obtain the best results from a relationship, it is advantageous if the supplier and the customer's belief systems are closely aligned. The belief system is the actual set of precepts from which you live your daily life, those which govern your thoughts, words, and actions [24]. As no complete alignment between the belief systems of the customer, as well as the supplier, at all levels, are realistically possible, one needs to focus on areas of miss-alignment that have the potential to turn a success event into a failure. According to the literature [25], the business belief system comprises of the following four elements:

- Behavioural Performance, Action, Inaction – How people respond to what is happening.
- Cognitions, Mind-sets, Clarity, Perceptions – How people think of what is happening.
- Philosophy, Core Beliefs, Personal Values – The meaning people attach to what is happening.
- Emotional Climate, Relationship Management, Emotional Information – How people feel about what is happening.

From this model, it seems that a positive consequence must be sought through careful planning of the sequential success event actions as well as a careful choice of the teams interacting with the customer.

3.6.3 Wisdom

Management is defined as a series of decisions combined with supportive actions. Knowledge, on the other hand, exists as tacit knowledge within the people as well as explicit knowledge within the enterprise [26]. Knowledge Management is one of the key factors that drive competitiveness within an enterprise [27]. The making of enlightened decisions by combining good insight based on experience and one's own belief system, augmented by appropriate knowledge levels, gives rise to the concept of wisdom [28].

3.6.4 Organizational culture

Organizational culture is the behaviour of humans within an organisation and the meaning that people attach to those behaviours. Culture includes the organisation's vision, values, norms, systems, symbols, language, assumptions, beliefs, and habits [29].
This industrial belief system manifests itself in different corporate culture forms like:

- An Innovation Culture stemming from the need for urgent renewal at the forefront of technologically based competition [30].
- A learning-based culture with the underlying premise of natural growth for an enterprise [31].

Although this breakdown compartmentalises specific cultures, reality on the ground actually consists of a combination of the above with one or more taking the dominant role.

As is the nature of the complex human, we do not expect these four factors to be all inclusive nor do we believe that they will be completely independent or mutually exclusive.

4 THE FRAMEWORK FOR SUCCESS

In order to allow a more detail view on the problem, we must investigate the various elements that potentially make up the framework for success.

- The first element that is potentially part of the framework is the success event. The success event is any opportunity that can be used to obtain and increase the customer's actual and perceived value expectation through direct and honest interaction.
- The next part of the framework is the definition of the processes required to execute the normal business. These processes spans within and across three business domains defined as the product, the enterprise as well as the customer domains. This part of the framework is simply called the executable factors.
- In order to study the human potential effect on the required processes of the executables, four specific study domains of leadership, relationships, wisdom and culture were considered based on the literature reviewed as well as own experience. These factors are not intended to be all inclusive as defined by their inter-relations, however, it allow us to study their specific effect on the success of the outcome when viewed separately. These factors grouped together, are termed the enabler factors.

The executables, the enablers and the success events is combined to form the framework in depicted in figure 7 as follows:

The process starts with an idea and this knowledge baseline is developed by applying all the normal business processes in the strategic tactical and operational areas through the product, enterprise and customer domains to end with value realised by the customer when he deploys the product successfully. This part of the framework is called the executables. The second part of the framework considers the human factors that can enhance (or hinder) the success of the outcome of applying the executable processes. These factors are defined as the enablers.

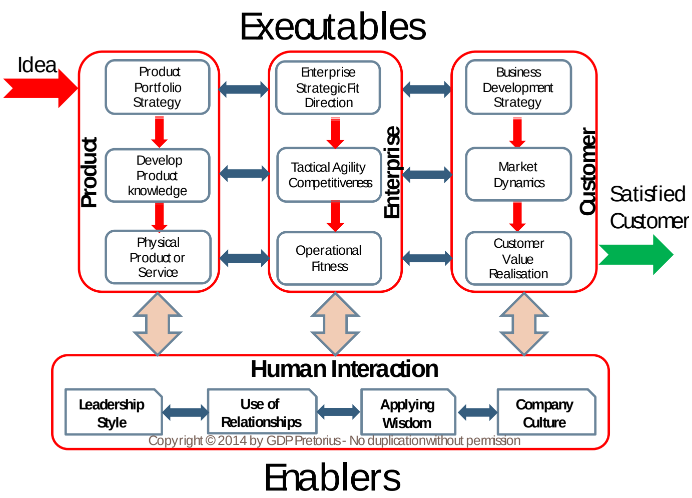

Figure 7: The Framework for Success

The effect of the human interaction (enables) on the executable factors can now be investigated by means of the case studies of three different products spanning five enterprise life cycle phases and four engineering phases in a military vehicle system supplier environment.

5 CASE STUDIES

5.1 Introduction to the Case Studies

The guidelines of Yin [1] were used in choosing and construction the specific case studies defined below. The cases considered for this research spans the life cycle of the enterprise from growth through to maturity and finally, decline. It is also set against the backdrop of the USA and NATO forces activities in Iraq and Afghanistan where both the RG31 and RG32 were successfully deployed by various armed forces.

Table 2: Summary of Case Studies

Case no:	*Project Name*	*Description*	*Customer*	*Product Life Cycle*	*Enterprise Life Cycle*	*Specific Atributes*	*Financial Outcome*	*Customer Satisfaction*	*Success Rating*
1	RG 32 Development	Develop of new vehicle against a specific user requirement	Europe	Development	Growth	New Cusomer and New Product. User very satisfied with outcome	Medium	Very High	4
2	RG 32 Production Batch 1&2	Production of first two batched of vehicles	Europe	Production	Maturity	Production runs resulted in new level of quality demand for enterprise	Low	Medium	3
3	RG 32 Production Batch 3&4	Production of final two batched of vehicles	Europe	Production	Decline	Quality expectation gap grew out of control resulting in "Pain Plan" by customer	Very Low	Very Low	1
4	B Vehicle Support	Support of aging B vehicle fleet for the South African Army	South Africa	Support	Maturity	Need to support local customer with low budget	Low	Low	2
5	RG 31 MRAP Production	Supply of Urgent Operational Requirement	USA	Production	Growth	Urgent Operational Need in Iraq to save lives	High	Very High	5
6	RG 31 MRAP Upgrade	Midlife Upgrade of the MRAP fleet returning fom Theatre	USA	Support	Maturity	Re-use of vehicles as part of USA army inventory	Very High	Very High	6

The different cases that make up the case study are further described below:

5.1.1 Cases 1, 2 and 3: RG 32 Development and Production (2004 - 13)

The development of the RG 32 started as an evolutionary development process from a previous design. This was a complete design to order project with the Swedish government procurement agency against the user specific specification. Within a two-year period, the team concluded the development process to the point where the senior project officer wrote a poem to thank the development team in Swedish, tone set it and promptly sang it in the design review meeting. This can be seen as the highlight of the entire program. This project was conducted in the growth phase of the company.

The next project in the RG 32 program was the production of two batches of 100 vehicles each. During this time the project lead was moved to a program manager who brought his own value set to bear on proceedings. This changed the frequency of the success events between the customer and the company teams. This project was conducted mainly in the mature phase of the company.

After a production gap of about two years, two new batches of vehicle orders were concluded with the customer. These vehicles were needed for urgent use in Afghanistan. In this process the customer program team changed as well, which resulted in a new dynamic interaction and relationship between the customer and the company teams. This result was that very few success events were noted and an overall dissatisfied customer.

5.1.2 Case 4: B Vehicle Fleet Support (2005 - 14)

The South African customer purchased a fleet of logistic trucks in the previous century and needed to keep up the maintenance on them as the replacement programs were not funded.
The company set up a wide range of support centres throughout the country close to the user bases in order to support these aging vehicles and conducted the maintenance business at a very low cost base.

5.1.3 Cases 5 and 6: RG 31 MRAP Production and Upgrade Projects (2007 - 12)

During the Iraq war the USA realised that their Humvee unarmoured fleet of vehicles were not capable to withstand the Incendiary Explosive Devices (IED's) and that they needed an urgent solution. One of the solutions they decided on was the RG 31 Mine Protected Vehicle design and owned by the company being researched. The company was put under a challenge to produce circa 150 vehicles within a nine-month period as this was an urgent purchase program from the USA. It took on this challenge and proceeded to produce the vehicle successfully on time.

As indicated above more than a thousand RG 31 MRAP vehicles were built for the USA army and deployed in Iraq and Afghanistan where they performed very well. This resulted in the USA decision to keep this fleet of RG 31 MRAP vehicles and to perform a midlife upgrade program on them before being shipped back to the USA from Afghanistan. This project was conducted in the mature and early decline phases of the company. By this time the USA customer was very satisfied with the RG 31 vehicle's performance and this remains rated as very high.

5.2 Questionnaire

The relative contribution towards the success of the enterprise (project) of the enabling factor's interaction with the executable factors was interrogated by means of a structured questionnaire. This questionnaire was constructed by comparing and defining a question on any potential interaction of the enabler factors on each of the detail executable factors.

5.3 Statistical Analysis

In the case where the data is presented in the Likert scale format, a statistical regression model was used to study the effect of the enabling factors relationship, wisdom and culture on the successful outcome of the projects, thereby defining the most influential factor.

5.3.1 The Initial Regression Model

The first step in the analysis involved the compilation of the relevant questions' influence on the possible outcome of the cases defined in the "generic" regression model below:

$$Y_{ProjectSuccess} = \beta_0 + \beta_1 Q1 + \beta_2 Q2 + \beta_3 Q3 \ldots\ldots\ldots\ldots + \beta_n Qn$$

where:
$Y_{ProjectSuccess}$ = Project Success Rating from 1 to 6
β_0 = Correction factor
β_1 = Contribution factor related to question 1
β_n = Contribution factor related to question n

Using the R software [32], we can test for the validity of the Gauss Markov Assumptions to define that the OLS regression is reliable:

5.3.2 Multi-collinearity

The next step is to test the data for Multi-collinearity.
Gauss Markov assumptions state that there must be low to zero multi-collinearity between the independent variables of the model.

5.3.3 Heteroscedasticity

The test for Homo or Heteroscedasticity is performed next.
The revised model with no multi-collinearity is now test for Heteroscedasticity. Heteroscedasticity is tested using Breusch-Pagan test, with the below hypothesis:

$$H_0: Homoscedasticity$$

$$H_1: Heteroscedasticity$$

Using R software again [30], we run the test of the P-value of the Breusch-Pagan test is 0.5685 which is significantly higher than 0.05. We can therefore not reject the H0 and assume the model is homoscedastic.

5.3.4 Stochastic Regressors

Gauss-Markov theorem requires any of the explanatory variables to be uncorrelated with the error terms. Correlation of regressors to the residual should be close to if not equal to zero.

5.3.5 Hypothesis Test

The Hypothesis Test is then carried out which results in the ranked significance of the factors actually having an effect on the outcome. These are presented by a final regression model and also represents the outcome of the research questions posed as:

What are the significant human related factors contributing towards the success of a project or enterprise during the acquisition phase of a complex system, when interacting with a customer?

5.4 Results

5.4.1 Leadership

Some of the questionnaire answers where only a specific indication (e.g. yes or no answers) were required, were analysed by means of graphic results. This is done to observe the effect of the leadership styles on the successful outcome of the projects in the various phases of the enterprise. The confirmation of leadership styles prevalent during the different enterprise phases as defined by Ward are the creator (creation), the accelerator (growth), the sustainer (maturity), the transformer (turn around) and and the terminator (decline) resulted in a close correlation overall. A remarkably close correlation between the theoretical and observed leadership style was observed in Cases 1, 2 and 3 (see to Figure 8 below) where a lot of leadership focus was expended in order achieve success.

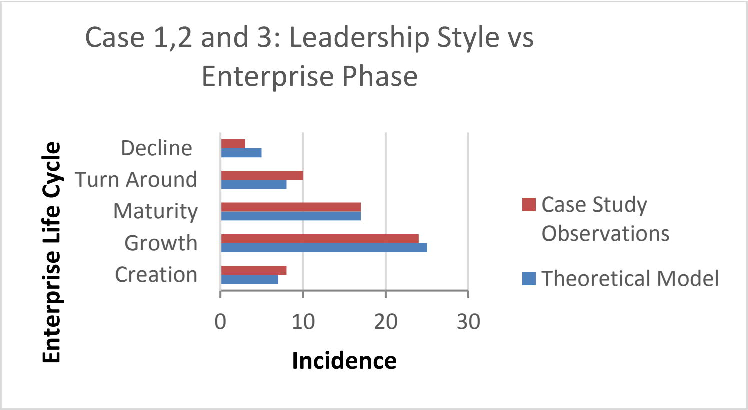

Figure 8: Mapping Leaderships Style on the Enterprise Phase

The example above shows the RG 32 cases (1, 2 and 3) which were challenged in their execution by the customer and required specific leadership focus in both the development and the production phases. We therefore see a very good alignment between the theoretical and the observed leadership styles during each enterprise phase.

5.4.2 Relationship

Table 3: The results of the Relationship Analysis

Question	*Number*	*β Value*	*Question Topic*
The company's senior management got on very well with the customer's senior management	2.2b	0.36	Relationship: Senior Management
The project team got on very well with the customer's project team	2.2c	0.33	Relationship: Project Team
The operational / quality team got along very well with the customer's quality team	2.2d	-0.34	Relationship: Quality Team
It is very difficulty to do business with the customer's quality team	2.3d	-0.43	Relationship: Quality Team
Which of the following areas did the company's operational and quality teams not see eye to eye with the customer?	2.4c	-0.29	Relationship: Quality Team

As seen from the results presented in table 3 the relationships of the senior management had a significant positive contribution to success, while the quality team's interaction resulted in a significant contribution to the failure of the specific projects.

5.4.3 Wisdom

As depicted in table 4 below the respondents agree that informed decision making from a tacit and explicit knowledge base in all cases were a major contributor towards their success.

Table 4: The results of the Wisdom Analysis

Question	*Number*	*β Value*	*Question Topic*
The company's documented product knowledge i.e. functional design, data pack and specifications were well defined	3.1b	0.44	Wisdom: Company's Project Team Explicit Knowledge
The customer's tacit?? product knowledge contributed significantly towards the success of the project	3.4a	-0.54	Wisdom: Customer Project Team Tacit Knowledge
The customer's documented product knowledge i.e. functional design, data pack and specifications were well defined	3.4b	0.42	Wisdom: Customer Project Team Explicit Knowledge
The customer's project management made very good decisions	3.5b	0.60	Wisdom: Customer Project Team Decisions

The company and the customer's project teams, through their expression of wisdom (good decision making supported by structured information) contributed significantly to the success of the company. However in case 2 and 3 the customer had more tacit knowledge about the product as the company lost its knowledge base of the company's chief design engineer that left the company and this contributed negatively to the outcome of these projects.

5.4.4 Culture

The statistical analysis indicates that there is no correlation between the project success and culture. We can therefore conclude that the culture of the organisation did not significantly influence the success of the organisation.

5.5 Triangulation of the results

The following table summarises the outcomes of the statistical analysis of the case studies, and compares it to the executive management opinion of the company studied, as well as the primary author's own experiences about the cases that were studied.

Table 5: Triangulation of Results

Enabling Domain	*Case Study Results*	*Company Executive*	*Researcher*
Leadership	Close correlation between the theory of the specific leadership style against the leadership style	Agree with the outcome. Leadership style needs to be adapted depending circumstances. This can create confusion, since employees sometimes find	Leadership style were constantly adapted for specific application. I concur with the observation of a close correlation between the

	observed	the change in "character" of the leader difficult to understand.	theoretical and actual leadership styles observed
Relationship	The positive relationship with the customer's senior and project management were observed. There were also a very negative result regarding the customer quality team relationship with the operational team of the company contributing towards failure.	Agree with the outcome: Excellent relationships between Management and the Customer remains the single most important factor during difficult times on any contract. The value of a "good" contract is secondary. The opposite is true in terms of the respective QA teams, where pre-agreed quality standards usually ensures a successful relationship between the QA teams.	In the case of the RG 31 and early RG 32 development the company had excellent relationships with both customers. This observation agrees with the view that good relationships in both the senior management and the program management level significantly contributed to success of these cases. The negative contribution of the customer quality teams' relationships can be identified with the RG 32 production cases as well as the B vehicle support program where both the Swedish and local embedded quality teams did not contribute towards success.
Wisdom	The contribution of explicit knowledge with both the customer and the company's teams were defined as having a positive influence on the outcome. However when the customer's tacit knowledge becomes more dominant than the company's tacit knowledge it resulted in a negative influence. It also helps if the customer makes robust decisions to promote the project as a whole	The retention of tacit knowledge on both the technical and commercial aspects of a project is a key factor, amongst others, for successful project execution.	The company and both the RG 31 and RG 32 customers have an extensive process of defining the explicit knowledge of the product. The loss of the senior design engineer on the RG 32 after development left an imbalance of tacit knowhow between the customer and the company and this was exploited by the customer's team resulting in a negative influence towards success. The RG 31 customer on the other hand demonstrated very sound judgement and decision making and this contributed towards the success of these two cases.
Culture	No correlation between culture and company success were evident in the case studies under review	Partially agree with the outcome: Company culture is normally enforced and cultivated from "above". Strong governance and policy enhances a strong culture which is needed when a project experience major challenges, especially if corporate interference is at stake. Cultural differences between the company and the customer can however lead to friction and/or conflict and sometimes need careful management.	The underlying culture of learning as well as the "forced " BAE corporate culture did contribute to inherent capability and order within the company however there are not one significant event that I can recall that had a direct bearing on the successful outcome of these cases. I therefore support the case study observation.

The various results and opinions defined in the table 5 above indicate a close correlation between the case study results, the company executive as well as the experience of the researcher who worked at the same company for thirty-three years.

6 CONCLUSION

6.1 Interpretation of the Summary Results

It can be concluded that all four Enabler Domains contribute towards the corporate success. However, the perceived contribution varies between the cases. The following detail observations are made:

- The more leadership focus is required; the more defined correlation is demonstrated with the theoretical leadership style.
- In all cases relationships are a prerequisite for success with a marked increase of the relationship contribution in the most successful project (case 3).
- The prevalence of bad decision-making results in a less successful project.
- Enforcing a corporate culture from the top does not necessarily contribute to the success of the company.

The Success Event Roadmap can be used to establish the potential contribution of any of the defined factors within the various processes. It also facilitates understanding of the contribution of the most appropriate factors in a specific scenario.

The analysis defined above considered all the detail answers to the all the questions in the questionnaire but through the statistical model application only isolated only those answers which were clearly tested to have a significant contribution to the successful outcome.

The results reflected in this article is therefore only as summary of the ongoing analysis of the case studies. More detail conclusions regarding the sub-factors interaction of both the enablers and the executables in different phases of both the product development and the enterprise phases will be reflected in the final study.

6.2 Recommendations and Supplementary Research

This study contributed the following knowledge items:
- A framework for success that defines all the conceptualisation of a success event.
- A specific relationship model.
- Some insight as to the importance of relationships and collective wisdom within the business framework.

The following future research topics will broaden our knowledge about conducting successful projects and enterprises:
- The study of the interrelationships between the different parts of the Executable Factors
- The study of the application of the framework for success in the non military and non complex business environments.
- The further development of the relationship model in all human interface applications.
- The study of knowledge growth in relation to risk of a specific product under development.

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APPLICATION OF BERNOULLI PRINCIPLE IN ADDRESSING BOTTLENECKS AT A LOCAL PRODUCTION COMPANY IN THE VAAL REGION

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ABSTRACT

Production flow is similar to most physical flows, especially liquids that frequently encounter bottlenecks, an issue being addressed by the current paper. This paper investigates the applicability of the concept of the Elementary Law of Energy Conservation in fluid flow given by the Bernoulli Principle as one of the approaches of addressing production bottlenecks. Empirical data on managerial behaviour, managers' attitudes towards workers, production rate and the extent of bottlenecks were analysed following the concept of Bernoulli Principle.

It was found that the total effort required in executing a job is a function of production rate, the managers' closeness to workstations and "pressure" imposed by the bottleneck. Where pressure imposed by the bottleneck was high, the production rate was reduced. Increased pressure on operators by managers was equivalent to a reduction of distance from managers to workstations that led to increased speed of job-flow and/or reduction of bottleneck. It was concluded that the Bernoulli Principle is useful when applied correctly to address bottlenecks.

***Keywork*:** bottleneck, conservation of energy, height of management structure, productivity

Introduction

“Energy can neither be created nor destroyed: it can only be converted from one form to another” (i.e. energy cannot be lost from the “entire universe”, it can only be transferred from one system to another) is a fundamental law of nature that forms the foundation of most dynamic systems [1]. The field of energy science and energy engineering have been derived from this law, which subsequently have given birth to most popular subfields such as thermodynamic [2], steam plants [3], locomotive [4], aerodynamics [5] and so on. Energy is elementary defined as the “ability’ to do work, which can be stated in a simple term as the “effort” required to do work [1]. In the same light, the effort required to do work can neither be created no destroyed: it can only be converted from one form to another or the effort can only be transferred from one system to another (i.e. in a typical physical system, energy is converted from potential energy to kinetic energy and the energy due to frictional losses or pressure against motion). This simply means that the “total effort” required to do work in a production system should be “constant” i.e. for a system that is well monitored and managed, if an additional effort or resource, which is unnecessary (e.g. unnecessary raw material, unnecessary management, unnecessary workstation, and so on), is added in performing a piece of job then the additional effort or resource would be available by the completion of that job, which would lead to a situation of under utilization of resources [6]. Most managers are aware of the impacts of the under utilization of resources and, hence, are engaged in capacity planning [7] and line balancing [6] so as to avoid or minimize this lost of or wasted effort.

In most production systems, series of processing operations (known as work or tasks or jobs) are performed on a product before the good that is finally acceptable by the external customer is produced [7]. Since energy (or work) is represented by the effort employed to produce a product, it follows that the effort required to produce a product from a production system should neither be created nor destroyed i.e. the effort should be constant. Production effort can only be converted from one form to another: the resources deployed by management are production efforts that can be seen from the variations in production speed (Known as production rate) and level of pressure at the workstation or degree of bottleneck.

The above premise opens up an interesting point of discussion and investigation. This is because, for a simple physical system, work is defined as the product of “force and distance”, which are quantities that can be easily measured with measuring instruments; while in a production system the flow of work-piece is determined by the physical processing operations and other service activities. Because of the integration of both product processing and service activities, the interpretations of the variables involved in defining work have to be handled with care. For example, the word “pressure” has a simple meaning or interpretation in a physical system, but its interpretation can be confusing in the service sector. Thus, this article is aimed at attempting to apply a typical physical theory to an integrated product processing and service sector.

Method

Most products require several processes to be performed on them before they are acceptable as finished goods by external customers [7]. In order to improve on productivity or to achieve mass production or mass customization, job specialization is required where each process being performed on the product is assigned to an “operator ” or a “workstation” [7]. If not well controlled, there will arise occasions where some operators will have to share the same space or stage so as to perform their operations, which will lead to congestion and traffic related issues on the stage. Thus, flow line production is recommended where each process is assigned to its own workstation [7] and each workstation has its designated space. This flow line production also allows for mass production or mass customization [6,7]. The flow line production is adopted in this report as it allows for easy interpretation of terminologies and collection of relevant data.

Bernoulli Principle [8,9,10] is a concept that has been widely proven to be very useful for fluids flowing in pipes of “different” sizes. It states that the energy or effort required for fluid or liquid to flow across different cross sections of a pipe is constant, or the total energy required to ensure fluid flow in a pipe can neither be created nor destroyed: it can only be converted from one form to another. That is to say, the total work done on a fluid at different cross sections of a pipe is constant. Bernoulli Principle is given by the following equation for a unit mass (i.e. unit mass is equivalent to “per unit product” produced in the current research) and for an incompressible flow as, [8,9,10]

$$E = \frac{v^2}{2} + gx + \frac{p}{r} \qquad (1)$$

where *E* is energy of (or effort required by) a fluid flowing in a section of a pipe, *v* is the velocity of the flow, *g* is a (gravitational) constant, *x* is a distance from the reference point, *p* is pressure on the fluid at that section and rho *(ρ)* is the density of the fluid. It should be noted that on the right-hand-side of equation (1), the first term stands for the kinetic energy (k.e.), the second term represents the potential energy (p.e.) and the third (last) term represents the frictional energy. It is common knowledge, in physical system, that when a body that had been raised to a height falls then it loses its potential energy, which is being converted to a gain in the kinetic energy and frictional (or resistance) energy. One has to return to the theme of the current project: a manufacturing system and not a mere physical system where every quantity in expression (1) can be measured with a measuring instrument.

As stated earlier, the key issue is how to interpret the parameters found in equation (1) for an integrated product and service industry (i.e. for a production system). The scenarios given below are used as examples. Before such an attempt, it is imperative to translate those parameters found in expression (1) to terminologies used within production settings. In this regards, ***E*** can be interpreted as the total investment made available to produce a product, *v* should be proportional to the production rate or feed rate or the "speed" at which a product is produced, ***g*** is also a constant that is related to the "speed" at which managers move closer to operators or workstations i.e. a function of management respond time, ***x*** is the distance or hierarchical position of managers (who take decisions) away from the operators/workstation with (+***x***) representing when managers consider themselves to be above operators (overhead managers or white collar managers) and (-x) being managers who listen to operators or consider themselves to be below operators, with (*zero* ***x***) being blue collar managers or those who also perform the operators' tasks, ***p*** is the pressure imposed by the operator or workstation and rho (*ρ*) is the production density or production quantity per unit space. In this work, as also applicable to the initial Bernoulli Principle, it is assumed that one is dealing with a constant density flow, which is tantamount to incompressible flow or a production system with zero scrap rate or rework. In this case, a section of the case-study company that deals with final packaging of soft drinks was chosen for the case study.

Data collection

Data were collected at an isolated (one) workstation and also at a group of workstations as given in the scenarios below. It should be noted that within a production setting, the speed of production or what is normally termed the production rate is a depended variable that depends on the managerial attitude (or managerial pressure) and/or the pressure from the workstations (or bottlenecks). The management/overhead is responsible for providing production resources whenever and wherever they are needed. The pressures from the workstations (i.e. bottlenecks) are indicated by its cycle/standard times, which can vary with machine deterioration or changing machining speeds leading to bottlenecks [11].

Scenario 1: changing managerial closeness (*x*) towards a single or particular workstation

The management/overhead contribution in the effort required to produce a product is represented by the second term on the Right Hand Side (RHS) of expression (1). So, when the speed of respond of the manager is constant or the speed with which a manager moves closer to workstation is constant, where ***g*** is constant as to be assumed in this project, the distance between the workstation(s) and the manager ***x*** can be represented by the time it takes the manager to respond to a call i.e. tall managerial (reporting) structure increases the ***x*** or ***time***. In a simplistic form, an increment of +1 in ***x*** can be used to represent the next (management) level at which decision is made with the assumption that it takes the same time for decision to move from one level to the next e.g. ***x***=+2 represents a situation where an operator has an immediate Line Manager who in turn has his/her own Line Manager i.e. a second Line of command. In this case, when a call is made, the First Line Manager spends a given time T in an attempt to address the problem, and if the problem cannot be addressed, then the matter is escalated to the Second Level Line Manager who takes the same time T (in an attempt) to address the problem. It must be noted that the effective time spent before the Second Line Manager addresses the problem from when call was made is 2T.

Scenario 2: changing managerial closeness (*x*) and attitude towards different workstations (*p*)

When managers have different attitudes towards different workstations, then it is natural that bottlenecks will (or can) arise: this typically represents a situation where the line is not balanced (i.e. poor Line Balancing) and management does not take serious the non-uniform workloads at the different workstations. Obviously, different workstations will experience different pressures (p). The pressure induced by a workstation or bottleneck *(p)* was studied by varying the cycle time, more specifically by reducing the amount of resources at the bottleneck workstation so that it created a situation whereby unfinished products started accumulating in front of the bottleneck stations. This led to more increase pressures on the bottleneck stations. The managerial closeness *(x)* to a workstation was changed as stated in scenario 1 above.

Scenario 3: Increase pressure or effort from manager

Under this scenario care has to be taken when interpreting (uncontrolled) pressures from managers and those pressures from workstations because these should be the common sources of misinterpretations and wrong results. The increased pressure from workstation is when the workstation is under serious strain because it is overloaded (or under resourced) thus leading to a state where the workstation slows down the entire production plant; and the increased pressure from the manager is when more resources are deployed onto the production line in the form of additional investments (e.g. manager spending more time at the workstation, incentives, overtimes, paying more attention to workflow, etc.). Obviously, under this second situation of increase pressure or effort from management, the operators perform their tasks harder so as to derive the benefits thus increasing the output. This situation of increase pressure or effort from manager is equivalent to reducing the distance (x) from the workstation. It is simply called increased pressure on the workstation because, more often, the operators are said to work under pressure because of the sight of their managers

The above three scenarios were used during investigation and data collection process, and the results are presented and discussed below.

Results and discussion

The results are discussed as per the three scenarios above, with scenario 1 being split into three sub-scenarios: 1.1, 1.2 and 1.3.

Under scenario 1.1, it was practically observed that the closer the manager (or decision-making process) was to the operators (*+x↓0 i.e. for positive x with x approaching zero from above or manager getting closer to the shop floor*)

1. the ***fastest speed*** of flow (i.e. the highest the production rate) occurred when management focused on maintaining or reducing the pressures on the workstations or operators. In this case, the operators appreciated the fact that management was committed to appraise their performance that should end with proper recognition

2. in other cases, the operators/workstations experienced *higher pressures*, which in some instances led to *reduction in production rates or slight increase in the production rates* when compared to case 1 above. Some operators even complained that they were not reporting to Top Managers who were at their shop floors.

3. In some cases, minor incidences of *reduced production speeds with very high working pressures* from the operators/workstations were also recorded and were explained to be due the fact that the operators were panicking because their managers were around them leading to the operators not being able to focus on producing the products. Basically, those involved were of the view that could be expressed in their own words as "keep Top Management away from stalking our daily activities".

These above three sub-scenarios were all as predicted by the Bernoulli Principle and can be used for job appraisals i.e. reducing *x* may lead to increase speed with constant pressure from workstation (case 1.1.1); or higher pressure with either reduced or increased speed as in case (1.1.2); or a complete reduction in speed due to very high (uncontrollable) pressure on the operators (as in case 1.1.3).

Under scenario 1.2, where (x=0) or decisions were made at the level of the operators or the operators were given powers to make decision as in Total Productive Maintenance (TPM) where operators are empowered to take decisions, it was observed that

4. There were cases of both increase in production rates and increase of pressures from the workstations/operators since the workloads of the operators were indirectly increased

5. In the case where operators were empowered to reduce the pressures from workstations such as in Total Productive Maintenance (TPM), the highest speed of production or the highest production rates were recorded.

6. In the case where the pressures on the workstations were unchecked and they became so high, less increase in production speeds or complete reduction in production rates were observed.

Under scenario 1.3 of (-x↑0), where the management was advised to approach the operators in their decision making processes with the perception that the managers were there just to endorse the views of the operators and to recognise them for those views, it was observed that

7. Cases of very high production rates were achieved where the pressures on the workstations were monitored so as not to have them increased.

8. Cases of not so high production rates or reduced production rates were also recorded when the pressures on the workstations were not monitored to stay the same or were allowed to increase due to abuse of procedures by operators since they were the ultimate decision makers with no checks-and-balances.

Under scenario 2 or bottleneck situation, it should be recalled that this is the situation where there is an increase in pressure on/from the workstation.

9. Changing management structure as outlined in scenarios 1.1 –to - 1.3 above, then the production speeds or production rates were equally getting higher, as the management gets closer to the operators.

10. For a constant management structure, it was observed that increased bottleneck brought about a reduction in production rate.

Hence the best approach to manage bottleneck was to bring management closer to the bottleneck workstations/operators.

Under scenario 3 or additional investment or increase effort or pressure from managers, it was observed that

11. the production rate increased

12. there were also increase fatigue and Musculoskeletal Disorders (MSD)

It can be seen from all these subcases (1)-(12) above that the correct application of the Bernoulli Principle can give useful information about the sources of success and threats in a SWOT analysis [12]. It was generally observed that increased pressures on workstations or increased bottlenecks brought about reduced production rates, and an approach of alleviating it was by suggesting that management should get closer to the sources of the bottlenecks.

Quantifying the parameters of the Bernoulli Equation is a bit involved. It requires quantifying bottlenecks or pressures from bottlenecks, the closeness of management to the shop floor and the production rate. Quantifying the first two parameters are not trivial issues since it involves quantifying human inward attributes and also one mostly encounters additional constraints such as scrap production with variable respond times or speeds with which management gets closer to the workstations.

Conclusion

As a concluding remark, with a manager being defined as someone who is allowed to take critical decisions represented by x, it has been demonstrated by employing Bernoulli Principle that bottleneck can be addressed by reducing the tall management structure or empowering the operators to make decisions (although with checks-and-balances); and investing additional resources or pressure from management may also be exploited for solution although it has its own cost implications. It is advisable to bear in mind that there is a need for a proper interpretation of the word “pressure”, most especially where it is coming from. It would also be interesting to quantity those parameters of Bernoulli Equation so that the outcome can be fully quantified, which is a bit involved and is a subject matter of a different study.

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CRITICAL SUCCESS FACTORS FOR IMPLEMENTING A LABOUR PRODUCTIVITY IMPROVEMENT INITIATIVE IN A COMPETITIVE SOUTH AFRICAN MANUFACTURING PLANT FOR GREATER INTERNATIONAL COMPETITIVENESS

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ABSTRACT

High manufacturing competitiveness in South Africa has the potential to contribute towards mitigating the poor economic performance and high unemployment rate prevailing in the country. However, manufacturing competitiveness is lacking, majorly due to labour productivity issues that are idiosyncratic to South Africa. One of the dilemmas is how to increase manufacturing productivity without major capitalisation, as doing so usually leads to redundancy and retrenchment of employees. A possible solution is to implement manufacturing performance improvement programmes without major capital investment (or capital-labour substitution). Although various programmes exist and are successful elsewhere in the world, these have been found to fail in South African firms due to implementation challenges.

This study assesses the results from implementing a manufacturing performance improvement programme called Integrated Work Systems (IWS) in a South African factory of a multinational company, which has already proven successful in the multinational's factories in other parts of the world, to determine the critical success factors and develop a framework for the successful implementation of such a programme in South Africa.

It is expected that the critical success factors for implementation in a South African firm will differ from other parts of the world, providing valuable information for practitioners.

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1 INTRODUCTION

1.1 Background and motivation

The research is based in a multinational fast-moving consumer goods (FMCG) company ABC that has recently embarked on implementing a manufacturing performance improvement programme in a number of its factories around the world. The method called 'Integrated work systems' (IWS) was developed by P&G (another multinational FMCG company). P&G has factories globally running at 85-90 percent equipment efficiency, which is extremely high compared to ABC. They have achieved this through combining various best practices and partnering with Toyota to develop a customised manufacturing system after over 30 years of development (now called IWS) [1].

Broadly summarised, IWS aims at improving equipment efficiency through integrating a set of activities, systems and tools to eliminate manufacturing losses and defects. This is achieved by engaging the entire organisation, and through autonomous maintenance practices, builds the culture and capability of machine operators and the line leadership structure [1]. The system combines elements of Lean in waste elimination, six-sigma in process control, Total Quality Management (TQM) and Total Productive Maintenance (TPM) to drive equipment efficiency [1]. IWS pillars focus on the production line and involves rigorous monitoring to eliminate line stoppages through daily management systems such as clean-inspect-lubricate (CIL), Centre-line and Defect Handling that serve as preventive countermeasures to any loss or defect experienced [2].

A 12-week proof of concept (PoC) was conducted in three ABC factories in 2014 around the world and after being deemed a success (after demonstrating significant improvements on pilot production lines in key performance indicators such as increased throughput by 20 percent in Russia and decrease in line stoppages by 54 percent in Switzerland) was rolled out to strategic ABC factories including South Africa.

The purpose of the research is to assess the results of implementing a manufacturing performance improvement programme without major capital investment in a South African factory that has already proven to be successful in similar factories in other parts of the world. Critical success-factors are identified that are used for the development of a framework for successfully implementing manufacturing performance improvement initiatives in South Africa without major capital investment.

1.2 Research question and hypotheses

The question is: 'What are the critical success-factors for implementing a manufacturing performance improvement initiative that is not technology or automation-related, in a South African manufacturing environment with idiosyncratic labour characteristics such as low productivity, inadequate skills, poor education, and industrial relations dynamism and related unrest?

The hypotheses are:

- H1: A manufacturing improvement programme that is not driven by capital investment can achieve significant change in manufacturing performance in a South African plant not withstanding labour constraints characterised by low productivity, inadequate skills, poor education and strong trade union influence
- H2: Critical success-factors for implementing a manufacturing improvement programme that is not driven by capital investment in a South African plant differ from other manufacturing improvement programmes that have been successful elsewhere
- H3: Operators in the selected South African plant will generally demonstrate a different view from senior staff regarding how the improvement programme should be implemented, given their background of poor education and inadequate skills.

1.3 Assumptions

The following assumptions were made:

- The ABC SA factory is a microcosm of the South African manufacturing environment as the social characteristics and challenges are similar to those faced by other factories in the country, that includes the environmental influences such as shortage of skilled labour, more cost-competitive international factories and inflexible labour regulations that are similarly faced by manufacturers in the country.
- Implementation of the IWS project influences the workforce and organisational culture, and implementation of the initiative requires employing change management.
- The limiting factors influencing the manufacturing sector including education levels, skills availability, government support and exchange rates will continue to exist in the foreseeable future.

2 LITERATURE REVIEW

The South African manufacturing sector is judged to be in decline according to measures such as the Kagiso Manufacturing Purchasing Managers Index (PMI) [3], the World Economic Forum's [4] Competitiveness index and Global Manufacturing Indices [6]. A Deloitte [6] report pointed out that one of the key issues in South Africa is that of labour costs increasing at a faster rate than productivity. According to the report, the issue of labour costs and availability is driven by shortcomings in the country's education, skills development, spatial development and community safety. With the bulk of South African manufacturers producing basic or low-technology products, competition from countries with lower unskilled labour costs is stronger [6]. Additional challenges to productivity during the tough economic conditions that South Africa is in [7] includes the availability of capital to invest in technology and automation as firms come under increasing financial strain, as well as the weakening rand that hinders the ability to import equipment and raw materials [8]. This provides a challenge for local manufacturers to improve cost-competitiveness to survive in the global market place.

Human capital in South Africa is often regarded as a constraint on the economy and particularly the manufacturing sector's productivity [9] [10] [11].According to Kleynhans and Labuschagne [9], the nature of labour supply quality and availability in South Africa is restrictive. These views suggest that the workforce is generally a constraint on South African manufacturers' international competitiveness. The literature points out that the negative effect of labour supply on productivity is caused by the mismatch of skills supply and demand where there is high availability of low to unskilled labour with unmatched demand for greater skills that is partly attributed to the poor education system [10], inflexible labour laws and regulations that favour employees such that additional difficulties and costs are incurred by employers [9], as well as increasing events of industrial action and social unrest that directly and indirectly impacts economic and plant productivity [11][9].

Manufacturing performance improvement initiatives (MPIPs) in this paper refer to implementation of Lean, continuous improvement and improvement of organisational culture or change management, all with the purpose of increasing productivity, quality or reliability of the production process. Various frameworks are suggested by studies such as Ahrens [12] and Jozaffe [13] on the basis of surveys and investigations into why manufacturing improvement initiatives tend to fail or lack sustainability in South Africa compared to other parts of the world such as Japan and Germany. The literature on manufacturing improvement specific to South Africa is focused on lean implementation. Such literature generally overlaps with change management, changing organisational culture and continuous improvement. Nevertheless, only a few studies could be found regarding similar manufacturing improvement initiatives that were implemented in a South African plant and assessed for impact (success or failure). In particular, a study on positive cultural impact that can be directly related to a quantified labour productivity measure (continuous improvement philosophy e.g. lean thinking) for a South African manufacturing plant could not be found and is therefore scarce.

Based on the findings of the studies, there is some indication that continuous or manufacturing improvement initiatives that affect the ways of work or culture of a plant's workforce have a very low success rate both locally and internationally. The study in this paper, based in a large South African manufacturing plant, sets out to demonstrate a measured productivity improvement, without capital-labour substitution, while incorporating the critical success-factors identified from the literature and confirmed through empirical methods hence making a contribution.

To undertake measurements for the study, performance indicators in the literature were considered and the most relevant key performance indicators (KPIs) were found to be overall equipment effectiveness (OEE) and throughput [14]. Average number of production line stoppages per day or 'stops' was another KPI chosen for analysis in the study because it is fundamental to the IWS methodology, as a leading indicator of production efficiency.

2.1 CSF framework from the literature reviewed

A thematic method of content analysis was used to develop a CFS framework from the literature [15]. Critical success factors (CSFs) from studies on manufacturing improvement initiatives and their success or failure [12][16][13][17][18]were grouped according to themes and consolidated where CSFs were closely related. The CSFs and the corresponding themes are indicated in table 1 below. This framework formed the basis for the survey used in the study at ABC SA.

Table 1: CSFs from the literature review

#	Critical success-factor	Theme
1	Leaders and supervisors motivate, coach, train and facilitate the work of those adding value rather than to tell them what to do	Bottom-up approach
2	Employee pull (employees fully understand the benefits of the programme for themselves)	Bottom-up approach
3	Employees are free to allocate time to improvement (empowerment)	Bottom-up approach
4	Resources freed up by productivity gains are reinvested into the search for still greater improvements	Bottom-up approach
5	Converting from top-down leadership to bottom-up initiatives	Bottom-up approach
6	Getting shop floor commitment and employee trust	Employee engagement
7	Involving operators through empowered Kaizen teams	Employee engagement
8	Enrolment of stakeholders for commitment, i.e. workers' council	Employee engagement
9	Avoidance of any linkage between the project and headcount reduction	Employee engagement
10	Employees understand company objectives	Employee engagement
11	Employees are engaged proactively on the project throughout the company	Employee engagement
12	Employees learn from personal and colleagues' positive and negative experiences	Employee engagement
13	Creation and communication of a vision attainment plan	Employee engagement
14	Linking successes experienced to the project	Employee engagement
15	Employee input for measuring performance to stimulate understanding and accountability	Employee engagement
16	Management demonstration of trust in employees' abilities	Employee engagement
17	Finding a good change agent or champions to remove blocks in the organisation	Key resource
18	Experienced and full time programme facilitator	Key resource
19	Organisational structure should enable the programme to succeed	Key resource
20	Executive or senior manager appointed to oversee the project	Key resource
21	Creation of a programme office or lean promotion office to support implementation	Key resource
22	Board and top management actively driving and supporting change	Leadership commitment
23	Top management presence and availability on the shop floor, engaging with employees	Leadership commitment
24	Managerial push (mandatory participation in workshops and training)	Leadership commitment
25	Executives join kaizen events on a regular basis	Leadership commitment
26	Managers actively demonstrate commitment to the CI programme at all levels	Leadership commitment
27	Building internal customer-supplier relationships (by integrating support functions) such that employees work effectively across boundaries at all levels of the organisation	Organisational integration
28	Integrating suppliers and customers into the transformation	Organisational integration
29	Employees have a shared set of cultural values that influence the way CI is incorporated in everyday work	Organisational integration
30	HR Partnership with production management with involvement in issues and concerns of people on the shop floor	Organisational integration
31	Employee recognition or reward system linked to the programme	Recognition and reward
32	Performance monitoring	Regular review of performance
33	Define measures for critical processes	Regular review of performance
34	Availability of a crises or strategic need that motivates the organisation to change	Strategic importance
35	Top management support should be established before communicating or	Strategic importance

	beginning implementation	
36	Company structure, systems and procedures are regularly assessed to ensure the CI system is supported	Support system
37	Beginning as soon as possible with an important and visible activity	Timing and planning
38	Setting a Kaizen agenda for the organisation	Timing and planning
39	Management identification of which tools will work best in their organisation	Timing and planning
40	Target areas of rapid success first and communication of successes	Timing and planning
41	Organisational stability at each stage before advancing implementation	Timing and planning
42	Comprehensive training such that everyone has necessary skills and understands the philosophy	Training
43	Standardised portion of a manager's work day	Work standards
44	Standardisation of work for operators and lower-level employees	Work standards
45	Standardised management system	Work standards
46	Discipline in adhering to standardised work	Work standards
47	Individual and group learning is captured and deployed systematically	Work standards

3 METHODOLOGY

A mixed method approach, both qualitative and quantitative, is used. For qualitative, a survey is carried out to determine participant views and characteristics in the population that have a relationship to performance trends[19], while for quantitative a document review is done to study the recorded data.

3.1 Document review

This involved reviewing trends of key performance indicators by analysing weekly OEE and brand changes, average weekly number of stops, and throughput since implementation of IWS on Line E, past OEE performance of ABC SA's factory, planned versus actual capital expenditure in ABC SA's factory.

3.2 The survey method and participants

Pre-testing of the questionnaire was done through a set of interviews with a sample of the population of ABC SA employees that was to eventually complete the survey. They were asked for approximately ten CSFs from their perspective, to be checked against the questionnaire's list of CSFs to confirm completeness and applicability of the success-factors in the survey.

Everyone directly involved in the IWS programme participated in the final survey, making a total of 37 respondents. This includes operators of two production lines, technicians responsible for both lines, Shift Leads (supervisors), the line structure responsible for this section of the factory including Line Lead, Process Lead and Maintenance Leads, Manufacturing Manager, IWS Programme Manager, and programme coaches.

A Likert scale was used for respondents to rate each success-factor on the level of impact it had on transforming culture or improving performance. To improve the quality of answers given, respondents were additionally asked the extent to which each success-factor was applied in ABC SA. This was to mitigate the risk of respondents rating a success-factor highly because they like the idea of the factor itself even though it wasn't a prevalent feature in ABC's implementation. This becomes useful during analysis as a check for consistency whereby factors that were deemed by respondents to be partially applied or not applied are given a lower impact on the results, regardless of the Likert rating given. The outcomes should therefore be success-factors considered to be prominent in ABC SA's implementation, and thought to have a highly positive impact on the results and/or culture.

3.3 Survey data analysis

Survey data were prepared by checking if the data for all variables fall within the rules of the survey. There are two categories of variables in this study, namely the respondents and the success-factors (SFs), which were treated separately. The first check was conducted on the 94 SF variables with 37 cases (responses) and no violations were found. The second check was conducted on the 37 respondents as variables with 94 cases (two answers for each of 47 SFs). In this instance two violations were found against the rule of maximum percentage of cases in a single category. These two respondents were therefore removed from the data, resulting in 94 items and 35 cases for further analyses. A test for unusual cases in the data was then conducted using SPSS to identify any cases that may warrant further examination. This procedure creates a model to identify clusters within the data and then isolates cases outside the clusters as anomalous cases [20]. The benefit of this procedure with regards to the current study is that it also assigns cases to peer groups through its analysis of relationships between the variables that are the basis of the clustering process [20]. No anomalies were found in the 35 cases, which were statistically split into two peer identification groups.

Two rankings were required by respondents for each SF to reduce bias and intended to prompt the respondent into thinking more objectively about each SF and the role it played at ABC SA. SFs ranked according to mean criticality rating were identified and deemed to be the CSFs forming the basis of the framework recommended by this study.

An aggregated analysis of the survey results according to the themes behind each SF in various ways provided further insights into where industry practitioners and managers should focus their efforts, as well as greater direction when planning improvement initiatives. Two types of graphs were developed to provide these insights. A pie chart of CSF themes for each respondent group takes the top 20 ranked CSFs according to the themes assigned to each and shows which themes appear most frequently as a percentage, where a frequency of 20 would be 100 percent. This shows which themes the respondent group was most drawn to in answering the survey (even though they did not know which CSF belonged to which theme), indicating the areas that industry practitioners and managers should focus on when implementing initiatives like IWS. Because themes that were allocated to a greater number of CSFs would have a higher probability of showing up in the pie chart with a higher percentage, a bar graph was developed to indicate out of the frequency of a certain theme in the 47 CSFs, how many times the theme appeared in the 20 most critical CSFs for a given respondent group (figure 5).

4 RESULTS

4.1 Impact of the MPIP in ABC SA

Figure 1 below indicates key performance results for the duration of the study on the pilot production line in ABC SA including OEE and average number of stops per day and throughput. Note that baseline (BL) results at the start of each graph indicate the average weekly performance of the total month’s data before implementation of the programme.

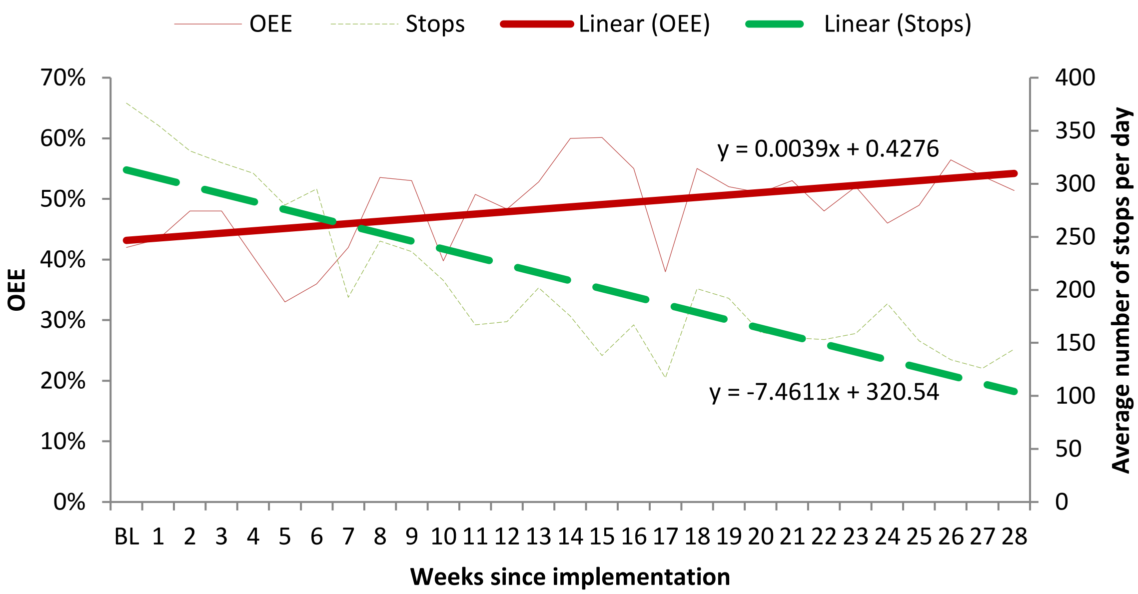

Figure 1: Trends of OEE and stops for pilot line in ABC SA

Table 2 below summarises the KPIs before, during and after the implementation period. Implementation of IWS began in April (quarter two) of 2015, with roll out onto three lines out of 27 by quarter three and a number of IWS principles were partly applied throughout the factory in this period . OEE for the given period and recent history is provided in figure 2 below.

Table 2: Analysis of KPIs since IWS implementation in ABC SA

Line E	Baseline	Weeks 1-12 average	Weeks 13-16 average	Improvement
OEE (%)	42	45	54	29%
Average stops per day (#)	376	235	150	60%
Throughput (volume)	4.61	4.73	5.42	18%

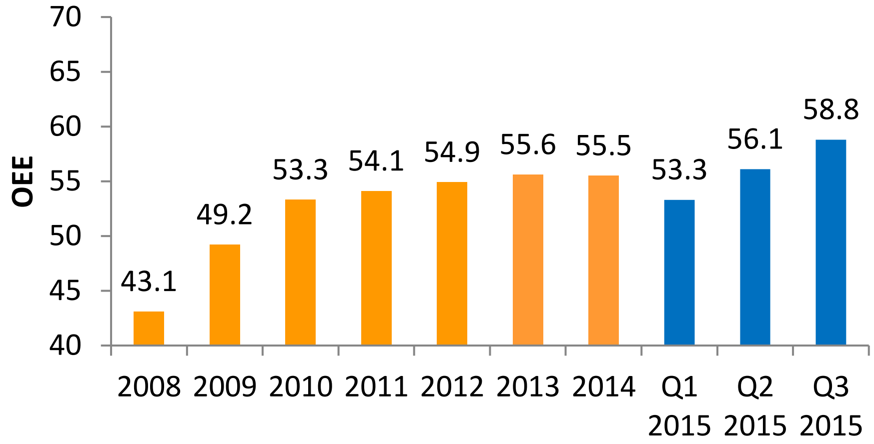

Figure 2: Historical OEE trend for ABC SA

Comparing trends of OEE and capital expenditure (CapEx) shows a particular relationship in the graph of Figure 3 below.

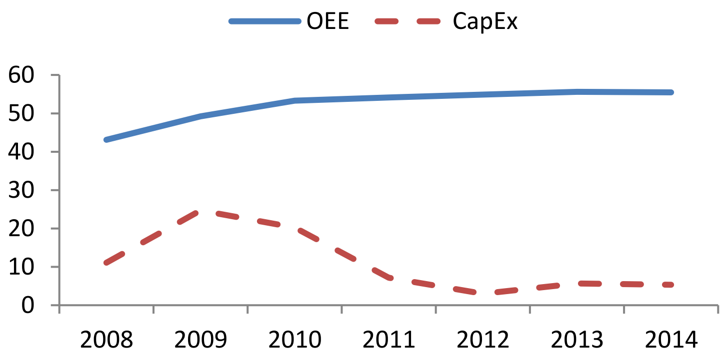

Figure 3: Comparing OEE and Captial Expenditure (CapEx) at ABC SA

4.2 CSFs of the MPIP implementation in ABC SA

4.2.1 Survey results - CSF rankings

The top 20 CSFs according to the survey results for the total respondent group is shown below in Table 3. SFs ranked according to mean criticality rating were identified and deemed to be the CSFs forming the basis of the framework recommended by this study. The mean score (out of 5) and percentage score are shown adjacently. Shading used in darker colour (e.g. green) highlights the higher values obtained from respondents while lighter shade (e.g. shades of yellow) indicates lower values.For the ranking, the darker shade indicates the first ten SFs considered most critical by respondents while the lighter shade indicates the next 10 most critical SFs.

Table 3: CSFs for total respondents

Ranking	Success-factor description	Application		Criticality	
1	Top management joins improvement events/meetings on a regular basis	4.17	83%	4.40	88%
2	Addition of leading KPIs that operators understand (stops, MTBF)	4.43	89%	4.37	87%
3	Clearly defined measures for key performance areas, with regular monitoring	4.37	87%	4.34	87%
4	Targeting areas of rapid success first	4.37	87%	4.34	87%
5	Clearly defined measures for critical processes, with regular monitoring	4.17	83%	4.34	87%
6	Management identification of which tools will work best in their organisation	4.11	82%	4.29	86%
7	Financial investment to support programme success	4.31	86%	4.26	85%
8	Setting and communicating an improvement agenda and roll-out plan	4.29	86%	4.26	85%
9	Employee 'pull' the new ways of working as they understand the benefits of the programme for themselves	4.11	82%	4.26	85%
10	Standard work with visual management	4.11	82%	4.26	85%
11	Standardised management system	4.23	85%	4.23	85%
12	Managers actively demonstrate commitment to the programme at all levels	4.20	84%	4.23	85%
13	Executive or senior manager appointed to oversee the project	4.34	87%	4.17	83%
14	Discipline in adhering to standardised work	4.03	81%	4.17	83%
15	Organisational structure should enable the programme to succeed	4.00	80%	4.17	83%
16	Reliable data enabling regular detailed analyses	4.11	82%	4.14	83%
17	Conducting an important and visible activity of the programme as soon as possible (e.g. leadership deep clean)	4.11	82%	4.14	83%
18	Comprehensive training such that everyone has necessary skills and understands the philosophy	4.09	82%	4.14	83%
19	Standardisation of part of a manager's work day	3.97	79%	4.14	83%
20	Employees learn from personal and colleagues' positive and negative experiences	4.09	82%	4.11	82%

When the results of table 3 above are separated into the two category of participants in the study, namely operators and senior staff, table 4 below is obtained. The shades used here (green colour) indicate SFs that are common to both operators and senior staff.

Table 4: Comparing CSFs for operators and senior staff

Operators		Senior staff	
Ranking	Success-factor description	Ranking	Success-factor description
1	Addition of leading KPIs that operators understand (stops, MTBF)	1	Clearly defined measures for key performance areas, with regular monitoring
2	Management identification of which tools will work best in their organisation	2	Reliable data enabling regular detailed analyses
3	Top management joins improvement events/meetings on a regular basis	3	Standardisation of work for operators and non-management employees
4	Setting and communicating an improvement agenda and roll-out plan	4	Clearly defined measures for critical processes, with regular monitoring
5	Employee 'pull' the new ways of working as they understand the benefits of the programme for themselves	5	Targeting areas of rapid success first
6	Targeting areas of rapid success first	6	Top management joins improvement events/meetings on a regular basis
7	Managers actively demonstrate commitment to the programme at all levels	7	Standardised management system
8	Clearly defined measures for critical processes, with regular monitoring	8	Financial investment to support programme success
9	Clearly defined measures for key performance areas, with regular monitoring	9	Conducting an important and visible activity of the programme as soon as possible (e.g. leadership deep clean)
10	Standard work with visual management	10	Addition of leading KPIs that operators understand (stops, MTBF)

4.2.2 Survey results – CSF Themes

The frequency of theme representation in the theoretical framework of 47 CSFs is shown below, followed by theme representation according to the ranking of top 20 CSFs by the total respondent group.

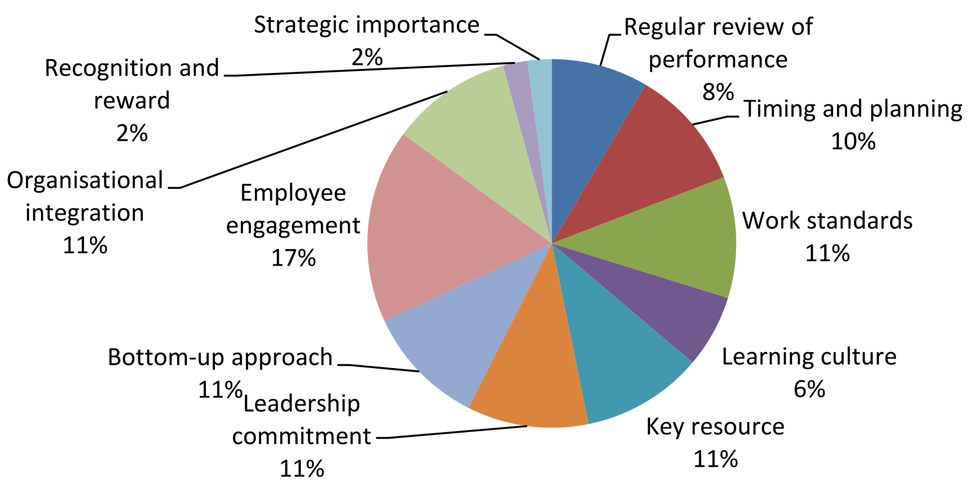

Figure 4: CSF Themes from theoretical framework

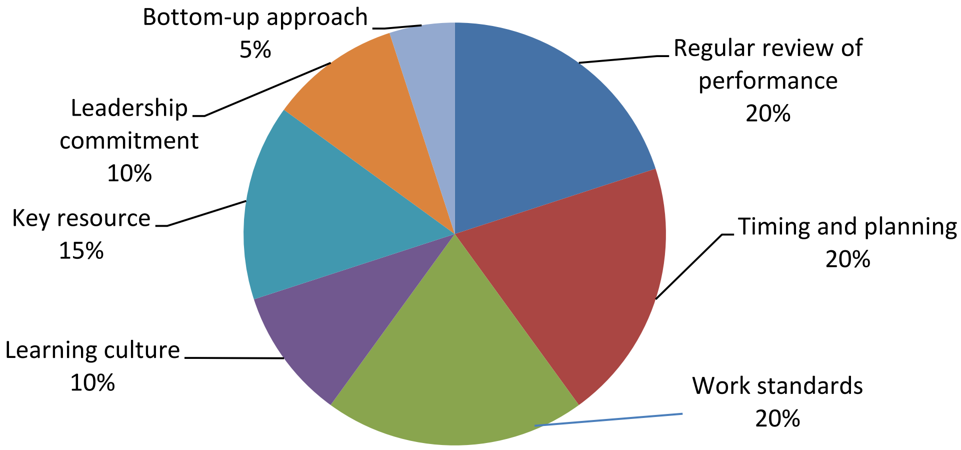

Figure 5: CSF Themes for total respondents

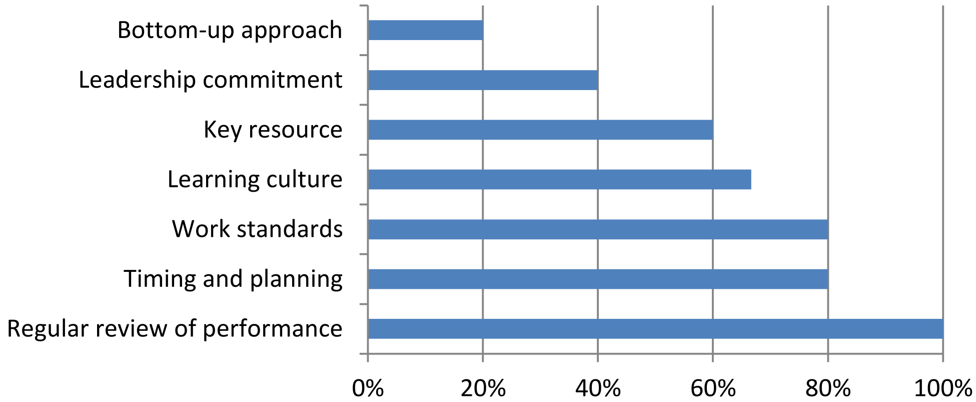

Figure 6: Percentage of items per theme considered critical by total respondents

5 DISCUSSION

5.1 Impact of the MPIP in ABC SA

The trend lines in Figure 1 of increasing OEE and decreasing number of daily stops show that the programme had a significant and almost immediate positive effect on manufacturing performance of the lead line in ABC SA. The gradients of the trend lines for 'OEE' and 'stops' indicate that 'stops' (the downward trend) improved at a faster rate than OEE (the upward trend) for observed period of 28 weeks after implementation commenced. This is understandable because the IWS methodology is focused on reducing the most frequent type of stops on a daily basis that should in turn increase OEE [1]. 'Number of stops' is therefore a leading indicator of efficiency or performance (less stoppages equals higher running or uptime), while OEE is a lagging indicator in relation. The survey results for the total respondent group found "the addition of a leading indicator that operators understand" to be second most highly ranked CSF (Table 3: CSFs for total respondents). This could indicate that 'stops' is a measure or KPI that is more effective on the production floor than OEE possibly because operators find it more tangible and easier to understand and influence instead of OEE. Significant throughput improvement of 18 percent after 16 weeks on the pilot line, shown in Table 2: Analysis of KPIs since IWS implementation , is the main business benefit in a factory as it generally enables the reduction of overheads such as energy usage, overtime and crewing. This table also shows a reduction from 376 to 150 stops on average per day. This less tangible benefit could hypothetically have a positive impact on employee morale as operators would exert less energy in repairing line stoppages throughout their shift.

Knowing that ABC factories are constantly pursuing OEE improvements , it is evident from the trends in Figure 3 (of OEE and CapEx) that OEE improvements came largely as a result of capital expenditure in ABC SA and efforts in more recent years to improve OEE were largely unsuccessful and resulted in stagnating performance from 2010 to 2014. With the OEE results in Figure 2 showing an increase from 55.5 in 2014 to 58.8 in Q3 2015, evidence of performance data indicate that the MPIP of IWS is delivering breakthrough performance improvements in light of ABC SA's recent history, and without capital-labour substitution (indicated by the lack of CapEx). This is heavily supported by the KPIs tracked for the lead line in OEE, number of stops and throughput.

In light of these results, the research value seems quite significant in understanding what the CSFs were that drove these KPI improvements in ABC SA for managers and practitioners in the South African manufacturing community.

5.2 CSFs of the MPIP implementation in ABC SA

Table 3 presents the ranking of CSFs for the total group of respondents. Top management is seen to have the biggest influence on results and driving the sought after culture by regularly joining meetings or programme events. Even though this factor was not applied to its fullest extent in relation to other factors according to the respondents (83 percent), the criticality of 88 percent indicates that if more of this were to happen then results in ABC SA could be even better. 'Clarity of what performance areas to focus on' and 'which processes are most critical', both with clearly defined measures, is another point deemed vital for successful implementation by ABC SA, seen in CSF's three and five. 'Targeting areas of rapid success first' as a CSF ranked in the top five is not surprising when aiming to drive a certain culture and implementing a programme that requires operator buy-in to work. This is because it gives the opportunity to everyone associated with the project to see positive results and experience the improvements, which in turn drives motivation and belief in the programme. 'Standardisation of work' and 'standardisation of the management systems' as CSFs 10 and 11 illustrate how important it is for everyone to know what to do, and for everyone to do it in the same way by following the same routine.

From Figure 4 (the pie chart of theoretical framework themes) it is worth noting the prominence of certain themes, with employee engagement seen as the biggest area to consider when implementing a MPIP with 17 percent of the SFs, followed equally by organisational integration, bottom-up approach, leadership commitment, key resources and work standards all with 11 percent. However, according to the total group of survey respondents in ABC SA with regards to IWS implementation, the results of Figure 5 depict a contrasting picture. Only seven out of the 11 themes derived from the literature chosen by respondents feature in the 20 CSFs, with a notable absence being 'employee engagement' that is clearly seen by ABC SA as less critical. 'Standardisation of work', 'timing and planning the way the programme is executed' and 'focusing regularly on key processes and performance dimensions' are deemed the most critical areas to consider, each represented by 20 percent.

Figure 6 indicates that all four out of 47 SFs under the theme 'regular review of performance' were deemed critical by appearing in the top 20 CSFs by the total group of respondents. This factor has a possible correlation with South Africa's labour supply idiosyncrasies where it was discussed in the literature review that skill and education levels are low, indicating that close controlling, reviewing and focusing on key processes and performance dimensions on a regular basis is necessary to influence results and culture positively. Work standardisation, particularly for non-management employees is logically a vital input for the achievement of discipline and productivity improvement in a workforce with low skills and education levels – this is reflected in Figure 6 with 80 percent of items of the theme considered critical.

The top 10 SFs chosen to be most critical for both the operator and senior staff group are compared in Table 4. 50 Percent of the CSFs are common to both operators' and senior staff's top 10, as indicated by matching colours (numbers 1, 3, 6, 8, 9 on the left, and numbers 1, 4, 5, 6, 10 on the right). It could be argued that the two CSFs marked in a separate colour (number 10 on the left and 3 on the right) are also common as they are similar in construct in that both speak to standardisation of work. As seen in table 4, the top 10 SFs chosen to be most critical for both the operator and senior staff group are compared and it is seen that the CSFs from the top 10 SFs have fifty percent that are common to both operators' and senior staff (this is shown by shading numbers 1, 3, 6, 8, 9 on the left, and numbers 1, 4, 5, 6, 10 on the right). It can also be argued that two other CSFs marked (number 10 on the left and 3 on the right) are also common as they are similar in construct in that both speak to standardisation of work; the only difference between these two being that one includes visual management and the other emphasises non-management.

From the findings, it is noteworthy that both operators and senior staff hold similar views regarding CSFs, which indicates alignment between managers and the shop floor operators in understanding the programme and what drove its success thus far, despite generally different perspectives. None the less, differences are to be expected in the above comparison, specifically where operators and senior staff are exposed to different elements of the programme. This can be seen in CSFs 2 and 8 of the senior staff's list, where operators do not have as much interaction with aspects like data analysis beyond a single shift, as well as implementation costs.

6 CONCLUSIONS AND RECOMMENDATION

In line with the hypotheses proposed:

1. Implementation period showed 29 percent OEE improvement, 60 percent reduction of stops per day and 18 percent increase in throughput. A negligible OEE improvement was seen in preceding years. H1 was therefore supported.

2. Of the top three CSF themes in the ABC SA survey results, only 'work standards' features in the top five themes of the theoretical framework. H2 was therefore supported.
3. Although many of the CSFs ranked in the top 10 were common for both employee groups, comparing the themes indicates a significant difference as to what factors each group would emphasise in implementation of the improvement programme. H3 was therefore supported to an extent.

A framework is proposed similar to Table 3: CSFs for total respondents that should be used by managers and practitioners in South African manufacturing plants when implementing MPIPs (manufacturing performance improvement programmes) that require a change in mind-set or shift in culture on the factory floor for the new processes, ways of working or systems to succeed.

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FACTORS AFFECTING THE QUALITY OF SERVICE DELIVERY IN A GOVERNMENT DEPARTMENT OVERSEEING EFFICIENT MAINTENANCE OF PHYSICAL ASSETS IN HEALTHCARE SERVICES IN A SELECTED PROVINCE IN SOUTH AFRICA

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ABSTRACT

An efficient delivery of healthcare service depends on reliable, safe and readily available infrastructure and equipment for use. This necessitates a well-planned and managed maintenance programme that is able to guide and support maintenance of the infrastructure and equipment. Inefficiencies on the maintenance programme have detrimental effects on the healthcare services. This study investigates the factors affecting quality of service delivery by a selected provincial government department of infrastructure development (PGDID), particularly factors that affect management and its maintenance arm in ensuring maintenance of the physical assets at public health institutions. The study was based on the perceptions of the PGDID personnel that were directly involved in the service delivery. Data were collected using a structured questionnaire from a sample of 91 PGDID personnel consisting of engineers, inspectors, foremen, artisans, Supply Chain Management (SCM) staff and regional directors. The results of the study provide insight on the importance of soft issues such as bureaucracy, motivation of staff, and communication as being comparable to the execution of the maintenance task itself. Jointly, the soft issues play a significant role and should be taken seriously as it has implications when planning maintenance of physical assets in healthcare services at provincial level.

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1. INTRODUCTION

Increased allocations of the national budget towards the health sector in the recent years has seen the construction of more health and social development physical infrastructure and capital assets [1][2]. However, inadequate attention has been given to the maintenance of already existing infrastructure and equipment, and this has led to a deteriorating state of infrastructure and equipment, particularly at the oldest institutions [1]. On the other hand, 80% of South African population rely on the government for healthcare, as influenced by socio-political and economic issues [3], hence a need for government institutions to be continuously and efficiently operating all the time. It is imperative to prolong the life of public infrastructure, improve accessibility and keep equipment in a functional state for the proper and safe functioning of the health and social development institutions in order to maximise the benefit to the communities they serve [4][5]. Management of operations and maintenance of infrastructure and equipment are critical to the service delivery of the departments of Health and Social Development.

The selected provincial government department of infrastructure development (PGDID) is mandated to maintain or procure all maintenance services for the maintenance of all the infrastructure and equipment at the Department of Health and Social Development institutions in the selected province of South Africa. Ever since PGDID was formed, there has been a negative public/government/stakeholder perception on the service delivered by PGDID [6]. The challenges affecting PGDID are not limited to but include the under-expenditure of the allocated budget when there is increased deterioration of public infrastructure and equipment at institutions and the frequent equipment breakdowns at institutions resulting in unavailability of critical equipment such as boiler, chiller plant or autoclave are adversely affecting service delivery of the client department. Also, there is a high number of cases of poor or non-performance by the contractors PGDID appoints or sub-contracts to provide service to its client department and the slow turn around in processing payments to consultants on services rendered to GDID.

The objectives of the investigation are to identify the factors that are affecting the effectiveness of maintenance management by GDID and to provide recommendations for improvements on the factors identified to be affecting service delivery.

2. LITERATURE REVIEW

Equipment and buildings deteriorate depending on age, usage, method of design, materials and environmental conditions [10]. These conditions make it essential to perform maintenance work, so as to preserve the buildings and equipment and allow them to continue operating efficiently [11]. Maintenance work is also done to ensure that facilities are safe to work in, and that they meet specified working standards. According to [12], maintenance management ensures the protection of capital investments and guarantees acceptable working environment for users. However, maintenance work increases operational costs, and some organizations resort to inadequately maintaining their facilities in order to lower costs, but by so doing, they compromise safety. Neglecting maintenance has long-term negative financial consequences due to reduced asset life and premature replacements [10]. Also, inadequate or lack of attention given to maintenance of facilities often results in large and unbudgeted expenditure occurring [13].

The requirements for good practice in maintenance management have been established over a considerable period, but the achievement of good practice is by no means universal [14]. While some organizations consider planned preventive maintenance more economical as compared to ad hoc replacement of parts when they fail, some consider otherwise. In the case of hospital equipment and buildings, their performance depends largely on continuous and planned maintenance [15].

2.1 Maintenance management

Maintenance management is the planning and controlling of all aspects associated with maintenance of a plant or facility. It involves the administrative, financial, and technical framework for assessing and planning maintenance operations on a scheduled basis. An effective maintenance management system involves three separate entities of work, *viz*, maintenance, inspection and verification, which can be done by different groups in the same company or different companies specifically subcontracted for the purpose [16].

Good maintenance management keeps equipment and infrastructure in a state that helps protect operators' health and safety, as well as from environmental damage. It also yields longer asset life with fewer breakdowns, which in turn result in lower operating costs in the long run [17]. A good maintenance management system needs to be backed up with well-informed and competent maintenance staff.

Maintenance management is classified into planned and unplanned, where unplanned maintenance refers to work necessitated by unpredicted breakdowns or damage due to external forces [10]. Planned maintenance management is further subdivided into three categories namely reactive or corrective maintenance (CM), preventive maintenance (PM) and predictive maintenance (PdM) [18]. Each of the strategies is useful under different circumstances and has associated advantages and disadvantages, such that organizations are faced with the option of choosing one strategy or more to follow [12].

Optimal maintenance of equipment cannot be achieved by utilising only one maintenance strategy, but a well-orchestrated maintenance program will include a practical and reasonable mix of the different maintenance strategies. The right maintenance mix should be adopted, where the three types of maintenance strategies are distributed across different equipment. The right maintenance mix should be decided upon after considering a number of factors, for example, the type of equipment or assets and costs of replacement *versus* costs of maintaining [18]. Figure 1 provides a correlation between the maintenance costs and repair costs associated with the three different maintenance strategies.

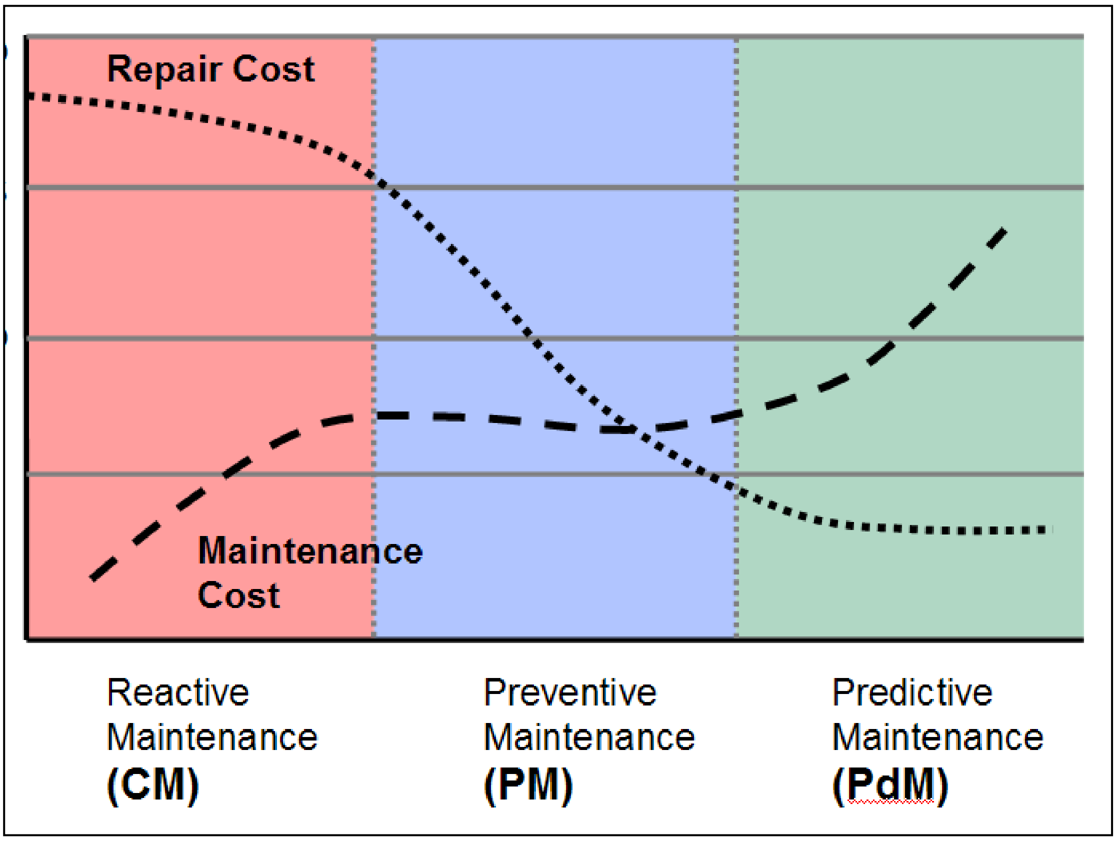

Figure 1: Association between repair cost, maintenance cost and maintenance strategies [18]

Figure 1 shows that Predictive Maintenance (PdM) generally has the highest maintenance cost, but it will result in the lowest repair costs. On the other hand, Reactive Maintenance (CM) has the lowest maintenance cost but the highest corresponding costs associated with asset repairs. The costs of repairing equipment are generally higher as compared to maintenance costs, implying that in order to lower costs, CM should be allocated a smaller ratio of the maintenance mix [19]. As much as PdM result in the least repair cost, the installation of indicators that help predict failures brings additional costs. With the given information, Preventive Maintenance (PM) should be allocated the highest percentage of about 70% in the maintenance mix [20].

2.2 Factors affecting maintenance management at health institutions

Public hospitals find it difficult to compete in a market-driven economy due to their nature, characteristics and structure. In general, the structure in the hospitals promotes inefficiencies and inflexibility, and allows for the imposition of bureaucratic impediments to operational effectiveness [21]. These factors instil researchers to investigate public hospitals with regard to their performance and maintenance, in order to suggest ways of improving services provided by these institutions.

[22] investigated the strategies that are employed in rolling-out a maintenance plan and identified the challenges in managing hospital maintenance in the Eastern Cape Province. The factors identified in the study included realistic budgets, adherence to occupational health and safety regulations, engagement of qualified and skilled maintenance staff, good record management in relation to the equipment under maintenance, availability of tools and materials and keeping abreast with the latest technologies and trends of machinery

advancement. [22] recommended that for maintenance to be effective, strategic planning that takes into account carefully thought-out maintenance management systems should be the first step in the direction of setting out definite tangible objectives and goals.

To explain the ineffective and sub-sequent poor performance of medical equipment in hospitals and health centres in developing countries, [23] incorporated a management perspective onto the way in which health care equipment is acquired and used. The management related factors identified include poor equipment acquisition procedures, poor maintenance and repair procedures, poor equipment replacement procedures, poor management of human resources development and poor equipment performance evaluation procedures. Other factors identified in the study which contribute to poor maintenance management at health and social development institutions include lack of trained maintenance staff, lack of trained equipment operators, weak technical support system, inadequate finances for equipment management, poor logistics support (transport, information), poor equipment conservation culture and weak infrastructure and organisation [23].

[24] identified the main reasons for the poor service delivery as attributed mainly to the non-existence of good governance framework with proper checks and balances particularly in the purchase of sophisticated equipment which were underutilized or never used due to lack of technical expertise, bad usage and maintenance which reduce life of equipment. Other important maintenance management related factors identified were the over-purchase of accessories and extra spare parts and modifications to facilities initially unforeseen due to lack of expertise in choosing appropriate equipment, over-buying due to corruptive deals, lack of standardization resulting in increased cost of spare parts or additional purchases and extra workload on limited competent staff, excessive down time of equipment due to lack of preventive maintenance, inexperience in repair and lack of spare parts and unfavourable purchasing contracts. The high percentage failure of equipment led to resource wastage and poor quality of health care delivery in public sector hospitals.

[25] identified maintenance management system adopted by an organisation as an important factor for the service delivery of maintenance of equipment. A maintenance management system that prioritizes medical equipment for maintenance decisions to ensure safety and reliability of medical equipment was proposed. It is highlighted that in order to mitigate functional failures, significant and critical devices should be identified and prioritized. Reliability Centred Maintenance (RCM) was proposed as a solution to achieve this.

2.3 Best practices in maintenance management

Best practices are good practices that have been used and worked well elsewhere. They are proven and have produced successful results. In maintenance management, [26] provided a set of best principles as given below:

- The maintenance budget must be drawn from the maintenance needs on the ground and adequate funding must be provided
- Occupational health and safety regulations must be followed
- Maintenance plans must be in place to guide maintenance and are adhered to
- Maintenance records of service history must be available
- Maintenance is carried out by skilled personnel
- Personnel operating machinery are competent
- The right tools and adequate spares must be available for maintenance
- Maintenance and equipment replacements are carried out as per manufacturer's specifications and scheduling
- Competent contractors are sub-contracted for specialised services
- Procurement processes enable the appointment of the best competent contractor
- Availability of adequate support resources such as transport, computers, fax and telephones.

3. METHODOLOGY

The purpose of the research was to investigate the factors affecting service delivery by PGDID so as to give recommendations on how to improve PGDID maintenance management. A quantitative research methodology was used in the study. The method makes use of numerical data to explain a particular phenomenon and can be used where there is a large amount of data that can be standardised [27]. A quantitative descriptive research approach was used in the study where some of the data collected was descriptive whilst the other data was numerical. The type of research was chosen because substantial amount of data could be collected at low costs, and the method gives a description of the state of affairs as it exists, which suits the purpose for this research to explain why PGDID was failing on its mandate.

Preliminary interviews in the form of a focus group which consisted of eight PGDID engineers were conducted to discuss the problems PGDID is facing. The factors affecting PGDID service delivery were identified and hypotheses were drawn based on the factors identified by the focus group interviews. Self-administered questionnaires (which were semi-structured) were then designed based on the hypotheses to be tested and administered to 120 respondents that are directly involved in PGDID service delivery for their participation in the research. The research participants included PGDID engineers, inspectors, foremen, artisans, supply chain management (SCM) staff and regional directors.

A set of research hypothesis tested are as follows:

i. The maintenance management system (MMS) in place is not effective
ii. Infrastructure and equipment are not effectively maintained
iii. PGDID is not adequately resourced to provide an efficient service
iv. The PGDID Supply Chain Management (SCM) department is not efficient
v. The staff are not motivated and morale is low
vi. There is no effective communication between top management and the staff
vii. There are no significant effects of bureaucracy on the service delivery

The Cronbach's alpha was calculated to test the reliability and internal consistency of the factors measured and a reliability of 0.70 or higher is acceptable [28].

4. RESULTS AND DISCUSSION

The mean score for each hypothesis tested obtained from a semi-structured questionnaire was calculated as shown on Table 1. The mean score determined whether the hypothesis was accepted or rejected.

Table 1 : Summary of results of hypothesis testing

Item	Hypothesised factors	Mean score	Hypothesis
1	The maintenance management system (MMS) in place is not effective	2.624	Accepted
2	Infrastructure and equipment are not effectively maintained	2.308	Accepted
3	PGDID is not adequately resourced to provide an efficient service	3.399	Rejected
4	The Supply Chain Management (SCM) department is not efficient	2.849	Accepted
5	The staff are not motivated and morale is low	2.719	Accepted
6	There is no effective communication between top management and the staff	2.505	Accepted
7	There are no significant effects of bureaucracy on the service delivery	3.684	Rejected

4.1 Maintenance Management System (MMS)

The research findings indicated that the maintenance management system (MMS) currently in place at PGDID is inefficient. This explains why the department is experiencing budget under-expenditures and failing to maintain infrastructure and equipment effectively as evidenced by the research findings. Similar findings were obtained by [22] on the investigation of effective management of machinery in government operated hospitals in the Eastern Cape province of South Africa. Based on these two research findings, it raises concerns on the MMS that are in implementation at the government maintained institutions in South Africa. A sound MMS will inform of the maintenance needs of equipment and infrastructure, maintenance resources, spares and tools necessary and when they should be available. The budget that is required to implement maintenance is also extracted from the MMS. MMS will also assist maintenance record keeping which is essential for an effective maintenance management by PGDID.

4.2 Supply Chain Management department efficiency

The perceptions shown by the research findings indicate that the SCM is ineffective which explains some of the problems the department is facing which include the sub-standard quality of service provided by the contractors, the poor or non-performance by contractors which has led to a significant number of contracts terminated. Since PGDID externally procures the bulk of services it provides to the client department, thus the quality of service the PGDID provides to its client department is dependent on the quality of contractors it appoints, therefore the SCM department within PGDID plays a critical role and it is imperative that it operates efficiently. The research findings indicate the SCM contractor appointment process is not yielding the appointment of the right competent contractors which is significantly contributing to the poor service delivery by PGDID.

4.3 Availability of resources

It is essential that adequate resources be available for effective maintenance of infrastructure and equipment. The research findings show that PGDID is generally resourced as shown by the average mean rating of 3.399 given to the availability of resources. This is contrasting to the research findings obtained by [21] where insufficiency of funds for maintenance programs was identified as one of the main factors affecting maintenance management of public hospital buildings in Lagos state, Nigeria. This differentiates the situation of PGDID maintained institutions to those of Lagos government run institutions. However, since PGDID is perceived not delivering a quality service to its client department despite being resourced, it is an indication that the resources available to PGDID are under-utilised. However, the availability of resources in PGDID also provides a foundation on where improvements can be built upon.

4.4 Motivation and morale of staff

The employees play a significant role in the quality of service delivery by PGDID. It is important that the staff be motivated and the morale to be high in order to obtain maximum productivity from the employees. From the below average rating of 2.719 that the research results showed on the perception of staff motivation and morale, the poor service delivery by PGDID can be attributed to lack of motivation and low morale of the staff.

4.5 Communication

The research results have showed a negative perception on the effectiveness of communication within PGDID. This has contributed to the staff not understanding the vision and mission as well as a perception that management is not addressing the concerns of the staff as shown by the research findings. Communication plays an important role in an organisation. It is important for management and the staff to have aligned goals in their approach to maintenance. The staff needs to be informed of the vision and mission of the organisation and understand the strategies that are in implementation to achieve the set targets as well as their role in contributing to the attainment of the vision and mission. The staff also need to be able to inform the management of the challenges and concerns on the ground which need to be addressed. This can only be achieved through effective communication. Lack of effective communication within PGDID also contributes to the poor service delivery by the department.

4.6 Bureaucracy in PGDID

The survey results indicated that there is bureaucracy in the organisation and that it is impacting on the service delivery by PGDID. The bureaucracy is causing delays in contractor appointments even when unplanned critical breakdowns occur which is resulting in negative perception on effective maintenance of infrastructure and equipment by the client department. Implementation of changes even where they are critical is also slow due to bureaucracy within the system. The bureaucracy is attributed to top management centralising decision making which is also affecting the morale of the PGDID staff who indicated that they are not consulted in decision making. For PGDID to give efficient service to its client department, it is imperative that the barrier of bureaucracy be eliminated.

5. CONCLUSION

The study findings indicated that the perceptions on the current maintenance practices show inadequacy for an efficient service delivery by PGDID. It is concluded that there is poor service delivery by PGDID to its client department which is attributed to: an ineffective maintenance management system in place; infrastructure and equipment not being effectively maintained; inefficiency of the supply chain management within PGDID; low morale and motivation amongst the staff; the ineffective communication in PGDID and bureaucracy within the organisation systems.

6. RECOMMENDATIONS

- It is recommended that PGDID make use of term contracts with contractors for the maintenance of its electro-mechanical equipment to improve responsiveness and to minimise the effects of bureaucracy that is inherent in PGDID procurement processes.
- Delegation of authority to regional management will assist in minimising the bureaucracy that is in the PGDID systems.
- PGDID needs to increase the percentage of services that are done by its in-house staff so as to increase its responsiveness in case of breakdowns. Recruitment of technical staff is essential to achieve this.
- Renovations on all old infrastructure to give a facelift to the institutions and the replacement of all obsolete equipment is recommended to reduce age related breakdowns on machinery and improve the plant availability and productivity.
- It is recommended that PGDID introduce a computerised maintenance management system (CMMS) to guide maintenance. CMMS will enable a better record management system and informs the maintenance plans, material required and budget needs.
- Rating of performance of every contractor appointed after execution of services so that all poor performing contractors can be removed from the PGDID contractor database.
- Top management is recommended to engage in regular meetings with the staff and that issues raised by the staff be taken into consideration in decision making so that there will be buy-in from the staff. Internal workshops will assist in informing the staff of the vision and mission of PGDID and also that they understand their role in contributing to the department's vision and mission.
- Best practice benchmarking can be used by PGDID to improve its service delivery. Private hospitals, clinics and forensic mortuaries which are perceived to be efficiently maintained can be used as benchmarks for PGDID institutions.

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ENGINEERING WORK INTEGRATED LEARNING: A CASE STUDY IN PROBLEM-BASED RESEARCH AND DEVELOPMENT PROJECTS

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ABSTRACT

The case study presented in this paper is based on an internship program at a company located in Johannesburg South Africa. It aims to show an innovative problem-based research and development approach through an engineering work-integrated learning program with technologist engineering interns. Through the case study, theoretical, practical and proper decision making have emphasized the understanding of problem solving strategy in research and development with interns. A thorough follow-up of the processes described in this paper could potentially enable decision makers to develop the skills of more engineers. A working model is presented to show how the system can be replicated.

Keywords: Work-Integrated Learning, Research and Development, Internship, Interns, systems engineering.

1. INTRODUCTION:

Over the past two decades, a considerable number of people have moved to South Africa for diverse reasons such as political and economic stability and advancement [1]. Similarly, the population growth has increased over the same period [2, 3]. The increasing number of people has created the need for infrastructure development, better life styles and commercial opportunities which stem from engineering activities. Engineering activities require specific competencies [4]. Many of these competencies, including infrastructural and industrial design as examples, must be addressed by engineers. Engineers are considered crucial to economic development, sustainability and national growth. The question that arises is whether adequate engineering skills are available to address the growing South African economy.

According to the Engineering Council of South Africa (ECSA), one engineer serves 3000 people in South Africa in comparison with 227 in Brazil and 543 in Malaysia. This statistic validates the shortage of skilled engineers in South Africa [5].

In order to address the shortage, the development of engineering skills can be achieved through normal tuition supported by work-integrated learning (WIL). Practically, most graduates lack industrial problem solving exposure and effective mentoring which may be attributed to the absence of industry placement. However, for certain companies, employing engineering interns shift them from their economic targets since the time of productive staff is absorbed to mentor future graduates. Due to the recursive nature of this situation, it becomes a problem for students to graduate with their National Diploma (ND) of which the Work Integrated Learning (WIL) component is an exit-level outcome as required by ECSA. Furthermore, the graduation certificate confirming a degree or an ND in engineering technology does not automatically translate to experience, expertise and resultant employment. Consequently, recent graduates seeking their first job opportunity may lack realistic expectations and experience relevant to the kinds of challenges and responsibilities encountered in the work place [6]. According to Leinhardt *et al*. (1995) and Entwistle and Entwistle (1997), the theoretical learning from universities has been of huge criticism for focusing much effort on 'declarative knowledge' and unsatisfactory efforts on relevant professional understanding [7, 8]. In response, the combination of theoretical knowledge and industrial exposure could be seen as the bridge to link graduates with industry for the development of skills and value-adding engineers.

In this paper, the case study presented indicates how a well-managed ND engineering technicians' intern can be integrated into industrial projects to add value; maintaining budget and time constraints in a scenario where a new group of up to 300 interns is enrolled every 6 months.

2. BACKGROUND

The introduction of the practice for linking theory and practical work to enhance education is unclear. Historically, a practical program was introduced for engineering and architecture students in 1903 at Sunderland Technical Collage in Northern England [9]; and in1906, at the University of Cincinnati, Herman Schneider, an engineering lecturer believed that professional concepts and skills acquisition required more than just classroom lecturing. In order to master professional concepts and skills, he understood that students must undertake intense practical experience development. He suggested the key solution would be to alternate employment experiences on a work site with theoretical work on campus [10]. The notion of "learning by doing" has been in formal operation for over a century and from the late 1950s to mid-1980, led by the United States of America (USA), this notion has expanded globally [10].

Many papers have been published by a large spectrum of authors on the WACE International Conference portal to examine the effects of WIL on the students [11]. In 2009, Matsutaka *et al*. studied students' consciousness and its related effects on their academic and employment outcome by means of a sample of over 1300 students at a University in Japan [12]. Carlson and Kwan (2010) explored the effects of WIL on learning outcomes by means of 1040 students from a Hong-Kong University [13], and in 2009 and 2010, Green and Mendez focused smaller groups of engineering students to study the effects of work employment on academic performance in some Universities in Great Britain [14, 15].

In Australia, research has shown the importance and effectiveness of WIL in preparing university students for their work readiness on completion of their studies. From the employers' point of view, as revealed by the survey conducted for the Office of the Chief Scientist (OCS) in 2014, the key difficulties encountered when recruiting graduates were deficiencies in interpersonal skills, understanding of business and workplace experience [16]. As such, practical learning and critical thinking can be visualized as the two most important attributes a graduate should be equipped with on entry to the workplace [17]. According to the Australian Survey of Student Engagement (AUSSE), students who have experienced WIL are less likely to drop out of the University as compared to those who have no WIL experience [16]. The data retrieved from the AUSSE state that students who have experienced WIL have been learning things in their academic program that 'improved knowledge and skills that contribute to employability' [18, 19].

Most of underdeveloped countries such as Uganda, Cameroon and Ivory Coast are agricultural-based economy countries with young and fast growing populations. Uganda, as an example, has a population estimated at 34 million people with a growth rate of 3.2% per annum, endowed with low industrialization and engineering value addition [20]. In spite of the economic structural transformation over the past two decades, it still faces huge challenges, which include high unemployment and inadequate skills development [21]. Due to the lack of organisational forecast, some efforts in addressing WIL are often not visible. Providing an answer to the skills development would definitely warrant economic growth through entrepreneurship and job creation. This applies to most of the underdeveloped countries worldwide.

In South Africa (RSA), the unemployment rate is in the range of 26.7% for the first quarter of 2016 [22]. Globally, the economies of first-world countries are recovering from recession whereas South Africa is entering one which may be attributed, to some extent, to the lack of a proper employment policies. In RSA, some opportunities aimed at contributing to the economic growth also lack specific engineering skills such as electrical, electronic, civil and chemical engineering as listed on the national scarce skills list [23]. Therefore, it is imperative and expected from the Universities to produce graduates who are job ready through WIL. But in reality, a large amount of students are not exposed to WIL due to a deficiency of opportunities offered in the local industrial environment. Additionally, the labor market fluctuates between skills scarceness and graduates without work. According to Coll and Zegward (2006), skills scarceness and graduates without work might arise because most students do not have behavioral or soft skills such as analytical and team work skills, and are therefore unable to organize and manage themselves [24]. The Resolution Circle (RC), a company based in Johannesburg, is a dedicated research and development environment with multi-disciplinary student teams. These teams are supported by internal technical experts. RC is an initiative of the University of Johannesburg (UJ) that aims to address specific technological challenges brought forward by industry partners. The RC internship WIL program was designed to address the lack of opportunity for engineering skills development in industry and to provide a platform for graduate employability skills development.

Previous studies conducted in first-world countries determined the technical and individual abilities required of engineers by today's industry [25, 26]. These studies have influenced countries like the United States of America [27], the United Kingdom [28] and Australia [29] to revise their national accreditation criteria for engineering programs. In these countries, the accreditation requirement has moved from what is being taught to what is being learned [30]. Therefore, current engineering programs must demonstrate that graduates achieve sets of learning outcomes but they have autonomy in implementation methodology [31]. Two concepts arise from the studies, including problem-based learning and project-based learning and in South Africa, these concepts are integrated in the WIL outcomes. Problem-based learning assists students to develop problem-solving, team and interpersonal skills; whilst project-based learning introduces methods for effective design and completion of projects.

Several universities that have introduced problem-based learning courses, including Monarch University, Curtin University and Griffith University in Australia. Project-based learning courses have been introduced at Hogskole Telemark in Norway, the Colorado School of Mines, Rose-Hulman University of Technology in the USA, Aalborg and Roskilde in Denmark, and TU Berlin in Germany [31]. In South Africa, the combination of problem-based and project-based learning is provided at RC under the umbrella of WIL.

3. A RESEARCH AND DEVELOPMENT WIL CASE STUDY

3.1 The Resolution Circle

In South Africa, universities receive subsidy from the government when students graduate. However, many students are unable to graduate since they have not received placement in companies to fulfil their WIL requirements. In order to overcome income loss and address this challenge, the University of Johannesburg (UJ), has invested in the Resolution Circle to recruit students for their WIL internship program. An on-site range of services is orchestrated in the company (RC) to support marketable projects throughout the commercialization life cycle, including research, development, prototyping, and incubation. Through commercialization, interns who have shown entrepreneurial skills and have developed product based ideas are selectively granted few sits to our incubation program.

RC attempts to close the gap between industry and academia by providing training opportunities and industrial support. The services offered by RC are presented in Figure 1.

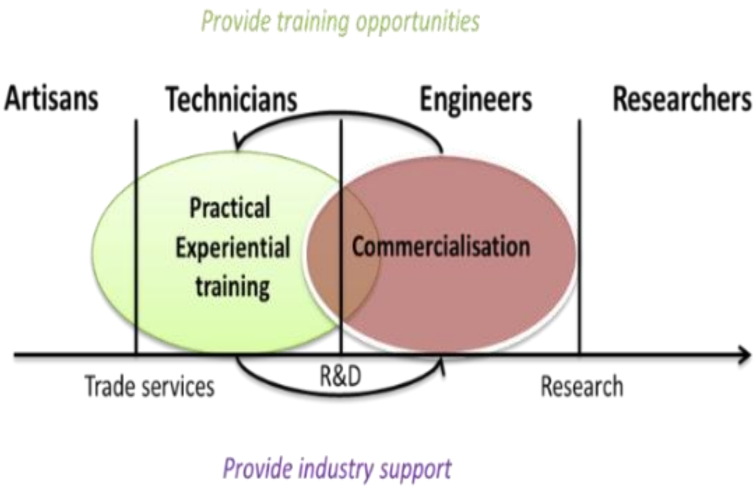

Figure 1. Services offered at the Resolution Circle

Figure 1 indicates that the services offered by RC lie between providing of training opportunities for students and industrial support. The interns, led by technicians and engineers, are exposed to experimental training and commercialization projects through the research and development (R&D) department. Another important focus of RC is research-based projects. The layout of the RC R&D WIL program with its functionality is presented in Figure 2. Figure 2 displays the interaction between the main components of the company with respect to the WIL program. As required by ECSA, the ND WIL students must undertake practical training for a period of one year of which they do Practical 1 (P1) and Practical 2 (P2) for the first and second semester respectively in their final year of study.

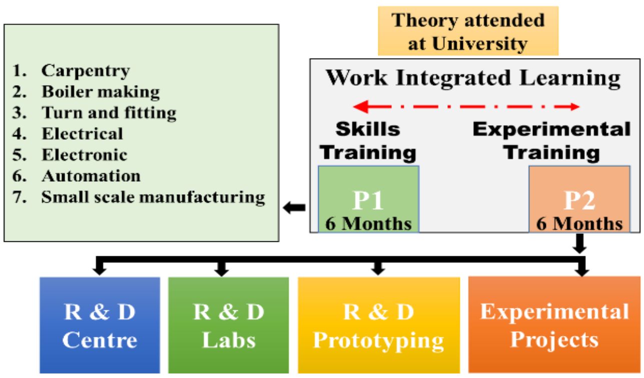

Figure 2. Resolution Circle R&D WIL program layout

One hundred and fifty engineering technician interns from the electrical, mechanical, electronics and instrumentations disciplines are enrolled each semester to complete P1 training for a period of six months. The interns are exposed to six trades which include boiler making, carpentry, turn and fitting, automation, electronic and electrical skills. Exposure to the six trades trains the interns with the necessary hand skills required by the respective disciplines. When the R&D department is executing a project with a manufacturing component, the P1 interns may be involved as well. After completing the six trades, the P1 graduates receive certificates as proof of completion and then move to the P2 phase for another 6 month period.

During P2 the interns are mostly exposed to soft skills (technical report writing, formal presentation, interview readiness and engineering ethics), problem solving, team work and design. The WIL program includes students from other Universities as well.

3.2 Resolution Circle P2 WIL Layout

In the RC P2 WIL program layout, the interns are grouped per engineering discipline for a period of two months. They are exposed to individual stations for two weeks and then rotate to the next station. In mechanical engineering as example, the stations are: G-coding [32], Solidworks [33] and 3-D printing, small-scale manufacturing, and Revit mechanical-electrical-piping [34]. During the two week period, the interns are guided and monitored by trained instructors (senior and junior technicians). Relevant computer-assisted design (CAD) or other software packages are introduced to all the interns at the respective stations. The station arrangement for electrical engineering is presented in Figure 3.

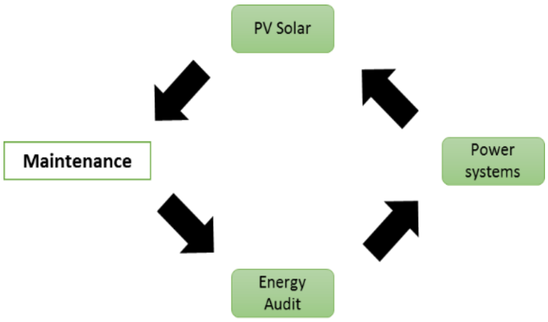

Figure 3. Station rotation layout for electrical engineering interns

Figure 3 indicates that the interns enrolled for electrical engineering are exposed to four stations where they learn relevant software packages such as ETAP [35] for power system, photo voltaic (PV) SOL [36] for solar PV systems and national instruments [37] programming packages. Professional report writing, presentation and entrepreneurial skills are introduced to each team. The interns enrolled for instrumentation and electronics are few and kept in small groups where they are introduced to programing using micro controllers such as Arduino [38], and conveyor belt control technologies using Allen Bradley Programmable Logic Controller (PLC) [39]. This last group is also introduced to electronic software for simulation and Printed Circuit Board (PCB) design.

Report writing is an important aspect of the WIL training program required by ECSA, and monitored weekly. At the end of each station period, the interns write group and individual reports aimed at providing personal and team work reflection and development. After the two month period rotation, all the interns are expected to use their skills to solve relevant problems from industry. The program is structured to satisfy the practical requirements set by the various universities, and to provide the interns with exposure to real-world problem solving. A minimum of 24 weeks must be completed by the interns per semester.

3.3 Resolution Circle P2 WIL R&D Problem Solving

After the initial two-month period, the interns are introduced to higher activity. During this time the P2 interns are placed in smaller groups per speciality. For diversity purposes, interns from different Universities are represented in each group.

The projects are multi-disciplinary including electrical, mechanical, instrumentation and electronic engineering. Some projects are engineering-based whilst others may not be. Clients range from government, the banking sector, industry and entrepreneurs. As projects are received, they are placed in a protocol pool and ranked by time and cost. The projects are then distributed to teams with the relevant discipline requirements; and managed by the Agile project management scheme [40]. Agile is employed since most customers are not fully aware of their requirements at the start of the project and the needs of the project cannot be clearly defined during inception. The project execution flow chart is presented in Figure 4.

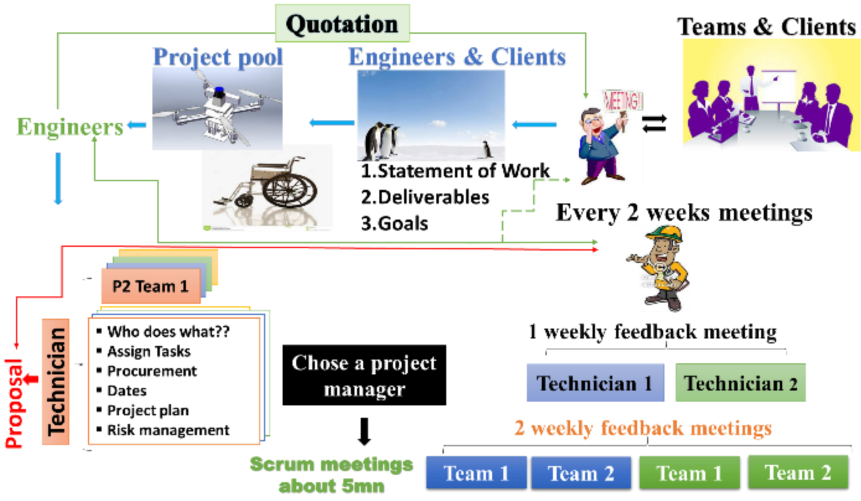

Figure 4. Project management WIL layout.

Projects are selected from the available projects pool and a meeting is organized between the clients and the engineering teams. The engineering teams consists of senior engineers as the project owner, the R&D P2 project manager, a team of four interns per group per speciality and a senior technician per project per speciality. A statement of work is drafted and a list of deliverables are drafted from the meeting including the project due dates. In preparation of the draft proposal, the teams meet to discuss the time needed for the project, the materials or components required, the risk involved, the remedies for risk, the schedule for the deliverables and the project plan. The project backlog is often used in the Agile project management scheme [40]. The project backlog provides a clear vision as an important factor. The backlog is converted into tasks and then assigned to each team respectively during execution. In order to execute the project, a specific time frame of not more than two weeks must be defined respectively. This time frame is known as the Run [40]. A run period is the time interval when teams come together to review the project's progress. When the teams are satisfied with their draft proposal, it is forwarded to the project manager who reviews, edits and forwards it to the senior engineer responsible of the specific project. The senior engineer is the project owner and the scrum master is someone in the execution team [40]. When the senior engineer is satisfied with the draft proposal, s/he sends it to the scrum master for pricing. If modifications are required, the senior engineer sends the files back to the teams and the process reiterates until consensus is reached. When this occurs, the scrum master discusses the proposal with the client and issues the project term sheets and the quotations. The term sheets clarify stakeholder expectations and the respective deliverable dates. The project commences officially once the term sheets are signed by all stakeholders.

A senior technician can work with up to four teams in his speciality on different projects. At commencement, each team selects its leader who holds a local scrum meeting every day on the progress of the project. The technicians hold informal meetings with the project manager twice a week. At the completion of the project, the scrum master and senior engineers hand over to the customer. The project and the client satisfaction is fed back to the teams after which the project is closed.
As an example, one of the projects that involved more than one team was the electric car which comprised of the electrical, mechanical and electronic engineering teams. At the commencement of the project, all the teams meet to discuss the project backlog and the assigned tasks. The project team elected one-week runs run for the project. Team leaders were chosen and procurement and communication issues were addressed. Project management was allocated to the interns as a learning experience. The interns held local scrum meetings every morning which were monitored by a senior technician. The mechanical team was assigned to design the car, the suspension, its road worthiness and the aerodynamics and suspension system.

The tasks assigned to the electrical team were to design the electric drive system, the battery size and the electrical wiring of the car. Through team consultation, cost effective and high performance parts were designed. The task allocated to the electronic team was to design a charger for the battery bank and the lighting of the car. The project was executed according to plan and is a showcase project for WIL development.

3.4 Challenges of WIL projects

A challenge in performing projects with a new groups of interns every six months makes management of the R&D P2 project a complicated task. A new group of interns introduces new personalities and new cultural dynamics. Placing the new group at the level where the previous P2 left becomes more difficult with unwilling interns. Human behavioural and cultural implications therefore make the program both exciting and challenging. This transition and human factor challenge necessitates the introduction of a systems engineering approach.

According to the International Council of Systems Engineering (INCOSE), Systems Engineering (SE) is an interdisciplinary approach that provides the means to enable the realization of successful and complex systems [6]. SE focuses on:

- Defining customer needs and required functionality early in the development cycle;
- Documentation requirements;
- Proceeding with design synthesis; and
- Structure validation and verification whilst considering the complete problem.

SE integrates all the disciplines and specialty groups into a team effort forming a structured development process that proceeds from concept to production to operation. SE considers both the business and the technical needs of all customers with the goal of providing a quality product that meets the user needs.

Challenges experienced during the execution of WIL projects at RC include: interns with no industry experience; limited budgets; inefficient procurement processes; and cultural differences in the team composition (age, gender, religion, ethnic group and race). On the other hand, the computer labs, workshops and experienced senior engineers and technicians are available to support the intern teams. The systems engineering approach facilitates the execution of projects as follows:

- Clients' needs are defined as soon as possible in the project process as per project backlog;
- Drafting the statement of work clarifies team expectation and the project deliverables and dates,
- The teams involved in one project discuss, design, harmonize costs and optimize the human resources; and
- The system validation and verification are addressed using the systems engineering V-model.

The V-model works well with small projects where requirements are very well understood and where tasks are completed individually. The V-model is presented in Figure 5.

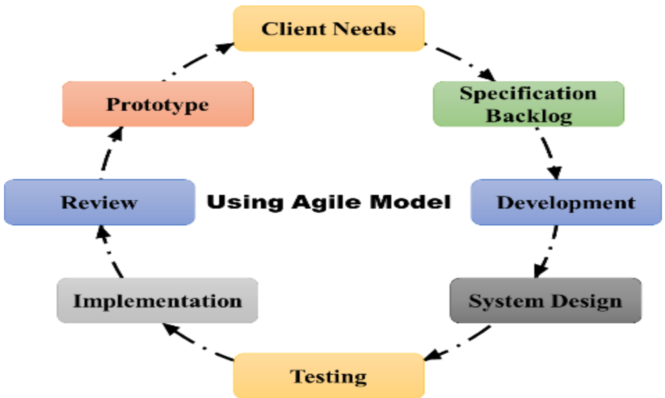

Figure 5. R&D Project Agile project management model.

From Figure 5, the life cycle of the project is implemented with the interaction with the client until completion.

4. RESULTS

A number of WIL projects at RC have been success stories. These include the circuit board project, the intelligent solar inverter, the electric car and the thin film solar modules testing project. The success of all the projects is ensured by a clear definition of the project scope, as well as the execution of project with the Agile project management techniques. Another important element of project success is communication amongst team members which is facilitated by the systems engineering approach.

5. CONCLUSION

The involvement of the Resolution Circle with the internship program of the ND interns has not been an easy task. The lessons learned have channeled the P2 program to important results in terms of a project's effectiveness, consistency, management and repeatability. The authors provide solutions to engineering skills development though WIL problem solving R&D at the Resolution Circle as a specific case study. The value added through the program was both shared by the interns and RC. The interns have specifically gained and earned their skills through the program whilst RC has contributed by providing a future strategy for engineering skills development in South Africa. Therefore, after their graduation at respective Universities, these former interns would possibly address the needs from clients and effectively contribute to the economy. As recommendation, decision makers and business owners may replicate the model presented in this paper for enhanced skills development to reduce technical skills shortage in South Africa and Africa.

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ASSESSMENT OF CONTINUOUS IMPROVEMENT INITIATIVES' IMPACT WITHIN THE MANUFACTURING SECTOR IN SOUTH AFRICA

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ABSTRACT

The aspect of sustainability has been widely debated in the Industrial Engineering and Operations management fields, with researchers arguing that many companies are doing at least one initiative of continuous improvement to make their businesses profitable, by minimizing operations costs and the world-wide involvement of companies are taking part in process improvement activities. However, these arguments were based on work done in the UK and USA and not covering the South African (SA) perspective on the sustainability issue. This paper addresses the issue of sustainability with special attention to the work done by the SA government through agencies, such as the Automotive Industry Development Centre (AIDC) in order to ensure that SA manufacturing companies remain competitive. The project specifically focused on process improvements done by the AIDC. The argument is that SA companies are not sustaining these process improvements and therefore not realizing the benefits of these government funded projects. The research findings indicate that generally South African companies in manufacturing sector feel that they are sustaining continuous improvement initiatives to a minimum level, therefore new approach is needed to structure government funded initiatives differently in order to ensure sustainability at a benchmark level of 75%.

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1. INTRODUCTION

Sustainability is a very important aspect in continuous improvement. It is through this aspect that productivity and efficiency benefits are realized. Statistics SA reports that: "the manufacturing sector continues to occupy a significant share of the South Africa economy, despite its relative importance declining from 19 percent in 1993 to about 17 percent in 2012 in real terms"(STATISTICS SA. Economic Growth, 2015).
The South African government in view of reports like these, is encouraging South African businesses to embark on process improvements in order to be more efficient and productive. This is evident because the government, through its agencies such as the Automotive Industry Development Centre (AIDC), The Innovation Hub (TIH), Enterprise Propeller and Productivity SA, etc. is making funding available for such developments. The AIDC is a government agency that is primarily mandated to increase efficiency and productivity more especially in the automotive sector. Funded by the Gauteng government, the AIDC is running several programmes in order to make process improvements through their Supplier and Enterprise Development Department (SEDD). All of these programmes are designed to assist companies to reduce wastes and be more efficient in their operations. They are also designed to improve the way people think in terms of continuous improvement and to help companies improve their efficiencies and maintain them. These structured programmes range from 3-month to one year long during which the AIDC proves to the participating companies that with dedications, continuous improvements are possible. Figure 1 shows some of the process improvement tools that are used by the AIDC (AIDC SEDD Templates, 2012). These tools are also widely used throughout the entire world.

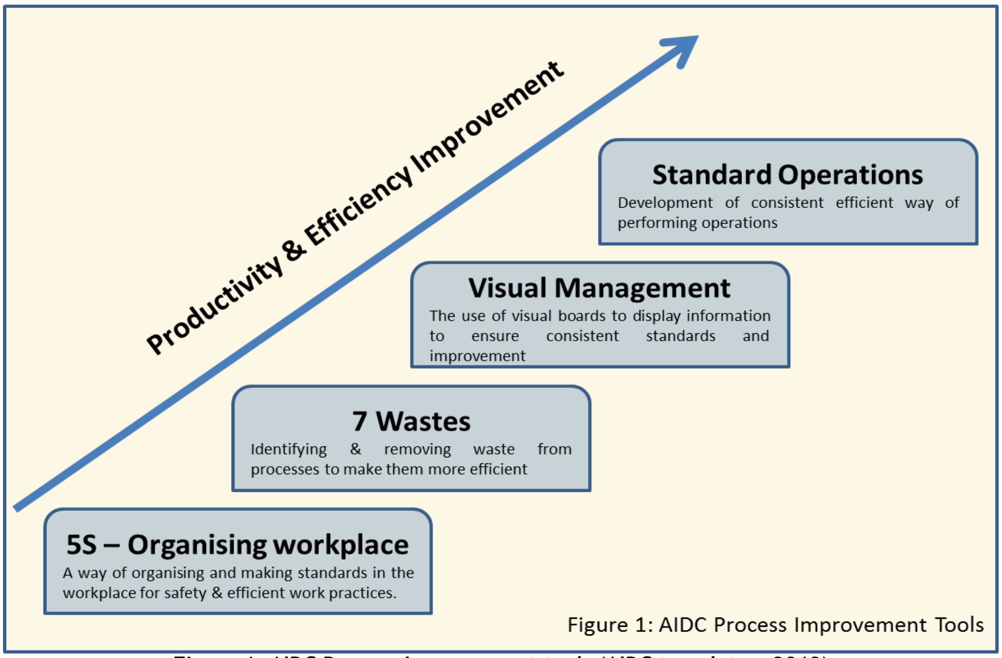

Figure 1: AIDC Process Improvement tools (AIDC templates, 2012)

Although not limited to, the AIDC makes use of these tools in their specialized programmes such as Total Productive Maintenance (TPM), Lean Manufacturing and Rapid Process Improvement (RPI).
This study is done to establish if the companies, that took part in one of the AIDC's programmes, have maintained the process improvements, and have also continued implementing the methodologies as learnt during the AIDC's intervention and what impact has this made to their company. The study also aims to develop a framework which will enable the organisations in the South African manufacturing sector to sustain their continuous improvement initiatives should it be found that the sector does not maintain the improvement or if there is room for improvement.

2. BACKGROUND

2.1 Report Analysis

In 2011/12 financial year, the SED department in AIDC have interacted with 89 companies by doing at least one of the development programmes in each company. The BlueIQ annual report for the same year indicated that all companies achieved a range between 9% and 34% productivity and efficiency improvements. (GAUTENG GROWTH AND DEVELOPMENT. Automotive Industry Development Centre. 2012. Annual report. GGDA).
In 2013/14 financial year, the AIDC continued their programmes with 15 different companies and it is reported that 15% average efficiency was achieved in that financial year. The percentage here ranges from 10% to 30%. (GAUTENG GROWTH AND DEVELOPMENT. Automotive Industry Development Centre. 2014. Annual report. GGDA).

The AIDC has produced the same reports for 2014/15 financial year, with 25 companies, and showed an efficiency improvement of 45% on average. (AUTOMOTIVE INDUSTRY DEVELOPMENT CENTRE. Supplier and Enterprise Development Department. 2015. Annual report, Pretoria: AIDC).
Given the information above it is obvious that whenever the AIDC is involved in a continuous improvement initiative at a company, positive results are yielded. Since the AIDC is only at these companies for a limited period of time, it is necessary to establish whether these companies are sustaining the improvements made during anyone of the SEDD's programmes and whether they are actually using the methodologies learnt during the intervention with AIDC to improve their businesses.

2.2 Literature Review

Sustainability is viewed by the AIDC as the important measure for performance because it is through this measure that the benefits are realised. For this reason, it is very imperative for companies to have a clear strategic focus in achieving sustainability of improvements made. Ali, A.J. 2012 came to a conclusion that Strategic Focus, management of Continuous Improvement (CI) and learning/knowledge sharing were the most influential factors of sustainability of CI. Since the element of sustainability is growing at a very fast pace, sustainability thinking is challenging businesses to change how they operate (Lubin and Asty, 2010). As a developing country, South Africa cannot afford to ignore the direction that the developed countries have taken in terms of the element of sustainability of continuous improvement to gain competitive advantage and to respond to the major trends that include growing of human population, rapid response to developing economies, both of which they put a major train to the resources and create unpredictable pricing in commodities (McPhee 2014).
According to literature, several models that aim to measure sustainability in business were identified. In the main scientific databases like Scopus, Ebsco, Web of Science, and Wiley, for example, approximately 64 models were identified(Satolo and Simon, 2014).
Meanwhile, in Mexico, Suárez and et al (2011) conducted an empirical study in 49 different Mexican industries. The study focused on the application of Kaizen and reported the main causes of abandonment of Kaizen philosophy, among others, is resistance to change from employees, lack of proper implementation and monitoring of Kaizen projects. AIDC in one way or the other do meet the above challenges especially at the beginning of the project but the willingness to participate is overcome by introducing the issue of change management to participating companies. The study will also establish whether the companies continue managing this change or not.
According to Garcia and Rivera (2013), the continuous Improvement (Kaizen) philosophy, "was applied for a large number of entrepreneurs, restless and highly competitive managers that were eager to employ methodologies that strengthen the highly competitive environment where they were involved". Despite this argument, Rink J, 2005 reported that in the 3000 industrial organisations that took part in the survey conducted with the US Manufacturers, 90% had implemented continuous improvement projects; however, only 10% felt they were achieving the results they desired. Japanese companies on the other hand are seeing more value in implementing the Kaizen projects than anywhere in the world. Cheser, 1998, has conducted a research in Japanese manufacturing industries, and concluded that the Kaizen generated an increase in motivation and positive change in attitude in employees.
Bateman, (2001) argued that globally not all companies that embark on process improvements are able to sustain those improvements and continue to make further improvements. She in fact states that some of the companies will go back to where they were before the improvement was done.
The United Kingdom (UK) has adopted what they termed Industry Forum MasterClass where a formal process structure to continuous improvement was established.
In a study that was done in UK by Bateman (2001), where the various phases of an improvement activity was followed and studied over time considering the outcomes of each phase in terms of sustainability. Bateman, 2001, came up with a model for sustainability that explains the findings of her study in 2001. She concluded her study by classifying the companies into Class A to Class E (Class A being good, Class E being worse). The summary of the findings as described by Bateman (2001) is as follows:
"During the post follow up phase, Class A activities continue to improve and Class B activities only continued for few weeks and maintain the current situation. Class C activities only maintained the improvement done during the intervention. All other classes literally dropped from the achieved improvement with class E going back to the original state. Continuous Improvement takes place when team uses the tools and techniques that were learnt during the workshop to solve new and to improve further the performance of the model area. The activities that achieve this are defined as class A activities".

Figure 2 below shows a Sustainability Model as defined by Bateman, 2001.

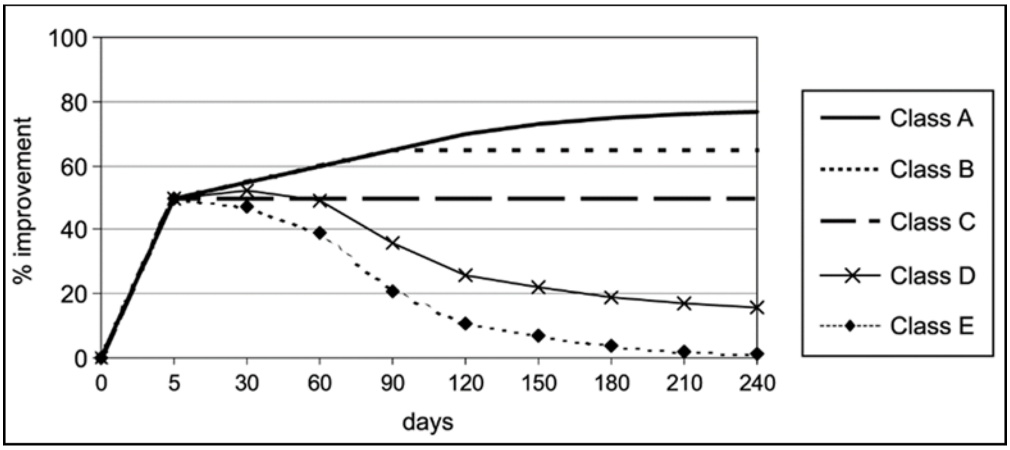

Figure 2: Sustainability Model (Bateman, 2001)

Bateman, 2003, further looked at the differences of these classes in terms of what A and B are doing versus C, D and E, and she found out that companies in class A and B have the following in place:

i. Daily time dedicated to 5S activities,
ii. Quality, cost and delivery measures are displayed at cell level,
iii. Problems are communicated properly from situational level,
iv. Managers stay focused on continuous improvement activities,
v. Operators are involved in decision making,
vi. The companies are supporting "evidence based management".

3. THE SOUTH AFRICAN CONTEXT

3.1 South African operating environment

Majority of manufacturing companies in South Africa are multi-national automotive component suppliers who understand the global status core. These companies are the biggest role players in the enforcement of lean manufacturing in South Africa, hence the government is encouraging them to have a supplier and enterprise development programmes with their suppliers.

Through the AIDC programmes, it has been realized that companies are keen to pursue continuous improvement programmes. While the above is true, not all companies are realizing the full potential of such programmes. Sustaining process improvements is the key to a competitive manufacturing sector. In view of the above literature, the study is very important and relevant for South Africa to start understanding our position in terms of sustainability of continuous improvement. In realizing that the government is investing capital in industry development to enhance the competitiveness of the industry, it is also imperative to find out if the investment is worthy or to be improved.

3.2 Research Questions in South African context

The questions, therefore, are: Are South African companies in the automotive and manufacturing sectors sustaining their Kaizen projects? What interventions do these companies need in order to see value in their Kaizen projects? And what is the role of the government and the support agencies like AIDC in developing the manufacturing companies in the automotive sector?

The above literature does not make mention of the state of affairs with regards to general manufacturing in South Africa never mind the automotive industries in South Africa. This paper will therefore, focus on South African manufacturing industries in comparison with the above literature.

3.3 Current Processes and Frameworks

Currently, the AIDC has no defined model but are carrying out work in a manner that is shown below:

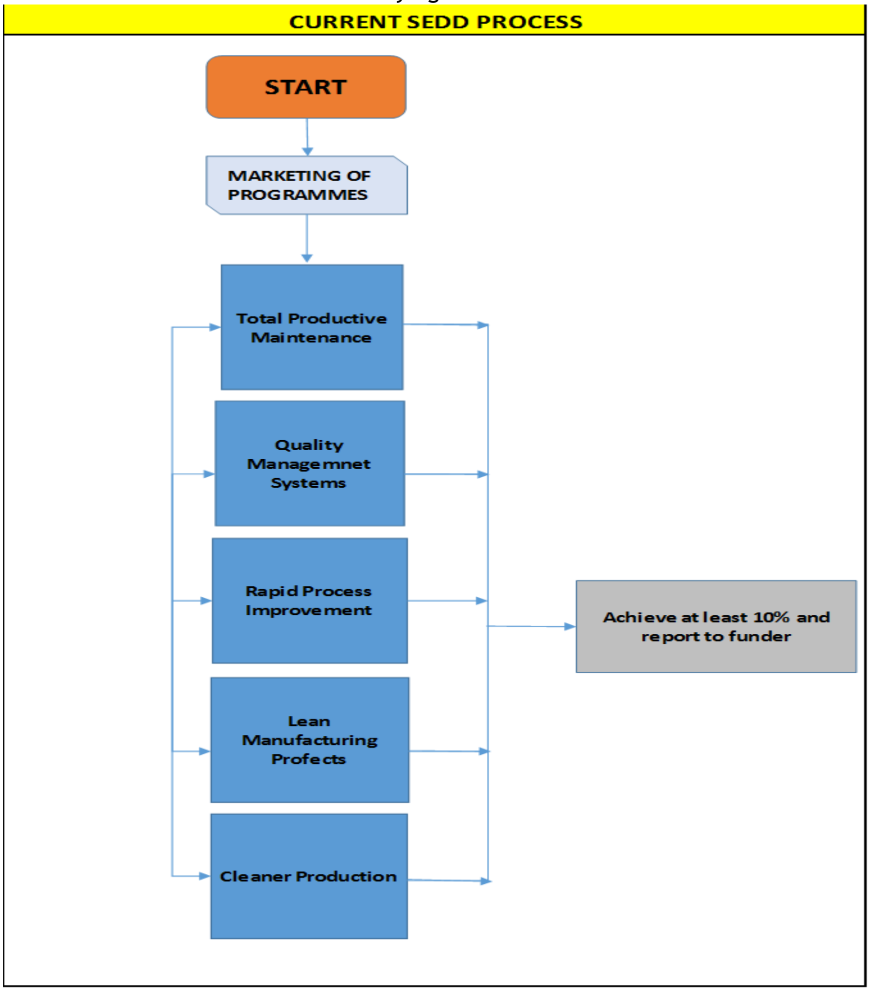

Figure 3: Current SEDD process (AIDC templates, 2014)

The current approach used to carry out the above programmes, is based on the target set by the AIDC for the SED department. The department then allocates the targets for each project manager or each programme. The project manager is then responsible for ensuring that the targets are met, so from marketing to project completion, project manager for each programme focuses on what the programme targets are and strives to achieve those targets.

Since the approach is target driven, marketing of the programmes depends largely on the individual project managers. Once the project manager has reached their number of companies to be sign on to the programme, then implementation with the individual companies starts immediately. The project manager will then report progress on a bi-monthly basis and the implementation results are summarized at the end of the financial year which is end of March each year. Figure 11 in section 5.3 shows the draft of the current process within the AIDC. Although the above is the way the process is conducted currently, the process is not formally described anywhere within the AIDC

The disadvantage of the current operations (figure 3) is that programmes are conducted by companies that avail themselves and but are not necessarily ready for some of these interventions. This results in companies not sustaining their improvement and therefore not realizing the benefits.

4. RESEARCH METHODOLOGY

The study was characterized by primary research which involved quantitative research methods. The research was primary in that it consisted of questionaire that was sent directly to the respondents by means of SurveyMonkey. In this way, the research was as interactive as possible as it was conducted electronically with an allowance to ask clarity to questions by e-mail. This research is based on some underlying philosophical assumptions about what constitutes a 'valid' research and the research methods that are appropriate for the development of knowledge in a given study. An example of the assuptions is that the respondents will give answers to the best of their knowledge. The research method is a strategy of enquiry, which moves from the underlying assumptions to research design, and data collection (Myers, 2009).

Thethree common classifications of research methods were considered during this research, namely: qualitative - research that relies primarily on the collection of qualitative data, quantitative - research that relies primarily on the collection of quantitative data and mixed - research that involves the mixing of quantitative and qualitative methods or paradigm characteristics. These self-explanatory terms are really dependent on the assumption made before the data collections, the way data is collected and the way that data is analysed.

4.1 Research Strategy

There is certain esearch strategies that could be considered for a particular project depending on their ability to answer the research questions and meet the objectives of the study. This could be in the form of survey, case study, experiment, action research, ethnography, and so on. (Saunders et al., 2012). All research strategies carry the same value when compared to each other hence the researcher is urged to select the one strategy that best suits their research.

The research design included literature reviews and studies where existing information was analyzed and equated to the South African environment. A descriptive investigation was conducted using a qualitative survey. This method was chosen because it allows the study of things in their natural setting, attempting to make sense of certain type of behaviours.

4.2 Target Population and sampling strategy

A questionnaire was sent in a form of monkey survey targeting a sample of 40 companies that formed part of the AIDC' Supplier and Enterprise Development programmes in the past 4 financial years. Although this study accommodated companies that took part in other programmes within the AIDC, more emphasis was placed on companies that attended the Rapid Process Improvement programme as they appear in the AIDC data-base. This means that all such companies were invited to take part in the study. In order to achieve the goal, the cluster sampling approach under probability sampling was used. The targeted population for this purpose is approximately 150 companies that interacted with the AIDC in the past 4 years.

A sample is the representative of its own population if it has to produce valid and reliable estimates of the population from which it was drawn. The Longman South African school dictionary defines a sample as a noun that means the small amount of something that shows what the rest is like, (Maskew Miller Longman, 2011). So in other words a sample is a subset of a population.

Sampling methods can either be non-probability, where sample members are not selected randomly, or probability, where sample members are selected randomly.

During this study, a probability sampling method was employed, and the following steps were followed:

- Based on the research questions and objectives, a suitable sampling frame was identified,
- A decision taken on what sample size would best represent the population,
- The most suitable sampling technique was then selected
- The sample was rechecked to ensure it is the representative of the population (Saunders et al, 2009)

For this research study, the cluster sampling approach which is classified under the probability sampling was used. The sample size was 40 companies, representing a response of hundred percent.

4.3 Data collection strategy

Each participant was requested to complete the self-administered online survey and return it to the researcher electronically via Survey Monkey so that it could be collected at a central point. It was made clear to all participants via the information leaflets that the information will be kept confidential, and that companies can choose to remain anonymous.

On receipt of the data the researcher used statistical methods such as Bar Charts, Percentage, Weighted average, etc to analyze, quantify and interpret it.
All questions in the questionnaire were structured in such a way that they aggressively determine the attitudinal instrument of the respondents.

4.4 Questionnaire construction and format used

The questionnaire in this research study was structured in such a way that it starts with all the general questions about the respondents and their personal experiences, then grouped into the following measures of lean to ensure that all the learnings from the AIDC interventions were assessed:

- Continuous Improvement Initiatives,
- Quality Policy Deployment,
- Operator Involvement in Decision Making,
- Communication Strategies,
- Visual Management,
- Performance Measuring and
- Standard Work Procedures.

These measures are more company specific and assess how the respondent see or view their company. All questions pertaining to the above measures were structured. This means that they were either closed-ended or fixed questions. The researcher did not use any open-ended questions to avoid ambiguity and any non-specific responses.

This attitudinal study, as explained under aims above, was set out to understand the attitudes of companies towards continuous improvement initiatives. The weighted average score of 63.4 % was achieved. This figure was calculated as follows:

The study was divided into these seven elements of sustainability , which each contained a set of questions related to it. Each question within the elements was then weighted against the number of responses received. The weight was then averaged per sustainability element. By dividing the average weight of each element by 5 (the maximum possible score per question), we could get the percentages as shown in table 2.

5. FINDINGS

5.1 How was data analysed

The data collected was analyzed per questionnaire sections as outlined in section 4.4. The following indicators were used to determine the attitudes of the respondents towards each one of the topics discussed:

Table 1: Defined decision indicators

0%–50%	*Poor Sustainability*
51%–75%	*Sustainability can be Improved*
76%–100%	*Good Sustainability*

These are the main indicators that were used to draw conclusion based on the collected data.

5.2 Findings from the Study

The study has found that South African companies in manufacturing sector are sustaining their improvement although there is room for improvement. Table 2 shows the findings of the study in terms of the 7 elements as discussed in section 4.4 above.

Table 2: Results per sustainability element

SUMMARY OF RESULTS	
01. CONTINUOUS IMPROVEMENT	61,4%
02. QUALITY MANAGEMENT SYSTEM	60,8%
03. OPERATOR FLEXIBILITY	69,8%
04. COMMUNICATION	56,6%
05. VISUAL MANAGEMENT	66,6%
06. PERFORMANCE MEASUREMENT (INTERNAL)	58,8%
07. STANDARD WORK	69,8%
AVERAGE	63,4%

This means that the majority of the respondents felt that although there is room for improvement, there is some level of sustainability of improvements. So according to this assessment, the current continuous improvement initiatives by government agencies have the minimum required impact, as discussed in table 2 above, but can largely be improved by restructuring and refining the current programmes further. According to the set indicators, these companies are really not rewduced in sustaining improvements but are also neither very good. This means that by redefining the current programmes, the sustainability of improvements within these companies will be achieved much better than the current findings.
Figure 4 shows a radar graph outlining the results of the study and also comparing these results to world class companies. As can be seen the red line shows the lower limit for the companies to be deemed as being able to maintain their continuous improvement while the grey line is showing the sustainability target for companies to be deemed as reaping the benefits of continuous improvements. The orange line is the maximum target that is available for companies to strive for. There are very few companies, if any at all, that are achieving the maximum benefits of continuous improvements. This means that with the gathered information as discussed in section 2.2, shows that generally companies around the world are not sustaining their improvements.
The blue line indicates the results of this survey. It denotes that South African manufacturing sector is meeting the minimum level of sustainability but is not reaping the benefits of improvement sustainability as yet.

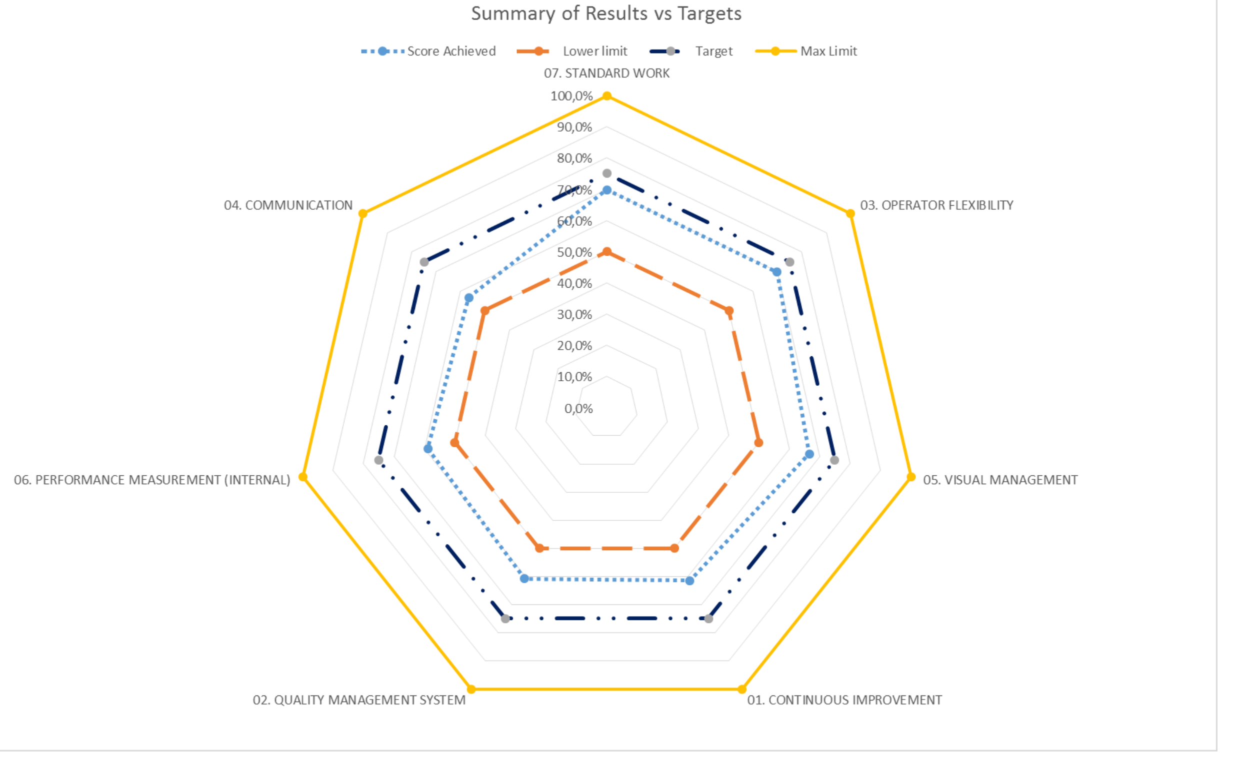

Figure 4: Overall results of the study - All measures fall within the 50% and 75% range

According to literature, 90% had implemented continuous improvement projects; however, only 10% felt they were achieving the results they desired (Rink, 2005). The fact that Japanese companies are seeing more value in implementing and maintaining Kaizen projects (Cheser, 1998), is an indication that continuous improvement initiatives can be sustained and make the required impact. Also the fact that Bateman (2001), could classify the companies into the five (5) categories as described in section 2.2, means that there are companies that are sustaining their improvements by practicing a standardised organisational culture.
Since the element of sustainability is growing at a very fast pace, sustainability thinking is challenging businesses to change how they operate (Lubin and Asty, 2010). As a developing country, South Africa cannot afford to ignore the direction that the developed countries have taken in terms of the element of sustainability of continuous improvement. This is necessary to gain competitive advantage and to respond to the major trends that include growing of human population, rapid response to developing economies, both of which they put a major train to the resources and create unpredictable pricing in commodities.

In order for manufacturing companies in South Africa to grow the national GDP contribution, the current approach needs to change for the following reasons:

- Companies need their top management to commit fully in the continuous improvement programme, but current no assessment of such commitment at the beginning of the programme and therefore government's investments to these programmes end up being null and void.
- Supplier and Enterprise development programmes, especially when funded by the government, should be given to the companies that need them and to the companies that are realizing the need. Currently companies are being begged to come on board in order to meet the targets.
- Companies need to continue the process with little or no assistance at all from the AIDC. This means that after achieving at least 10% efficiency and productivity improvement at the end of such intervention, the company should continue instead of stopping just on 10% improvement.
- To ensure that companies have the required commitment, in order to grow their revenues and in turn growing the most important pillars of sustainability, such as Social, Economic development, and environmental protection.

5.3 Researcher's proposed way forward from the study

The proposed frame-work (figure 5 below) requires the AIDC SEDD to first do a thorough assessment before allowing companies into the longer term projects. These include working with these companies on a shortened version of the Rapid process improvement workshop and analyze the willingness of the company to change.

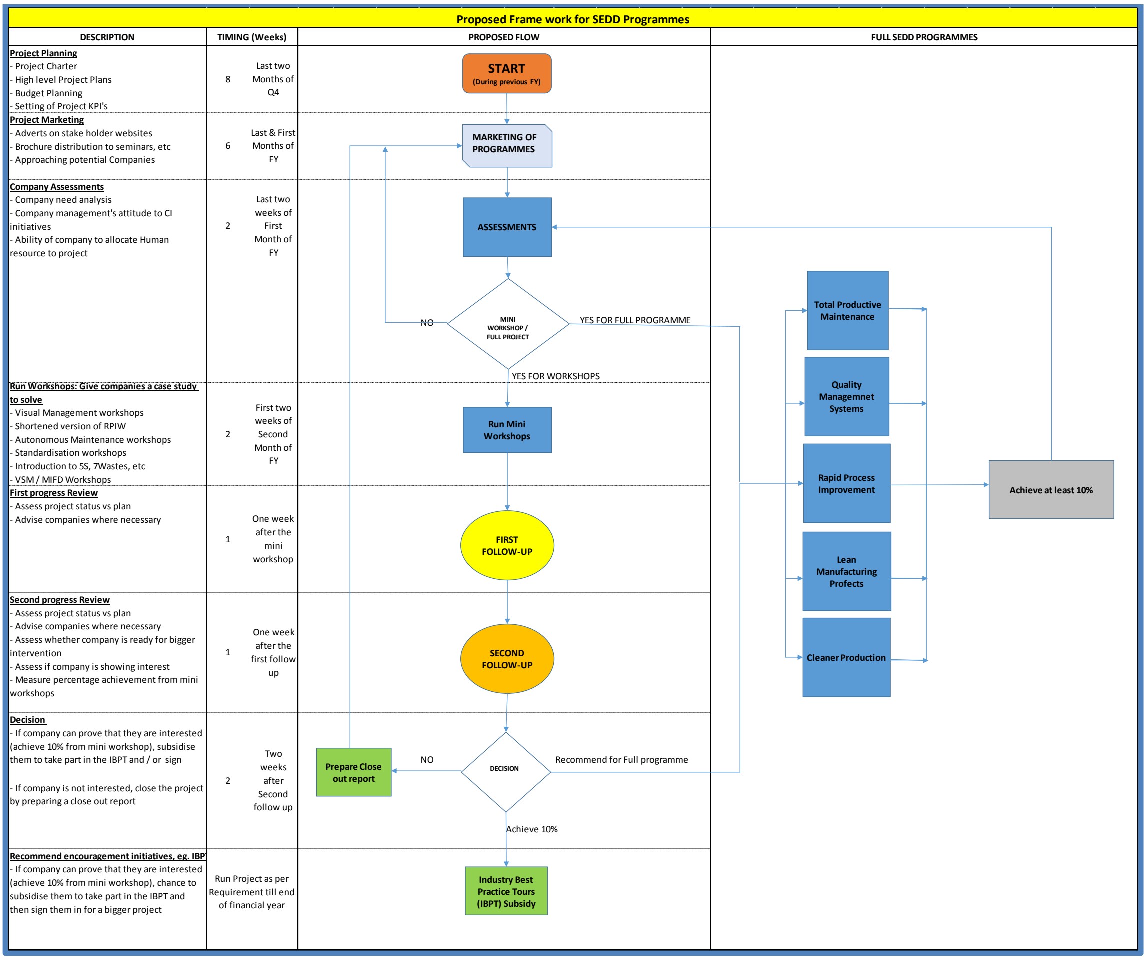

Figure 5: Proposed frame work for SEDD programmes

This frame work also stipulates that if the company does not qualify in the assessment stage, recommendations will be made to that company explaining exactly what the requirements are. The company will then be left alone to address those challenges and will be considered in the future. This way only companies that are ready get to benefit from the government subsidized programmes.
It also ensures that companies continue the process with little or no assistance at all from the AIDC. This means that after achieving at least 10% efficiency and productivity improvement at the end of such intervention, the company will be re-evaluated to ensure that they continue instead of stopping just on 10% improvement.

6. CONCLUSION

Literature present that continues improvement sustainability has been studies in UK, Spain, US, etc however nothing has been done in South African environment, literature also indicated that factors that contribute to sustainability is the approached followed during the interventions.
The research findings indicate that generally South African companies in manufacturing sector, feel that they are sustaining continuous improvement initiatives to a minimum level, therefore new approach is needed to structure government funded initiatives differently in order to ensure sustainability is at a benchmark level of 75%.
Using the study results and the literature review finding, the research developed a new approach which can be followed to ensure high level of sustainability, this new approached will be tested in 2017 during new cluster programs and if find not suitable revision will be effected therefore.

7. AREAS FOR FURTHER RESEARCH

This study has only determined where South African manufacturing companies are in terms of sustaining their improvements. More research and factors need to be considered in order to fully contribute to the sustainability and growth of the industry through improvement initiatives. Although the impression and practical findings in this study are not far-reaching, it does provide a useful groundwork for further investigation of other relational elements essential in improving sustainability of improvement in manufacturing industry.

Future studies may explore the following:

1. This study measured the attitude of the respondents towards sustainability of continuous improvement initiatives, but did not physically measure to confirm the finding. It is the researcher's view that further comprehensive time series studies should be conducted with sampled individuals being observed over a period of time in order to provide more concrete evidence.
2. Since the sustainability concept is growing in manufacturing industry, a study should be conducted to compare the local industry with other developing countries world-wide.
3. Future studies could also look at frame work to educate South African individuals in management positions to drive lean manufacturing concepts in order to enhance sustainability of improvements by overcoming cultural challenges through continuous improvement sustainability.

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